Outdoor Ambient Air Pollution and Health Consequences

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INFO 247: Information Visualization, Spring 2022
https://astoriah.github.io/info247-final-aap/index.html

Table of Contents

1. Project Goals

Clean air is essential to human health, but because of climate change and anthropogenic factors air pollution is at an all time high. Air pollution consists of gas contaminants including various volatile organic compounds (VOCs), sulfur dioxide (SO_2), nitrogen oxides (NO_x), ozone (O_3), carbon monoxide (CO) and other toxic compounds, as well as particle contaminants (PM2.5 and PM10) that are present in the atmosphere. They can be directly released into the atmosphere or formed in the air through chemical reactions. Outdoor ambient air pollution is detrimental to human health and the environment. In January, the Health Effects Institute released a report discussing the long term effects of PM 2.5 on mortality in three different countries: Canada, Europe, and the United States. They concluded that there is a causal relationship between long-term outdoor air pollution exposure and mortality (Dominici, 2022). Air pollution has been associated with a myriad of health diseases such as lung cancer, stroke, dementia, diabetes, obesity, and heart disease.

Practically everyone in today's world is affected by air pollution. The goal of this project is to raise awareness to the negative impact of air pollution on our health, especially to unaware and vulnerable populations through an information web page that illustrates the inevitability of outdoor ambient air pollution and its associated health damages. To achieve this goal, the webpage contains both flat and interactive data visualization elements introducing outdoor ambient air pollution as well as sources of pollution, the impacts of air pollution on health and mortality around the world, and actions or personal interventions that individuals can take to better protect themselves.

2. Discussion of Related Work

2.1 McDuffie E, Martin R, Yin H, Brauer M. (2021) - Link

This report was published in December of 2021 by the Health Effects Institute. They looked at the global, region, and country level of air pollution sources and its disease burden (as attributable mortality rates). This is the first study that quantified the contributions of multiple fuel consumption types (previous studies combined all the sources for scale analysis or aggregated the fuel types of specific countries) on multiple levels.

The relevance of this report is directly related to our project focusing on the health consequences of air pollution. We accessed their data for our final project such as: PM2.5 measures per country, total attributable mortality, and attributable mortality contributions for specific diseases.

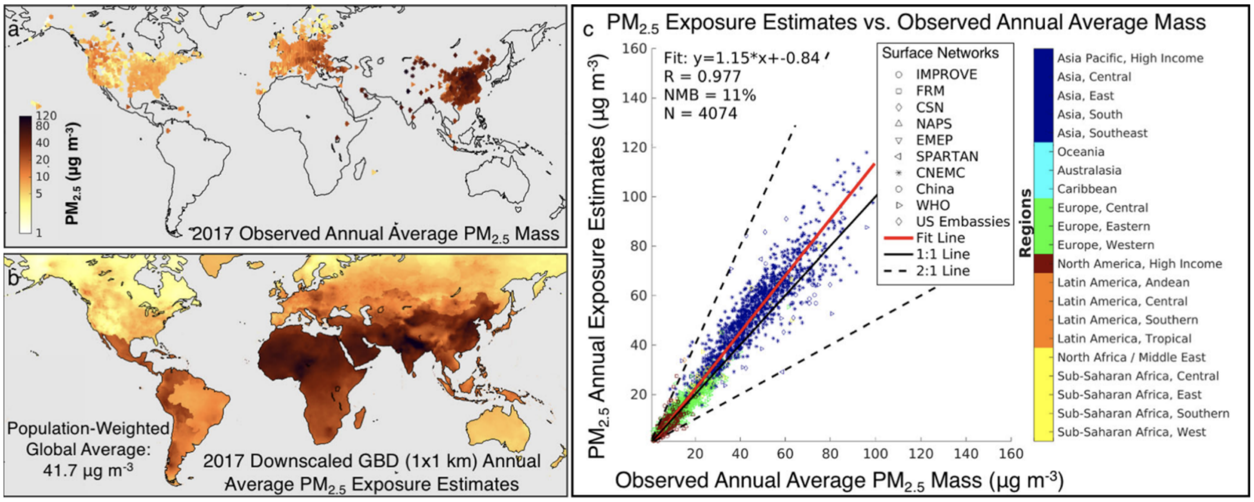


Figure 1. Global PM2.5 Exposure

Note. This graphic was produced from “Source sector and fuel contributions to ambient PM2.5 and attributable mortality across multiple spatial scales,” by McDuffie et al, 2021, Nat Communications 12, 3594.

Figure 1 (above) is from the McDuffie et al. article published by Nature Communications as an additional material to the HEI report. We were interested in the dual visualization of the map of the world on the left and the scatterplot on the right. We found that the color coding of the scatterplot showing the regions of the world was effective and made us think about how the side-by-side visualizations could be combined or communicate with each other.

2.2 Dominici F, Zanobetti A, Schwartz J, Braun D, Sabath B, Wu X (2022) - Link

This is a 4-year study, released in January 2022 by the Health Effects Institute, looking at the effects of ambient air pollution. The focus of this report is on the health effects on the population living In the United States. Cohort data was collected from Medicare enrollees, medicaid enrollees, and Medicare Current Beneficiary Survey enrollees. Various statistical models and approaches focused specifically on air pollutants: PM2.5, NO2, and O3. They found increased risk of mortality for adults who were exposed to low-levels of long-term air pollution. The framework to understanding the relationship between health and air pollution is complex.

This paper contributes to identifying and comparing multiple frameworks while sharing techniques in data harmonization of health data and air pollution geospatial data. The findings of this report is consistent with our project argument that ambient air pollution has detrimental health effects, in this case measured as all-cause mortality.

2.3 Bekkar B, Pacheco S, Basu R, DeNicola N (2020) - Link

This review was published in 2020 by PubMed in attempts to understand the association between climate change related events and adverse pregnancy outcomes across 19 different states in the United States. Specifically, PM2.5, ozone (O3), and heat were factors that the review focused on. 68 studies published between 2007 to 2019 fit their study criteria. They found that exposure to air pollution (PM 2.5 and ozone) was associated with preterm birth and low birth weight.

The finding of this review forwards our project argument, drawing a conclusion that air pollution had an effect on health consequences regarding maternal health in the United States. Adverse pregnancy outcomes is a possible example that could be used when we discuss health consequences in our project.

2.4 Schraufnagel, Dean E et al. (2019) - Link

This is a review from the Forum of International Respiratory Societies' Environmental Committee in 2019. They put together a comprehensive list of all of the different medical conditions that are associated with air pollution. While previous research focused on the harm of lungs and brain, there have also now been air pollution associations found with harm to the eyes, heart, liver, joints, and skin.

We were drawn to Figure 2 (below) that was included in the research review which maps an organ in the body to a list of conditions that were found to be associated with air pollution. For example, a brain icon was used next to brain conditions like dementia and Parkinsons.

This chart led us to thinking about how we could represent these related-terms in a word visualization. In our introduction to health consequences of air pollution, we created an animation word visualization that introduces a few of these conditions that are grouped by organ.

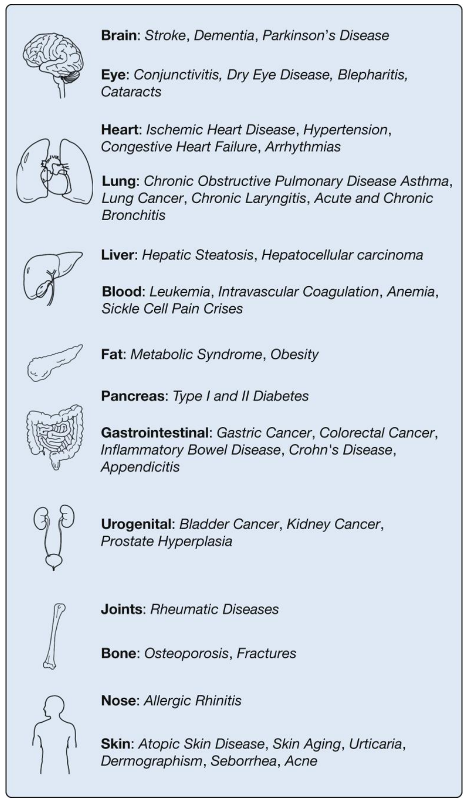


Figure 2. List of conditions that have been found to be associated with air pollution
Note. This graphic was produced from "Air Pollution and Noncommunicable Diseases," by Schraufnagel, Dean E et al., 2019, Chest.

2.5 Laumbach, Robert J, and Kevin R Cromar. (2021) - Link

Published December 2021, this review looks at the most common interventions that individuals can use to protect themselves from outdoor air pollution such as staying indoors, air cleaners, modifying physical activity, and respirators/face masks. For each intervention, the authors explained the effectiveness as a percentage of particulate matter reductions as a result of the solution. They also discuss different factors that would affect the solutions' effectiveness and the potential drawbacks of each one. For example, while masks and respirators have been found to be one of the most effective methods, they are overall uncomfortable, decrease oxygen concentration, and increase humidity because of the tight seal.

The conclusions drawn in this paper were of interest to us because we wanted to introduce some possible personal interventions to mitigate air pollution. This paper was clear on the effectiveness of each solution and provided context of how the solutions should be used and when. In our project, we used their conclusions to create our animations showing how effective a specific method was at decreasing particulate matter concentrations.

2.6. CalEnvironScreen (2021) - Link

CalEnviroScreen 4.0 is the fourth edition of the tool developed by the the California Environmental Protect Agency and California Office of Environmental Health Hazard Assessment used to evaluate environmental conditions, socioeconomic conditions, and health conditions in California communities, most recently updated in October 2021. CalEnviroScreen uses environmental, health, and socioeconomic information to produce scores for every census tract in the state so that different communities can be compared.

CalEnviroScreen provides an interactive map allowing users to explore how air pollution affects various communities. The mapping tool that helps identify California communities that are most affected by many sources of pollution, and where people are often especially vulnerable to pollution's effects.

The CalEnvironScreen tool gave us important context about pollution burden such as: ozone, PM2.5, and diesel particulate matter. In addition to pollution burden, we were able to identify particular communities affected through population characteristics such as cardiovascular disease or poverty. Understanding the nuances to environmental conditions and socioeconomic conditions is important as we discuss the topics more broadly in our project.

