Economic Costs and Philosophical Considerations of

Air Pollution on Human and Environmental Health.

Interdisciplinary Honors Thesis

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Jessica Harris

B.A Economics & B.A Philosophy

Minor: French Language Studies

Advisers

Dr. Devon Gorry, Department of Economics

Dr. Todd May, Department of Philosophy and Relgion

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Acknowledgement and Special Thanks

As outlined by the Clemson Honors College, this project officially commenced the Fall term of my third year of university (September 2018). However, if it weren't for the Summer term of 2018 and my experience with the St. Peter's academic programme at Oxford University, I wouldn't have had the inspiration and foundation to spend two years writing this thesis. I am immensely grateful to the Duckenfield family and Clemson Honors College for funding my experience abroad, allowing me to study *Climate Change in the Anthropocene: Global Catastrophic Risk and Management* with Dr. Ken Addison, an Emeritus fellow of Earth and Climate Systems Science. Dr. Addison's course introduced me to the scientific foundations of climate change, which provide the framework of this paper. At the end of the course, he encouraged me to conduct my own research and, given how curious I became about the subject matter, it certainly wasn't a difficult decision.

After returning from the UK, I met with Dr. Devon Gorry in the Department of Economics, who was my Health Economics professor the Spring of my second year. I am beyond grateful she agreed to be my advisor for the Economics component of this paper. I came to her with a rough question and broad outline and she helped me organize and settle on the material covered in this final draft (the climate crisis impacts human health in many more ways than just poor respiratory health, so choosing one specific area was challenging). She has been an amazing help, providing the best feedback, resources, thoughts, and was willing to read my very long drafts multiple times!

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I am very grateful for all the help, guidance, knowledge, and extra time Dr. Ken Addison, Dr. Devon Gorry, and Dr. Todd May gave as professors and advisers. The knowledge and skills I developed in their courses gave me the foundation to formulate this question and appropriately address it. They've also been crucial in preparing me for postgraduate studies and hopefully a career in minimizing corporate environmental impact and sustainable development. Thanks to their guidance and support, I'm excited to continue my studies after I complete my degrees in Economics and Philosophy to pursue a Master of Science in Sustainable Development at the University of St. Andrews in Scotland.

I. Introduction

1.1 Anthropogenic Climate Change and the Role of Air Pollution

2019 was the second hottest year on record. Behind 2016, it is among the 43 consecutive years in which global land and ocean temperatures have been above average (NOAA, 2020). 2016 also set the record for CO_2 emissions – the highest it has been in the last 800,000 years with a staggering concentration of 402 ppm. As seen in **Figure 1.1** the previous record was 300ppm roughly 300,000 years ago. Running parallel to emissions trapping heat in the atmosphere, air pollution also contributes to the deaths of nearly 7 million people around the globe annually (WHO, 2020). Within the context of these greater global effects, this paper will quantify the costs of excess emissions with a focus on the relationship between these pollutants and human health (See Appendix A.1 *Negative Externalities*).

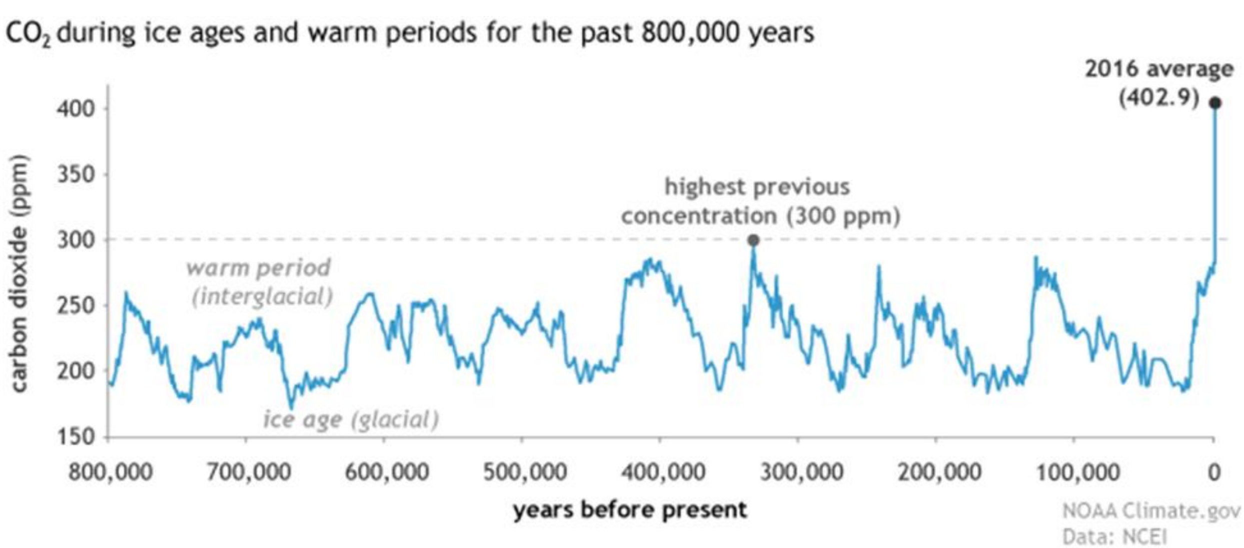


Figure 1.1: (Image: NOAA climate.gov. July 2018)

We now understand that human and earth systems are "… not wholly independent but partially interactive" (H.H Lamb, 1985), and these anthropogenic increases in CO_2 and other greenhouse gases work with earth systems to trap heat and lead to global temperature increases. For example, increases in temperature will then melt glacial surfaces which can then impact the Thermohaline and Atlantic meridional overturning (IPCC 2014 & Bostrom, Cirkovic, 281). In short, these excess emissions have a domino effect: they immediately impact human health, trap excess heat which accumulates, then these global temperatures throw many of Earth's climate forcing systems out of equilibrium. This explains the extreme weather events (hurricanes, wildfires, blizzards, flooding) extreme temperatures, and an overall increase in global temperatures in recent years.

If no action is taken, and we continue to emit greenhouse gases that exceed 450 ppm, it is possible the global temperature could increase as much as 3 ℃ by 2100 and at our current rate, we will see an increase of 1-2℃ (IPCC, 2014). As **Figure 1.2** shows, the projected changes in temperature are dependent on these levels of greenhouse gases in the atmosphere and they are projected to occur before the end of the century.

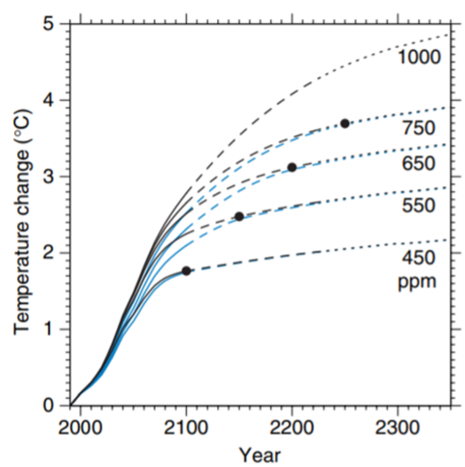


Figure 1.2: From the Intergovernmental Panel on Climate Change 2014 report, Chapter 9: Projections of Future Climate Change. Page 558

Simply put, it is greenhouse gas emissions that lie at the heart of Anthropogenic climate change. Additionally, the same processes which release carbon and other gases are responsible for preventable noncommunicable diseases and other health issues. Sustained exposure to these greenhouse gases and particulate matter is linked to poor respiratory health, increased risk of cardiovascular mortality, and premature death. Clearly, the global community is faced with two sets of problems, one that has immediate deadly effects on the current human population and one with long-term worldwide environmental devastation for generations to come. However, addressing one of these problems simultaneously addresses the other. They both are caused by the same source: excessive greenhouse gas emissions.

1.2 Objectives of this Paper

The aim of this paper is to conduct a wide literature review of the quantified costs of air pollution from the world's heaviest polluters: China, the United States, and the European Union. This will present the results of extensive econometric and statistical data modeling which express the relationship between air pollution and cardiorespiratory health diseases, other morbidities, and premature mortality.

After presenting this data, I then consider the social, ethical, and political implications that a reduction in emissions will have for our generation. Abandoning our complacency to combat climate change and the health consequences associated with it, will ask that this generation make significant sacrifices. I use the frameworks of historical and contemporary philosophical theories to form my argument for institutional responsibility to reduce greenhouse gas emissions. What are the global, generational, and theoretical issues which prevent us from forming a proper ethical response? One explanation I offer is the central role epistemic moral corruption plays in justifying inaction. Given this, a cohesive moral theory of climate ethics is essential to guide us through the change towards a more carbon neutral lifestyle.

Taking these two components, the economic and the philosophical, I then consider current policies in our three entities of focus, their effectiveness, and some suggestions of an effective framework for developing successful international policy moving forward. I hope that by looking at the problem through a different perspective – that of the immediate impacts on human health – our current generation of policy makers, industrialists, corporations, citizens, and institutions will be more inclined to make the necessary and significant changes. Excessive greenhouse gas emissions and the burning of fossil fuels has no longer become a problem of our grandchildren's health and wellbeing but also of our own. So why not act to improve the lives of both present and future generations?

As these case studies will show, current emissions come at high and preventable costs. This thesis has been written during the coronavirus, COVID-19 pandemic where it has become apparent that healthy immune systems and respiratory health are more important than ever. I end my paper with a special note on COVID-19 and lessons learned from observing this ongoing global crisis.

II. Pollutants

2.1 Ambient Air Quality and TSP (Total Suspended Particulates)

This paper compiles and presents data from a series of studies which analyze the impact of different pollutants on human health. Some consider the broader, overall impact of Ambient Air Quality or TSP. This type is the combination of all air pollutants considered harmful to human health and are monitored by the National Ambient Air Quality Standards (NAAQS) set by the EPA in the United States. These pollutants include carbon monoxide, ozone, nitrogen dioxide, lead, particulate matter (of all diameters), and sulfur dioxide (EPA, 2017).

2.2 Particulate Matter: PM2.5 and PM10

Perhaps one of the most damaging pollutants in the following studies is particulate matter. Particulates are solid or liquid particles found in the air, some of which are visible in smoke while others are too small to see (CDC, 2019). There are two ways these pollutants can be produced- from primary sources such as wood burning and forest fires. Additionally, power plants, coal fires, factories, automobiles, and construction are secondary sources of pollution (CDC, 2019). Gases such as Sulfur dioxides and nitrogen oxides emitted by automobiles, industries, and power plants produce particulate matter when they react with other atmospheric elements naturally found in the atmosphere (EPA, 2018).

However, not all particulate matter is the same. Particles vary by size and production. This paper will focus primarily on studies concerning the most common types: $PM_{2.5}$ and PM_{10}, the numerical values indicate the size of the diameter in microns of each classification of particles. Of these two types, $PM_{2.5}$ is considered the most harmful since its significantly smaller size allows for an easier penetration into the human respiratory system (Ho et al., 2015).

2.3 Ozone (O_3), Nitrous Oxides (NO_x), Sulfur Dioxides (SO_2)

The main ingredient in smog is a gas created by three atoms of Oxygen (Ozone) which can be harmful when it resides at ground level (EPA, 2019). This pollutant is formed through chemical reactions in the presence of sunlight between volatile organic compounds (VOC) and nitrogen oxides (NO_x). These NO_x emissions can be traced to cars, chemical plants, refiners, industrial boilers, and power plants (EPA, 2018). Another problematic air pollutant comes from Sulfur dioxide (SO_2). Sulfur dioxide enters the atmosphere through the burning of fossil fuels from industrial processes and power plants (EPA, 2019). Independent of its harmful role in contributing to Ozone, Nitrogen Oxides, NO_2, can have a harmful impact on health when there is a sustained, excess exposure.

III. Economic Costs: Case Studies by Country

3.1 Costs of Air Pollution in China

It is no secret that China has developed a reputation in recent years, especially with the publicity surrounding the 2008 Olympics, for having poor air quality conditions and high levels of pollution. In 2015, of 360 cities in China, over 90 percent were unable to meet the national air quality standards (Levin, 2015). Broadly, one study revealed that in 2010, air pollution in China is estimated to have contributed to 1.2 million excess deaths annually (Hanlon and Tian, 2015).

China's relationship between air pollution and economic growth is a helpful method of quantifying some of the impacts of poor air quality on life expectancies. With fast paced economic growth, researchers wanted to better understand why improvements in overall health were lagging relative to this dramatic economic boom. Ebenstein et al. (2015) compared overall health and its relationship with rising average incomes. Between 1991-2012, China experienced an unprecedented economic boom seeing the average income rise from $894 per capita to $9,087 (PPP). With rising incomes, it would be expected that individuals would gain access to better health care and in the case of non-respiratory and communicable diseases the authors found this to be true. Since 1991, they found that deaths resulting from non-respiratory diseases have fallen dramatically from 432 to 221 deaths per 100,000. This is consistent with rising incomes enabling improvements in public health and sanitation reducing the number of deaths associated with individuals of lower incomes. Despite this economic growth, mortality from cardiorespiratory diseases: strokes, lung cancer, and heart disease had not changed as should be expected.

