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User's Manual for the Co-Benefits Risk Assessment Health Impacts Screening and Mapping Tool (COBRA)

Version: 5.1



**Developed for
State and Local Climate and Energy Program**



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LIST OF ACRONYMS

| Acronym | Definition |
|--------------------------|---|
| $\mu\text{g}/\text{m}^3$ | Micrograms per Cubic Meter |
| AVERT | AVoided Emissions and geneRation Tool |
| BenMAP | Environmental Benefits Mapping and Analysis Program |
| CAMx | Comprehensive Air Quality Model with Extensions |
| CDC | Centre for Disease Control |
| CMAQ | Community Multiscale Air Quality model |
| COBRA | Co-Benefits Risk Assessment Health Impacts Screening and Mapping Tool |
| C-R | Concentration-Response |
| eGRID | Emissions & Generation Resource Integrated Database |
| EGU | Electric Generating Unit |
| EPA | U.S. Environmental Protection Agency |
| FIPS | Federal Information Processing Standard |
| GB | Gigabyte |
| MDA8 | Maximum Daily 8-hour Average |
| MOVES | Motor Vehicle Emission Simulator |
| MWh | Megawatt hours |
| NAAQS | National Ambient Air Quality Standards |
| NH ₃ | Ammonia |
| NO ₂ | Nitrogen Dioxide |
| O ₃ | Ozone |
| PM _{2.5} | Particulate Matter 2.5 micrometers or smaller |
| ppm | parts per million |
| SO ₂ | Sulfur Dioxide |
| S-R | Source-Receptor |
| VOC | Volatile Organic Compound |
| WECC | Western Electricity Coordinating Council |
| WP | Woods & Poole Economics Inc. |

INSTALLATION INSTRUCTIONS

COBRA is available in two editions: a desktop application and a web-based version. The desktop edition of COBRA requires installation. This section discusses the process of installing the desktop edition. Note that the web version does not require installation and can be used on any web browser.

System Requirements

Users must have at least 6 GB free hard drive space, 6+ GB of RAM, i5 processor or AMD equivalent, and Windows 7 or newer. As a general recommendation, COBRA will perform better with a faster processor and a faster hard drive. A SSD drive is preferred. COBRA performance is strongly impacted by hard drive performance. Typical COBRA run time is 5 to 15 minutes.

Installation

COBRA can be downloaded from www.epa.gov/cobra. Note that the installer file is large (1.2 GB) and the amount of time required to complete the download will depend on your connection speed. Find the program ‘setup.exe’ in the location where the installer file was saved and open it.

During installation, follow the prompts on your screen. COBRA is a large program, and depending on the configuration of your computer, it will take five minutes up to an hour to complete the installation.

Launching the Model

To launch the model, go to **Start... Programs... COBRA**.

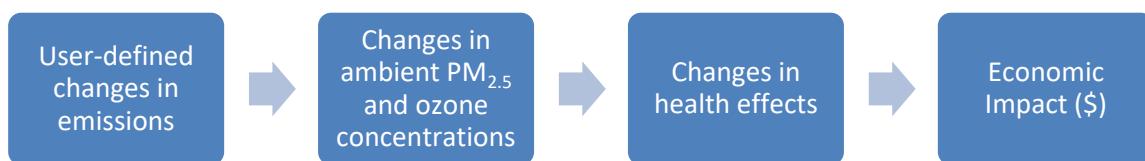
Technical Assistance

For more information, please contact cobra@epa.gov.

CHAPTER 1. Introduction

What is COBRA?

COBRA is a screening tool that provides estimates of the impact of air pollutant emission changes on ambient fine particulate matter ($PM_{2.5}$) and ozone (O_3) air pollution concentrations, translates this into health effect impacts, and then monetizes these impacts,¹ as illustrated below.



The model does not require expertise in air quality modeling, health effects assessment, or economic valuation. Built into COBRA are emissions inventories, a simplified air quality model, health impact equations, and economic valuations ready for use, based on assumptions that the U.S. Environmental Protection Agency (EPA) currently uses as reasonable best estimates. COBRA also enables advanced users to import their own datasets of emissions inventories, population, incidence, health impact functions, and valuation functions. Analyses can be performed at the state or county level and across the 14 major emissions categories (these categories are called “tiers”) included in the National Emissions Inventory.² COBRA presents results in tabular as well as geographic form and enables policy analysts to obtain an estimate of the benefits of different mitigation scenarios under consideration. More sophisticated, albeit time- and resource-intensive, modeling approaches are currently available to obtain a more refined picture of the health and economic impacts of changes in emissions.

EPA initially developed COBRA as a desktop application. In 2021, EPA released a web-based version of the tool, known as the [COBRA Web Edition](#). Although the desktop version and web versions of COBRA both use the same methodology to calculate outdoor air quality and health impacts from changes in air pollutant emissions, the

¹ In calculating health impacts, COBRA generates mean estimates of health impacts. This is in contrast to a risk assessment, which typically builds in a margin of safety by presenting 95th percentile estimates.

² The emissions inventory in COBRA includes fourteen broad tier 1 categories (e.g., on-road motor vehicles); within each of these larger categories there are tier 2 (e.g., diesels), and tier 3 (e.g., heavy duty diesels) categories. The fourteen tier 1 categories include: Chemical & Allied Product Manufacturing, Fuel Combustion: Electric Utilities, Fuel Combustion: Industrial, Fuel Combustion: Other, Highway Vehicles, Metals Processing, Miscellaneous, Natural Resources, Off-Highway, Other Industrial Processes, Petroleum & Related Industries, Solvent Utilization, Storage & Transport, and Waste Disposal & Recycling.

desktop version offers additional advanced features that are not included in the more streamlined web edition.

In particular, the desktop version is preloaded with input data on emissions, population, and baseline health incidence for 2016, 2023, and 2028; the web edition includes data only for 2023. Similarly, the desktop version allows users to import custom input datasets, while the web edition does not. The web edition, however, does not require the user to download or install additional software, and it runs more quickly than the desktop version. Users might choose to use the desktop version if they would like to use advanced features, such as custom input data and/or use the preloaded data for 2016 or 2028. Otherwise, users may choose to use the web edition for data analysis relevant to 2023.

The process for entering emissions input data into COBRA is very similar for the desktop and web versions of the tool. The remainder of this User’s Manual focuses on the steps required to run the desktop version of the tool. The same general process can be used with the web edition.

How is COBRA used?

COBRA can be used to assess and evaluate changes in air quality and health impacts under different types of air pollutant emission control options. Using the mapping capabilities in COBRA, users can identify the locations and types of emissions sources that contribute to local air quality problems. When considering different policy options, COBRA can help identify those options that are likely to maximize health benefits, or that could be expected to achieve health risk reductions in the most cost-effective manner. Once state and local officials narrow the set of most promising policy options through COBRA, they can then conduct analyses with more sophisticated air quality models to finalize their policy choices.

The model contains detailed emissions estimates for the years 2016, 2023, and 2028. These baseline emissions estimates account for federal and state regulations as of May

Who can use COBRA?

- ***State and local officials*** who would like to quickly identify important emission sources and compare the impacts of different control options;
- ***Analysts*** looking to improve their understanding of the air quality improvements and health benefits associated with clean energy policies under consideration;
- ***Environmental agencies*** trying to inexpensively screen through many options to identify those that maximize the health benefits and to quantify the economic value of health improvements;
- ***Energy officials*** looking to estimate and promote the air quality, health, and associated economic co-benefits of their energy efficiency or renewable energy policies; and
- ***Transportation planners*** interested in understanding the air quality and health impacts of fuel switching or reductions in vehicle miles traveled.

2018.³ The projected electric generating unit (EGU) emissions comply with the Cross-State Air Pollution Rule Update finalized December 27, 2016, the Mercury and Air Toxics Rule, and the Standards of Performance for Greenhouse Gas Emissions from New, Modified, and Reconstructed Stationary Sources.⁴

Using COBRA, you can create your own new scenarios by specifying increases or reductions to the baseline emissions estimates for the analysis year. Baseline data is preloaded for analysis years 2016, 2023, and 2028, and advanced users can analyze other years by importing custom datasets. Emissions changes can be entered at the county, state, or national level.

COBRA then generates changes in PM_{2.5} and O₃ concentrations between the baseline scenario (the “business-as-usual” estimates for the analysis year) and the control scenario (the analysis year modified by the user’s emissions changes). Source-receptor matrices translate the user-defined air pollutant emissions changes into changes in ambient PM_{2.5} and O₃ (for more information about the emissions inventory and the source-receptor matrix, see Appendix A). Using a range of health impact functions, COBRA then translates the ambient PM_{2.5} and O₃ concentrations changes into changes in the incidence of human health effects (see Appendices B through E). Finally, the model places a dollar value on these health effects (for more information, see Appendix F). COBRA estimates the change in air pollution-related health impacts, and estimates the economic value of these impacts, using an approach that is generally consistent with EPA Regulatory Impact Analyses, including the analysis of the National Ambient Air Quality Standards (NAAQS) for particulate matter (U.S. EPA, 2012). These analyses reflect the current state of the science regarding the relationship between particulate matter and adverse human health.