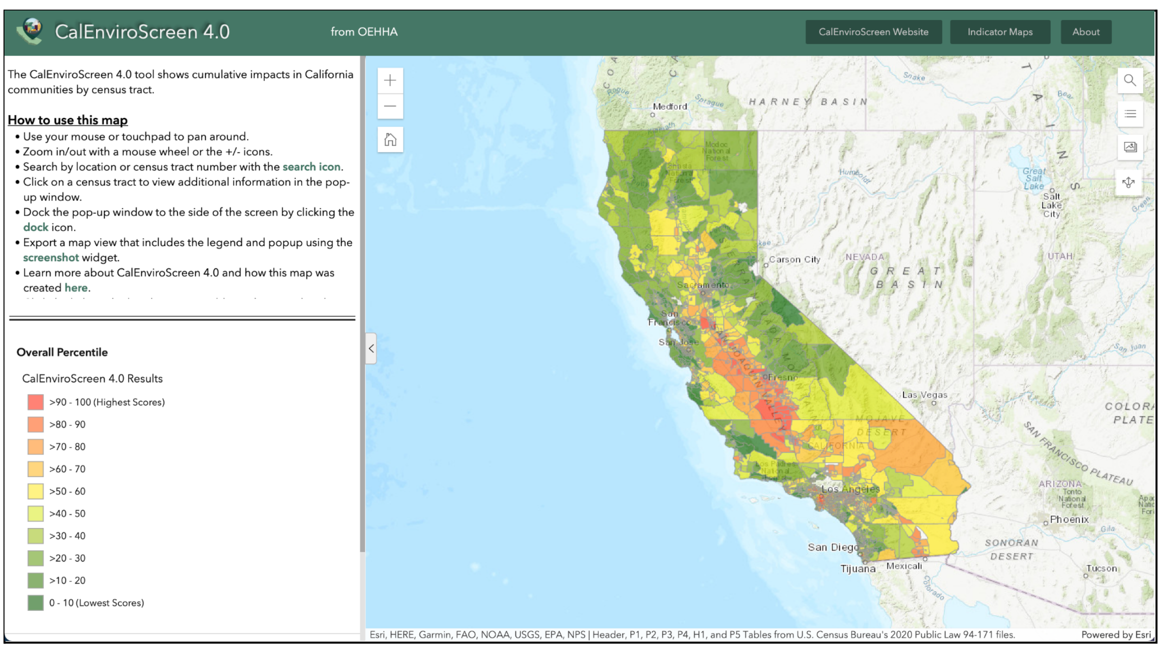


Figure 3. CalEnviroScreen 4.0 Indicator Maps Tool Screenshot
Note. This is a screenshot taken from the Office of Environmental Health Hazard Assessment (OEHHA) on May 10, 2022.

2.7. U.S. Environmental Protection Agency (EPA), Our Nation's Air (2019) - Link

The U.S. EPA publishes an annual air trends report in the form of an interactive web application. The report features a suite of visualization tools that allow the user to: compare key air emissions to gross domestic product, vehicle miles traveled, population, and energy consumption back to 1970, take a closer look at how the number of days with unhealthy air has dropped since 200 in 35 major US cities, and check out air trends where you live.

This one-page summary report has a similar focus to our project discussing air pollution and giving their viewers a foundation of understanding what air pollution is, how it is measured, and how we must respond to high concentrations of air pollution. We found many visualizations used to be effective and gave us inspiration for how to write a narrative page on the same topic. For example, Figure 4 (below) is a screenshot taken from the report illustrating the emissions by four source categories. We found the bar chart to be effective in showing the emissions per pollutant by million tons, however comparing the source distributions between pollutants was difficult. In our project, we used the same data to create radar charts better showing the distribution between the sources.

The distinct difference is that the EPA's page is focused on the United States, while our project has a broader focus looking at the relationship between global air pollution and negative health consequences affecting the global population.

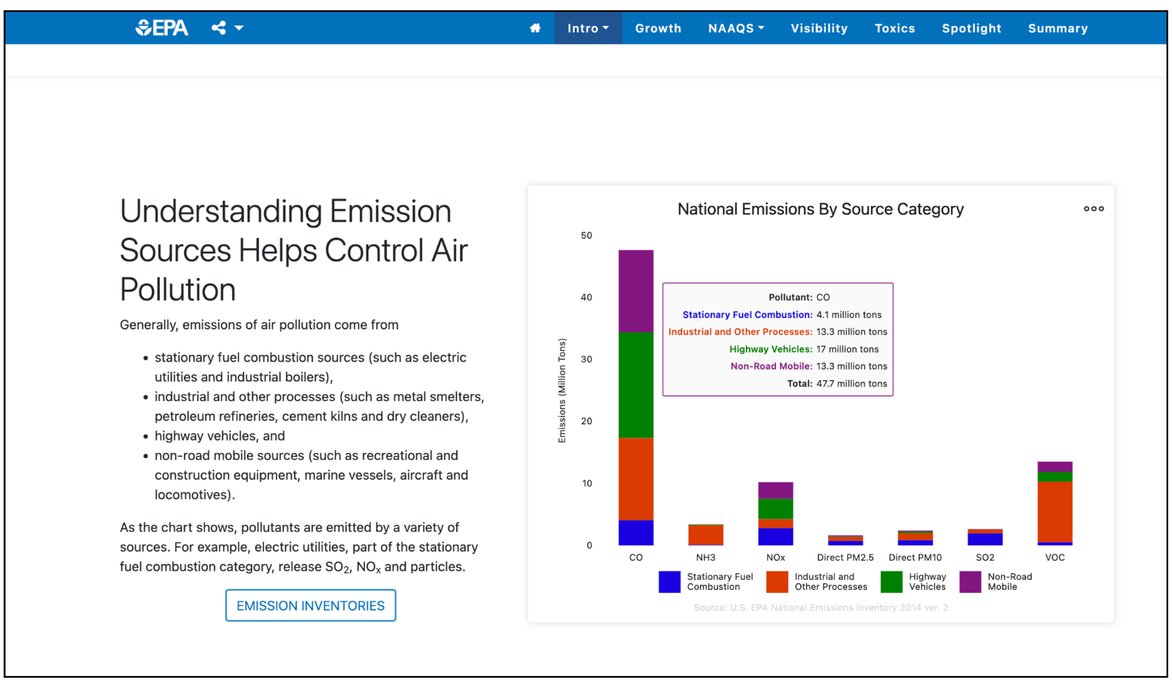


Figure 4. Our Nation's Air, National Emissions By Source Category
Note. This is a screenshot taken from the EPA Our Nation's Air website on May 10, 2022.

3. Visualization Walkthrough

Link to visualization: https://astoriah.github.io/info247-final-aap/index.html

3.1 Introduction to Topic and Visualization

The visual elements of this project are presented in a web page made up of flat and interactive data visualization elements to communicate to users the importance of caring about air pollution and the health consequences that pollutants cause. The focus of this project is specifically on outdoor ambient air pollution, which is made clear from the moment the user lands on the website's title page (Figure 5). The title of this project, "Outdoor Ambient Air Pollution and Health Consequences," is presented at the beginning of the website in a simple format, with only a background of particles floating to represent air particles and pollutants. At the bottom is an arrow with the word "Scroll" so that users know to scroll down to access the rest of the web page's information and visualizations.

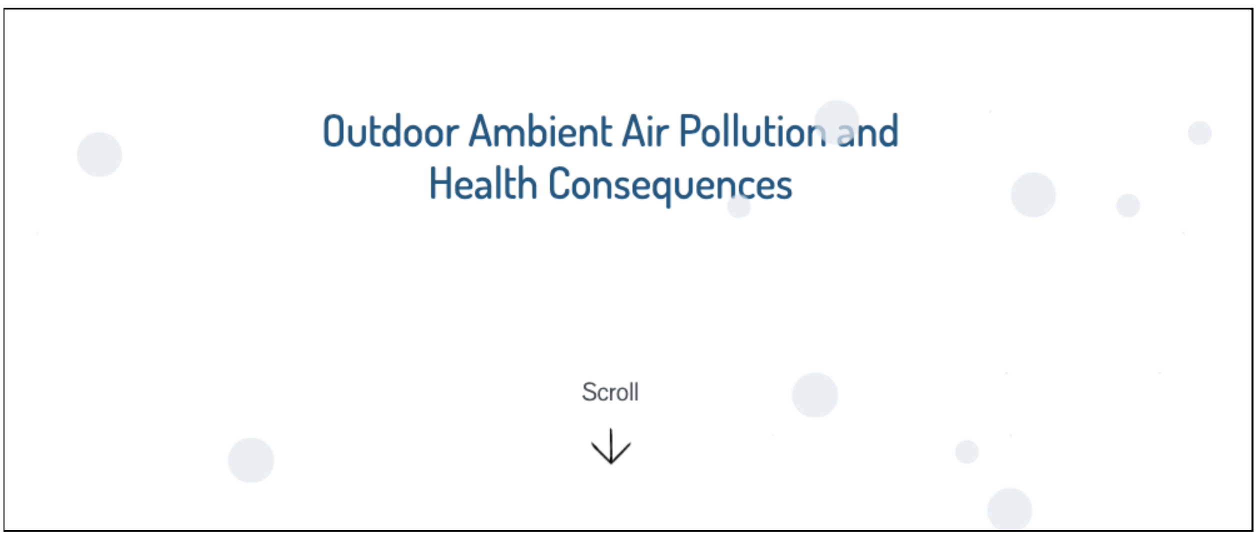


Figure 5. Title page of website. Particles are animated to float, representing air particles and pollutants that are present in the air.

Once users scroll past the title page, they are introduced to what the definition of outdoor ambient air pollution is, so that the concept of outdoor air pollution is consistent for this project. A brief introduction on where pollutants come from in today's society is also provided.

3.2 Air Pollution Sources Radar Chart

After users are given a brief introduction to outdoor air pollution, the first infographic style visualization appears. The visualization is a series of photographs and labels identifying the six criteria air pollutants that are monitored by the US Environmental Protection Agency (EPA). These pollutants include carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen dioxide (NO_x), lead (Pb), ground-level ozone (O_3), and particulate matter. The pictures associated with each pollutant show common sources of the pollutants, so that the users can better understand where these pollutants come from, and what anthropogenic actions may be contributing to the emission of these pollutants. The label and picture identifying the pollutant, a description of how the pollutant is released is also provided. The label of each different pollutant is in a different color so that they are easily distinguishable. The colors for each type of pollutant is maintained in the upcoming radar charts (Figures 7 & 8) that shows a more detailed breakdown of sources of each pollutant for consistency. Pollutants that are in the same category are marked in corresponding colors for the radar charts.