So, while an increase in income is associated with an increase in life expectancy, this increase in China is modest compared to the dramatic increase in economic growth. Ebenstein et al. (2015) concluded a 100 μ/m³ increase in PM_{10} exposure is associated with a decline in life expectancy of 1.5 years at birth and then increases to 2.3 years at age five.

While some studies aim to understand the relationship between air pollution and life expectancies, others aim to identify and quantify the risk of mortality associated with exposure to various pollutants. Ling et al. (2017) analyzed 14 studies to create a random-effect model to estimate overall excess risk associated with exposure to $PM_{2.5}$ and it was found to be 1.79% for cardiovascular mortality and 0.96% for respiratory mortality(See appendix *A.8 Random-Effect Modeling*). That is, due to PM exposure, the risk of individuals dying due to cardiovascular or respiratory diseases is 1.79% and 0.96%, respectively, higher than it would have been without sustained exposure. These same researchers also noted differences in short-term mortality effects for older and younger populations as well as those of a lower socioeconomic status. They found higher marginal damage curves (See appendix A.2 *Marginal Damage Curves*) for these populations as well as an overall conclusion that there was a relatively larger impact of $PM_{2.5}$ on human health than PM_{10}. They ran the same type of random-effect model for 17 studies on PM_{10}, and while there was a statistically significant association, the overall excess risk is smaller than for $PM_{2.5}$ with 0.38% for cardiovascular mortality and 0.48% for respiratory mortality

Perhaps one of the best studies which isolates the association between cardiorespiratory mortality and PM_{10}, is the Huai River Study (University of Chicago, 2019). Under the conditions of the Huai River Policy, during China's planning period (1950-1980), the government allotted residents north of the Huai river coal to burn during the colder winter months. As a result, the northern region became coal-dependent unlike their neighbors south of the river. Additionally, any movement from polluted areas to less polluted areas was restricted as a result of the household registration system (Ebenstein et al, 2019).

Researchers used data from 154 cities north and south of the river between 1981 and 2012. They isolated various causes of death such as those related to smoking, pre-existing health conditions, and dietary patterns from those with a direct link to air pollution. This led them to focus on cardiorespiratory illnesses and deaths related to heart, stroke, and lung cancers.

Given the quality of data, the results of this study were rather astounding:

1. Particulate air pollution was 46 percent higher in the north than in the south.
2. Relative to their southern neighbors, increased levels of particulate air pollution in the north shortened lifespans by 3.1 years.
3. For every 10 μ/m^3 of emitted pollution and sustained exposure to the pollutant, life expectancy is reduced by 0.6 years.
4. Had China adhered to pollutant standards, they could have prevented an accumulated loss of 3.7 billion life years.

As this study indicates, sustained exposure and inhalation of fine particulate matter can be directly linked to premature death and poor cardiorespiratory health. From a human health perspective, we can see how the burning of fossil fuels has a directly negative impact on mortality and quality of life.

Levy et al. (2007) took a different approach using a time-series study to study risk and exposure to PM_{10}. (See Appendix *A.9 Time-Series Modeling*). This indicated an estimated increase in daily deaths by 0.3% per each 10 μ/m^3 increase in daily PM_{10} concentration, further providing evidence that links PM with mortality (Levy et al., 2007).

As discussed, particulate matter isn’t the only pollutant with detrimental health effects. Yu Lei et al. analyzed the risks of mortality associated with Ozone exposure in the short term (2015). These researchers utilized a random-effect model over 10 studies to analyze the overall excess risk associated with Ozone. The researchers found a statistically significant relationship with a 0.46% excess risk of cardiovascular mortality and a 0.41% respiratory mortality linked to ozone exposure. Overall, ozone is considered to have adverse impacts on respiratory health (Yu Lei et al., 2015).

Independent of its harmful role in contributing to Ozone, Nitrogen Oxides, particularly NO_2 are associated with increased risk of mortality when there is a sustained, excess exposure. Over 18 studies, a random-effect model estimated a 1.46% excess risk for cardiovascular mortality and a 1.74% risk for respiratory mortality (Hualiang Ling et al., 2017).

These seasonal spikes in ozone contribute to creating a more severe threat to human health in the warmer summer months. As we have established earlier, ozone is a greenhouse gas which traps excess heat in the atmosphere. With increases in this gas, more heat will be trapped, leading to temperature increases in tandem with the excess production of other greenhouse gases which then drive more severe weather extremes and heat waves in a positive feedback loop (Ellis, 2018).

The 2013 summer heat wave in China saw a reported 5,758 cases of heat-related illnesses. S Gu et al. found that there was a positive relationship between high temperatures and heat-related illnesses with a nonlinear effect which could last for 3 days (2019). As was shown, ozone is linked to poor respiratory health with statistically significant associations between exposure and increased risk of illness. As a driver of anthropogenic climate change, ozone plays both a role in trapping heat which leads to heat-related illness (heat stroke etc.) as well as causes direct respiratory harm when people inhale smog.

Environmentally, sulfur dioxide can decrease growth of trees and plants and contributes to the creation of acid rain. Another study focuses on the health impacts of exposure to this gas over 17 studies and a random-effect model. These results yielded a statistically significant association with a 0.83% excess risk of cardiovascular mortality and a 1.25% excess risk of respiratory mortality to sustained SO_2 exposure (Hualiang Ling et al 2017).

As these first case studies show, exposure to these pollutants is associated with higher risks of premature mortality, cardiorespiratory and respiratory diseases. Seen in these reduced lifespans, lost life years, and the costs of living with these morbidities, air pollution in China is contributing to a serious public health crisis. Alongside a natural landscape experiencing environmental change, these studies also show the immediate impacts of these emissions on human health.

3.2 Costs of Air Pollution in the United States

Behind China, the United States is ranked second in the world for total greenhouse gas emissions, accounting for 15% of global fossil fuel and combustion emissions (EPA, 2014). However, the U.S. ranks number one for per capita carbon emissions, emitting at a rate of roughly 18.5 tons of CO_2 equivalent per person (Center for Climate and Energy Solutions, 2017). It is estimated that a shift to 100% renewable energy by 2050 would prevent 90 million premature deaths in the U.S alone from 2017 to 2050 (Simms, A, 2017).

U.S air pollution policies and standards have fluctuated with each presidential administration. From the sweeping regulations of the Obama Era (2008-2016) to the recent deregulations of the Trump Administration (2016-2020) the cornerstone of pollution policy has remained the Clean Air Act of 1970 (Albeck-ripka et al., 2019). And while supplemental policies have changed, the impacts of sustained exposure to air pollutants on human health have remained detrimental (although to various degrees based on which policies were enacted). The following studies examine the associations between: specific pollutants and mortality in various populations, the economic costs of pollution, costs of increased demand on the healthcare system, effectiveness of regional policies and standards, as well as risk of mortality related to specific forms of transportation.

A 1993 Harvard review, “Six Cities Study” compared exposure to particulate matter with early mortality in six U.S cities (Dockery et al, 1993). It is considered among one of the most influential and landmark studies in U.S air pollution policy. In 2012, Harvard researchers provided a follow up, expanding the results of the study with 11 additional years of exposure to PM (Dockery et al., 2012). They used a Cox Proportional Hazards Model to observe a statistically significant association between $PM_{2.5}$ exposure and cardiovascular and lung cancer mortality. Controlling for smoking, higher PM concentrations are associated with higher rates of cardiovascular mortality.

The results also indicate sulfate particles are as toxic as fine particulate matter. Consistent with Pope et al. (2007) a 2.5 μ/m^3 decrease in sulfate during an 8-month smelters strike was associated with a 2.5% decrease in the number of deaths in the region. Most striking is the wider implications the data from this study reveals. Health improvements can be expected almost immediately after a reduction in air pollution. In 2007, there were 2,423,712 deaths in the U.S with an average $PM_{2.5}$ of 11.9 μ/m^3 . Using this data and the association from the follow up study, the researchers suggest that a decrease of 1 μ/m^3 in average $PM_{2.5}$ would result in approximately 34,000 fewer deaths per year.

Focusing on specific populations and their risk of premature mortality, Kenneth Chay and Michael Greenstone’s 2003 paper “The Impact of Air Pollution on Infant Mortality” further shows the association between poor air quality and premature death with respect to children and infants (See Appendix *A.2 Marginal Damage Curves*).

This paper focuses on differential changes in TSP from 1980 to 1982 and geographical variation due to the 1981-1982 recession (Chay et al., 2003). The recession is important as it introduces a pollution shock in which there was a dramatic decrease in TSP. [1]Additionally, focusing on child mortality helps reduce omitted variable bias, as unknown lifetime exposure to pollution is not an issue, however income is still an important observable confounder. TSP levels were assigned based on the mother's exposure during pregnancy, and of the newborn during their first few months. Therefore, the study compared the changes in infant mortality rates in countries with large TSP reductions and in countries with little to no reductions. Estimates imply that over 70% of the overall reduction in infant mortality from 1980-1982 may be attributed to the fifteen-unit average reduction in TSP. 2,500 fewer infants died during this recession suggesting a 1μ/m^3 decline in TSP is associated with 5 less deaths per 100,000 live births.

The results have some powerful implications particularly with respect to quantifying the value of regulating TSP levels.

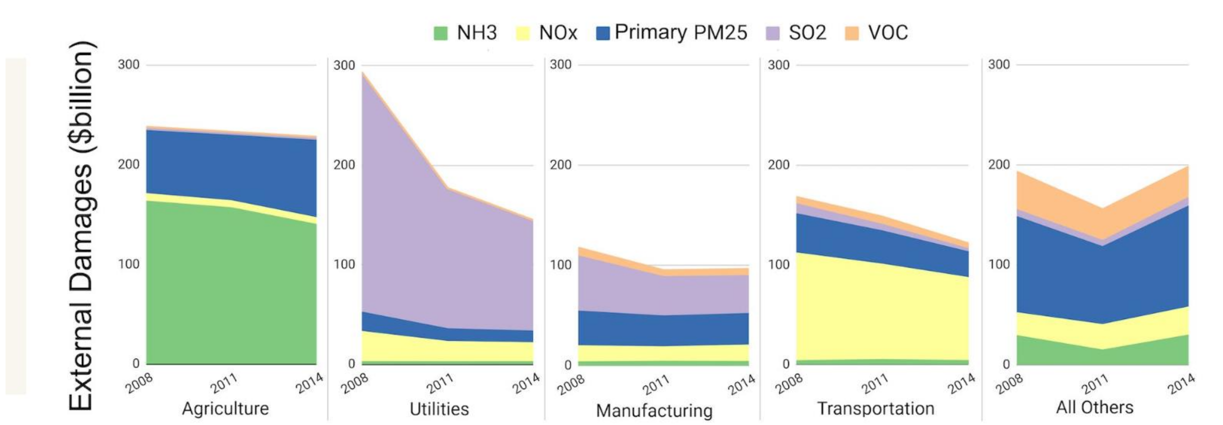
- In 2003: 4 million U.S Births annually. Using the implications of the study, a very basic estimate implies 1 μ/m^3 reduction in TSP leads to 200 additional infants surviving one year of age, with a value worth roughly $320 Million (Chay et al., 2003).
- Hedonic valuation of the housing market can also capture the economic value of health benefits- a 1 μ/m^3 decrease was associated with a 0.4-0.5 percent increase in housing prices in the 1970s. If these have not changed since then, this reduction would increase the value of the housing stock by $32 billion (Chay et al., 2003).

However, it is important to note that while the study focused on TSP, it is unclear if these results are from small or large particles as this recession was concentrated in the industrial sector.

[1] As will be discussed in "A Special Note: The COVID-19 Pandemic" many places around the globe are experiencing significant pollution shocks as many countries go under strict lockdown orders at the time this paper is being written.

Given this, combustion does tend to expel more small particles than larger ones, and as this paper has expressed, multiple studies show smaller particles have the most detrimental impact on human health.

The introduction of lifelong respiratory diseases and premature mortality from air pollution in the United States creates large economic costs. Azevedo et al. recently looked at the costs of these health damages related to pollution on the U.S economy (2019). As a result of premature death, it is estimated poor air quality cost the U.S $790 Billion in 2014, equivalent to 5% of GDP. While these external damages have fallen about 20% between 2014 and 2018, agriculture, utilities, manufacturing, and transportation account for 75% of these pollution damages. As shown in the graphic below, these types of emissions are not distributed evenly by sector. However, they do impose a very broad cost nationally in the form of being associated with premature deaths (Azevedo et al., 2019).