Outcomes can be modeled nationwide or for smaller geographic areas. Results include changes in ambient PM_{2.5} and O₃ concentrations, and changes in the number of cases of a variety of health endpoints that have been associated with PM_{2.5} and O₃. These health endpoints include:

- Adult and infant mortality (PM_{2.5} and O₃);
- Non-fatal heart attacks (PM_{2.5});

³ More details about the development of the 2016, 2023, and 2028 baseline emissions case are available in the supporting information for the 2016v1 Emissions Modeling Platform, available here: <https://www.epa.gov/air-emissions-modeling/2016v1-platform>

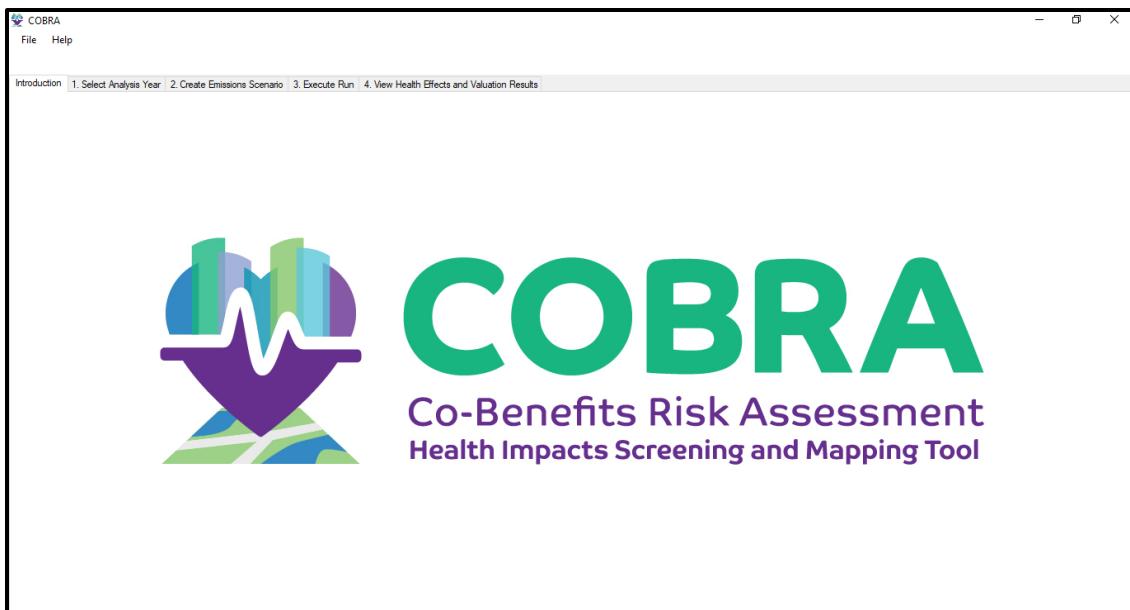
⁴ For more information on the electricity sector modeling used to develop the emissions baselines used in COBRA, see the Documentation for EPA’s Power Sector Modeling Platform v6 Using the Integrated Planning Model, available here: <https://www.epa.gov/airmarkets/documentation-epas-power-sector-modeling-platform-v6>

- Respiratory-related hospitalizations (PM_{2.5} and O₃);
- Cardiovascular-related hospitalizations (PM_{2.5});
- Respiratory-related and asthma-related emergency room visits (PM_{2.5} and O₃);
- Cardiovascular-related emergency room visits (PM_{2.5});
- Asthma incidences (PM_{2.5} and O₃);
- Lung cancer incidences (PM_{2.5});
- Hospitalizations from Alzheimer's and Parkinson's disease (PM_{2.5});
- Stroke incidences (PM_{2.5});
- Hay fever/rhinitis incidences (PM_{2.5} and O₃);
- Minor restricted activity days (i.e., days on which activity is reduced, but not severely restricted) (PM_{2.5});
- School loss days (O₃);
- Asthma symptoms, including albuterol use, cough, wheeze, chest tightness, and shortness of breath (PM_{2.5} and O₃);
- And work days lost due to illness (PM_{2.5}).

Users can view the results in tabular or map form as well as export the data for use in their own communications.

Overview of Model

The COBRA screening model is a stand-alone Windows application that contains all of the data needed for the analysis of alternative emissions scenarios; the user is only required to enter changes in emissions. Upon launching the model, you will see the **Introduction** screen. A web version of COBRA is also available at: www.epa.gov/cobra. The functionality of the web version is similar to the desktop version, but the user interface is slightly different. The instructions below are meant for the desktop version, but screenshots of the web version will also be included throughout.

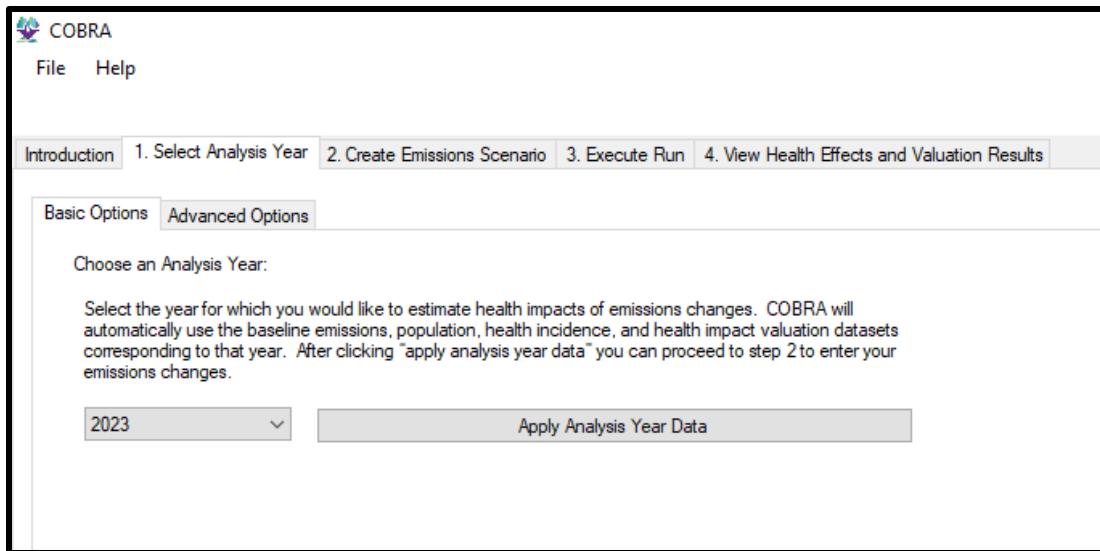


Desktop Version

A screenshot of the COBRA web edition homepage. It features the EPA logo and navigation links for "Environmental Topics", "Laws & Regulations", and "About EPA". A search bar is at the top right. The main content area has a blue header with the text "CO-Benefits Risk Assessment Health Impacts Screening and Mapping Tool (COBRA)". Below this is a section titled "COBRA Web Edition" with the COBRA logo. A paragraph describes COBRA as a screening tool for air quality and health benefits. At the bottom, a note says "You are using the web-based version of COBRA. For the COBRA desktop application, visit the [COBRA download page](#)." Social media sharing icons are also present.

Web Version

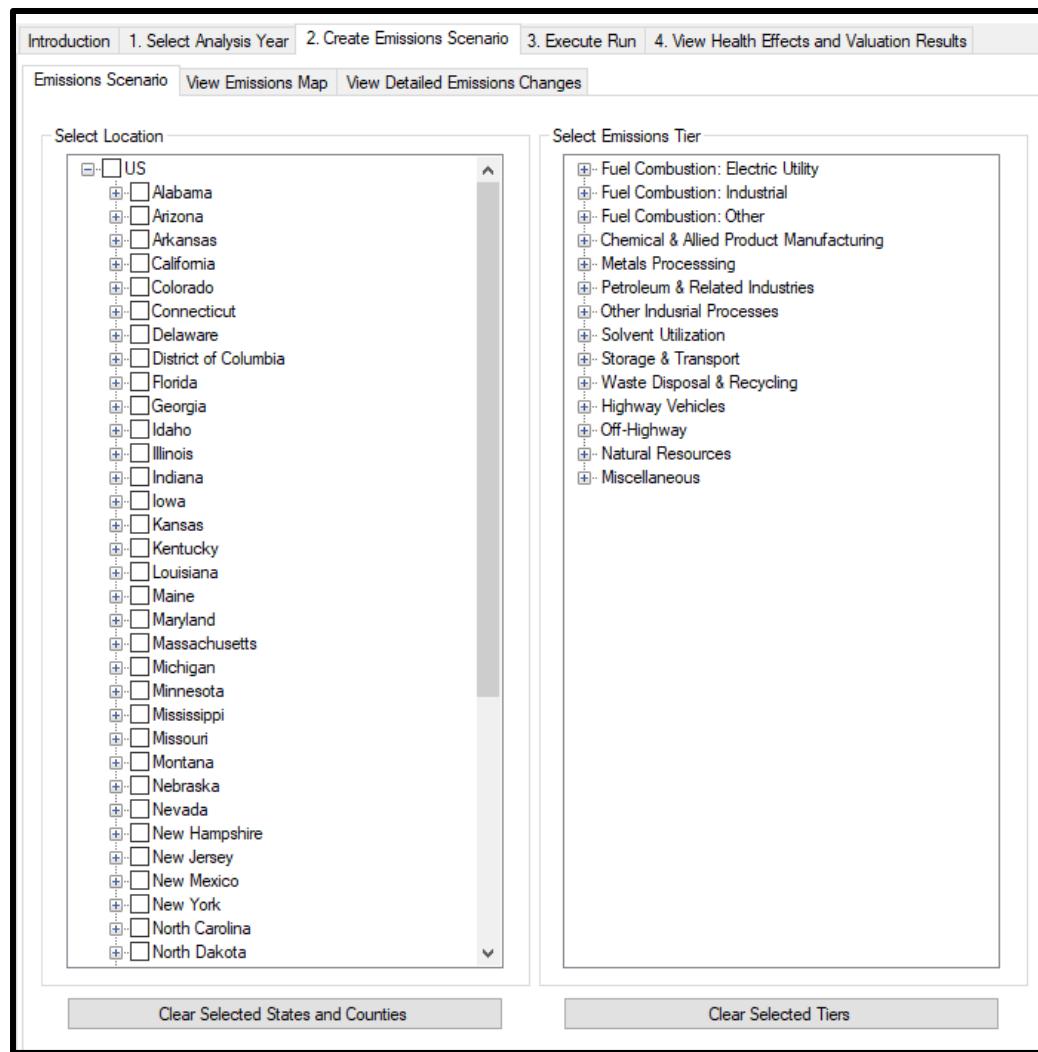
Once you are ready to run a comparison, go to the **1. Select Analysis Year** screen and select the analysis year of interest. Advanced users can load a customized baseline emissions inventory at this stage, which is discussed in more detail in Chapter 3. Note that the web edition of COBRA uses the 2023 baseline. Users do not have the option to select a different year or use a custom baseline in the web edition.