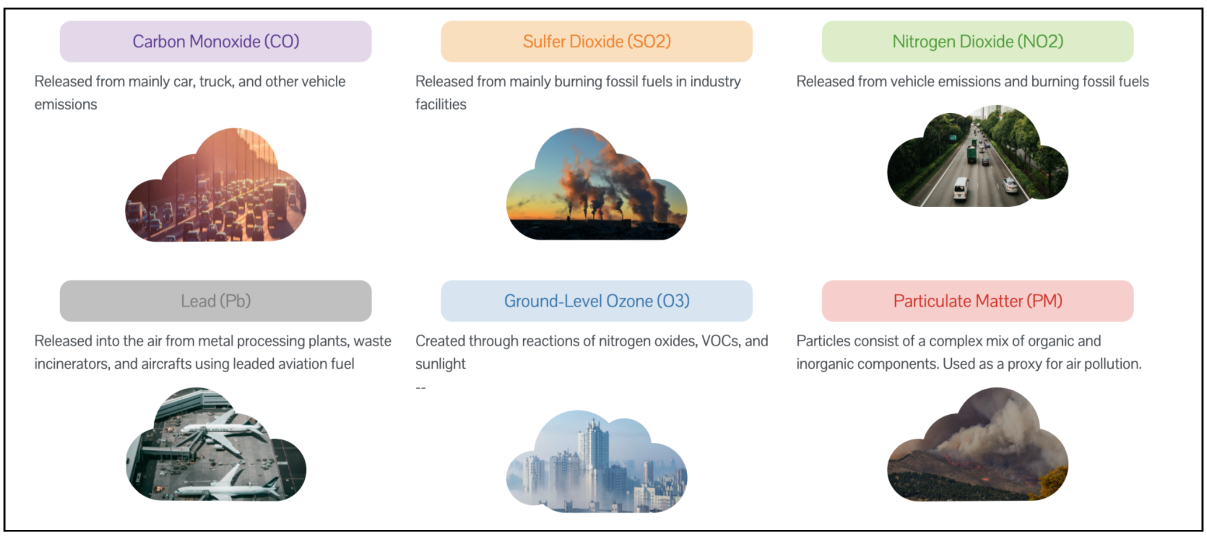


Figure 6. The six criteria air pollutants monitored by the US EPA. Introduces color scheme of the pollutant categories to be referenced in the radar charts.

Below the infographic introducing the six criteria air pollutants, small multiples of radar charts are presented (Figure 7). The radar charts in the small multiples each show the percent contribution distributions of a pollutant according to the Emissions Inventory Report that is part of the EPA's Our Nation's Air 2019 Report. The pollutants that are shown in the radar charts include ammonia (NH_3), carbon monoxide (CO), sulfur dioxide (SO_2), nitrous oxides (NO_x), volatile organic compounds (VOCs), PM10, and PM2.5. The categories for sources of pollution include stationary fuel combustion sources such as electric utilities and industrial boilers; industrial and other processes such as metal smelters, petroleum refineries, cement kilns, and dry cleaners; highway vehicles, and non-road mobile sources including recreational and construction equipment, marine vessels, aircraft, and locomotives. Using small multiples allows the users to easily compare the distributions of each pollutant to the others.

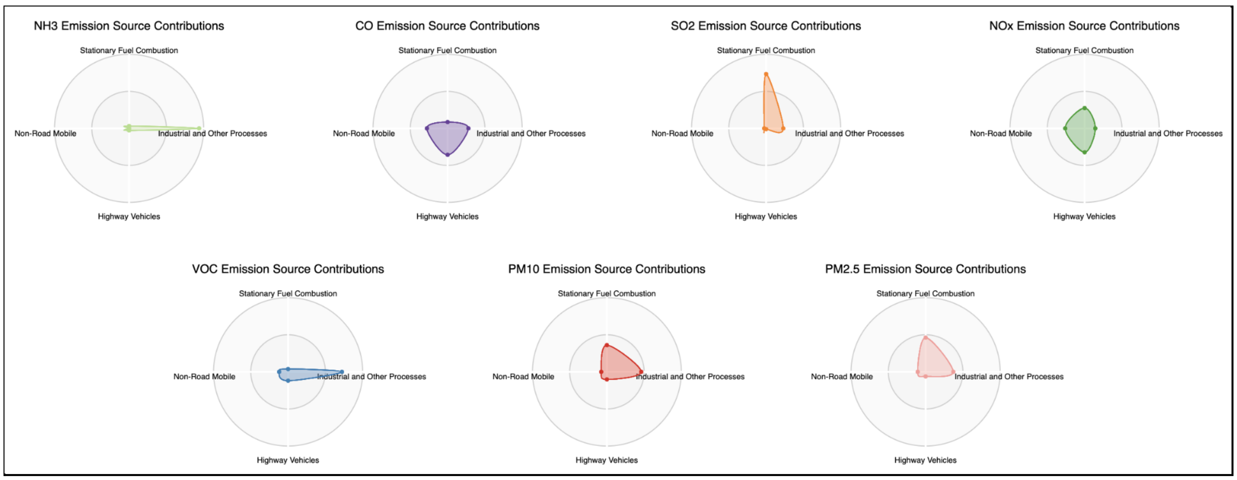


Figure 7. Small multiples of radar charts showing contributions from sources of pollutants for seven different common air pollutants.

Directly beneath the small multiples of radar charts is a combined radar chart with the percent contributions for the sources of each pollutant overlaid upon one another (Figure 8). The colors for each of the pollutants are consistent with the smaller radar charts above and continue to correspond with the categories of pollutants presented earlier. Providing an overlaid view for the pollutants helps to give the users another view of a direct comparison of the sources of the pollutants that may help them interpret the information better. In addition, because the combined radar chart is larger, it is easier to see the percent contribution of the sources for each emissions. The combined radar chart is interactive and contains a dropdown list that allows the users to select a specific pollutant to highlight against the rest of the pollutants. An example of when NO_x is selected is shown in Figure 9. The distribution for NO_x is highlighted and specific percent contribution for each emission source is shown.

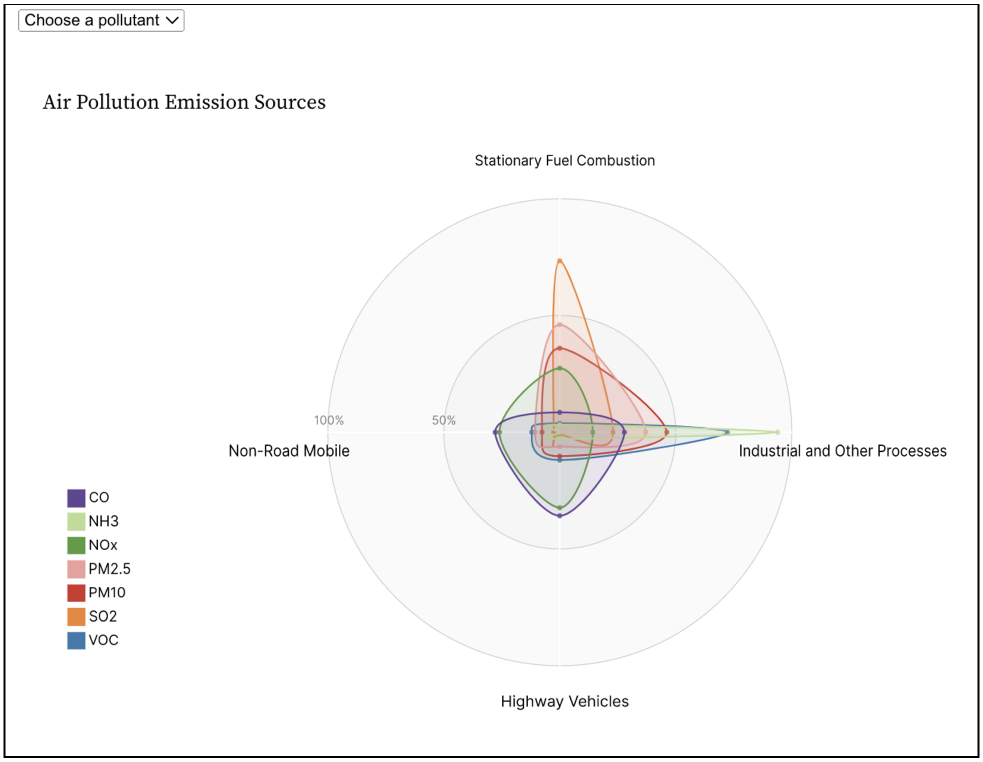


Figure 8. Combined radar chart to compare the air pollutants' differences in emission sources. Dropdown list allows users to choose a pollutant to highlight.

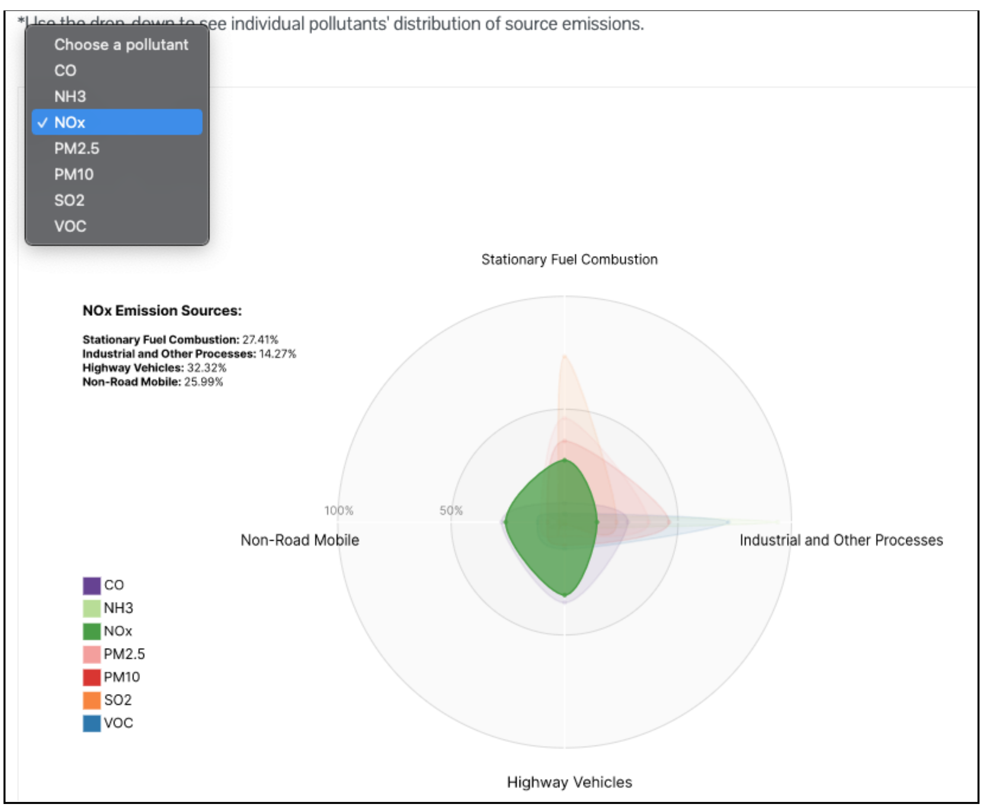


Figure 9. Combined radar chart with NO_x selected.

3.3 Particle Sizes Animation

One of the most important pollutants people are exposed to and concerned about is PM2.5. Particulate matter (PM) has been historial proxy for air pollution because it consists of a combination of organic and inorganic components. Particulate matter is measured by the unit micron, or micrometer (μm), which is equal to 10^{-6} meter. A PM2.5 particle has a width/diameter that is 2.5 microns or less, and is not visible to the naked eye, so people often inhale them without even knowing.