External damages from fine particulate matter air pollution by economic sector and precursor pollutant for 2008, 2011, and 2014 (in billions of dollars, 2018-adjusted). *(Image credit: Nick Muller, Ines Azevedo and Peter Tschofen)*

Figure 3.2: Damages from PM by sector from 2008-2011 (Azevedo et al. 2019)

Looking at these economic impacts at a local level, researchers in Pennsylvania directly quantified the costs of air pollution on economic growth in Pittsburgh. Here, the links between air quality and economic growth via "three pathways" were analyzed (Chari et al., 2013):

1. Health and related workforce issues and costs
2. Quality of life issues and location decisions
3. Air quality regulations and business operations

This study provides an analysis focused on the costs of poor health outcomes related to air quality in a way that takes a policy response into account. Using a literature review with extrapolated data and focus groups, the estimated costs of poor health as a result of noncompliance with National Ambient Air Quality Standards is worth an estimated $616 million in the Pittsburgh area alone. Here the main pollutants of concern were concentrations of particulate matter with a diameter of less than 2.5 microns ($PM_{2.5}$) and concentrations of ozone measured in parts per billion (ppb). These pollutants were linked to poor health outcomes in:

- Bronchitis
- Asthma
- Premature mortality
- Cardiovascular hospital visits
- General poor upper respiratory health

The paper analyzed the impacts of poor health from a perspective of worker and student productivity. These health issues impact the individual and introduce costs they and the healthcare system must carry, but also place economic costs on their respective workplaces as a loss of worker productivity. When students miss school, they incur the costs of a decrease in academic performance while the parent who must take off work to care for them may have to forgo wages.

The connection between lower productivity and air pollution has important implications. Businesses that comply with NAAQ standards are predicted to have more output and jobs than those that are not. Noncompliance is linked to about 1,900 fewer jobs and $299 million less in output. Specifically for $PM_{2.5}$, the researchers approximate 400 fewer jobs and $57 million of lost output. Thus, the summary of findings in each pathway are as follows:

1. Better Air Quality will reduce ER visits, work-loss days, and early death. These reductions are worth $128 million in meeting ozone levels and $488 million in meeting NAAQS standards.
2. Air Quality impacts where workers will move.
3. Despite the upfront costs of regulations, business will have an easier time relocating and supporting growth in Pittsburgh in the long run (Chari et al. , 2013).

As the Pittsburg study recognized, poor respiratory health requires more medical care incurring greater costs on the healthcare system for preventable diseases and respiratory conditions. Lipfert (1993) took a historical approach, analyzing the association between demands for healthcare services after air pollution events. In 1953, high smoke levels and SO_2 concentrations of 0.85 ppm settled over New York City creating a 24-hour average of 642 μ/m^3 TSP concentration. Thus, statistically significant increases were seen for upper respiratory infections at 3 of 4 hospitals and cardiac diagnoses at 2 hospitals. Seeing this rise in hospital and healthcare costs, we can begin to also see how the negative impacts of air pollution are costly for the patient, but also place additional burden on healthcare facilities and physicians.

From a policy perspective, researchers have studied the effectiveness of specific regulations and standards in various parts of the country. The results of which can be useful in guiding future policy. To further inform policy in the United States, researchers analyzed the risk of mortality associated with multiple vehicle types with different sources of fuel. As the complexity of the problem of air pollution in the country indicates, one single solution will be insufficient to address the multifaceted causes of pollution and their detrimental effects.

Therefore, Hill et al. compared the health impacts of PM concentrations of conventional modes of transportation and their 10 alternatives (2014). This was done using a spatially and temporally explicit life cycle inventory model.

The results of this comparison are as follows (Hill et al., 2014):

- Electric Vehicle: Wind, dynamic water, solar (WWS) are the best for improving air quality, tied to only 230 National mortalities
- Electric Vehicle: Corn Stover and Electric Vehicle Coal are the worst – connected to 3,200 mortalities per year.
- Comparing the standard to gas hybrids, air quality related health impacts decreased 30%
- Comparing the standard to EV Natural Gas: 50% decrease in health impacts.
- Electric Vehicle: WWS displayed a 70% decrease in health impacts.

Thus, the connection between poor human health and the emissions of vehicle transportation is shown and quantified by the comparison of different transportation methods as well. When it comes to policy making, these types of results are valuable in developing emission standards as well as which modes of transportation might be subsidized, if such a policy were suggested.

Graham et al. analyzed current $PM_{2.5}$ standards and their impact on individuals in the Northeastern United States (2005). At the time of the study, the standards in 8 states only impacted 16% of the population. If the region were to adopt more protective standards such as those in California and Canada, they would impact 84-100% of the population. The study also showed current standards still allowed for exposure to $PM_{2.5}$ that was associated with heart and lung disease as well as premature mortality. 4-18% of adults had cardiopulmonary or diabetes conditions while 12-15% of children had respiratory allergies or lifetime asthma. Of the data, 72% of people live in heavily populated areas (Boston, New York etc.) which increased exposure.

Similar to China, the U.S faces the same costs to health with exposure to pollutants. As these studies have shown, air pollution has higher risks of poor health but direct economic costs that go into the millions just in a single city. These excess emissions and their association with premature mortality and cardiorespiratory morbidities vary by region (due to compliance with various regional policies) and are easily preventable costs to healthcare systems and forgone wages. Following these trends of the various costs in multiple sectors and effectiveness of policies, the following section will consider the European Union.

3.3 Costs of Air Pollution in the European Union

In addition to the United States and China, another major contributor to overall global emissions comes from Europe. Third globally, the 28 countries in the European Bloc are responsible for 9% of the world's emissions (EPA, 2014). Given the various countries in the European Union, these studies examining the costs and health consequences associated with emissions are broad in scope. Some focus on particular European cities and countries, while others consider the health impacts on the entire European Bloc.

The WHO Regional Office for Europe sought to find an estimated value on the costs of premature death or illness related to air pollution in the EU. In 2010, nearly 600,000 premature deaths were recorded, with the overall loss totaling $1.483 trillion in VSL and morbidity costs alone (WHO, 2015) (See Appendix *0.3 Morbidity vs. Mortality*). Since the EU contains various countries with different resources and demands for energy, pollutant concentrations are not consistent. In one of the following papers, researchers concluded Eastern Europe and the Mediterranean coast more polluted than countries on the Atlantic coast and Scandinavia (Dechezlepretre et al, 2019).

While particulate matter is associated with the most severe health impacts, how much more severe is it relative to other pollutants? A 2019 study broke down the atmospheric pollutants and the degree to the severity of their respective health impacts. From NO_2 exposure alone, 723,000 years of life were lost in 2013 (Koolen et al., 2019). The researchers found the impact of NO_2 is four times larger than that of ozone, and less than PM which has a negative health impact six times larger than NO_2.

Looking at the overall impact of air quality in Europe, researchers have captured some of the monetary effects of prolonged PM exposure on economic productivity. Dechezlepretre et al (2019) regressed economic activity on instrumented pollution and controls. Here, they found the market benefits of reducing $PM_{2.5}$ emissions through an analysis of lost working days, built environment damage, increased healthcare costs, and the decreased value of crops. Reducing $PM_{2.5}$ by 17% would directly impact the market in avoiding a loss of 1 billion euros annually. If that reduction were increased to 25%, the number would jump to avoided annual costs of 2 billion euros (Dechezlepretre et al., 2019).

Chanel et al. (2016) used 10 European cities and 6 countries to examine the impacts of air pollution on childhood asthmatics and adults with coronary heart disease. They concluded an average of 33,200 children with asthma (under 18 years of age), and 37,200 adults with coronary heart disease (over 65 years of age) are likely to have developed these health conditions due to their proximity to busy roads. If WHO air quality guidelines for NO_2 and PM_{10} were met, 21 asthmatic hospital admissions and 140 cardiorespiratory hospitalizations could be avoided on average in all cities. The distribution of these health costs is spread throughout three actors- 66% falls on the health system (medical resources, professionals, etc), 30.3% on the patient/family (direct monetary costs, lost work, lost time), and 3.7% on other payers (employers, sick leave).

Looking at some individual countries, Martinez et al. (2018) took a closer look at the burden of disease as a result of PM exposure in Skopje, Macedonia. In 2012 alone, researchers estimated long term exposure was responsible for 1,199 premature deaths, or 16,209 years of life lost. And the estimated social costs of premature mortality were estimated at around 570-1470 million euros. Additionally, particulate matter responsible for 547 hospital admissions due to poor cardiovascular health and 937 for respiratory issues. If the city were to lower their PM levels to the EU limit at the time, the researchers estimated 77% of attributable PM mortality could have been avoided, showing the potential better air quality and healthier citizens has for economic gains in a single city.

As has been mentioned, some populations are more vulnerable to the impacts of air pollution, particularly infants, children and the elderly. In France, Baldi et al. analyzed the impact of air pollution spikes on the elderly population in Bordeaux (2003). They found a significant association between mortality on days with higher concentrations of ambient air pollutants. Interestingly enough, the results showed elderly women were at a greater risk of dying on high pollution days than men, with one possible explanation being that men's lungs allow more ventilation. They found there to be no threshold in exposure which would indicate there is always some part of the population vulnerable, despite varying levels of pollution.

We can also see the intersection of human and planetary health through the consequences of heatwaves and wildfires. In 2010 a major heatwave in Russia triggered major wildfires throughout the country. In 2014, researchers studied the impact this combination of extreme heat and polluted air (as the smoke increased the PM levels) had on mortality rates in Moscow (Dmitry Shaposhnikov et al., 2014). After 44 days of average temperatures between 75.2 °F and 87.8 °F, and PM_{10} exceeding 300 μ/m^3, there were an estimated 11,000 excess deaths, mostly among the 65+ population with an increased risk of illness or premature death in children. Again, we can see how this type of study shows the truly intertwined relationship between air quality, human health, and detrimental environmental impact of anthropogenic activities.

Trends in the EU follow those in the U.S and China- which indicates an association between air pollutants and poor respiratory health, lost life years, wide economic costs, and shorter life expectancies. Additionally, as the heat waves in China and Russia indicate, these emissions have initial impacts on human health upon inhalation, the natural environment and climate patterns, and the altered environment which then causes other health related health issues. As these studies show, there is a global case for limiting air pollution to protect human health. These associations and models are not limited to a single country, region, or organization but are the work of many independent Economists and Scientists.

With all this data in hand, the next sections will interpret what this implies within an environmental context ethically, and politically.

IV. Philosophical Analysis

Introduction

In this section, I aim to address some issues which complicate a global and (even local) response to air pollution mortalities and greenhouse gas reductions. First, it is important to touch on some of the difficulties which make the climate crisis partly an issue of ethics. Then I will discuss some ethical issues epistemological climate skepticism raises, and the duty governments have in protecting the health and wellbeing of their citizens.

Stephen Gardiner makes the case for climate ethics in his book *A Perfect Moral Storm: The Ethical Tragedy of Climate Change* (2009). Here he points to three issues which are central to our difficulty to address the climate crisis: The global storm, the intergenerational storm, and the theoretical storm.

The Global Storm

The global nature of the problem is an issue in itself. With 195 countries looking out for their own interests, it can be difficult to coordinate these entities (some with corrupt institutions) to a global commitment to reduce their emissions. Many tend to appeal to game theory and the tragedy of the commons to explain why this is a challenge. Essentially, it is a game of costs and benefits. When all countries take on the upfront costs, the results are the most effective. However, this incentivizes one country to deviate from their agreement, since everyone else is doing the work, they can still benefit from the results without having to undertake any costs. Within these efforts to develop meaningful international agreements, Gardiner argues many are shadow solutions- giving the appearance and false confidence they are doing more good than they are in reality.

In economic terms many countries are situated unevenly- some emit more than others, many have significantly less capital than others. What would a fair global solution ask of these countries? How will the world be held accountable for reaching these goals?

Intergenerational Storm

The intergenerational storm addresses the backloaded impacts of the climate crisis on the following generations. This analysis brings attention to the inherent wrongness of our leaving the world a worse place than when we found it. Essentially, there appears to be no ethical accountability to care for future generations who, by no actions of their own, will suffer the greatest consequences of the climate crisis previous generations have caused. It is incredibly difficult for current decision makers to try and account for the preferences and needs of people they will never meet, and of a world they will never inhabit.

It is the intergenerational storm I found the most troubling and wished to address in this thesis. If we could see the impacts of climate change more immediately, then we might be more compelled to act. Since the climate crisis is fueled by these excess emissions, I chose to study air pollution since the evidence is clear these emissions, when inhaled, also have serious health effects.

While it is important to reduce our emissions motivated by our immediate health, we must acknowledge the serious wrongdoing on the following generations. As I explain in section *4.2*, John Rawls offers a compelling view of justice which extends to future generations and ought to guide us in addressing not only immediate air pollution issues, but long-term environmental issues which is fair to citizens of today and of tomorrow.