Desktop Version

Then, go to the **2. Create Emissions Scenario** screen. Use the ‘Select Location’ panel on the top left of the **Emissions Scenario** tab to indicate the geographic level at which you wish to make your emissions changes. ‘US’ means that any emissions changes will be applied to all sources in that category throughout the entire U.S. Alternatively, you can enter emissions changes for selected states or selected counties.

Next, select the category of emissions that a policy or action is expected to affect in the ‘Select Emissions Tier’ panel. For example, to assess the impacts of a renewable energy or energy efficiency policy that is expected to affect utility-related emissions, you would select ‘Fuel Combustion: Electric Utility’ as the first tier. COBRA provides three levels of emissions sources (tiers) in a directory tree structure. If you know the specific fuel source within the utility category that would be reduced or displaced (e.g., coal or natural gas), you can select the appropriate second tier. If you do not know the specific fuel source within the utility category that would be reduced or displaced, you can enter emissions changes at the tier 1 level. For a policy that involves vehicle electrification or reductions in transportation through vehicle miles traveled, for example, you would select ‘Highway Vehicles’ as the first tier. If you knew the specific fuel (e.g., diesel) that would be reduced, you would select it in the second tier.



Desktop Version

Step 1: Build Scenario

Complete the sections below and click "Add to Scenario."

A. Select Location REQUIRED

Select the states or counties where the emissions changes will occur. [i](#)

> Alabama
> Arizona
> Arkansas
> California
> Colorado
> Connecticut
> Delaware
> District of Columbia
> Florida

[Select All](#) | [Deselect All](#)

B. Select Sector REQUIRED

Select the industry or sector where the emissions changes will occur. [i](#)

Sector
Select a sector

Subsector (optional)
All subsectors

Subsector (optional)
All subsectors

Web Version

Once your geography is determined, you can enter your emissions changes for the selected geography.

Exhibit 1. Basic Tools and Data Sources for Determining Emission Reductions

| Online Tool | Description |
|---|---|
| EPA's Emissions & Generation Resource Integrated Database (eGRID) (https://www.epa.gov/egrid) | Provides data on the environmental characteristics of electric generation by power plants in the United States. |
| EPA's AVOIDed Emissions and geneRation Tool ⁵ (AVERT) (https://www.epa.gov/avert) | Estimates displaced emissions (at the county, state, and regional levels) at electric power plants due to renewable energy, energy efficiency, or electric vehicle policies and programs. |
| EPA's Motor Vehicle Emission Simulator (MOVES) (https://www.epa.gov/moves) | Estimates emissions from mobile sources, including emissions from cars, trucks, and motorcycles. |
| National Emissions Inventory (https://www.epa.gov/air-emissions-inventories/national-emissions-inventory-nei) | Allows users to view emissions by sector (for 60 emissions inventory sectors) for specific pollutants at varying levels of geographic aggregation. |
| Power Profiler (https://www.epa.gov/egrid/power-profiler#/) | Allows users to view the emissions that can be attributed to electricity use in homes or businesses. |

Note: For more details on these basic tools and on other methods, see: (1) Chapter 4 of EPA's "Quantifying the Multiple Benefits of Energy Efficiency and Renewable Energy: A Guide for State and Local Governments" report (U.S. EPA, 2018), available at <https://www.epa.gov/statelocalenergy/quantifying-multiple-benefits-energy-efficiency-and-renewable-energy-guide-state>; or (2) Appendix I of EPA's "Roadmap for Incorporating Energy Efficiency/Renewable Energy Policies and Programs into State and Tribal Implementation Plans" (U.S. EPA, 2012c), available at <https://www.epa.gov/energy-efficiency-and-renewable-energy-sips-and-tips>.

Once you have determined the appropriate tier category and location, enter the emission changes for one or more of the five included pollutants in the '2. Create Emissions Scenario' panel at the top right of the COBRA screen. You can enter emissions changes in tons or percentages. Absolute emission reductions in tons can be estimated using a variety of methods. See Exhibit 1 above for a description of a few basic methods. Percentage reductions can be used to assess the benefits of a goal that results in reductions in activity levels or emissions from a particular source (or group of sources), such as a renewable portfolio standard, transportation policies requiring reductions in vehicle miles traveled, and energy efficiency programs.

⁵ AVERT users can easily export emissions changes into COBRA via their integrated web-based tools or through appropriately formatted export files.

Example: EPA's Emissions & Generation Resource Integrated Database (eGRID) website provides electric generation data and corresponding emissions rates for the United States.⁶ On the eGRID website, click on '**eGRID2022 Summary Tables (PDF)**'.⁷ Using the Western Electricity Coordinating Council (WECC) Southwest Region (which includes Arizona and New Mexico) as an example, you can obtain the following information:

- Electric Generation: The "Subregion Resource Mix (eGRID 2022)" table on page 3 summarizes electric generation data by region. The net generation for the WECC Southwest Region in 2022 was approximately 170,369,549 megawatt-hours (MWh).
- Emissions Rates: The "Subregion Output Emission Rates (eGRID 2022)" table on page 2 provides the WECC Southwest Region's non-baselload output emissions rate for SO₂: 0.121 lbs. per MWh.⁸

If a policy is expected to reduce electric generation by 2% in the WECC Southwest Region, you can calculate the reduction in MWh: $2\% \times 170,369,549 \text{ MWh} = 3,407,391 \text{ MWh}$. You can then calculate the emission reductions as:

$$\text{Emission Reduction} = 3,407,391 \text{ MWh} \times 0.121 \text{ lbs. SO}_2 \text{ per MWh} = 412,294 \text{ lbs. SO}_2.$$

This reduction is equal to about 206 tons ($412,294 \text{ lbs.} \div 2000 \text{ lbs. per ton}$) of SO₂.⁹

After you have calculated emissions changes, you can enter these changes for as many tier categories as you wish, and you can enter different sets of changes for each state or county (or groups of states and/or counties, if you choose to select more than one). After each change in emissions for a state, county, or group of states or counties, click **Apply Changes**.

⁶ While eGRID provides a basic approach for estimating changes in emissions from energy efficiency and renewable energy using annual data, another useful resource available for estimating changes in emissions is EPA's **Avoided Emissions and Generation Tool (AVERT)**. AVERT enables users to estimate the regional, state, and county-level emission impacts of different energy efficiency and/or renewable energy programs based on temporal energy savings and hourly generation profiles. For more information or to download AVERT, see:

<https://www.epa.gov/statelocalenergy/avoided-emissions-and-generation-tool-avert>.

⁷ This example uses eGRID 2021 data, so it would be most appropriate to choose the 2023 baseline for the analysis in COBRA.

⁸ Non-baselload emissions come from power plants that dispatch to the grid when demand for power exceeds baseload needs (U.S. EPA, 2020).

⁹ For more information on the benefits of reductions in SO₂ emissions, see EPA's "Quantifying the Multiple Benefits of Energy Efficiency and Renewable Energy: A Resource for State and Local Governments" report (U.S. EPA, 2018), available at: <https://www.epa.gov/statelocalenergy/quantifying-multiple-benefits-energy-efficiency-and-renewable-energy-guide-state>.