In order to demonstrate the size of a PM2.5 particle, an animation showing the relative size of a PM 2.5 particle compared to the diameter of a human hair is shown (Figure 10). The animation shows various cross sections, diameter, of small particles from largest to smallest including human hair, a grain of fine beach sand, grain of salt, grain of pollen, red blood cell, and particulate matter. Some of these are commonly known objects such as hair and sand, so it is easier for users to grasp exactly how small PM2.5 is. The animated visualization also includes an outline of where the particles that are not visible to the human eye begin, and since the focus of this visualization is PM2.5, the PM2.5 particle is colored in orange so that it can be easily distinguished from the rest of the particles which are colored in various shades of blue. Figure 11 shows screenshots of the animation at different times as it zooms into and out of the PM2.5 particle.

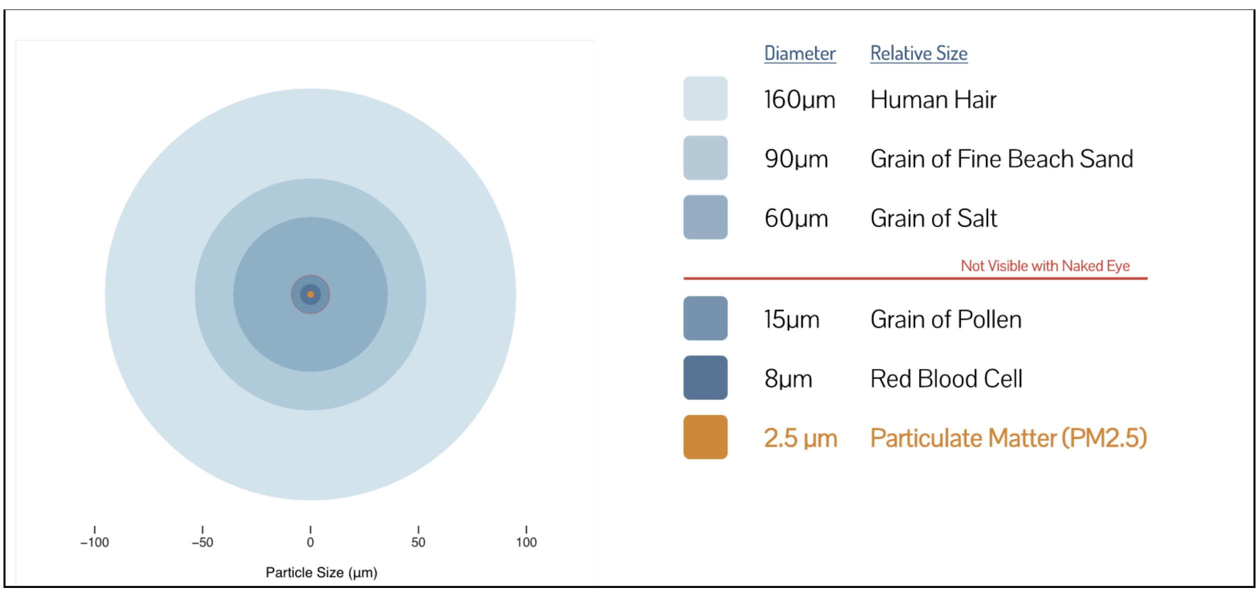


Figure 10. Relative size of PM2.5 in comparison to other small particles in an animation that zooms into and out of the PM2.5 representation.

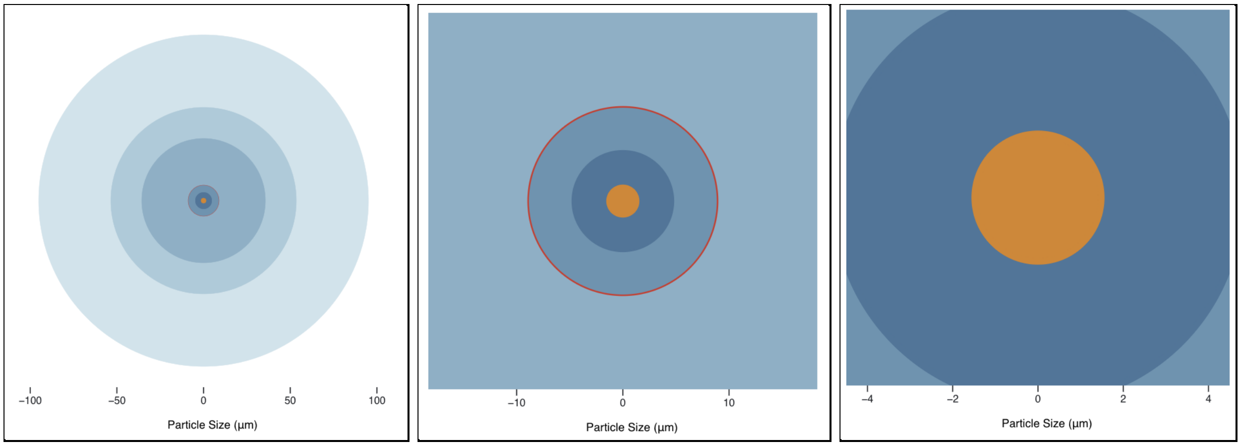


Figure 11. Visualization of particle sizes at different stages of the animation.

3.4 PM2.5 Scatter Plot and Map

The next visualization consists of a scatter plot with an accompanying map of the world (Figure 12). The scatter plot graphs the 2019 Average Annual PM2.5 Concentration against the Percent Attributable Mortality for PM2.5 for countries around the world. PM2.5 is measured as Annual Population Weighted Average PM2.5 Concentration. This metric links the concentration measured in an area with the number of people living there. Attributable Mortality measures the proportion of non-accidental deaths that were associated with air pollution. The higher the percent attributable mortality, the more air pollution plays a role in the cause of non-accidental deaths in a population.

Also included on the chart is the global average for PM2.5 and Attributable Mortality as well as the WHO Air Quality Guideline at the time that this data was collected. In 2005, WHO set their guideline value at 10 µg/m3 as a safe PM 2.5 concentration, which is presented in this scatter plot. However, in 2021, WHO decreased the value to 5 µg/m3 reflecting the severity of air pollution harm on population health and wellness.

This visualization allows for brushing and selecting so that users can highlight and explore points or countries of interest. Users can brush to highlight a group of points of interest on the scatter plot, which colors the points and the corresponding countries in purple. This allows users to explore if certain geographical areas are associated with different trends of PM2.5 and Attributable Mortality. Users can also select specific points on the scatter plot or select a country on the map, which will highlight the corresponding point and country on the map in blue, and will show the specific statistics for that country. A selected country can be clicked on again to be unselected.

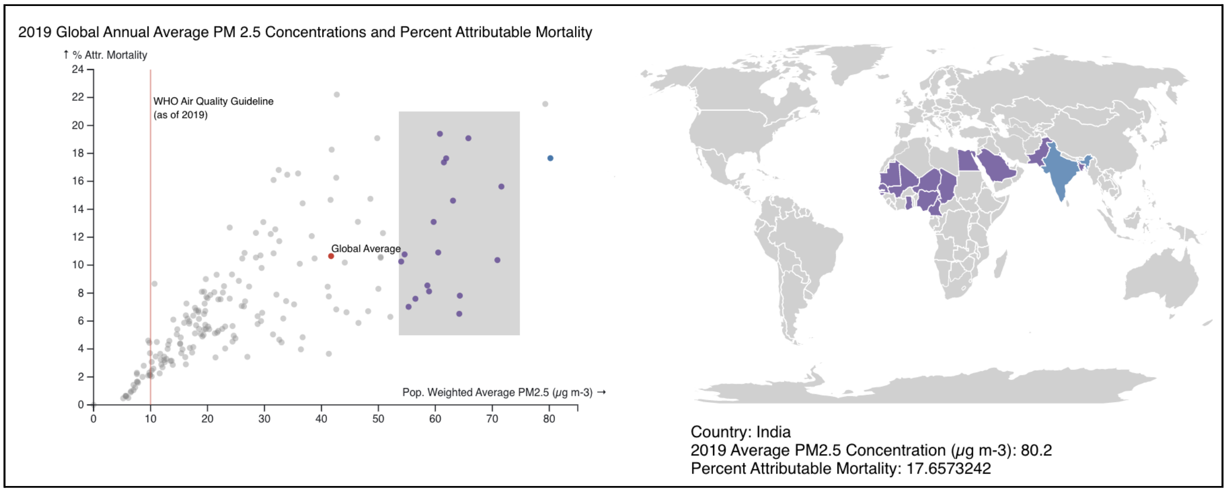


Figure 12. Global Annual Average PM2.5 and Percent Attributable Mortality graphed in a brushable scatterplot. Individual points on the plot or countries on the map can be selected to view specific statistics.

3.5 Contributable Diseases Word Cloud

The following section on the web page begins to describe the relationship between outdoor air pollution and human health. An introduction to the contributable diseases is presented in the form of a word cloud (Figure 13). The world cloud is animated so that the diseases float into the page in a way that is reminiscent of air particles. Because users may not be very familiar with some of the diseases, the word cloud is arranged such that the diseases are clustered based on the part of the body that they primarily affect. An icon representing each body part appears in the center of each cluster so that the categories can be easily identified.

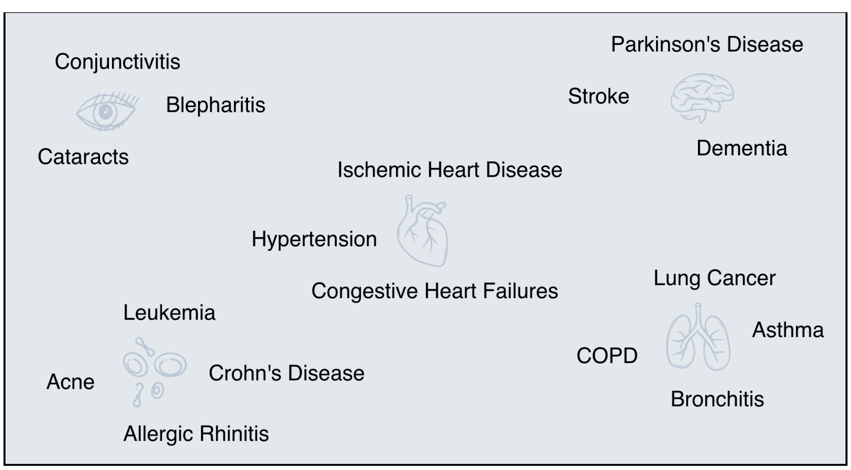


Figure 13. Word cloud of air pollutant contributable conditions clustered by part of the body that they affect.