The Theoretical Storm

And finally, Gardiner discusses our lack of an ethical framework to help guide us through the climate crisis. Unlike issues of political philosophy where we have always sought to define a just political scheme, the climate crisis has never been faced before. Given its novelty, we have no theoretical framework we can turn to for ethical guidance.

These three storms are important to note as they crop up in our ways to address or understand the crisis. And while Gardiner argues "the global environmental tragedy is most centrally an ethical failure" (page 3, 2009), I argue that an ethical approach is important but appealing to it alone will not create a sufficient response. These issues need to be acknowledged and addressed out of a moral duty to protect the health of ourselves and of our environment. However, focusing on air pollution to motivate action in an appeal to our immediate interests may be necessary to get the momentum going. Alongside this direct appeal to protect our immediate health, I will use the following sections to highlight the issue of moral corruption and role of governments in combatting the crisis.

5. 1 The Ethics of Climate Change: Epistemic Moral Corruption

As has been discussed in developing the environmental background which frames the studies compiled in this paper, greenhouse gases are the core cause of the climate crisis (See section *1.1 Anthropogenic Climate Change and Air Pollution*) And within this impending environmental challenge, the negative impacts of air pollution and inhalation of these emissions on human health is supported by a strong and growing body of evidence (See Section *3: Economic Costs*).

Since the degree to which the impacts will be felt is dependent on the amount of carbon, scientists have run models expressing the impacts of levels in various scenarios. Within the impacts of these emissions, human health is at risk from these environmental changes for future generations, but at the immediate level, poses a serious threat to the respiratory health of current generations.

I aim to extend and further support Stephen Gardiner's claim that denying climate science on epistemological grounds is morally corrupt. First, I will clarify what I mean when I refer to epistemology and moral corruption.

Epistemology is the study of how we know what we know, or in more formal terms is "an attempt to understand how our degrees of confidence are rationally constrained by our evidence" (Neta & Steup, 2020). Essentially, it is how we prove what we know or don't know and by what means. When one rejects the validity of the climate crisis on epistemological grounds, a potential claim is that climate science is not to be considered valid knowledge since the science is not certain enough, and therefore unknowable. This type of logic is then used to justify inaction- If the consequences are uncertain, how do we really know they are valid? Since we don't know, we can't justify action.

Moral Corruption can sometimes be difficult to spot, since it is subtle and hides itself under the guise of moral justification. In this case, one alters a moral claim to support their ends in a way that maintains the image they are acting in good faith. Essentially it requires one to distort the problem and be dishonest about not seeing it properly (Gardiner 2009).

I will respond to three arguments for scientific doubt and show the ways in which their rejections of climate science on knowledge-based objections reveal moral corruption. The first argument shows how climate skeptics distort the problem, the second exhibits dishonesty, and the third's unfair use of selective skepticism as a method of casting doubt on one scientific field.

Distortion

The first objection grounds its rejection of climate science on the foundation of uncertainty as not enough to justify the costs. Here, the claim is that the actions necessary to reduce emissions come at too high of a cost to act without complete certainty. If a reduction in emissions asks that one dramatically changes many aspects of their lifestyle there needs to be absolute certainty that their efforts will not be unnecessary. Therefore, one cannot consider the scientific evidence sound until it is proven certain. Since climate science is using knowledge about the past patterns of climate systems and trends which predict what might happen, it is too costly to rely on this uncertain and unobservable future evidence to guide our actions today. This dynamic nature of climate science legitimately opens room for doubt- if there are multiple scenarios, which one are we supposed to believe?

In reply, this objection against the validity of climate science is a distortion of the problem- one of the two components of moral corruption. First, an appeal to costs to show that the science can only be believed when it is certain exemplifies interests clouding *how* the issue is seen. Rather than stepping back, viewing the entirety of the problem, then considering the costs later- the costs are considered upfront and influence how the issue is seen. The more devastating the projected the impacts, the more it will ask of the current generation to reduce emissions and alter their lifestyles more drastically. These costs are most certainly a component of the problem, but they should not be used to disqualify scientific evidence because the findings are financially "inconvenient."

When one views the problem in entirety, they will see that these various projections exhibit the respective changes in climate systems as a result of levels of CO_2 in the atmosphere. Degrees of uncertainty do not mean impossibility. Since CO_2 is dependent on human activity, those are subject to policies, and how behavior is either predicted to change or not change in the future. What these models do predict and with certainty is: the less greenhouse gases the less catastrophic, and the more greenhouse gases the more catastrophic.

Furthermore, using potential costs to reject scientific evidence isn't an ethical way of thinking about current crises the international community faces. This type of logic would imply we shouldn't prepare for a global pandemic because we aren't *certain* when it will occur and where. As history, and the COVID-19 outbreak have shown, this type of logic lets the costs of the mitigation and preparation distort and downplay the problem and therefore the action necessary to address it. It is necessary that costs are discussed and considered when discussing the climate crisis but using them as a justification for inaction on epistemological grounds is a subtle way of reasoning away from the original claim for scientific validity while appearing to act in good faith.

Conflicting Interests and Dishonesty

A second objection to climate science denial as a matter of moral corruption makes an appeal to direct interests and is dishonest about it. Take for example, a coal miner whose life is supported by the income and work provided by the coal industry. Without this work, they would be unable to provide for themselves or support a family. If an individual heavily reliant and influenced by the coal industry or other fossil fuel industries rejects climate science on epistemological grounds, it seems unfair to label them "morally corrupt". They are simply misguided by their interests. Accepting this science puts their entire livelihood at stake with dire consequences. If anything, they are more ignorant than they are morally corrupt, and are genuinely buying into climate skepticism.

There are a few different things occurring in this type of claim. The issue of dishonesty in moral corruption, and the intergenerational storm. First, we can see how this type of objection shows a rejection of knowledge is influenced by dishonesty. The coal miner who rejects the science because it threatens their lifestyle and therefore justifies inaction claiming the science is "incorrect" is being dishonest- they let their interests distort how they view the issue and don't admit it. This subtle reasoning away from valid scientific evidence to support their own interests, without admitting this claim is influenced by reasons outside of scientific reasoning is morally corrupt.

However, this ethical issue of moral corruption only applies in the instance of distortion and dishonesty being used to challenge scientific evidence. The main issue here is they reject climate science not because they have valid, peer reviewed scientific findings that disprove climate change, but because they allow interests to influence their acceptance of evidence and inaction but do not admit that. Reasoning away from scientific evidence as a matter of epistemology and not admitting conflicting interests is corrupt. By contrast, if they do agree that the science is valid, but cannot justify action because it threatens their immediate livelihood, they are not attacking the climate crisis on the basis of knowledge. Rather, they are falling into the complications of the intergenerational storm and current lack of an ethical framework to guide how they weigh their interests against the interests of later generations.

Empiricism and Selective Skepticism

Another rejection of climate science on epistemological grounds argues that only observable data can be believed and stands on strict *empiricism* grounds, a theory of knowledge which relies only on observable data and experimentation. Here, knowledge can only come from empirical observations or tests repeated and confirmed. When there is a lack of observable data, empiricists typically turn to skepticism. Much of the climate crisis concerns how human activity will severely impact the planet in the *future* in unprecedented ways. All climate scientists can do, is observe the world around them and make empirical observations. Skepticism might argue that there is no proof this will continue to happen unless it is observed. If it is *hypothesized* that these changes are human produced, we won't *know* that until we see these future predictions validated by observable data in the future. So, a rejection of climate science is a simple matter of empiricism, not ethics.

In reply, I wish to extend Gardiner's similar response: "To invoke such skepticism selectively against climate science ignores the fact that all science, and almost everything else that we claim to know, is vulnerable to the same charge" (462). First, this type of narrow reliance on absolute certainty is constrained *only* to climate science. It is apparent, we do not hold this same standard in the other sciences. Further to this end, a pure empirical approach can have dangerous consequences if it is the only foundation of how we define all our scientific knowledge. Of course, observable data is essential, but this information indicates trends, associations, and relationships which have future implications and require a rationalist approach as well. *Rationalists* would also see that reason can provide an additional layer of knowledge. On top of this observable data, we can reasonably conclude these trends and observed associations will impact climate systems if emissions continue. Therefore, selectively using a purely empirical approach subject *only* to climate science, which excludes reason (as defined in *rationalist* terms) also indicates moral corruption.

This type of objection borrows from Hume's problem of induction, which Gardiner also considers. For Hume, empirical knowledge assumes that all events of the past will resemble the future. Therefore, he casts doubt on the strength of the foundation of an empirical claim in the first place. While it is philosophically worthwhile to ponder, sticking to this idea of knowledge and the practical applications of this thinking would have deadly consequences.

These consequences can be seen especially with regards to the results of some of the studies presented earlier in this paper. Many of these studies require an extrapolation of current observations, providing a regression (or line of best fit) which explains current associations, and if they continue to follow the observed trend, they are projected to be responsible for *x* number of deaths in the future or *x* number of dollars lost in life years and productivity (*See Section 3: Economic Costs* for these figures per region).

If one were to hold this knowledge to strict empirical claims, an empiricist wouldn't reject any of the observed findings, but would find issue with any projections or trends which aim to explain phenomena which hasn't been measured yet. Appealing to Hume, they might argue that just because these events have happened in the past is no guarantee they will occur in the future (Hume's problem of Induction). This seems self-defeating since it might imply that the previous data is valid but won't rely on that same data to inform future decisions. So how is this knowledge beneficial if it can't be used to save the lives of future people? Clearly, we *aren't* holding air pollution science to the same epistemological standards as climate science. This way of thinking again exemplifies the selective skepticism used to deny the climate crisis.

Another layer of reason, statistics, data extrapolation and probability can allow us to address air pollution and also the climate crisis backed by strong evidence supporting its likelihood of occurring. Both climate science and air pollution studies rely on the same method of knowledge- observable data, and future projections supported by that data and reason. However, we are more compelled to address air pollution before climate issues partly because we are holding it to a different standard of knowledge. Many won't ask of air pollution studies the same certainty they ask of climate studies. As Gardiner points out, if we aren't doing this for other fields of science, it is morally corrupt to *selectively* hold climate science to this standard.

4.2 Reducing Emissions and Institutional Responsibility

From a social and political perspective, I now turn to an institutional responsibility for reducing emissions and combatting climate change. The ramifications of anthropogenic climate change present current political institutions with a problem. In accordance with their theories of civil society and justice, I will look at how the ideas of John Locke and John Rawls point to justified institutional responsibility for preventing the continuation of excess greenhouse gas emissions and air pollution.

John Locke and the State of Nature

Political institutions are responsible for preserving and protecting our equal liberties and natural rights from interference. This notion espoused by Philosopher John Locke, plays a central role in his framework for the roles and responsibilities of governments in *The Second Treatise of Government (1690).* It also has strong implications when considering the effects of climate change. According to Locke, a state of nature grants us equal freedom. When the will of another imposes itself against our own, these rights are violated, placing the two parties in a state of war. Locke proposes that to protect these equal freedoms, we relinquish a few natural rights to gain the protection of civil society. Such protections are at a very minimalistic level, in which the individual is allowed protection from interference but not to the extent in which the government explicitly bestows privileges beyond non-interference upon them. Locke claims we tacitly consent to join a civil society which enforces retribution and restraint on our behalf while protecting our rights to life, liberty, and property from interference.

Individuals who aren’t the primary producers of greenhouse gases which drive climate change will severely suffer the consequences of carbon producers (Stern, 2015). There are entire populations already altering their way of life in response to changing environments (Robinson

2018). The will of carbon producers negatively interferes with these vulnerable, predominately poor, impacted populations- placing them in a state of war. Dirtier air and increased temperatures are linked to premature mortality and illness, a violation on one's right to life. In the U.S, the coal industry donates heavily to members of legislation, influencing decisions on regulatory policies, violating individual liberty (Davenport, 2019). When privately owned land is vulnerable to flooding and destruction powered by stronger storms, the right to property is also violated in this state of war. Civil society is responsible for upholding the "...mutual preservation of their lives, liberties and estates [property]" (Chapter IX). Thus, political institutions are responsible for protecting these rights from interference.

However, one might object to institutional responsibility as argued through this framework of government and justice. Looking at it from the other side, how might this type of institutional implementation of justice be carried out on the producers of carbon dioxide in a way that doesn't grant exclusive rights? Most emissions are not from a single point source, so how can one possibly match the violated individual to the responsible offender, allowing civil society to offer justice in a way that protects freedom from interference? To this point, the rights to clean air and protected land would be rights conferred upon a preferred population. Arguably, any institutional interference to protect one class of citizens, would come at the cost of violating the rights of the opposing group. As many leaders have proposed, we need to completely alter the ways in which we live to prevent pushing Earth's beyond its temperature threshold (IPCC, 2013). These policies would violate the liberties of carbon producers and firms in order to prioritize poorer citizens already impacted by climate change. Political institutions serve to protect against interference, not interfere on behalf of one group at the expense of another.