Modify Emissions

| | | Emissions Scenario / Baseline |
|--------|---|--|
| PM 2.5 | <input checked="" type="radio"/> reduce by <input type="radio"/> increase by | 25.00 <input type="button" value="▼"/> <input checked="" type="radio"/> pct <input type="radio"/> tons 1,600.41 [tons] / 1,600.41 [tons] |
| SO2 | <input checked="" type="radio"/> reduce by <input type="radio"/> increase by | 25.00 <input type="button" value="▼"/> <input checked="" type="radio"/> pct <input type="radio"/> tons 286.27 [tons] / 286.27 [tons] |
| NOx | <input checked="" type="radio"/> reduce by <input type="radio"/> increase by | 25.00 <input type="button" value="▼"/> <input checked="" type="radio"/> pct <input type="radio"/> tons 49,815.10 [tons] / 49,815.10 [tons] |
| VOC | <input checked="" type="radio"/> reduce by <input type="radio"/> increase by | 25.00 <input type="button" value="▼"/> <input checked="" type="radio"/> pct <input type="radio"/> tons 34,086.10 [tons] / 34,086.10 [tons] |
| NH3 | <input checked="" type="radio"/> reduce by <input type="radio"/> increase by | 0.00 <input type="button" value="▼"/> <input checked="" type="radio"/> pct <input type="radio"/> tons 2,160.62 [tons] / 2,160.62 [tons] |

[Desktop Version](#)

C. Modify Emissions

REQUIRED

Enter emissions changes for **at least one** of the four pollutants below. [i](#)

PM_{2.5}

reduce by **increase by**

enter # tons percent

SO₂

reduce by **increase by**

enter # tons percent

NO_x

reduce by **increase by**

enter # tons percent

VOC

reduce by **increase by**

enter # tons percent

NH₃ [i](#)

reduce by **increase by**

enter # tons percent

ADD TO SCENARIO

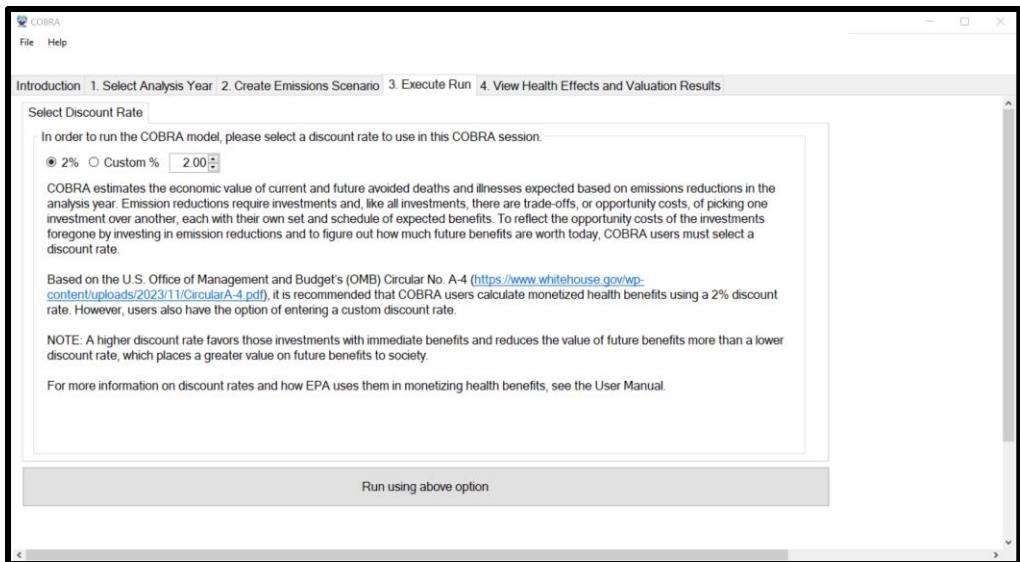
Web Version

Note that previous versions of COBRA also included ammonia (NH_3) as an input.
Starting with COBRA 5.0, the air quality model included in COBRA does not consider NH_3 as an input to estimate changes in $PM_{2.5}$ concentrations at this time.

To review your scenario, click **View Detailed Emissions Changes**.

Desktop Version

Then, go to the **3. Execute Run** screen to select settings for running your scenario. This tab asks you to choose a discount rate (described in more detail in the Chapter 2 Tutorial). Choose a 2% discount rate or enter your own discount rate and click **Run using above options** to run the comparison between the scenario you have just created and the baseline scenario.



Desktop Version

Step 2: Review Scenario

Review the scenario below. To add changes to more locations or sectors, repeat Step 1 to continue building your scenario.

| Location(s) | Sector | Emissions Modification(s) |
|------------------------|------------------|--|
| Alabama - All Counties | Highway Vehicles | PM _{2.5} reduce by 25% SO ₂ reduce by 25% NO _x reduce by 25% VOC reduce by 25% |

Need to continue adding emissions changes to locations or sectors? Repeat Step 1.

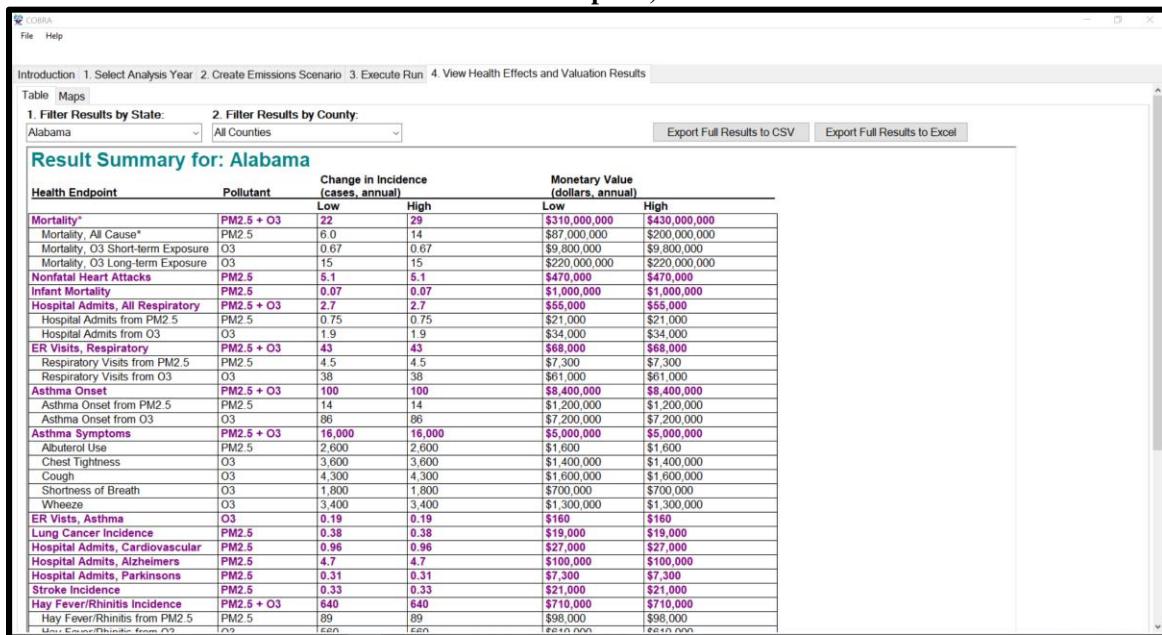
Discount rate:

2%
 Custom:

Web Version

The model may take 5 to 15 minutes to run, depending on your computer. When the model is done running, you can examine the results in the **4. View Health Effects and Valuation Results** tab. Regardless of the geographic level at which you made your emissions changes, you can examine the results for every county in every state in the country. For each county, COBRA calculates three types of results: the change in ambient PM_{2.5} and O₃ concentrations; the change in health effects associated with that change; and the dollar value associated with the change in health effects.

These results can be viewed in a table (in the Table tab) or geographically on a map of the United States (in the Map tab).



Result Summary for: Alabama

| Health Endpoint | Pollutant | Change in Incidence (cases, annual) | | Monetary Value (dollars, annual) | |
|---|------------------------------|--|---------------|-------------------------------------|----------------------|
| | | Low | High | Low | High |
| Mortality* | PM2.5 + O₃ | 22 | 29 | \$310,000,000 | \$430,000,000 |
| Mortality, All Cause* | PM2.5 | 6.0 | 14 | \$87,000,000 | \$200,000,000 |
| Mortality, O ₃ Short-term Exposure | O ₃ | 0.67 | 0.67 | \$9,800,000 | \$9,800,000 |
| Mortality, O ₃ Long-term Exposure | O ₃ | 15 | 15 | \$220,000,000 | \$220,000,000 |
| Nonfatal Heart Attacks | PM2.5 | 5.1 | 5.1 | \$470,000 | \$470,000 |
| Infant Mortality | PM2.5 | 0.07 | 0.07 | \$1,000,000 | \$1,000,000 |
| Hospital Admits, All Respiratory | PM2.5 + O₃ | 2.7 | 2.7 | \$55,000 | \$55,000 |
| Hospital Admits from PM2.5 | PM2.5 | 0.75 | 0.75 | \$21,000 | \$21,000 |
| Hospital Admits from O ₃ | O ₃ | 1.9 | 1.9 | \$34,000 | \$34,000 |
| ER Visits, Respiratory | PM2.5 + O₃ | 43 | 43 | \$68,000 | \$68,000 |
| Respiratory Visits from PM2.5 | PM2.5 | 4.5 | 4.5 | \$7,300 | \$7,300 |
| Respiratory Visits from O ₃ | O ₃ | 38 | 38 | \$61,000 | \$61,000 |
| Asthma Onset | PM2.5 + O₃ | 100 | 100 | \$8,400,000 | \$8,400,000 |
| Asthma Onset from PM2.5 | PM2.5 | 14 | 14 | \$1,200,000 | \$1,200,000 |
| Asthma Onset from O ₃ | O ₃ | 86 | 86 | \$7,200,000 | \$7,200,000 |
| Asthma Symptoms | PM2.5 + O₃ | 16,000 | 16,000 | \$5,000,000 | \$5,000,000 |
| Albuterol Use | PM2.5 | 2,600 | 2,600 | \$1,600 | \$1,600 |
| Chest Tightness | O ₃ | 3,600 | 3,600 | \$1,400,000 | \$1,400,000 |
| Cough | O ₃ | 4,300 | 4,300 | \$1,600,000 | \$1,600,000 |
| Shortness of Breath | O ₃ | 1,800 | 1,800 | \$700,000 | \$700,000 |
| Wheeze | O ₃ | 3,400 | 3,400 | \$1,300,000 | \$1,300,000 |
| ER Visits, Asthma | O₃ | 0.19 | 0.19 | \$160 | \$160 |
| Lung Cancer Incidence | PM2.5 | 0.38 | 0.38 | \$19,000 | \$19,000 |
| Hospital Admits, Cardiovascular | PM2.5 | 0.96 | 0.96 | \$27,000 | \$27,000 |
| Hospital Admits, Alzheimers | PM2.5 | 4.7 | 4.7 | \$100,000 | \$100,000 |
| Hospital Admits, Parkinsons | PM2.5 | 0.31 | 0.31 | \$7,300 | \$7,300 |
| Stroke Incidence | PM2.5 | 0.33 | 0.33 | \$21,000 | \$21,000 |
| Hay Fever/Rhinitis Incidence | PM2.5 + O₃ | 640 | 640 | \$710,000 | \$710,000 |
| Hay Fever/Rhinitis from PM2.5 | PM2.5 | 89 | 89 | \$98,000 | \$98,000 |
| Hay Fever/Rhinitis from O ₃ | O ₃ | 650 | 650 | \$610,000 | \$610,000 |