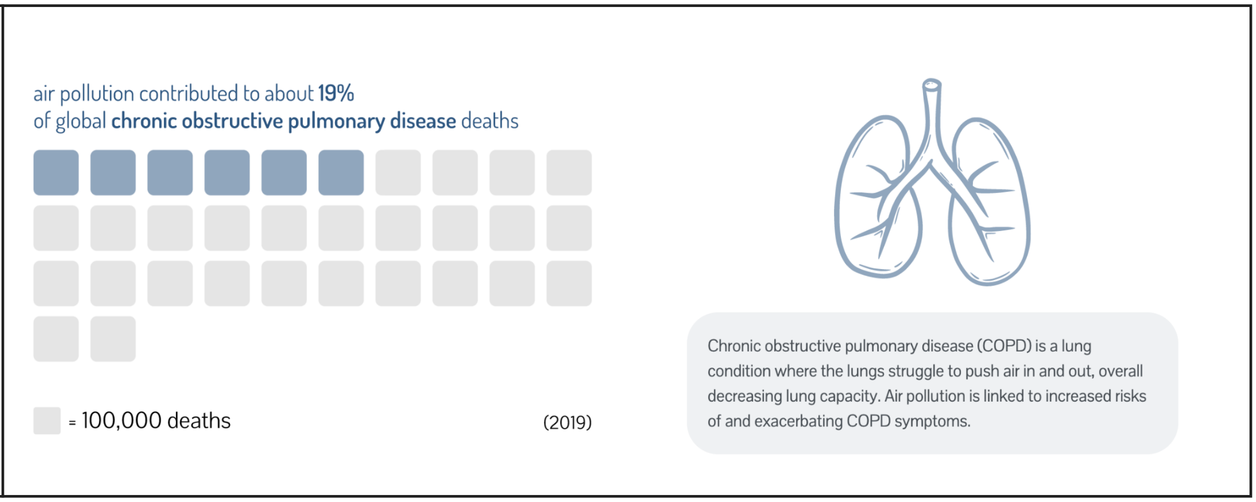
3.6 Air Pollution Attributable Disease Mortality Infographics

After the word cloud is presented, an estimation of the global number of deaths attributable to air pollution in 2019 is provided. Then, a series of infographics looking at the attributable mortality contributions of air pollution for four specific diseases are presented (Figure 14). These four diseases account for the top four most prevalent causes of death worldwide– ischemic heart disease, stroke, chronic obstructive pulmonary disease (COPD), and lower respiratory infections.

Chronic obstructive pulmonary disease (COPD) is a lung condition where the lungs struggle to push air in and out, overall decreasing lung capacity. Air pollution is linked to increased risks of and exacerbating COPD symptoms. Ischemic heart disease is the buildup of plaque in heart arteries which limit blood and oxygen circulation in the body. Studies found long-term exposure to air pollution accelerates calcium buildup in arteries. Lower respiratory tract infections (LRI) are infections that take place in the trachea, bronchi, and lungs such as pneumonia, bronchitis, or the flu. Rates of LRI found in both children and adults have been highly correlated with air pollution. Strokes are found to be positively associated with increased ambient air pollution or dust storms. As air pollution worsens, an increased number of cardiovascular events occur.

Next to each disease's infographic is an icon with the body part that the disease affects. The number of deaths globally in 2019 for each disease is represented by a series of boxes, with each box equaling 100,000 deaths. The boxes that are shaded in represent the number of deaths for each disease to which air pollution contributed.

a



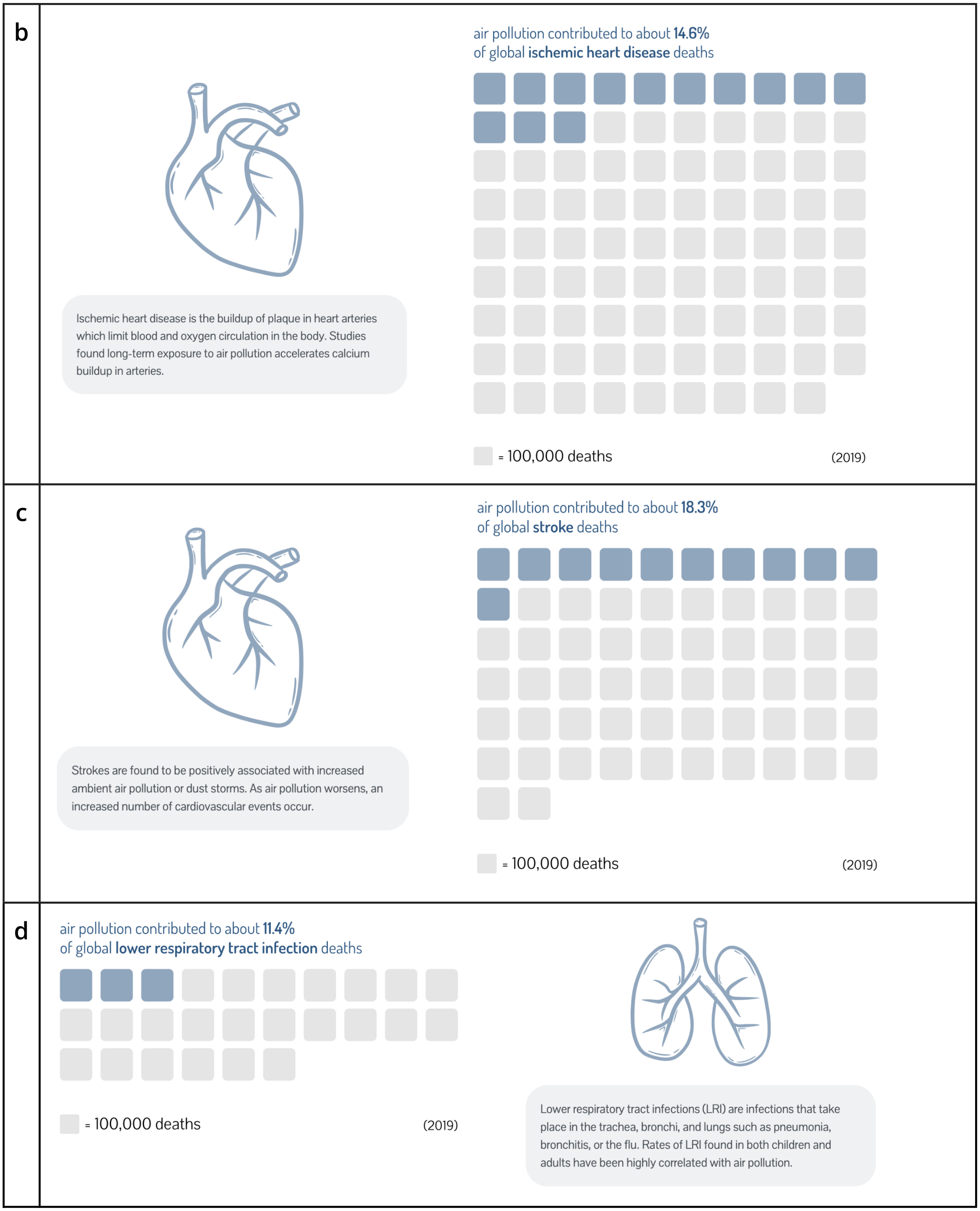


Figure 14. Infographics showing air pollution attributable disease mortality contribution for **a)** chronic obstructive pulmonary disease, **b)** ischemic heart disease, **c)** lower respiratory tract infection, and **d)** stroke.

3.7 Personal Protection Intervention Animations

In addition to raising awareness of health consequences and why being concerned about air pollution is important, another goal of this project is to provide some insight on actions people can take to protect themselves. Animations on the web page demonstrate the effectiveness of various personal protection interventions, namely wearing masks, using indoor air filters, and staying indoors with the windows closed (Figure 15). These animations were created based on research from the Laumbach et al. (2021) study.

Each personal protection intervention is represented by an icon. For each intervention, the blue dots on the left of the icon are successfully filtered by the intervention, while those that turn red and move to the right are not filtered. N95, KN95, FFP2 masks are all standardized by various governments and agencies to have at least a 95% filtration of particulate matter. Indoor air filters provide on average about 70% filtration of particulate matter. Air filter effectiveness depends on the type of filter, placement, and frequency of use. Outdoor air pollution affects people even when they are not outside. PM can enter through windows, vents, and other openings. Staying indoors with windows shut can provide about 20% filtration of ozone, but for PM 2.5, this strategy is not effective. The variability on filtration depends on the building's windows, building materials, and filtration system.

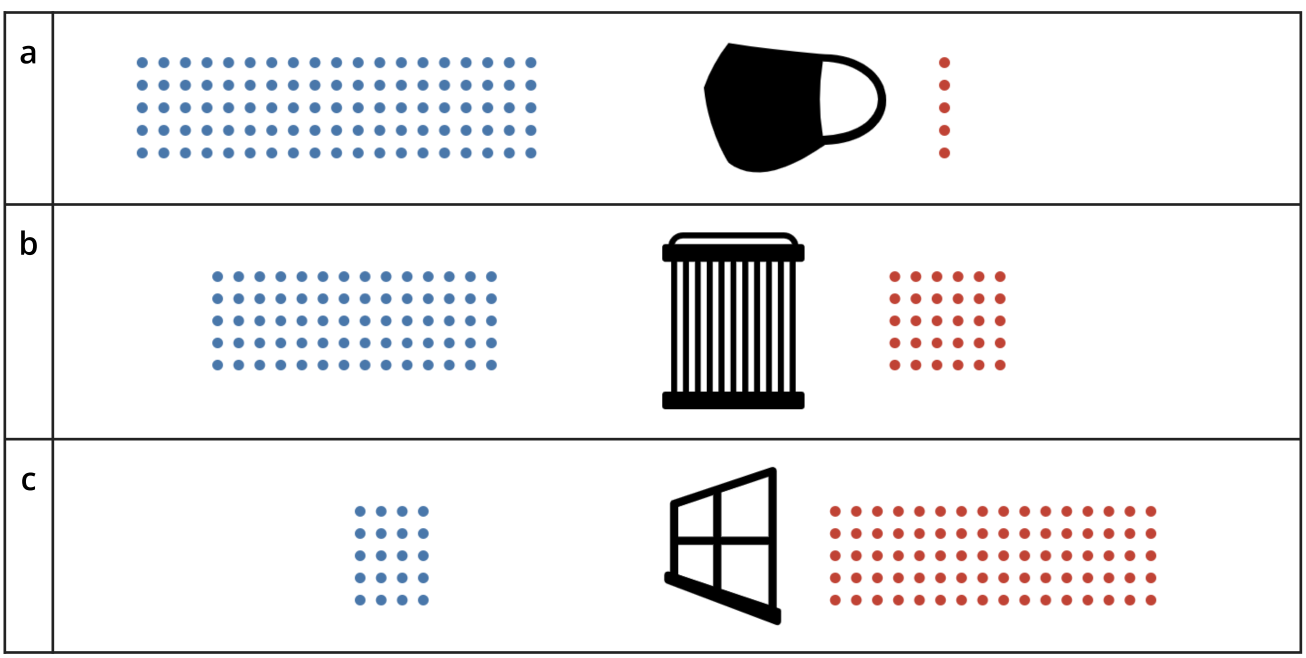


Figure 15. Animations showing the effectiveness of **a)** wearing masks to protect oneself from PM2.5, **b)** using indoor air filters to protect oneself from PM2.5, and **c)** staying indoors with windows shut to protect oneself from ozone.