In reply, Locke would reaffirm that these immediate negative impacts on health would place the two populations in a state of war. Had the civil state upheld its aim to protect life and ensure equal liberties, it would have stepped in at these first signs of polluters imposing their will upon the rights of vulnerable citizens. However, breathing dirty air, and mining for coal have direct consequences on human health- one's right to life.[2] Institutional involvement would still maintain these rights from interference without bestowing preferential policies on the vulnerable, as justified by a clear indication the two populations are in a state of war. Both the polluters and most severely impacted entered a civil society which offers retribution on their behalf- policies which limit the emissions of carbon producers are not preferential but a part of the society these producers tacitly entered. Thus, political institutions are justified in taking responsibility for combatting climate change that maintains equal rights and provides protection from interference for *all* citizens.

John Rawls and the Difference Principle

What differentiates John Rawls' ideal theory of justice from his predecessors is that it includes future generations. Within the context of climate change, this consideration has important implications. Rawls lays this out in *Justice as Fairness: A Restatement (2001)*, specifically in conditions for the *difference principle*. For Rawls, "The most fundamental idea in this conception of justice is the idea of society as a fair system of social cooperation over time from one generation to the next." (Rawls, 2001) This generates a just system of cooperation constructed in a way that maintains fairness for all citizens of today and of *tomorrow*. A central

[2] As was indicated by the Great Smog of 1952 in London which is estimated to have killed 10,000-12,000 people. See National Geographic Society "Dec. 4 C.E: Great Smog of 1952" 17 December 2013 https://www.nationalgeographic.org/thisday/dec4/great-smog-1952/ web accessed 28 April 2019

problem of addressing climate change, is that its most devastating effects fall on future generations who have by no action of their own contributed to it. For Rawls, this is unjust.

Rawls formulates this ideal theory of justice using the *original position* and *difference principle*. "… fair equality of opportunity and that social and economic inequalities be governed by the difference principle."(Rawls, 47) He argues we would select this principle behind what is called "the veil of ignorance", where individuals are asked to choose principles of justice in a society where they don't know how or *when* they will be situated. Therefore, the consensus falls on ensuring both the "least advantaged" and "most advantaged" have equal liberty and ability to create meaningful lives for themselves. This means the "least advantaged" still have the *absolute* best position in society and opportunities for mobility. This is intended to combat luck, where inequalities are a product of circumstances beyond the individual's control yet still allows for the natural inequalities in what Rawls calls a well-ordered society. "It should express a principle of reciprocity, since society is viewed as a fair system of cooperation from one generation to the next between free and equal citizens." (Rawls, 77) The actions of carbon producers today will impact future generations, harming the opportunities and necessary conditions in which these later generations create meaningful lives. The *difference principle* implies that a well-ordered society ought to be structured in a way which protects these conditions, allowing future citizens the equal opportunities and necessary conditions regardless of the actions of their predecessors.

One might reject Rawls's claim since placing any type of restraint on fossil fuel production in the name of the *difference principle* promotes a single comprehensive doctrine. Such an objection might argue that the *difference principle* is convenient because it *follows from* a specific doctrine and is vague in what the necessary conditions are for supporting opportunities for creating a good life. Laying claim to the conditions for future generations with different values and goals could be considered preferential and even paternalistic. Arguably, the least advantaged enjoy the benefits of a fossil fuel-powered society since it provides more affordable consumer goods and cheap transportation. However, this comes at the cost of harmed environmental and human health. A meaningful life for individuals living forty years from now may be satisfied by access to cheap power and transportation without regard to living on the coast, while a meaningful life is defined by enjoying earth's unaltered landscapes and weather conditions for others. Must we paternalistically favor one individual or group in the future over another?

Rawls would reply to this by emphasizing that the *difference principle* is arrived at through an *overlapping consensus.* This allows for a basic structure that avoids domination by a single comprehensive doctrine. A government structured with the *sole* intent of protecting the interests of a targeted generation or socioeconomic population would be paternalistic and comprehensive. It is important to emphasize the theory does not support this. Rather, the proper conditions will follow from the *difference principle*, allowing the least advantaged of future generations to have the same equal liberties as the generation of today.

The *difference principle* is not about pushing for an environmentalist doctrine enforced by the government but rather, is about maintaining the ability for the least advantaged of today and tomorrow to create meaningful lives. When climate systems are pushed out of equilibrium, it alters the ability of future generations to live healthy lives, meaning they will not have access to the same environment and climate conditions as their predecessors- which is unjust in Rawls' social cooperative scheme. With the *difference principle,* a basic political structure will have an obligation to preserve those equal liberties against any threat. Climate change and poor respiratory health due to poor air quality are threats. Thus, responsibility *follows* naturally from the *difference principle*. It provides support for institutional action and initiatives which maintain a well-ordered society. Therefore, political institutions would be justified in their actions to reduce emissions that protect citizens' opportunities to create meaningful lives, providing justice for *all* individuals of *today* and *tomorrow*.

V. Global Environmental Policy

As this paper has shown, it is irrefutable greenhouse gas emissions are detrimental to the health of the planet and pose an immediate threat to human health. Considering this evidence, I have argued that institutions have an ethical obligation to act in promoting the wellbeing of their current and future citizens. I have also considered a potential philosophical roadblock and responses to appropriate climate and health action: that epistemological claims against climate science are morally corrupt.

In this section, I discuss the types of policies, legislation, and other major tools for air pollution control in China, the U.S., and the European Union. As the most recent Paris Accords (2015) show, many of these policies are enacted to align with international efforts to gather the global cooperation necessary to reducing worldwide emissions. Solving this problem requires the participation and cooperation of all polluting entities fulfilling their commitments internationally. Some of these agreements and summits have been successful while others have dramatically failed. At the end of this section, I will discuss the characteristics of a successful international policy and what can we learn from failures to guide future agreements.

5.1 China: Current Legislation and Policies

Many of China's environmental policies are found in their Five-year plans (FYPs) which are centralized and nationally enacted in addition to separately established standards, rules and special actions outside of the FYPs (Andersson et al., 2016). In 1979 the third Chinese Constitution included an environmental commission and since then China has issued roughly 30 environmental control laws, with one being the Law on the Prevention and Control of Atmospheric Pollution. However, it has been noted that many of these policies are weak and difficult to enforce in recent decades. This issue of enforceability is not limited to China, as it also poses a problem for nations in the EU and the U.S.

The Ministry of Environment has established a series of emission standards and air quality standards that are aligned with global ones and are notably stronger and more stringent for power plants than those in the U.S. and Japan.

The country relies on both price and non-price policies. Using price, they have implemented standards and taxes (pollution fees for excess emissions). From a non-price perspective, they require all construction projects to include environmental impact assessments before building. They also use the good favor of the centralized government to encourage local governments to reduce their emissions. As I will discuss later, a majority of unsuccessful international accords and agreements have relied on non-price policies.

Some issues that accompany these nationwide policies have proven to inhibit their effectiveness and show that broad policies are not as efficient due to the heterogeneity of China's local departments and districts. Marginal abatement costs differ by each sector, demands that drive the production of pollutants vary, and an overall difficulty of the administration to accurately track and enforce these measures limits the impact of decreasing air pollution.

While the country still has a long way to go in its battle against air pollution, it has made some considerable steps in cleaning air quality and reducing emissions. A regionally specific plan to improve Beijing's air quality in anticipation of the 2008 games was considered incredibly effective- plants were closed and traffic was controlled. However, by late 2009 these changes were not sustained and the quality decreased. It wasn't until the 2013 crisis in which a severe haze triggered by excess $PM_{2.5}$ covered much of China that they considered air pollution a top priority. The government developed The Action Plan to:

Air Quality Improvement Goal

1. By 2017, the urban concentration of PM_{10} shall decrease by 10% compared with 2012; annual number of days with fairly good air quality will gradually increase
2. Concentration of $PM_{2.5}$ in the BTH, YRD and PRD regions shall respectively fall by around 25%, 20% and 15%
3. $PM_{2.5}$ annual concentration in Beijing shall be controlled below 60 mg/m^3

Ten Tasks

1. Increase effort of comprehensive control and reduce emission of multi-pollutants
2. Optimize the industrial structure, promote industrial restructure
3. Accelerate the technology transformation, improve the innovation capability
4. Adjust the energy structure and increase the clean energy supply
5. Strengthen environmental thresholds and optimize industrial layout
6. Better play the role of market mechanism and improve environmental economic policies
7. Improve law and regulation system. Carry on supervision and management based on law
8. Establish the regional coordination mechanism and the integrated regional environmental management
9. Establish monitoring and warning system. Cope with pollution episodes
10. Clarify the responsibilities of the government, enterprise and society. Mobilize public participation

(Andersson et al., 2016)

It should be noted, however, the importance of trustworthy and transparent institutions facing domestic and international crises. Currently, political power is centralized in China's communist state. Many of the studies from this paper analyzing Chinese air pollution were conducted by researchers outside of the state. Accurate data, transparency of air pollution information, and commitments to follow through with carbon reductions will be necessary not only to domestic policy but also when signing international agreements.

As things stand, China acknowledges the serious threat air pollutants pose to their citizens and to their environment. While steps are being taken, and the public begins to express a further interest in reducing their emissions, China as the largest global polluter will need to make some drastic changes. A combination of price and non-price policies, alignment and participation in international agreements, Institutional transparency and cooperation, and lifestyle altering decisions will be necessary tools vital to a reduction in emissions. Hopefully the direct threats to human health will motivate the necessary changes now, but an international cooperative scheme will be helpful in holding countries to some accountability, as well as providing solidarity. If these changes are to have a global impact, it will require the global participation, starting at the country level.

5.2 The United States and the Clean Air Act (1970)

In the United States, visible smog in many of the nation's cities, powered by the environmental movement brought about the landmark Clean Air Act in 1970. Since then, it has been ratified in 1977 and 1990 (EPA, 2017). Broadly, the Act established national ambient air quality standards (NAAQS) for six common pollutants and requires states to enforce those standards. As the studies in Section 3 reveal, strictness of enforcement varies by state. The later ratifications accounted for targeting the emergence of acid rain, and new data which suggested stricter standards to prevent further damage to the ozone layer. The act proved successful in reducing emissions by 73% from 1970 to 2017 (EPA, 2017).

The NAAQS monitor levels of pollution and sets limits to which they cannot exceed. However, as this paper has shown, these standards could certainly be lowered, or altered regionally. Additionally, they face issues of enforceability. Figure **5.2** below shows the current standards and limits on the six "criteria" air pollutants.

Pollutant	**Primary/ Secondary**	**Averaging Time**	**Level**	**Form**
Carbon Monoxide (CO)	primary	8 hours	9 ppm	Not to be exceeded more than once per year
		1 hour	35 ppm	
Lead (Pb)	primary and secondary	Rolling 3 month average	0.15 $\mu g/m^3$ (1)	Not to be exceeded
Nitrogen Dioxide (NO_2)	primary	1 hour	100 ppb	98^{th} percentile of 1-hour daily maximum concentrations, averaged over 3 years
	primary and secondary	1 year	53 ppb (2)	Annual Mean

Pollutant		Primary/ Secondary	Averaging Time	Level	Form
Ozone (O_3)		primary and secondary	8 hours	0.070 ppm [(3)]	Annual fourth-highest daily maximum 8-hour concentration, averaged over 3 years
Particle Pollution (PM)	$PM_{2.5}$	primary	1 year	12.0 μg/m^3	annual mean, averaged over 3 years
		secondary	1 year	15.0 μg/m^3	annual mean, averaged over 3 years
		primary and secondary	24 hours	35 μg/m^3	98th percentile, averaged over 3 years
	PM_{10}	primary and secondary	24 hours	150 μg/m^3	Not to be exceeded more than once per year on average over 3 years
Sulfur Dioxide (SO_2)		primary	1 hour	75 ppb [(4)]	99th percentile of 1-hour daily maximum concentrations, averaged over 3 years
		secondary	3 hours	0.5 ppm	Not to be exceeded more than once per year

Figure 5.2 “NAAQS Table” EPA 20 December 2016

Many of the EPA's environmental decisions, as a governmental organization, have fluctuated with different presidential administrations. This can be concerning, since it lacks consistency and longevity, and is instead victim to political volatility. The Obama presidency implemented policies, standards, and regulations which closely monitored air pollution and other environmental harms. Having completed 58 environmental rollbacks, the Trump administration is currently processing an additional 37 (Popovich et al., 2019). For air pollution and emissions, 16 rollbacks have been completed with 9 still in process. When considering policy at the international and domestic levels, flexibility and amendments to accommodate a changing environment while maintaining the original purpose of the policy are important (as will be noted in the Montreal Protocol). However, the types of changes in the United States do not reflect a long-term commitment to environmental legislation and protection. These policies should not be subject to whims of changing administrations if they are to prove effective.