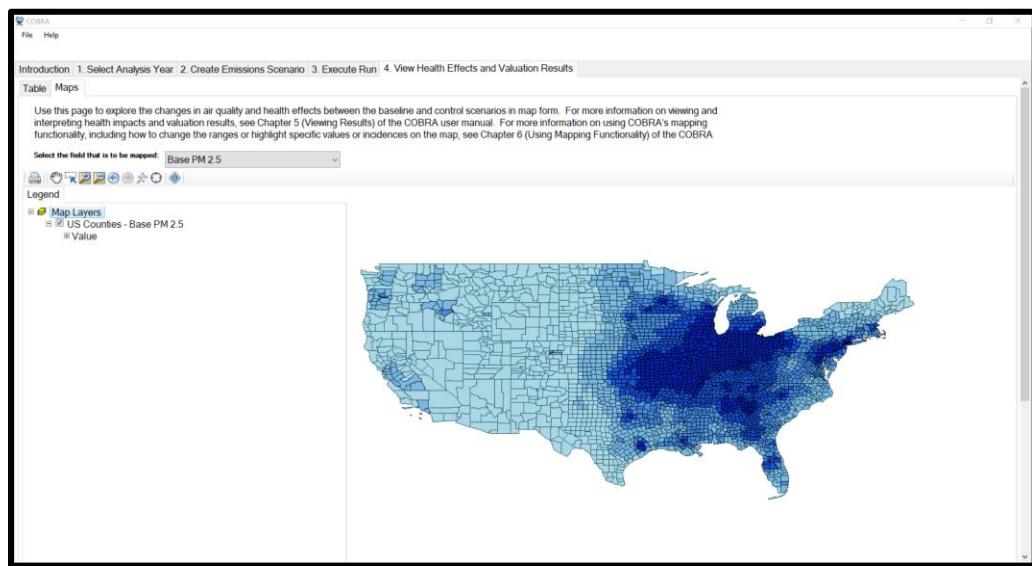
Desktop Version

The last row of the results table summarizes the total impact of the scenario. To view the impact of the scenario on a specific state, click the dropdown menu under **1. Filter Results by State** and select the state of interest. For example, results in the table above show estimated impacts of the scenario for Alabama. According to these results, the emissions reductions in 2023 would result in the following health effects in Alabama:

- 22 to 29 avoided premature adult deaths (over the next 20 years), valued at an estimated \$310 and \$430 million;
- 5.1 avoided nonfatal heart attacks (in 2023), valued at an estimated \$470,000
- 0.19 avoided asthma emergency room visits (in 2023), valued at an estimated \$160.

Note that health effects are not necessarily whole numbers. This is because COBRA calculates small statistical risk reductions which are then aggregated over the population. For example, if 150,000 people experience a 0.001% reduction in mortality risk, this would be reported as 1.5 “statistical lives saved.” This statistical life and its associated monetary value represent the sum of many small risk reductions and does not correspond to the loss or value of an individual life.

Result sets can be exported for use in outside programs and presentations. To save your results in a table form, click on **Export to CSV** or **Export to Excel** (depending on your preferred format) in the **Table** tab. To save your results in map form, navigate to the **Map** tab, right click on the data in the ‘Legend’ panel, then click **Data...Export Data**.



Desktop Version

Step 3: View Results

BUILD NEW SCENARIO

A. Summary of Health Effects Results

Below is a table with the health effects results based on your scenario.

Info You are viewing results for all contiguous U.S. states. This is because changes in air quality can impact health endpoints in multiple locations due to the transportation of emissions across state and county lines.

Use the filters below to see health effects for a specific state or county.

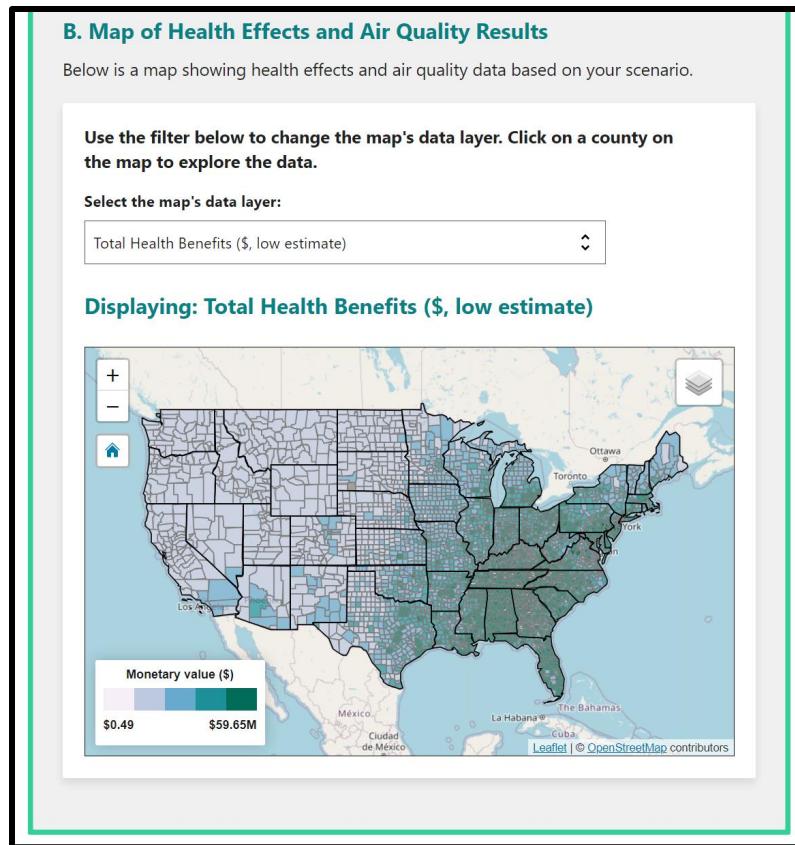
1. Filter by state: All contiguous U.S. states

2. Filter by county: (optional) All counties

Results for: All Contiguous U.S. States

x Export: All results | Current filter

| Health Endpoint <i>ⓘ</i> | Pollutant | Change in Incidence <i>ⓘ</i> (cases, annual) | | Monetary Value <i>ⓘ</i> (dollars, annual) | |
|------------------------------------|------------------------------------|--|--------|---|-----------------|
| | | Low | High | Low | High |
| Mortality * | PM _{2.5} O ₃ | 74 | 95 | \$1,100,000,000 | \$1,400,000,000 |
| Nonfatal Heart Attacks | PM _{2.5} | 14 | 14 | \$1,300,000 | \$1,300,000 |
| Infant Mortality | PM _{2.5} | 0.16 | 0.16 | \$2,600,000 | \$2,600,000 |
| Hospital Admits, All Respiratory | PM _{2.5} O ₃ | 9.4 | 9.4 | \$190,000 | \$190,000 |
| Emergency Room Visits, Respiratory | PM _{2.5} O ₃ | 170 | 170 | \$270,000 | \$270,000 |
| Asthma Onset | PM _{2.5} O ₃ | 390 | 390 | \$33,000,000 | \$33,000,000 |
| Asthma Symptoms | PM _{2.5} O ₃ | 61,000 | 61,000 | \$20,000,000 | \$20,000,000 |
| Emergency Room Visits, Asthma | O ₃ | 0.77 | 0.77 | \$630 | \$630 |
| Lung Cancer Incidence | PM _{2.5} | 1.1 | 1.1 | \$54,000 | \$54,000 |



[Web Version](#)

Caveats and Limitations

As a reduced-form model, COBRA is inappropriate for certain types of analyses:

- *Determination of attainment.* Modeling the attainment of NAAQS requires more sophisticated air quality modeling than that currently built into COBRA.
- *Estimating dynamic market effects.* COBRA does not account for changes in emissions that can result from changes in electricity market responses to policy. For example, emissions in some states and regions are “capped” by laws or regulations and emission allowances can then be traded across entities within a capped region. In these regions, a reduction in emissions in one location *may* result in an increase (rebound) in emissions in another area subject to the cap. COBRA does not automatically capture these types of potential effects in electricity market dispatch, so care should be exercised when interpreting COBRA results to analyze the net impacts of a change in policy. COBRA is more suited to an attributable risk assessment, which addresses the magnitude of an

emission source and the impact of controlling its emissions. That information can be used to develop policies targeted to the appropriate sources.