Figure 16 shows a screenshot of the animation in action as blue particles float from the left side of an air filter to the right side of the filter and become red. The blue dots on the left are particulate matter that are successfully filtered, while those that turn red and move to the right are not filtered.

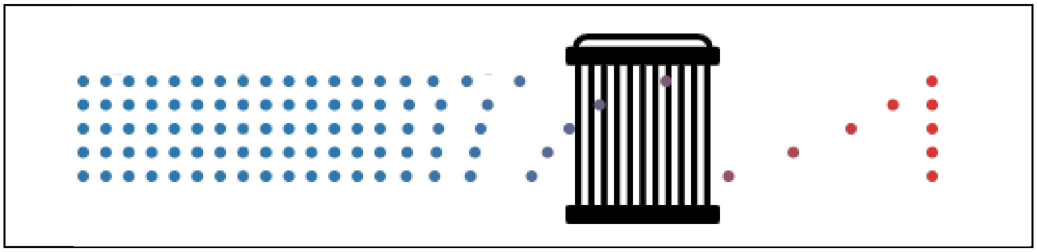


Figure 16. Animation in progress for the effectiveness of indoor air filters. Blue dots on the left are successfully filtered, while those that turn red and move to the right are not filtered.

3.8 Consumer Trends and Conclusion

The visualizations conclude with a display of various products that companies released. The display shows that air pollution has become such a large concern and there is a market for personal protection devices, especially with the rising awareness with the ongoing COVID pandemic and increasing frequency of wildfires. While these products are unlikely to appeal to everybody, an interactive question and poll are provided so that users can reflect on how they may or may not interact with these products and actions they may take to protect themselves from air pollution and/or contribute less to air pollution.

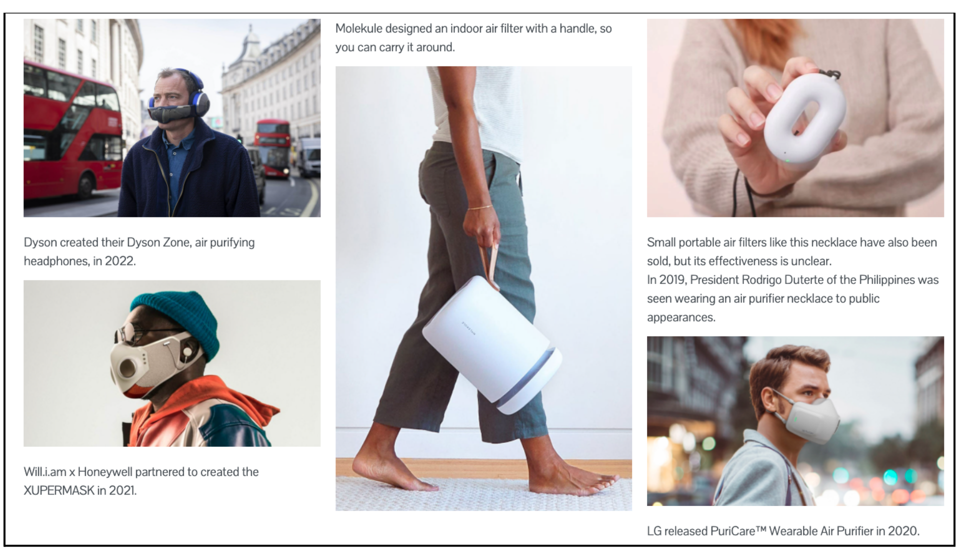


Figure 17. Examples of consumer products around personal protection from air pollution.

4. Data

Various data sets were used to analyse and convey information about air pollution to the users of the project web page. The data sets were collected through related research papers as well as from international organizations. Before each data set was put to use, exploratory data analysis (EDA) was completed through the use of Excel and Tableau to clean the data and to ensure that the data was relevant and useful to the project.

4.1 Supplementary Data 1 from McDuffie et al. (2021)

The dataset is available from the study by McDuffie et al. (2021) referenced in the discussion of related works. It can be accessed here as an .xlsx file: https://rdcu.be/cIofr.

This data set contains information for 21 world regions, 204 countries, and 200 sub-national areas. The size of the dataset is 425 rows and 42 columns. The data is split into three parts: composition of air pollution sources as percentages, total attributable mortality, and disease contributions by air pollution as percentages. For the total attributable mortality and disease contributions, they use two models: Global Burden of Disease (GBD) 2019 disease-specific concentration response functions (CRFs) and Global Exposure Mortality Model (GEMM). In this project, the data was used to determine air pollution's global attributable mortality for various diseases alongside WHO mortality estimates.

4.2 Supplementary Data 2 from McDuffie et al. (2021)

The dataset is available from the study by McDuffie et al. (2021) referenced in the discussion of related works. It can be accessed here as an .xlsx file: https://rdcu.be/cIofr.

This data set contains information for 21 world regions, 204 countries, and 200 sub-national areas. The size of the dataset is 425 rows and 9 columns. The data is split into three parts: annual average PM2.5 concentration, total attributable mortality by PM2.5, and source contributions for PM2.5 by percent. For the total attributable mortality and disease contributions, they use two models: Global Burden of Disease (GBD) 2019 disease-specific concentration response functions (CRFs) and Global Exposure Mortality Model (GEMM). For this project, the annual average PM2.5 concentrations and attributable mortality for each country were used in creating the scatter plot and map visualizations.

4.3 Global Health Estimates 2019 (WHO, 2020)

This data was prepared by the WHO Department of Data and Analytics and is available on the WHO website: https://www.who.int/data/gho/data/themes/mortality-and-global-health-estimates.

The data set contains estimates of deaths by cause, age, and sex, globally, by country and by region for the years 2000, 2010, 2015, and 2019 from the WHO Global Health Estimates (GHE) in the form of an .xlsx workbook. The workbook contains seven worksheets, namely Notes including a description of the data, Summary of the data, Top 20 estimated causes of death for 2019, 2019 mortality estimates, 2015 estimates, 2010 mortality estimates, and 2000 mortality estimates. In addition to cause/disease, age, and sex, each worksheet has data on the number of deaths, percent of total deaths, cummulative percent of total deaths, and death rate per 100,000 people for each disease. Mortality estimates are based on analysis of latest available national information on levels of mortality and cause distributions as of mid 2020 together with latest available information from WHO programs for causes of public health importance. For this project the worksheet containing data for 2019 was used. The size of the dataset is 215 rows and 25 columns. In this project, the data was used in conjunction with the Supplementary data from the McDuffie (2021) study to determine air pollution's global attributable mortality for various diseases including COPD, ischemic heart disease, lower respiratory tract infections, and global stroke deaths.

4.4 U.S. EPA National Emissions Inventory (EPA, 2019)

This dataset is from the US EPA National Emissions Inventory and was used in the Our Nation's Air 2019 (EPA, 2019) report. The dataset can be accessed as an .xlsx file here: https://gispub.epa.gov/air/trendsreport/2019/#air_pollution.

The dataset provides information on emissions by source category for air pollutants as percentages. The size of the dataset is 8 rows by 5 columns. The air pollutants in the dataset include carbon monoxide (CO), ammonia (NH3), nitrous oxide (NO), PM2.5, PM10, sulfur dioxide (SO2), and volatile organic compounds (VOC). The emissions sources include stationary fuel combustion sources such as electric utilities and industrial boilers; industrial and other processes such as metal smelters, petroleum refineries, cement kilns, and dry cleaners; highway vehicles, and non-road mobile sources including recreational and construction equipment, marine vessels, aircraft, and locomotives. The data was used in this project to create the radar charts that show emission contributions from each source for the seven different pollutants in 2019.

4.5 Other

In addition to datasets, air quality standards from the World Health Organization were also referenced in the project, specifically for PM2.5. Because the project focuses on PM2.5 in 2019, the standard during that time was used, but WHO has since updated their guidelines in 2021. WHO air quality guidelines can be found here: https://apps.who.int/iris/handle/10665/345329.

For the effectiveness of various personal interventions and actions, which are shown as animations in the project, the Laumbach et al. (2021) study was used. The estimates for the effectiveness of those various interventions in filtering out air pollutants were researched and analysed in the paper. The study is summarised in the Discussion of Related Work section of this report.

5. Tools

Exploratory data analysis for the project was initially conducted through Tableau. Visualizations were created using D3.js in Observable Notebooks. Github Pages and Bootstrap were used to create the website with HTML/CSS. Figma was used to prototype and ideate design elements for the web page.

6. Results

6.1 Web Page Design

The project is displayed on a single-page scroll web page. We chose a simple and minimalistic aesthetic with only two fonts (Dosis for headings and Pontano Sans for body font, available on Google Fonts) and four shades of blue. Because this page is focused on the visualizations and giving the viewer an opportunity to interact with the charts, we kept the context and writing on the webpage as concise as possible. We decided to use monochrome blue because blue is used commonly to represent the sky and air. Intentionally we did not use any green because people associate green with climate change and we want our viewers to be focused on air pollution rather than bigger climate change and global warming issues.

Overall the flow of the web page starts at the background of the issue, then goes to expand on the issue and how it affects the world, and ends with what we can do about it on an individual and global level. The goal of this webpage is to be informative about air pollution and human health, and draw more awareness about the topic.

I. **Introduction**

II. **Background on Air Pollution**

   A. Explain the different types of air pollutants
      1. Pollutants that EPA actively measure: carbon monoxide, sulfur dioxide, nitrogen dioxide, lead, ground-level ozone, and particulate matter

   B. Show the sources of air pollution
      1. Introduce four primary sources that EPA defines: stationary field combustion, industrial and other, highway vehicles, and non-road mobile
      2. Radar chart of different air pollutants and the distribution of 4 sources
         a) Include both individual charts for each pollutant and one chart with a drop down for each pollutant for better comparison.

   C. Show air pollution is poor around the world
      1. Introduce particulate matter (PM) as a proxy for air pollution
         a) Animation showing the relative size of PM2.5
      2. Scatter plot and map visualization of PM2.5 concentrations
         a) Allow for interactivity through brushing on the scatterplot and clicking on countries on the map

III. **Air Pollution and Adverse Health Consequences**

   A. Introduction
      1. Word visualization showing conditions that have been found to be associated with air pollution
      2. Statistic of deaths related to air pollution (2019)

   B. Show air pollution contribution to specific conditions
      1. Flat visualizations looking at conditions:
         a) COPD
         b) Ischemic heart disease
         c) Lower respiratory tract infections
         d) Strokes

IV. **Potential Solutions to Mitigating Ambient Air Pollution**

   A. Illustrate effectiveness of solutions through animation of moving particles:
      1. Masks
      2. Indoor air filters

3. Staying indoors

V. **Conclusion**

A. Solutions as a consumer good market trend

1. Add a poll asking if they could see themselves purchasing these products.

B. Response to air pollution

6.2 Usability Testing

The usability study for this project was conducted through interviews through virtual meetings on Zoom. Four participants were selected to be a part of this usability study. The four participants were selected through acquaintances who may be concerned with air pollution, but may have varying levels of familiarity or knowledge on the subject. All four participants in the study live in Los Angeles, which has a reputation for having unhealthy air, and are in their early to mid-twenties. Astoria and Clara each interviewed two of the participants.