5.3 The European Union

Despite being among the world's top polluters, the EU has some of the strictest environmental standards in the world (Library of Congress, 2019). With their 2015 emissions down 22% from 1990 levels, they provide guidance for member states in addition to their domestic policies. Of their environmental policies, air quality has been an important focus since the 1970s. In 2008, a binding Ambient Air Quality Directive on all EU states was implemented with the following goals:

- Thresholds, limit values, and target values for each pollutant covered by the directive.
- Specifically designated national bodies to carry out the tasks of the directive.
- Air quality plans to address situations where pollution levels exceed limit or target values in a zone or agglomeration. Air quality plans set out measures to attain the limit or target

values and may include specific measures to protect sensitive population groups, such as children.

- Short-term action plans if there is a risk that pollution levels may exceed one or more of the alert thresholds. These may include measures to reduce road traffic, construction works, certain industrial activities, or domestic heating, as well as specific measures to protect sensitive population groups.
- Provide information about ambient air quality, air quality plans, and other related topics to public and environmental, consumer, and other relevant organizations by means of any easily accessible media including the Internet.
- Publication of annual reports on all the pollutants covered by the legislation of EU Member States. (Library of Congress, 2019)

At a very broad level these are the general goals which frame many of the various environmental legislation the EU has in place. They have emissions standards for vehicles (light and heavy duty) and have banned fuels with lead and high concentrations of sulfur. With regards to industrial emissions, they have also set emission limits and integrated permitting in the initial plans and approval process for construction (Library of Congress, 2019).

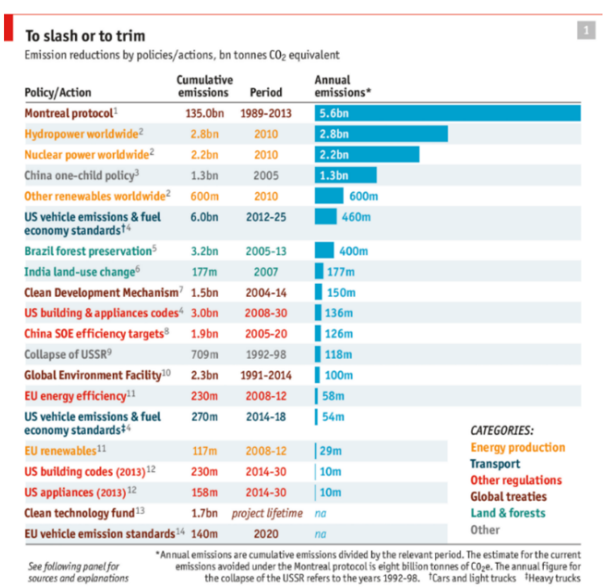
On top of these EU regulated standards and goals, many of the countries within the coalition have been placing their own standards on pollutants. While the air pollution and “London fog” that periodically covered the English city was a known phenomenon- it wasn’t until the middle of the 20th century, that the catastrophic impacts of air pollution on human health were made clear (Martinez, 2020). The Great Smog in 1952 is estimated to have killed 12,000 people (Klein, 2018). Caused by a stalled pressure system which trapped the stagnant cold air under a warm air layer, coal smoke was unable to rise. Without any wind, it stalled causing immediate and direct impacts on health and poor visibility throughout the city. The 1956 Clean Air Act passed as a direct response to the event- placed restrictions on coal and domestic fires in the city, and subsidized a domestic switch to oil, natural gas, electric or coal alternative heating sources (Martinez, 2020).

Again, while it is admirable that the EU and its respective states have air pollution laws in place- the studies in this paper reveal many citizens remain at risk of poor health. Similar to China and the U.S, these entities still have more room to improve their environmental policies on emissions for the benefit of their citizens today and the environment and health of the future.

5.4 International Cooperation: Success and Failures

While these internal measures can have beneficial impacts to citizens of those respective countries, reductions must be made globally to effectively slow the changes we are making to Earth’s climate. We can learn from some of the failures and successes of past policies to provide a helpful framework in developing future policy.

The Montreal Protocol of 1987 serves as a successful template for future international agreements in climate change management agendas. Prompted by the dangerous reduction of ozone because of hydrofluorocarbon emissions, 189 countries supported reducing their emissions



To slash or to trim

Emission reductions by policies/actions, bn tonnes CO_2 equivalent

Policy/Action	Cumulative emissions	Period	Annual emissions*
Montreal protocol[1]	135.0bn	1989-2013	5.6bn
Hydropower worldwide[2]	2.8bn	2010	2.8bn
Nuclear power worldwide[2]	2.2bn	2010	2.2bn
China one-child policy[3]	1.3bn	2005	1.3bn
Other renewables worldwide[2]	600m	2010	600m
US vehicle emissions & fuel economy standards†[4]	6.0bn	2012-25	460m
Brazil forest preservation[5]	3.2bn	2005-13	400m
India land-use change[6]	177m	2007	177m
Clean Development Mechanism[7]	1.5bn	2004-14	150m
US building & appliances codes[4]	3.0bn	2008-30	136m
China SOE efficiency targets[8]	1.9bn	2005-20	126m
Collapse of USSR[9]	709m	1992-98	118m
Global Environment Facility[10]	2.3bn	1991-2014	100m
EU energy efficiency[11]	230m	2008-12	58m
US vehicle emissions & fuel economy standards‡[4]	270m	2014-18	54m
EU renewables[11]	117m	2008-12	29m
US building codes (2013)[12]	230m	2014-30	10m
US appliances (2013)[12]	158m	2014-30	10m
Clean technology fund[13]	1.7bn	*project lifetime*	*na*
EU vehicle emission standards[14]	140m	2020	*na*

See following panel for sources and explanations

*Annual emissions are cumulative emissions divided by the relevant period. The estimate for the current emissions avoided under the Montreal protocol is eight billion tonnes of CO_2e. The annual figure for the collapse of the USSR refers to the years 1992-98. †Cars and light trucks ‡Heavy trucks

Figure 5.4 “To slash or trim” (Economist, 2018)

of the chemical (Graff-Zivin, Krumholz, 2018). These pledges were ensured by a strong incentive to comply- as those who broke their promise would be faced with trade penalties. This is important to note, since a criticism of the 2015 Paris Accord has been its lack of any type of incentive or enforcement mechanism. Additionally, a key to the protocol's success is found in its flexibility. Having had eight amendments since its implementation, it has evolved with further scientific developments and time, lending to its long-term relevance (Graff-Zivin, Krumholz, 2018).

The protocol has also been wise to consider the hurdles developing nations might face in meeting their goals. Therefore, it had developed countries cover their costs. Since its implementation and up to 2017, those total costs have been very small- totaling $3.1 billion. Furthermore, the United States alone can attribute saving a projected 1.5 million lives from skin cancer deaths, 283 million from skin cancer cases and 45 million cataract cases from 1987 to 2100 to the success of the protocol. **Figure 5.4** shows how significant of an impact this protocol has had relative to other initiatives. And it is projected that as a result, Antarctic ozone will return to pre- 1980 levels by 2050 (Graff-Zivin, Krumholz, 2018).

The *Kyoto Protocol of 1997* on the other hand is considered less successful. After the release of the first IPCC report in 1990 which concluded human activities would be responsible for a 0.3℃ increase in global temperatures per decade, an international summit was held to address the growing crisis (Gardiner, 2009). At the summit in Rio, countries committed to voluntarily reducing their emissions by 2000. Yet this proved to be wildly ineffective. In light of the second IPCC report in 1995 and a lack of commitment, the international community agreed on binding restraints on emissions in Kyoto in 1997. The agreement required that between 2008 and 2012 each country would reduce emissions to roughly 5% below 1990 levels. Unfortunately, before it was ratified by a handful of countries in 2005 (excluding India and China, since they were hardly big emitters at the time), the United States dropped out due to disagreements over compliance mechanisms (Gardiner, 2009).

It wasn't until halfway through the 1990-2012 period that the protocol became national law, at which point from 1990-2009 global emissions increased roughly 40% (The Guardian, 2011). While an admirable first step in at least *acknowledging* the threat of climate change on the international diplomatic stage, it did little in holding many countries accountable nor did it secure the cooperation of some of the world's biggest polluters. China and the United States emitted enough greenhouse gases during that time period to nullify any of the efforts made by the committed nations (The Guardian, 2011). This large failure highlights the necessity of having total global cooperation if these reductions and commitments are to be effective.

The Paris Accords of 2015. Perhaps the most anticipated of global agreements in recent years, an international body sought- yet again- to curb global emissions. This time supported by the United Nations Framework Convention on Climate Change (UNFCC). A broad agreement which relied on ratification and signature excluded any type of binding mechanisms, tariffs, or negative incentives to prevent noncooperation (NPR, 2017). Bold and ambitious, the pact sought to reduce emissions by "Holding the increase in global average temperature to well below 2℃ above pre-industrial levels ..." (NPR, 2017). However, it seemed to be more of a promise than a binding policy- lacking guidelines as to how countries ought to make these changes. It also asked that developed countries provide $100 billion a year to help developing countries make the move towards greener energy sources.

12 December 2015 was historic as representatives from 196 countries made the pact to adopt the suggested policies and reductions in the Accord. Without binding mechanisms, perhaps

this was an indication that the global attitude was shifting towards a serious need for a reduction in emissions. As I argued earlier in the Philosophical section of this paper, perhaps binding mechanisms weren't needed since many nations have come to accept their agreement was the ethical thing to do, that it was a duty to protect the health of their citizens and their environment. This optimism was short-lived. In 2017, the United States under the Trump administration withdrew from the agreement. Without the world's second highest emitter committed to the agreement, it is unlikely it will be as effective before the withdrawal. However, the sentiment is still there, and while this policy is unlikely to live up to it's potential to implement change, it is another step in acknowledging the global threat of the climate crisis.

Despite yet another acknowledgement, or what some have argued is nothing more than a mere "shadow solution",[3] we are running out of time. Urgent change is required, and effective policies are vital to assisting in this international effort and addressing the "global storm" (See *section 4*).

5.5 What do these past international efforts imply for successful future policy?

It is quite clear that global commitment and action is necessary to lift the fight against climate change off the ground. International policy and agreement, with the full cooperation of its member nations, is an excellent way to coordinate these reductions and responses to fight what Gardiner labels the "Global Storm" (2009). As an economics background would indicate,

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[3] As discussed by Stephen Gardiner in *A Perfect Moral Storm, the Ethical Tragedy of Climate Change.* In which a nonoptimal policy has the appearance one is doing more than they claim. This isn't the real thing and relies mostly on appearance or self-deception. Some argue these shadow solutions are first steps, as I have. But Gardiner would claim this view is dangerous as it gives the illusion of action. To briefly support my claim, I would argue change is gradual. And people require time to adjust and process life altering events. In the case of the climate crisis, acknowledging it gradually may allow people to see it rather than run from the overwhelming nature of considering it all at once. As we are running out of time, I would argue we have taken enough "first steps" and have failed and succeeded enough to allow for a successful framework moving forward.

people respond strongly to incentives. The differences in the Montreal Protocol and Paris Accords indicate this. If there are binding mechanisms that will hold nations accountable for upholding their end of the agreement with no incentive to deviate, it is more likely to effective. Additionally, the salience of the issue seems to have a greater impact on motivating action. What initially inspired the subject matter of this paper- a focus on human respiratory health linked to emissions followed from my earlier research on the Montreal Protocol. I noted how nations were more strongly motivated to act when their immediate health was at stake.

As I discussed earlier, the intergenerational nature of addressing climate change doesn’t seem to be compelling enough for institutions and individuals to act now. Perhaps focusing on the direct impacts of these emissions can go around this issue and produce the necessary changes before it is too late.

However, it is important that the intergenerational issue is still acknowledged when developing policy. As noted earlier, an ethical framework is vital to guide us through this global crisis. We must maintain our moral duties to uphold justice for people of all socioeconomic backgrounds and incomes. These policies should be enacted because we care about our own generation but are also upholding our moral duty to preserve the conditions and environment for later generations. We must also acknowledge the duty many institutions hold in maintaining the basic well-being of their citizens.

With binding mechanisms, an appeal to current generations, but also an acknowledgement of our moral duty to act ethically, future policies have the potential to produce more effective results.

VI Considerations and Conclusion

The evidence connecting emissions, respiratory diseases, premature mortality, and climate change is abundant. Despite this, the effort to reduce global greenhouse gases will not be an easy one. Each proposed policy, investment in green technologies, and lifestyle change will incur some cost. Inevitably these costs are and will continue to be weighed against the potential costs of climate change if we continue our complacency. These are important to consider and will play a significant role as we weigh these costs and benefits moving forward.