As with more complex air pollution benefits models, there is uncertainty surrounding the values of key components of COBRA, including:

- **Emissions inventories** in COBRA include reported data for 2016 and projections for 2023 and 2028. Scenarios involving a percentage reduction of the baseline emissions in a given location will have uncertainty, particularly for the projected analysis years.
- **The S-R matrix** is a simplified approach for air quality modeling derived from the outputs of a more complex model. See Baker et al. 2023 for more information.
- **Baseline incidence values** are best estimates, but in some cases county-level data is not available. For example, the incidence for work loss and school loss days is based on national-level estimates. See Appendix D for more information.
- **Population data** are derived from projections of the US Census and forecasting models derived by Woods & Poole (2015). These projections and models have greater uncertainty when considering smaller geographic units and years further into the future. See Appendix E for more information.
- **Health impact functions** are based on data from epidemiological literature on the impacts of PM_{2.5} and ozone on public health; however, this relationship between air quality and public health may differ in different locations or contexts.
- **Economic values** are based on the willingness to pay to avoid the health outcome and/or the cost of treating the illness. These values have uncertainty, including how costs may change over time.

Much of the uncertainty, however, reflects the insufficient level of knowledge about the true values of these model components. Users should exercise caution when interpreting the results of analyses.

The appendices discuss these issues and provide sources for additional information. However, developing a quantified confidence interval for the results is beyond the scope of this model. As an alternative, users should consider using sensitivity analyses to determine how their conclusions might change with differences in the location and the amount of emissions changes. When more detailed analyses are required, users should be cognizant of the model's limitations, and consider using more sophisticated modeling approaches.

Chapter 2 of this User’s Manual provides a quick tutorial for the new user. Baseline data are examined, and a simple new scenario is defined and run, and the results are displayed in tables and maps. Subsequent chapters provide more detailed information on each step, and describe additional options you can use for more complex analyses.

Chapter 3 describes the process of selecting and exploring baseline data.

Chapter 4 provides details on different ways to define your new scenario, and run the comparison between it (the control scenario) and the baseline scenario.

Chapter 5 describes the different ways to view and save your results.

Chapter 6 explains how to use COBRA’s mapping functionality.

A **Glossary** is provided at the end of the manual.

Additional Information

The Appendices to this manual provide additional information on the methods and assumptions used in the model.

- **Appendix A: Description of Source-Receptor Matrix and Emissions Data.** Describes the source-receptor matrix embedded within the model that translates the air pollutant emissions changes into changes in ambient particulate matter.
- **Appendix B: Derivation of Health Impact Functions.** Explains the derivation of the types of health impact functions used in COBRA.
- **Appendix C: COBRA Health Impact Functions.** Provides an overview of all the functions used to convert changes in ambient PM_{2.5} and O₃ into health effects.
- **Appendix D: Baseline Incidence Rates for Adverse Health Effects.** Lists the baseline incidence rates for each of the types of adverse health effects.
- **Appendix E: Population Forecasts.** Describes the forecasting procedure.
- **Appendix F: Economic Value of Health Effects.** Lists the equations and sources of the values used to monetize the health effects.
- **Appendix G: Instructions for Batch Functionality.** Explains how to run multiple COBRA scenarios in batch mode.
- **Appendix H: References.** Provides all of the sources referenced in the Appendices or used in the model.

CHAPTER 2. Quick-Start Tutorial

This tutorial will give you a quick introduction to how COBRA works, and how to work through the steps of a simple analysis. As described in the text box below, COBRA also includes more advanced options for users who want to change underlying assumptions (e.g., population, emissions baseline). Subsequent chapters describe how to use the more advanced features.

COBRA allows you to estimate the impact of a change in air pollution resulting from changes in emissions due to a new policy, program, technology, or other type of change. In this example, you will consider changes in one state (we have arbitrarily selected Pennsylvania) that result in a decrease in emissions from electricity generating plants. If a statewide plan to switch 25 percent of electricity generation to renewable sources were put into effect, what would be the difference in ambient particulate matter levels and health effects, compared to business-as-usual? This tutorial will show you how to use COBRA to examine this type of scenario through the following steps:

Step 1. Select the analysis year and view the baseline emissions data.

Step 2. Select the geography and tier category for emissions changes and define the emissions changes.

Step 3. Select a discount rate and run the comparison.

Step 4. View and save your results.

To open COBRA, click **Start... All Programs... COBRA... COBRA**. The model will open and COBRA will display the main screen. You will see five tabs at the very top: **Introduction, 1.**

Select Analysis Year, 2. Create Emissions Scenario, 3. Execute Run and 4. View

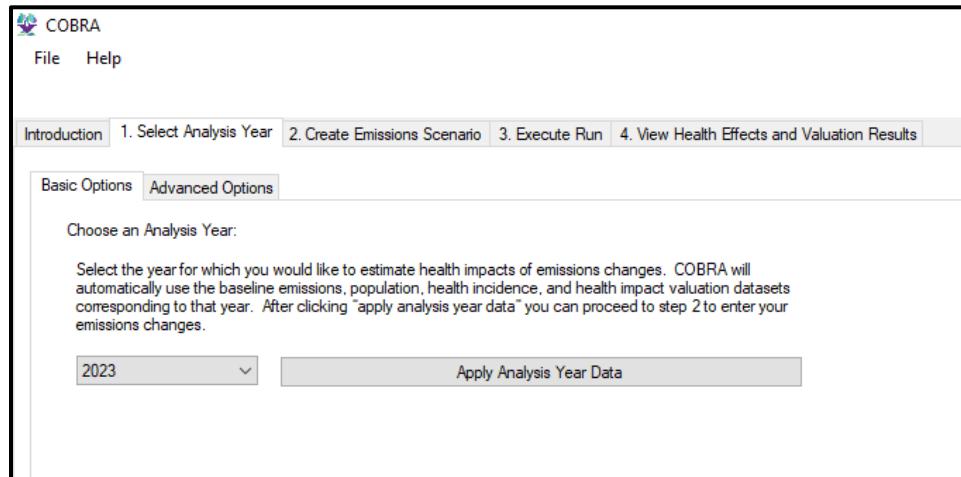
Starting with v3.0, COBRA offers additional functionality and flexibility for advanced users, while still being easy to operate for basic analyses. The table below compares COBRA's advanced options to the simpler, quick-start options. More advanced options will be discussed in subsequent chapters.

| Quick-Start Options | Advanced Options |
|--|---|
| Preloaded 2016, 2023, and 2028 emissions baseline | Custom emissions baseline |
| Preloaded 2016, 2023, and 2028 incidence data | Custom incidence data |
| Preloaded 2016, 2023, and 2028 population data | Custom population data |
| Preloaded health effect functions | Custom health effect functions |
| Preloaded 2016, 2023, and 2028 valuation functions | Custom valuation functions |
| Enter emissions scenario in user interface | Upload custom emissions scenario |
| Run COBRA separately for each emissions scenario | Run multiple emissions scenarios in batch mode |
| View default map output in COBRA | Customize map appearance and export for further |

Health Effects and Valuation Results. Below, we provide detailed descriptions of the steps needed to run a scenario.

Step 1. Select the baseline data.

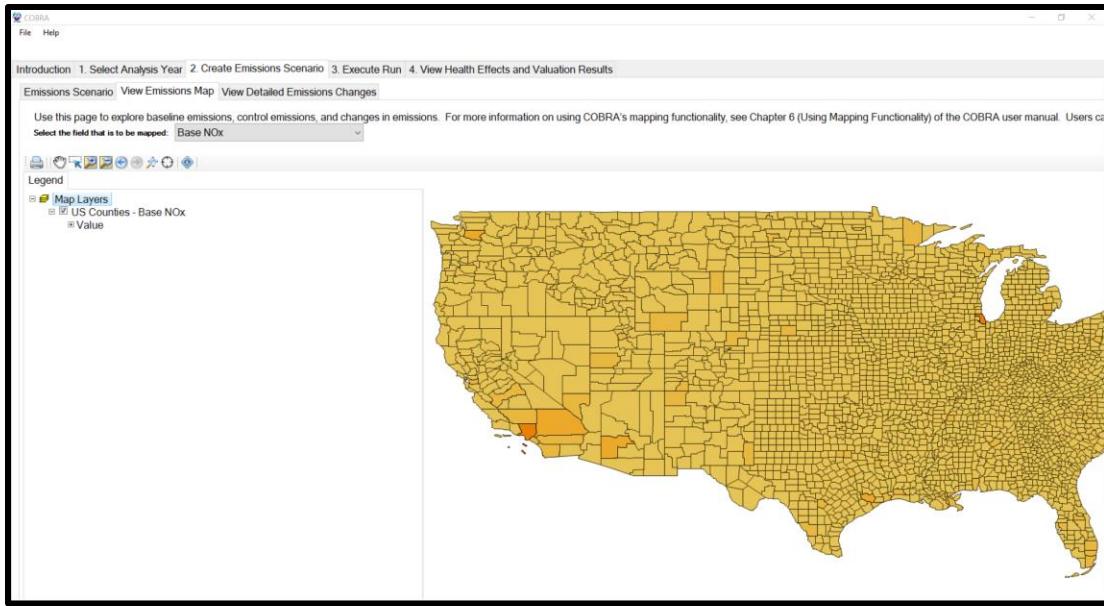
Click **1. Select Analysis Year** and you will see two tabs: **Basic Options** and **Advanced Options**. To do a basic screening analysis for analysis year 2023, select “2023” in the drop-down menu and click **Apply selected analysis year** in the **Basic Options** tab.