For each usability test, permission was first obtained from the participants of the study who consented to being interviewed for the study and have their responses and feedback recorded. Participants opened the website design on their computer and shared their screen during the Zoom meeting, so we could observe. The participant responses were recorded through taking notes of what the participants said and the actions that they took as they were being interviewed and exploring the design.

The usability study consists of both quantitative and qualitative measures of interest. Quantitative test measures that were considered during the usability study included the amount of time that the participants needed to explore the web page on their own as well as the time that it took them to more closely examine the three key visualizations. The time that it took participants to look at and examine the design and visualizations is important because it provides insight into whether or not the design is engaging based on whether or not the participant takes the time to closely examine and interact with the visualization or if they just scroll past.

An important qualitative measure that was tested was using a Likert scale to gauge the participants' concern and interest in air pollution before and after they completed the study. This was measured to determine the effect of the project's design and determine if the design was effective in drawing users in and having them become more interested in air pollution as well as communicating why people should be aware of air pollution and its health consequences. Other qualitative measures included having the participants think aloud as they explored the design, providing both positive and negative as they experienced using the web page and having them point out anything that they may have questions about or found confusing. The participants' summary and key takeaways were also an important part of the qualitative measures to determine if the design was effective in reaching its goal and communicating the message that was prescribed to the design.

There were three visualizations that the participants took a deep dive into and for which they provided more specific feedback. The three key visualizations that the participants focused on were Visualization #1: Sources of Pollutants, which consists of radar charts that show the percent contribution of various sources to seven different air pollutants in the United States; Visualization #2: Global Annual Average PM2.5 and Percent Attributable Mortality, which consists of a brushable scatterplot for the PM2.5 concentrations and percent attributable mortality for countries around the world and is also linked to a map with selectable countries; and Visualization #3: Attributable Disease Contribution, which consists of a word cloud of various diseases as well as icons indicating the percentage of deaths for each disease that is attributable to air pollution.

Feedback from the participants were taken into consideration, and improvements based on their feedback were made to the overall design as well as to specific visualizations.

6.3 Usability Test Results

The results of the usability study showed that the design at the time was generally effective in achieving its goal of communicating the importance of awareness of air pollution, but there are still improvements that can be made for the visualizations and overall design to improve the user's experience. Results from the usability study are broken down further in this section.

Results of the Quantitative Measures

The quantitative measure that was tested for the usability study was the time that the participants initially took to explore the web page on their own and undirected. This was the first task that was presented in the usability study, and was originally planned to take around five minutes. During the usability study, the participants spent more time than was originally planned to explore the design and interact with the visual elements, with all the participants spending between about ten and fifteen minutes exploring the website on their own. The participants took the time to look at each section of the design and did not skip any sections. This shows that the project was interesting and engaging, so they wanted to spend more time exploring. The amount of time that the participants spent more closely examining the three key visualizations was also measured. The participants spent around ten minutes interacting with these three key visualizations each, spending slightly more time on interactive elements and animations in comparison to flat elements.

Results of the Qualitative Measures

The first qualitative measure that was taken in the usability study was a Likert scale of the participants' concern and interest in air pollution. This test was also repeated at the end of the usability study to see if any changes had occurred in the participants’ perceptions. Most of the participants already were concerned about air pollution initially. Three of the participants had selected a rating of 8 on a scale ranging from 1 (not concerned) to 10 (most concerned), while one of the participants was not very concerned initially and had selected a 4 on the scale. When the Likert scale was repeated at the end of the usability study, the participants who were already concerned about air pollution provided the same rating and said that they were still very concerned, but felt that the web page was helpful in providing new information that they could learn from and were interested in learning more about actions they could take to protect themselves. The participant who was previously not very concerned about air pollution became more concerned and interested in learning about air pollution after exploring the web page, and selected a 9 as the level of concern for air pollution after the study. The results from this measure show that the design was effective in raising awareness about the importance of air pollution and health consequences, especially for people who initially were not as concerned. For those who were already concerned, their level of concern remained about the same, but they felt the web page was useful in helping them learn new information.

In addition to the Likert scale, the participants were also asked to think aloud during their exploration of the design and provide verbal feedback on the visualizations. A common comment that the participants gave was that they enjoyed the animations and interactive elements of the visualizations because they allowed for the most exploration and were the most engaging. However, they felt that the visualizations needed more of an introduction in their descriptions as well as instructions that could direct them to interact with the visualizations. For the Visualization #1: Sources of Pollutants Visualization, the participants found the visualization interesting and liked the colors used, but felt that more context needed to be given to understand what the areas measured and percent distributions meant. In addition, there was a comment that said that the small multiples of the radar charts were enough, and felt that the radar chart including all the pollutants together was unnecessary. For Visualization #2: Global Annual Average PM2.5 and Percent Attributable Mortality, the participants all enjoyed interaction and the exploration of information presented, but felt that there needed to be more direction to interact with the visualization as well as make the overall visualization larger so that it could be easier to interact with. For Visualization #3: Attributable Disease Contribution, the participants liked the animation of the word cloud, but felt that more context was needed for both the word cloud and the icons showing the percent of deaths of each disease attributable to air pollution. The participants all mentioned that the selection of diseases were unclear, and were wondering if they were the most common diseases. In addition, for the word cloud, they wanted a clearer distinction between the categories of diseases as well as highlighting which diseases were more prevalent, giving the suggestion of using different sizes for the fonts of each disease.

Overall, the participants felt that the design of the project at the time of usability testing was very effective in communicating information and providing a broad overview on air pollution, but that more direction was needed to determine which elements of the design were interactive and which were not. The participants thought that the visualization would be helpful for everyone who may be concerned about air pollution and want to learn more, as well as for the general public to understand why learning about air pollution is important.

6.4 Revisions to the Design

Based on the feedback received from the participants in the usability study, revisions were made to improve the design and visualizations. With respect to the overall design and interpretability of the visualizations, the participants of the usability study suggested that the design was overall effective, but more context and instructions should be added to the web page so that it is more clear and the visualizations are easier to understand and to follow.

Based on this feedback, more background information, labels, and descriptions were added to the visualizations as well as instructions directing the users so that they will know if a visualization is interactive and how to interact with the visualization. For example, more explanations of technical terms such as “attributable mortality” were added along with written summaries of the visualizations. Instructions were added for how to brush and select countries and points in the scatter plot and map visualization, and a legend of what certain colors, such as red or blue dots in the personal interventions animations were added.

The participants had pointed out in the usability study that certain elements were confusing, such as the down arrow in the title page that was meant to tell the participants to scroll down; many of the participants clicked on the arrow instead of scrolling. Because of this, the arrow was changed so that it is clear that the users need to scroll rather than click on the arrow (Figure 18).

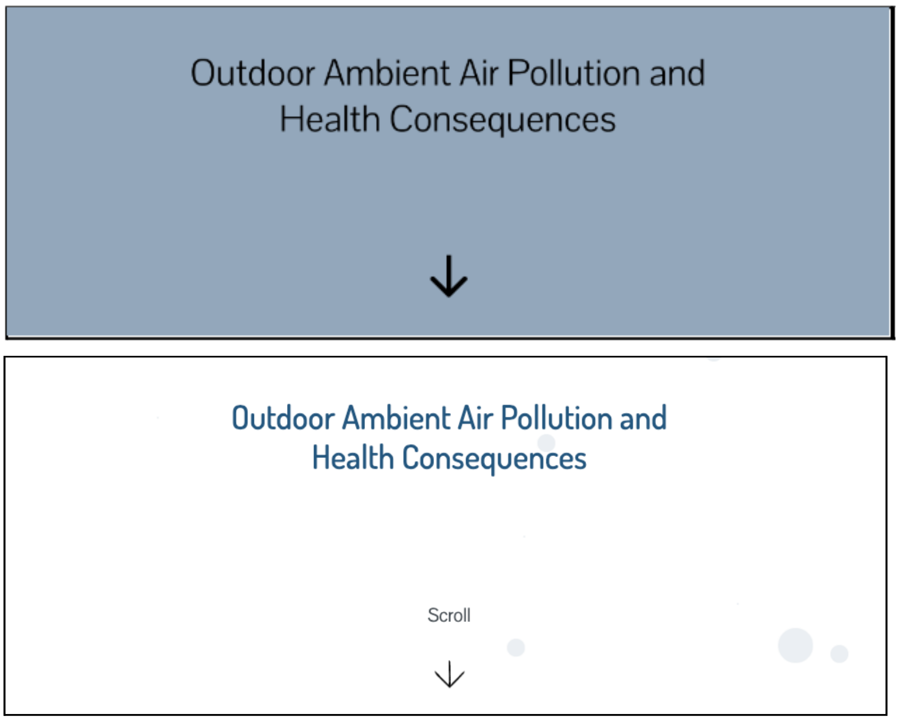


Figure 18. Title page of website prior to usability testing with only an arrow (top). Title page after usability testing including revisions indicating for users to scroll down rather than clicking on the arrow (bottom).

Revisions were also made to specific visualizations for which the participants provided feedback. For the radar chart, the participants found that the rings of the radar chart needed to be labeled with percentages to make the chart easier to understand and the font needed to be larger, so those labels were added to the final design (Figure 19). In addition, the drop down list was moved to the top of the visualization so that the user interactions were more clear. During the usability testing, some of the participants had mentioned that the small multiples of radar charts gave more context and they would have liked to see it before the combined radar chart as well, so the order of the charts were switched.

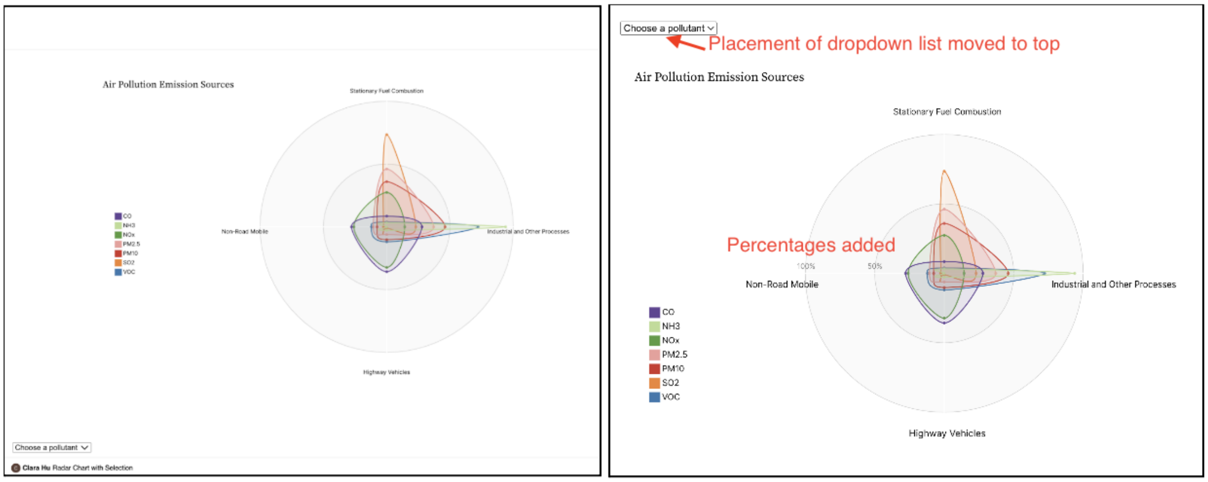


Figure 19. Radar chart before revisions (left) and after revisions (right). The dropdown list is moved to the top of the visualization and percentage labels are added to the chart for revisions.