Clearly some concerns arise surrounding the fossil fuel industry. What will become of miners, and the jobs created by other fossil fuels? At what point are people willing to accept that the costs of poor health far outweigh the benefits of finite energy sources? Evidence that these questions are being asked has become apparent. Take for example the citizens in Fos-Sur-Mer, France; one of Europe's most polluted towns but with plenty of jobs in factories, warehouses, gas terminals, and industrial sheds (Nossiter, 2020). For decades, they accepted the trade-off valuing good jobs over poor air quality, and now they are filing a criminal complaint against those companies that have risked their lives to support their industry. One of these citizens is Sylvie Anane.

> "Sylvie Anane, who lives within breathing distance of the industrial plants, has suffered a debilitating tally of illnesses: heart problems requiring a stent in 2001, ovarian cancer in 2002, diabetes in 2003, thyroid cancer in 2008, a heart attack in 2010, breast cancer in 2015 and another heart attack in 2018" (Nossiter, 2020).

Alongside other residents, the complaint attacks the permissibility of industrial plants to be so densely packed into human inhabited areas. While a great opportunity for economic growth and high rates of employment, this is balanced against the cost with regards to health- and its toll has been made apparent after decades of exposure.

What are the costs of decarbonization weighted against the costs of lost life years, higher morbidity rates and corresponding strain on the healthcare system? Hopefully this literature review, compiling just a fraction of the hundreds of studies quantifying the costs can provide information when making these decisions. The costs of decarbonization are valuable to consider but they go beyond the scope of this paper.

Beyond the logical, practical, and scientific reasoning for action to reduce emissions, there is a strong case for decarbonization on ethical grounds. The way in which we power our world is unfair. It is unfair to the millions who die of air pollution each year, and it is unfair to the generations who will follow us. As Rawls and Locke suggest, governments are justified in taking action to protect the lives of all their citizens for today and for tomorrow.

Air pollution takes a great toll on immediate human health. In addition to serving these interests, we have a moral duty to address the climate crisis. Before it is too late, we can reduce our environmental impact, prevent the premature deaths of millions annually, and prevent the most severe climate catastrophe. This path will not be an easy one, but the costs of inaction are too high to bear. We must take action to create cleaner air, healthier people, and a sustainable future. We must do this for ourselves, for our children, for their great grandchildren, and the fragile ecosystems and diverse array of life which is dependent on properly functioning climate systems. We have no other choice.

VII Special Note.

Writing about respiratory health during the COVID-19 Pandemic

Written on 8 April 2020, Modified 1 May 2020

This project has taken up roughly two years of my undergraduate career. Inspired during my studies during the Summer term of 2018, I began working that Fall term with completion planned for May 2020. As I began writing and editing my final drafts in the Spring of my final year, the novel coronavirus, COVID-19 had officially been declared a global pandemic. Following the example of many countries hit earlier this year (China, Spain, Italy, France) the United States began declaring state by state lockdowns and stay at home orders. Universities are closed, many international flights have been grounded, healthcare systems overrun, non-essential workers have lost jobs, and the death toll has been gradually rising in some locations, while peaking in others, with places like New York City at the epicenter of the U.S outbreak. Currently, 3.2 million people have been infected globally and 233,998 have died worldwide. While efforts to flatten the curve appear to be working the numbers are still rising in some parts of the country. As I have been editing and writing the final sections of this thesis, it has been under very unusual circumstances, of which I am constantly aware.

While urban areas have been presenting the most cases (that we are aware of based on current data and testing) Wuhan, Milan, Barcelona, Paris, Seattle, and New York City have seen the highest numbers of concentrated cases in one area. It makes sense that an incredibly contagious and infectious disease would have no issue spreading more rapidly and to more people in these densely packed urban environments. However, I wondered if sustained exposure to air pollutants has made some of these otherwise mild cases more severe. As many of the studies presented in this paper have shown, air pollution is responsible for compromised respiratory health. I hypothesized, based on these studies, that when faced with a serious respiratory disease it would be likely that these individuals with preexisting poor respiratory health linked to air pollution were more likely to have a severe case of the virus.

While this situation has evolved dramatically and will continue to evolve after I have submitted my thesis, researchers appear to have been asking the same questions. Given the current data, researchers at Harvard University conducted “A national study on long-term exposure to air pollution and COVID-19 mortality in the United States”. It is important to note that these results are likely to change as we gain a more robust picture of what is actually happening in the U.S as the spread of the virus develops over time, but the results supported some of my initial intuitions this thesis would suggest. Using data for roughly 3,000 U.S counties and adjusting for variables such as population size, hospital beds, numbers of individuals tested, weather, socioeconomics and behavior, they found a statistically significant result: an increase of only 1 μ/m^3 of PM is associated with a 15% increase in COVID-19 death rate (Braun et al. 2020).

The recent study at Harvard wasn’t the only one considering the links between a severe coronavirus case and exposure to air pollution. Following the SARS (Severe Acute Respiratory Syndrome- a strain of coronavirus) outbreak in 2002, Cui et al. (2003) noticed the geographical differences in fatalities and conducted a study to see if air pollution played a role in this geographical disparity. This study found a positive association between air pollution and an increased risk of dying from SARS.

Unfortunately, I’ve also noticed some parallels between those who feel the worst of the impacts as a result of this crisis and the climate crisis. People of color and lower incomes are suffering some of the highest death tolls and rates of infection. The Bronx in NYC is a hotspot within the city. Just as the poorest of us will feel the impacts of a changing climate first and the most severely, these groups are also breathing dirtier air and suffering from the pandemic.

What I've taken away from experiencing a global pandemic relative to addressing the climate crisis and excess air pollution, is the value in addressing preventable health diseases, the role of competent governments and institutions, and the capacity and preparedness of the international community to respond to a global crisis. There are lessons to be learned here for the future of infectious diseases, and for future global crises- particularly the threat of climate change.

Considering humanity's long relationship with infectious diseases: Bubonic plague, Smallpox, The Spanish Flu, Bird Flu, SARS, MERS, etc. it is no surprise that there is now another disease to add to the list, COVID-19. The question of the next global pandemic has never been an *if*, but *when*. And while we can mitigate the impacts through plans and protocols, it is hard to predict *when* the disease will arrive putting us at a severe disadvantage. However, it is clear competent institutions[4] with disease action plans and aggressive attention and response to potential threats will be more successful in slowing the spread and mitigating the devastation of a global crisis.

Currently the U.S is facing medical equipment shortages, lack of testing, and other issues due to a lack of preparedness and attention to the potential severity of the threat in its early stages. Instead of taking proactive steps to mitigate and plan for a potential crisis our country took a "let's wait and see" approach leading to a more severe and deadly crisis (at this time, the U.S has the highest death toll in the world, just surpassing 60,000). Without a federal plan, it has

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[4] At the time of this writing, Donald Trump has announced he will no longer fund the WHO to shift blame away from his mishandling of the situation. Even though the warnings and procedures of the National Security Council Playbook on infectious diseases and potential biothreats went ignored by the administration.

been the leadership of individual states and governors ordering uncoordinated lockdowns at different times and with degrees of severity. Granted, it is up to individuals to carry responsibility in how seriously they will social distance but having strong unified leadership that has prepared for a time of crisis is essential.

At this point in time (8 April 2020), Italy is beginning to report a decline in cases and daily deaths, and Wuhan, China has lifted restrictions after 11 weeks in lockdown. This crisis is showing that global and individual cooperation can yield effective results. Additionally, as the number of commuters has decreased, and some factories have closed, major cities are seeing dramatic decreases in air pollution and better air quality (Popovich, 2020). This type of pollution shock could prove useful to future climate and environmental studies. While these measures are temporary, it certainly proves that achieving clean air is possible. It has made me ask, how can we use new technologies and more efficient transportation and energy systems to sustain these low levels of pollutants once these areas reopen?

It is irrefutable this type of global pandemic has devastated lives and the global economy at an astounding rate. From patient zero identified on 31 December 2019 to 3.2 million cases and a near global shutdown of non-essential workers on 8 April 2020, the United States unemployment rate is roughly 14.7% with many other countries feeling the declining economic impact. The threat of a global pandemic has always posed some degree of risk. However, it is clear that the unpreparedness of many countries shows one of two things. They either assumed the probability of one occurring was too low to be considered a substantial threat or underestimated the impacts this disease could incur globally. Likewise, we see similar attitudes of underestimating the severity of air pollution and the climate crisis.

The global mood right now is not an optimistic one. With each new death, the weight of the lives lost is more than a distant statistic. Assumptions that we will immediately go back to business as usual once lockdowns end are mistaken. I will be graduating into one of the worst job markets in a century. It is possible I will not study in a classroom this Fall. I am part of a generation scarred by the loss of hundreds of thousands of people. The impacts of this crisis will stay with us long after a vaccine is developed. The effect on mental health following unemployment, isolation, and the loss of a loved one without a goodbye will carve deep marks in the global psyche once we emerge from this. I worry that sanitation efforts will take us one step back in terms of sustainability- the increase in use of single use plastics may rise, and many might avoid public transportation. I worry that the in-person relationships we forge with international friends will no longer be the same.

Despite all this, I remain optimistic.

I remain optimistic that in the face of a future looming crisis, there are many lessons we can learn from this pandemic. Just like our actions have consequences on the rate of infections, our actions have consequences in other respects. Seeing this, I hope we will take more accountability for the consequences our actions have on the environment and the respiratory health of others.

We are lucky that the climate crisis is *not* a question of *if* or *when*. Exposure to air pollution and resulting poor respiratory health is a known threat. We have the power of advance knowledge and information on our side. Millions die annually of air pollution. Excess emissions resulting in a warming planet, and catastrophic environmental devastation that will occur this century. Given this knowledge, excellent international collaboration on coordinating accurate scientific research, and detailed modeling and projections, we know when and how this crisis will occur. My generation and the ones that follow will certainly be impacted by it. I believe in particular, that mine still exists within a rare window of opportunity to do something about it.

In the limited time we have left before we reach the 3℃ threshold from which we cannot return, we can take action to mitigate these impacts and lessen the overall warming. We can protect our environment and the health of all who inhabit it. If this pandemic has taught us anything, we can start by protecting and saving human health. If we make the necessary changes now, the climate crisis does not have to be a catastrophic event for which we claim, “we were surprised”. Unlike the COVID-19 outbreak, we are facing a crisis where complacency is the only thing standing between our own immediate health, the health of future generations, and the long-term health of the planet.

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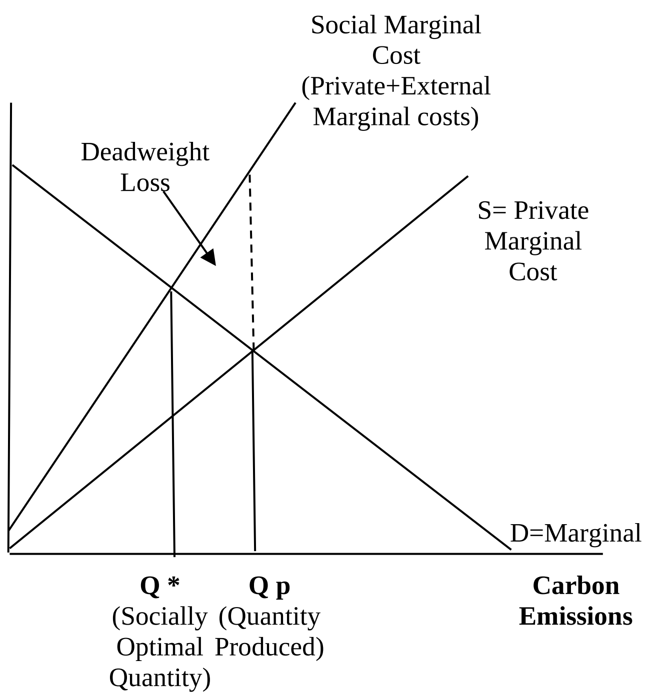
IX Appendix

A.1 Negative Externalities

The current way in which we power our societies through the burning of fossil fuels has individual benefits (for oil companies, investors, consumers of cheap energy etc.) but also comes at a social cost. The social harm (quantified in costs) of these emissions can be expressed as a **Negative Externality,** shown in ***figure 1***.

In this simplified graph of a negative externality, we can see how this market inefficiency looks visually. The effects of emissions (poor air quality, temperature increases, etc.) as well as private costs are expressed by the social marginal cost curve, which exceeds the marginal

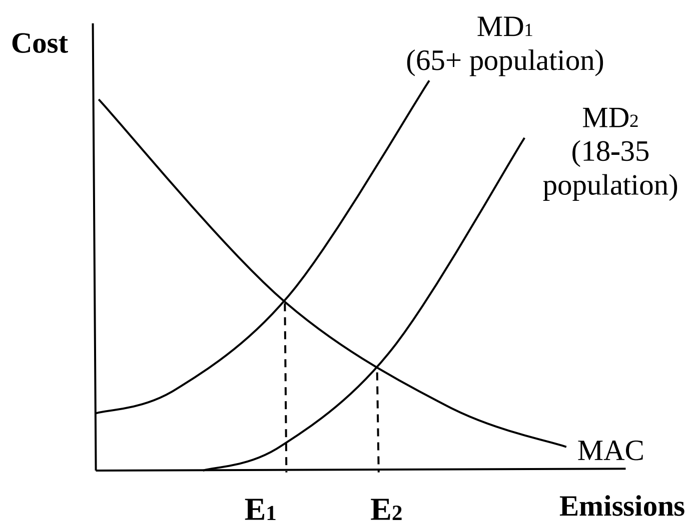


benefits at the quantity produced, thus resulting in a deadweight loss (the triangle depicted).