Desktop Version

To explore the preloaded baseline emissions data, go to the **2. Create Emissions Scenario** tab. On the top of this screen, you will see three tabs: **Emissions Scenario**, **View Emissions Map**, and **View Detailed Emissions Changes**. Click on the **View Emissions Map** tab. At the top of this screen, you will see a drop-down menu labeled ‘Select the field that is to be mapped.’ The first five options listed (Base NH₃, Base NO₂, Base PM_{2.5}, Base SO₂, and Base VOC) correspond to the baseline emissions of ammonia (NH₃), nitrogen oxides (NO_x), PM_{2.5}, sulfur dioxide (SO₂), and volatile organic compounds (VOCs), respectively, from all sectors. Note that previous versions of COBRA also included ammonia (NH₃) as an input. Starting with COBRA 5.0, the air quality model included in COBRA no longer considers NH₃ as an input to estimate changes in PM_{2.5} concentrations.

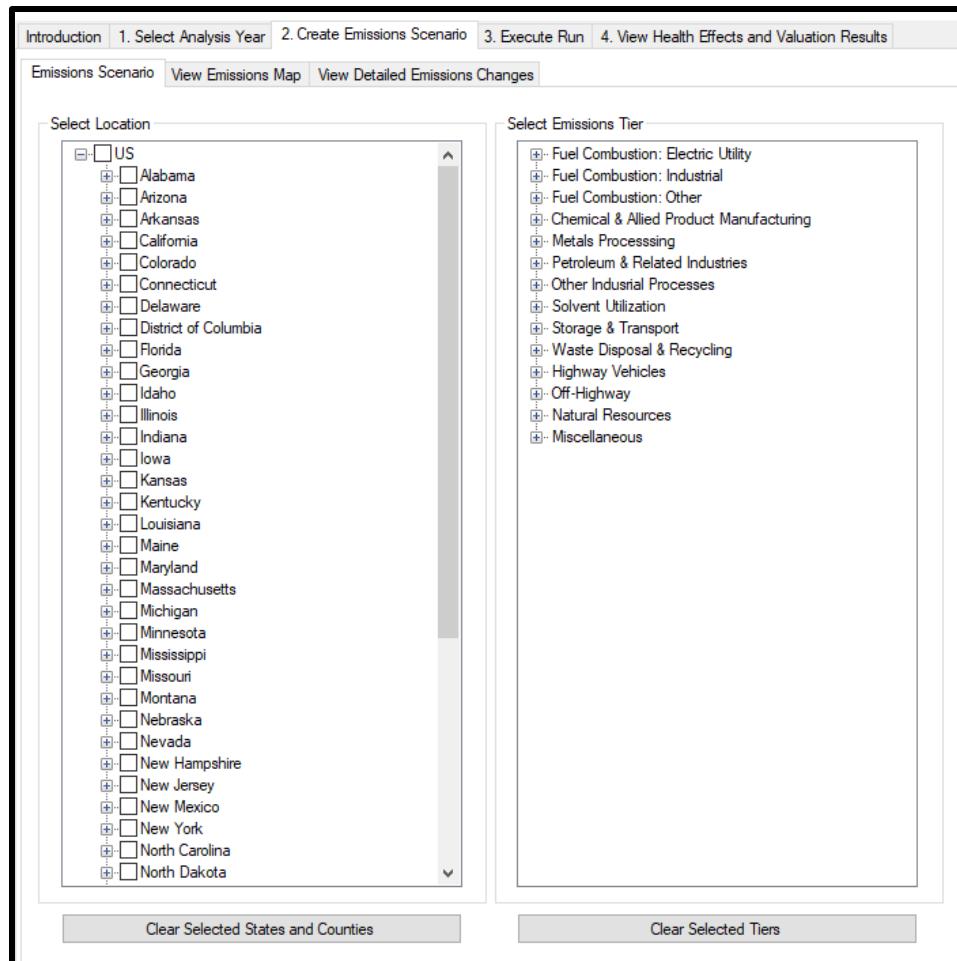
Select any of these emissions to view a map of county-level baseline emissions. See Chapter 6 for more details on how to use COBRA’s mapping functionality.



Desktop Version

Step 2. Define the emissions changes and select the geography for emissions changes.

Now that you have seen the baseline emissions, you can define the new (control) scenario to compare to the baseline scenario. Click on the **2. Create Emissions Scenario** tab. On the top of this screen, you will see three tabs: **Emissions Scenario**, **View Emissions Map**, and **View Detailed Emissions Changes**. Click on the **Emissions Scenario** tab.



Desktop Version

Step 1: Build Scenario

Complete the sections below and click "Add to Scenario."

A. Select Location REQUIRED

Select the states or counties where the emissions changes will occur. [i](#)

- > Alabama
- > Arizona
- > Arkansas
- > California
- > Colorado
- > Connecticut
- > Delaware
- > District of Columbia
- > Florida

[Select All](#) | [Deselect All](#)

B. Select Sector REQUIRED

Select the industry or sector where the emissions changes will occur. [i](#)

Sector

Select a sector

Subsector (optional)

All subsectors

Subsector (optional)

All subsectors

[Web Version](#)

In the top left panel, you can select the geographic area to which you want to apply the emissions changes. Note that once your comparison is run, you will be able to see results (changes in ambient PM_{2.5} and O₃ levels and health effects) for the entire country.

COBRA estimates changes in air quality for all counties in the contiguous United States; however, air quality changes tend to be largest in the areas closest to the emissions changes. In this example, we will analyze changes statewide in Pennsylvania. Check the box next to ‘Pennsylvania’ in the list.

If you wanted to vary the emissions changes across counties, or only make changes in some counties, you could click the ‘+’ button next to Pennsylvania and enter different emissions changes for each county. For instance, if you know the counties in which sources that are likely to be affected (such as power plants) are located, you can enter emissions changes in those counties only. However, in this example you are looking at a statewide change.

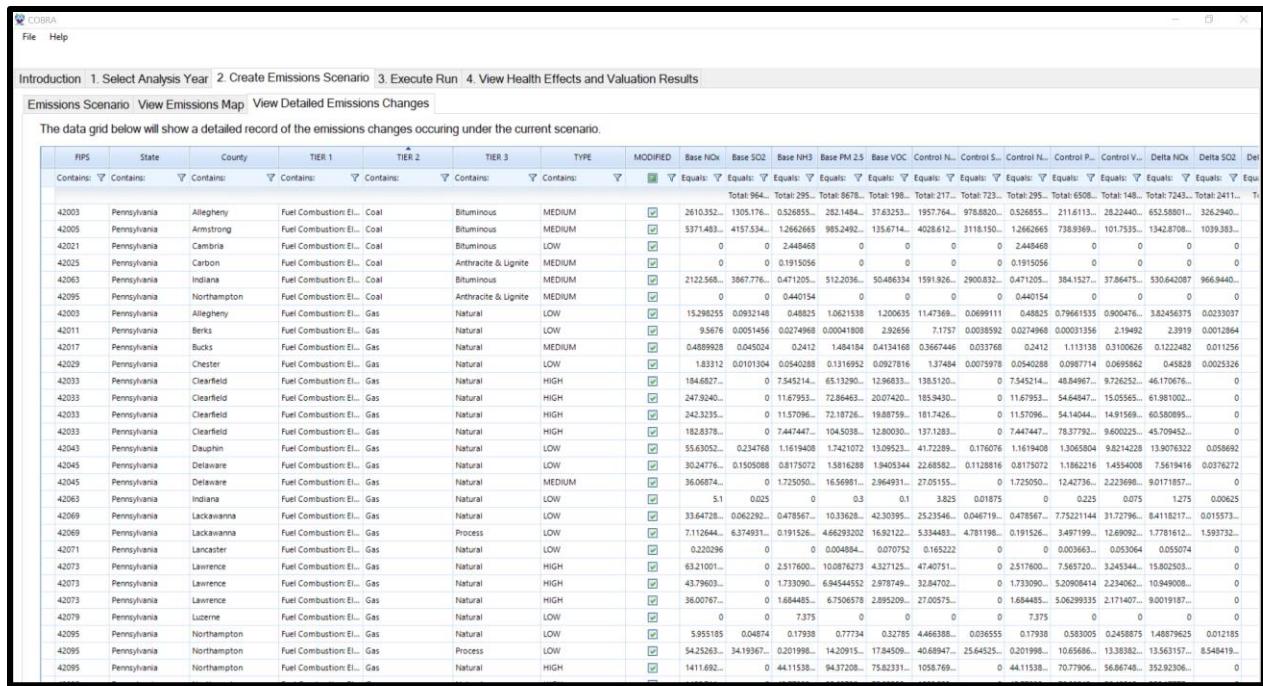
The next step is to define the categories of emissions affected. The middle panel contains a directory tree with all the tier 1, 2, and 3 source categories (see Appendix A for a list of source categories and their emissions). You can define emissions changes at any level, but each level always includes all the levels indented underneath it. In this example, you want to change all of the source categories that are electrical utilities, so click ‘Fuel Combustion: Electric Utility.’