For the brushable scatter plot and map of PM2.5 concentrations and attributable mortality, the participants liked the interactivity the most, but also all found the size of the points on the scatterplot and the map to be too small, causing the interactivity to be difficult at times. Because of this, in the final design the size of the points in the scatter plot were made larger and less opaque so that they could be more easily selected, and the text was made larger so that the visualization is easier to see and interact with (Figure 20). In addition, instructions on how to interact with the visualization were added as well as definitions for the technical terms used for more interpretability.

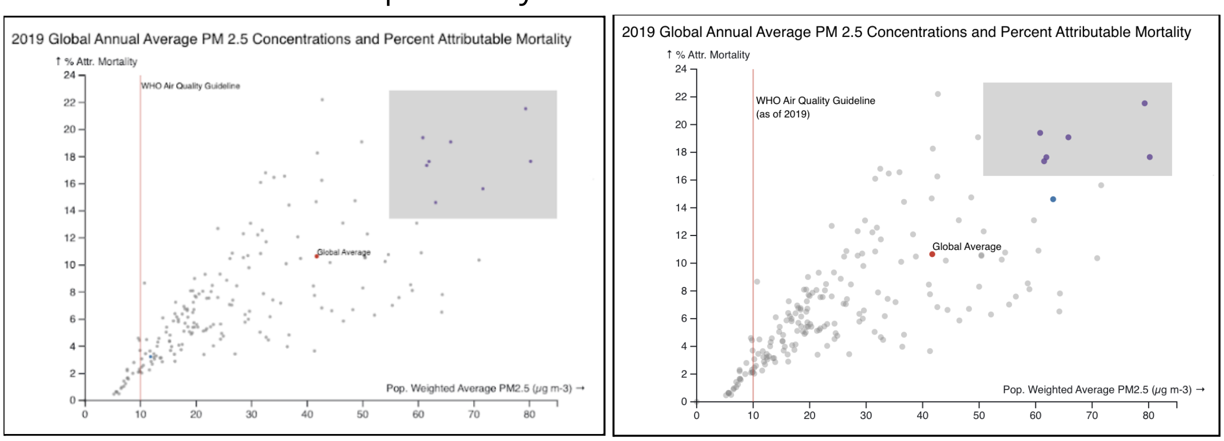


Figure 20. Scatterplot before (left) and after revisions (right). The points on the scatter plot and font of the text are larger after revisions so that the visualization is easier to read and interact with.

For word cloud visualization, which introduces the attributable mortality of various diseases to air pollution, the participants found the visualization effective and liked the design, but wanted more background context, so an accompanying description was added to each visualization explaining why the specific diseases are the focus in that section of the webpage. In addition, because some of the participants found the diseases in the word cloud to be difficult to comprehend and categorize, in the final design the categories were made more clear by adjusting the spacing between the words and introducing icons that signify which body part the diseases in each category affect (Figure 21).

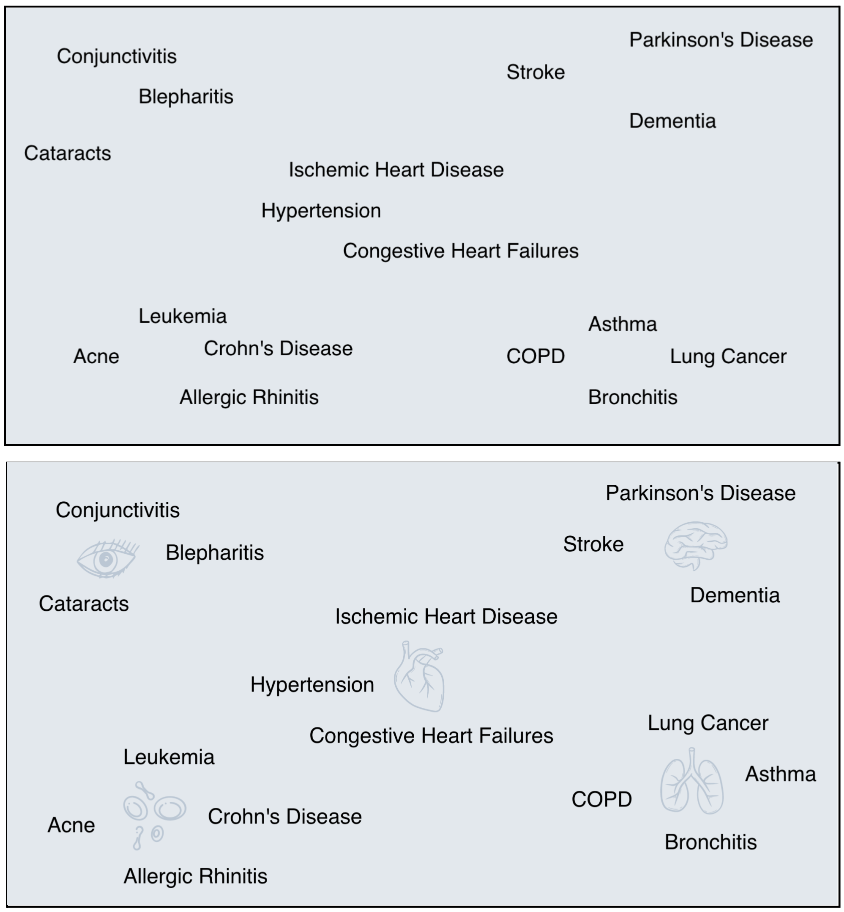


Figure 21. Word cloud visualization before revisions (top) and after revisions (bottom). Icons are added to the cluster of words to identify what part of the body each category of diseases affects.

Design elements that were not part of the three focus visualizations were also revised based on the feedback received from the usability testing participants. The visualization with zoom comparing various particle sizes to the size of PM2.5 was made into an animation, and the color indicating PM2.5 was changed so that it would stand out more in comparison to the other particles (Figure 22). The animation ensures that the zoom is centered on PM2.5 and the visualization is more controlled than a manual zoom, which may miss the PM2.5 particle. In addition, an outline dividing the visible particles and non-visible particles by the naked eye was added to the visualization.

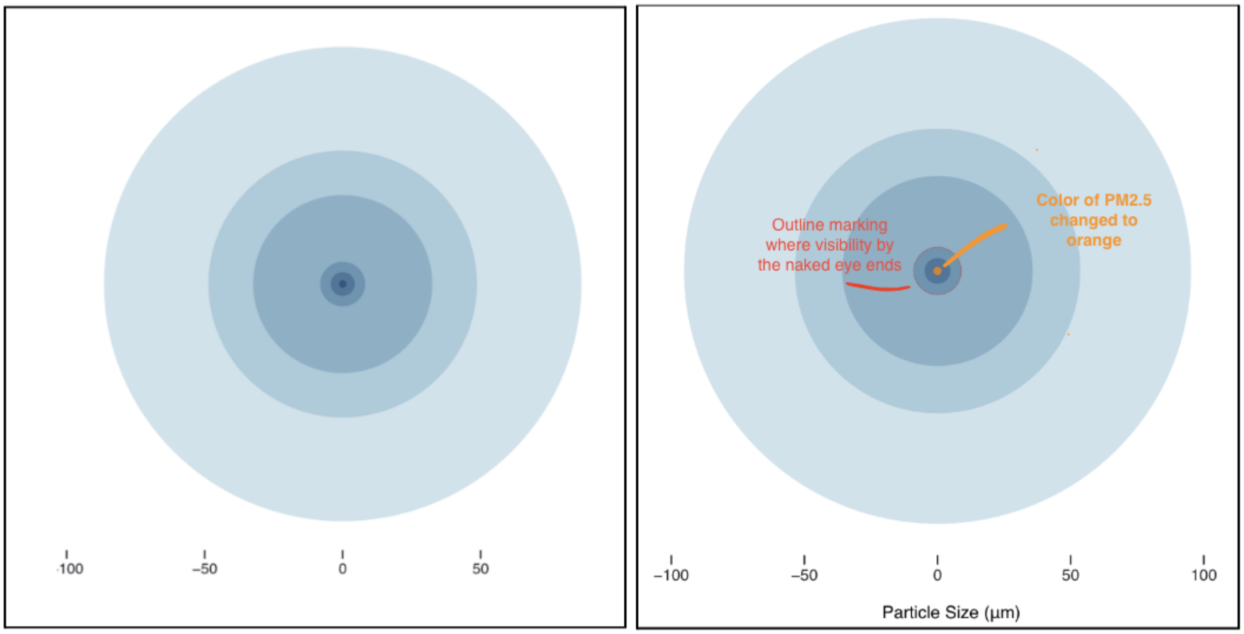


Figure 22. Visualization showing zoom of size of particles before (left) and after (right) revisions. The outline of where visible particles ends is added and the color of PM2.5 is changed to orange. The visualization is changed to become an animation so that the zoom is more controlled and the center stays on the PM2.5 particle.

7. Link to Data Repository and Code

Name	Link
Github Link to data for visualizations, code for web page, etc.	https://github.com/astoriah/info247-final-aap
Observable Links to Interactive and Animated Visualizations	https://docs.google.com/spreadsheets/d/1yNM5lqBiUKg3YszvzIGqaqHxQsLHCfnTsGXiC0EISDU/edit?usp=sharing
Figma Link to Flat Visualizations and Wireframes	https://www.figma.com/file/QIBNReUVcqeWaSWcZmqC9O/Final-Project-Flat-Visualizations-%2B-Wireframes?node-id=115%3A2

8. Team Contributions

Category	Task	Astoria Ho	Clara Hu
Preparation	Background Research	50%	50%
	Data Collection + Processing	50%	50%
Visualizations	Flat Visualizations	80%	20%
	Interactive Visualizations	5%	95%
	Web Development	100%	
User Testing	Test Design	60%	40%
	Testing	50%	50%
	Findings Analysis	20%	80%
Final Report Writing		35%	65%
	Average Contribution	**50%**	**50%**

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