Given the negative environmental impact, and health costs, the emitted gases and particulate matter produced by all these individual firms is more than what is socially optimal or efficient.[5]

A.2 Marginal Damage Curves

We can also view the impacts of air pollution in terms of different **Marginal Damage Curves** for different populations. Some of the studies discussed in this paper note different groups and their varying sensitivity to poor air quality. Populations 65+ and young children 0-17, are typically the most susceptible. For example, the Marginal Damage Curves (MD) for two populations (65+ and 18-35 can be shown in ***Figure 2***) examining cost vs. emissions on the axes of the graph, the Marginal Abatement Cost (MAC) shows the opportunity cost for a firm who must now use resources to reduce their emissions- called their abatement costs.



[5] For what is considered to be socially optimal, reference the IPCC reports for policy makers. These show the potential CO2 concentrations and their projected impacts on temperature and sea level rise https://www.ipcc.ch/report/ar5/wg2/. Of course it is then important to consider what level of emissions is feasible considering current costs of transportation and energy and Marginal Abatement Costs relative to marginal damages.

As the graph shows, a major issue facing firms and policy makers is determining how much companies should abate and at what cost. Given the variability of these population sensitivities, developing a single socially optimal standard can be challenging.

A.3 Morbidity vs. Mortality

Many of these case studies look at costs measured in premature deaths (**mortality**) and the healthcare costs associated with lifelong illness associated with exposure to poor air (**morbidity**). Measuring mortality is slightly less complicated than morbidity, which seeks to examine all the costs of poor health including those on the patient, healthcare professionals, resources, and the formal and informal care the individual receives. As one study acknowledges, morbidity requires multiple endpoints all of which vary per individual in length and severity (WHO, 2015). This makes it incredibly difficult to find and compile a reliable data set of willingness to pay values for populations in a country, let alone the diverse member states of the European Union.

A.4 Value of a Statistical Life (VSL)

Another concept used to calculate the costs found in these case studies comes from the value of a statistical life. While it is acknowledged that it is nearly impossible to place an exact monetary value on a human life, this method can be useful in giving some monetary expression of the costs of air pollution on human health. Here, economists look at the willingness to pay (WTP) for a marginal change in some particular risk reduction for a group of people. Thus, we can have some form of an estimate that tells us the willingness of an individual to give up some form of their consumption to reduce their risk of death. These calculations lend to better visibility of the magnitude to which air pollution costs individuals and also society.

A.5 Years Life Lost (YLL)

When measuring premature death, Years of Life Lost is a measurement taken into account in many of the studies included in this paper. The calculation takes the age of the person at time of death and the potential years they would have lived based on life expectancies for their demographic in that region (Gardiner et al. 1990). Different values are then assigned at different points for premature death and their respective years lost to measure the social and economic consequences of these early deaths. For example, a child who dies of cardiorespiratory disease will have a higher YLL value than an individual aged 65.

A.6 Loss of Productivity Costs (opportunity costs)

These types of costs are important to measure when accounting for a value of decreased productivity when people are sick. If they are unable to work, they forgo their wages and are unable to fulfil their productive role and job responsibilities. To valuate this, economics may use lost wages as a measure of the next best thing (working) the individual could do if they were not in the hospital or taking time off due to illness.

A.7 Random Effect Modeling in Statistics

When researchers are using random effect modeling, they are creating a model with random variables as the model parameters. Therefore, unlike a linear model in which the data is random and the parameters are fixed both the form of the regression and the data are randomized.

A.8 Time Series Modeling

As the name would indicate, in this method of analysis data points are indexed sequentially. Particularly in studies considering morbidities and the effects of long-term exposure, these types of models take into account health as it relates to long term exposure.

A.9 Summary Charts

Below are the main findings of each study referenced in the section outlining economic costs.

Case Study Summary				
Study	**Year**	**Pollutant**	**Key Findings**	**Authors**
China				
The impact of Sustained Particulate Matter on Life Expectancy: New Evidence from China's Huai River Policy	2017	Particulate Matter less than 10 Microns (PM10)	Sustained Exposure reduces lifespans by 3.1 years. For every 10 micrograms per cubic meter of pollution, lifespans are reduced by 0.6 years	Ebenstein, Fan, Greenstone, He, Zhou (Energy Policy Institue at the University of Chicago)
Estimating Health Effects of Air Pollution in China: An Introduction to Intake Fraction and the Epidemiology	2007	Particular Matter and SO2	Literature review of 2002 time-series studies which indicate an increase in daily mortality with exposure to certain pollutants. Figure x	Levy, Greco
Air Pollution and Mortality in China	2017	PM10, PM2.5, SO2, NO2, O3	**Statistically significant associations between *PM10* and mortality:** 0.38% for cardiovascular mortality 0.48% for respiratory mortality **Statistically significant associations between *PM2.5* and Mortality** 1.79% cardiovascular mortality 0.96% respiratory mortality **Statistically significant associations between *SO2* and mortality:** 0.83% cardiovascular mortality 1.25% respiratory mortality **Statistically significant associations between *NO2* and mortality:** 1.46% cardiovascular mortality 1.74% respiratory mortality **Statistically significant associations between *O3* and mortality:** 0.46% cardiovascular mortality 0.41% respiratory mortality	Lin, Mang, Liu, Li, Xiao, Zeng, Ma

Killer Cities: Past and Present	2015	Suspended particles from industrialization	China's air pollution contributed to 1.2 million excess deaths in 2010. One standard deviation increase in polluting industry share of urban district in china (0.27) is associated with an increase in mortality rate of 2.3% of the average	Hanlon, Tian
Benefits to Human Health and Agricultural Productivity of Reduced Air Pollution	2015	PM2.5, SO2, Nox	Secondary impacts of SO2 and Nox are linked with PM to contribute to poor health	Lei, Nielsen, Ho, Jorgenson
Atmospheric Modeling of Pollutant Concentrations	2015	PM2.5, O3, Nox	There are higher concentrations of PM2.5 over east China which is attributed to the number of anthropogenic combustion engines. A 100 yuan tax per ton of carbon using 2006 level would decrease Pm2.5 emissions by 10% relative to base case	Wang, Nielsen, Ho, Jorgenson
The Valuation of Health Damages	2015	—	Has shown an increase in projected value of statistical life from 340,277 (2005) to 517,221 (2010) to 789,443 (2015). Takes into account the income effect	Lei, Nielsen, Ho, Jorgenson
Growth, Pollution, and Life Expectancy: China from 1991-2012	2015	Particulate Matter less than 10 Microns (PM10)	Increases in income are associated with decreases in non respiratory illnesses and preventable diseases while respiratory illness/mortality continues to rise. A 100 miligram/M^3 increase in PM 10 exposure is associated with decline in life expectancy of 1.5 years at birth and then 2.3 years at age 5.	Ebenstein, Fan, Greenstone, He, Yin, Zhou

United States				
Links Between Air Quality and Economic Growth: Implications for Pittsburgh	2013	Particulate Matter less than 2.5 microns ($PM_{2.5}$) and Ozone	Meeting National Ambient Air Quality Standards has an estimated worth of $616 million in the city of Pittsburgh	Rand Corporation: Shanthi Nataraj, Ramya Chari, Amy Richardson, Henry H. Willis
Chronic Exposure to Fine Particles and Mortality: An Extended Follow-up of the Harvard Six Cities Study from 1974-2009	2012	PM2.5	Higher PM Concentrations associated with higher rates of cardiovascular mortality. 2007: 2,423,712 deaths in the US, with an average PM2.5 of 11.9 ug/m3. Results suggest that a decrease of 1 ug/m3 in average Pm2.5 would result in approx. 34,000 fewer deaths per year.	Johanna Lepeule, Francine Laden, Douglas Dockery and Joel Schwartz

The Impact of Air Pollution on Infant Mortality: Evidence from Geographic Variation in Pollution Shocks Introduced by a Recession	2003	Total Suspended Particulates (TSPS)	1 u mg/m3 reduction is associated with 4-7 fewer infant deaths per 100,00 live births Implies 2500 fewer infants died 1980-1982 than would have in absence of pollution reduction	Kenneth Y. Chay and Michael Greenstone
Life Cycle Air Quality Impacts of Conventional and Alternative Light-Duty Transportation in the United States	2014	Fuel emission from production and consumption	EV WWS are bests for improving air quality- 230 mortalities per year EV corn stover and EV coal are the worst- 3,200 mortalities per year Substantial decreases in air-quality related health impacts: gas vs gas hybrid vehicles (30% decrease) And EV Nat. gas (50% decrease) and EV WWS (70% decrease)	Christopher W. Tessum, Jason D. Hill, and Julian D. Marshall
Fine Particulate Matter Damages and Value added in the US Economy	2019	TSP	Air pollution costs the US roughly 5% of GDP in 2014, was $790 Billion, typically a result of premature death. External damages from air pollution have fallen 20 percent recently over just a six-year span, from 2008 to 2014.	Peter Tschofen, Inês L. Azevedo, and Nicholas Z. Muller
Fine Particulate Matter National Ambient Air Quality Standards: Public Health Impact on Populations in the Northeastern United States	2005	PM 2.5	Current PM2.5 standards in 8 states affect 16% of the population. More protective standards recommended/enacted by California and Canada would impact 84-100% of the population. Exposure is associated with aggravation of heart and lung disease, and premature mortality.	Philip R. S. Johnson and John J. Graham
A Critical Review of Studies of the Association Between Demands for Hospital Service and Air Pollution	1993	Sulfur and PM	Given NYC 24 hr avg of 642 ug/m3 TSP concentration (1953). Stat. Sign increases were seen for upper respiratory infections at 3 of 4 hosp. And cardiac diagnoses at two hospitals. Comparing results with averages of Nov of 1950-1953 and 1954-1956 with a larger morbidity effect than mortality during the episode of 200 excess deaths.	Frederick W. Lipfert
Air Pollution Damages from Offshore Energy Production	2014	PM 2.5, So2, Nox, VOCs, CO2, CH4	Estimates for 2000, 2005 and 2008: Western Platforms: $0.31 and $0.75 per unit of extracted oil- the damages due to air pollution Central platforms: .26 and .57	Nicholas Z. Muller

Europe				
Health Impacts and Economic Costs of Air Pollution in the Metropolitan Area of Skopje.	2018	Particulate Matter	Exposure to PM2.5 causes 1199 Premature deaths (16,209 years of life lost). Social costs of premature mortality: 570-1470 Million Euros. Reduction to the WHO standards would avert es77% premature deaths and 50% of hospital admissions, yield social cost savings between 407 Million euros and 1081 million euros	Gerardo Sanchez Martinez,Joseph V. Spadaro, Dimitris Chapizanis, Vladimir Kendrovski, Mihail Kochubovski, and Pierpaolo Mudu
The Hidden Economic Burden of Air Pollution related morbidity: evidence from the Aphekom group project	2016	PM10, NO2	Would prevent every year on average 21 asthma hospitalizations related to PM10, 140 MI hospitalizations for NO2 in 10 European Cities, 6 countries Economic burden of chronic morbidity effects is about 370 Euros- 66% cost burden on health system and 30.3% on family or patient.	Olivier Chanel, Laura Perez, Nino Künzli, Sylvia Medina and Aphekom group
Risk Factors Among Elderly for Short Term Deaths Related to High Levels of Air Pollution	2003	Ambient Air Quality	Significant association between daily elderly mortality and increased levels of pollutants. Elderly women at greater risk	L. Filleul, I. Baldi, J.-F. Dartigues and J.-F. Tessier.
Economic Cost of the Health Impact of Air Pollution in Europe: Clean Air, Health, and wealth	2015	PM	(2010) $1.431 trillion, annual economic cost of premature mortality.	WHO Regional Office for Europe, OECD
Air Pollution in Europe	2019	PM, Sox, Nox	(2013) 723,000 years of Life lost due to NO2 exposure. Increased relative risk of hospital admissions due to exposure to NO2 concentrations and respiratory illness. Increased by 1.56% per 10 ug/m3. And average of 8.5 days of admission for respiratory disease with an incidence rate of 1165 per 100,000	Cedric De. Koolen, Prof. Dr. Gadi Rothenberg.
Mortality Related to Air Pollution with the Moscow Heat Wave and Wildfire of 2010	2014	PM	11,000 excess deaths caused by respiratory illness in mostly 65+ citizens.	Dmitry Shaposhnikov et al.