The panel on the right-hand side of the screen lists each pollutant included in the model. Since this scenario reduces all baseline emissions by 25%, type ‘25’ in the box next to each pollutant. The default selections are ‘reduce by’ and ‘percent’; leave them as they are. Chapter 4 describes how to create more sophisticated emissions scenarios, such as scenarios that cover multiple geographies or involve different emissions changes for different pollutants. Click **Apply Changes** to save your changes. The changes apply to all the locations selected.

If you wanted to enter additional emission changes in another location, you would click **Clear Selected States and Countries**, then repeat the process of selecting a new geographic location tier and entering the emission change for that location. You must click **Apply Changes** after entering emissions changes for each location. If you make a mistake or want to start over, click the **Reset to Baseline** button, which will erase all entries. In this example, we are running the analysis for a single scenario affecting only one state, so we will proceed without applying any additional emissions changes.

NOTE: Users of EPA’s AVERT model can upload the emissions changes quantified in AVERT into COBRA so that the user does not have to enter all the changes manually. Chapter 4 describes the process for uploading AVERT outputs as COBRA inputs.

You can review your emissions scenario in table form by clicking the **View Detailed Emissions Changes** tab or in map form by clicking the **View Emissions Map** tab.



The screenshot shows the COBRA software interface. The title bar says 'COBRA'. The menu bar includes 'File', 'Help', 'Introduction', '1. Select Analysis Year', '2. Create Emissions Scenario', '3. Execute Run', '4. View Health Effects and Valuation Results', 'Emissions Scenario', 'View Emissions Map', and 'View Detailed Emissions Changes'. Below the menu is a message: 'The data grid below will show a detailed record of the emissions changes occurring under the current scenario.' The main area is a data grid with columns: FIPS, State, County, TIER 1, TIER 2, TIER 3, TYPE, MODIFIED, Base NOx, Base SO2, Base NH3, Base PM2.5, Base VOC, Control N., Control S., Control N., Control P., Control V., Delta NOx, Delta SO2, Delta NH3, Delta PM2.5, Delta VOC. The data grid lists various locations in Pennsylvania with their respective emissions data.

Desktop Version

Step 3. Run the scenario.

Next, go to the **3. Execute Run** tab. This tab asks you to choose a discount rate for the COBRA session. The discount rate you select is used to express future economic values in present terms. Not all health effects and associated economic values occur in the year of analysis (as explained in Step 5 below). Therefore, COBRA accounts for this ‘time value of money’ preference (i.e., a general preference for receiving benefits now rather than later) by discounting benefits received later. Based on OMB Circular A-4,¹⁰ it is recommended that COBRA users calculate monetized health benefits using a 2% discount rate. However, users also have the option of entering a custom discount rate. For more details on discount rates, see Appendix F.

In this scenario, you will use a 2% discount rate. Click **Run using above options**.

NOTE: COBRA may take 5 to 15 minutes to run, and COBRA may be “not responding” as it runs. The run time depends on your computer.

¹⁰ <https://www.whitehouse.gov/wp-content/uploads/2023/11/CircularA-4.pdf>

Step 4. View and save the results.

View the results

Once your run is complete, COBRA will automatically present the last tab, **4. View Health Effects and Valuation Results**. You will see a screen with two tabs at the top: **Table and Map**.

The **Table** tab shows a summary of the changes in the annual incidence for each health endpoint for PM_{2.5} and/or O₃, as well as the monetary value in 2023 dollars. All values displayed in the summary table have been rounded to 2 significant figures. The low and high values represent differences in the methods used to estimate some of the health impacts in COBRA. For example, the low and high results for avoided premature mortality are based on two different epidemiological studies of the impacts of PM_{2.5} on mortality in the United States. The last line of the summary table sums up the total PM_{2.5} and O₃ health effects. Note that a positive change in incidence and monetary value indicates a decrease in impacts (that is, fewer cases of illness/premature mortality or avoided economic loss).

The default view shows the whole country, but we can filter results to the state level to see more localized impacts. Filter to Pennsylvania by clicking the box under **1. Filter Results by State** and selecting ‘Pennsylvania’.

| Health Endpoint | Pollutant | Change in Incidence (cases, annual) | | Monetary Value (dollars, annual) | |
|-----------------------------------|------------|--|--------|-------------------------------------|---------------|
| | | Low | High | Low | High |
| Mortality* | PM2.5 + O3 | 38 | 66 | \$560,000,000 | \$960,000,000 |
| Mortality, All Cause* | PM2.5 | 25 | 54 | \$370,000,000 | \$780,000,000 |
| Mortality, O3 Short-term Exposure | O3 | 0.52 | 0.52 | \$7,600,000 | \$7,600,000 |
| Mortality, O3 Long-term Exposure | O3 | 12 | 12 | \$170,000,000 | \$170,000,000 |
| Nonfatal Heart Attacks | PM2.5 | 16 | 16 | \$1,500,000 | \$1,500,000 |
| Infant Mortality | PM2.5 | 0.18 | 0.18 | \$2,700,000 | \$2,700,000 |
| Hospital Admits, All Respiratory | PM2.5 + O3 | 3.3 | 3.3 | \$84,000 | \$84,000 |
| Hospital Admits from PM2.5 | PM2.5 | 2.1 | 2.1 | \$62,000 | \$62,000 |
| Hospital Admits from O3 | O3 | 1.2 | 1.2 | \$22,000 | \$22,000 |
| ER Visits, Respiratory | PM2.5 + O3 | 45 | 45 | \$73,000 | \$73,000 |
| Respiratory Visits from PM2.5 | PM2.5 | 16 | 16 | \$26,000 | \$26,000 |
| Respiratory Visits from O3 | O3 | 29 | 29 | \$47,000 | \$47,000 |
| Asthma Onset | PM2.5 + O3 | 120 | 120 | \$10,000,000 | \$10,000,000 |
| Asthma Onset from PM2.5 | PM2.5 | 51 | 51 | \$4,300,000 | \$4,300,000 |
| Asthma Onset from O3 | O3 | 69 | 69 | \$5,800,000 | \$5,800,000 |
| Asthma Symptoms | PM2.5 + O3 | 20,000 | 20,000 | \$4,000,000 | \$4,000,000 |
| Albuterol Use | PM2.5 | 9,700 | 9,700 | \$6,100 | \$6,100 |
| Chest Tightness | O3 | 2,900 | 2,900 | \$1,100,000 | \$1,100,000 |
| Cough | O3 | 3,400 | 3,400 | \$1,300,000 | \$1,300,000 |
| Shortness of Breath | O3 | 1,500 | 1,500 | \$560,000 | \$560,000 |
| Wheeze | O3 | 2,800 | 2,800 | \$1,000,000 | \$1,000,000 |
| ER Visits, Asthma | O3 | 0.22 | 0.22 | \$180 | \$180 |
| Lung Cancer Incidence | PM2.5 | 1.7 | 1.7 | \$83,000 | \$83,000 |
| Hospital Admits, Cardiovascular | PM2.5 | 3.5 | 3.5 | \$99,000 | \$99,000 |
| Hospital Admits, Alzheimers | PM2.5 | 9.7 | 9.7 | \$210,000 | \$210,000 |
| Hospital Admits, Parkinsons | PM2.5 | 2.0 | 2.0 | \$46,000 | \$46,000 |
| Stroke Incidence | PM2.5 | 1.5 | 1.5 | \$91,000 | \$91,000 |
| Hay Fever/Rhinitis Incidence | PM2.5 + O3 | 780 | 780 | \$860,000 | \$860,000 |
| Hay Fever/Rhinitis from PM2.5 | PM2.5 | 330 | 330 | \$360,000 | \$360,000 |
| Hay Fever/Rhinitis from O3 | O3 | 450 | 450 | \$400,000 | \$400,000 |

Desktop Version

The results table above shows health benefits and avoided health impacts for both PM_{2.5} and O₃ for Pennsylvania. Here, you see that the emissions scenario results in avoiding 38 to 66 adult premature deaths, which is a sum of PM_{2.5}- and O₃-related mortality. You can

also look at a specific county in Pennsylvania. To do this, filter the county level by clicking the box under **2. Filter Results by County** and selecting ‘Montgomery.’

COBRA

File Help

Introduction 1. Select Analysis Year 2. Create Emissions Scenario 3. Execute Run 4. View Health Effects and Valuation Results

Table Maps

1. Filter Results by State: Pennsylvania 2. Filter Results by County: Montgomery

[Export Full Results to CSV](#) [Export Full Results to Excel](#)

Result Summary for: Montgomery, Pennsylvania

| Health Endpoint | Pollutant | Change in Incidence (cases, annual) | | Monetary Value (dollars, annual) | |
|-----------------------------------|------------|--|--------------|-------------------------------------|--------------|
| | | Low | High | Low | High |
| Mortality* | PM2.5 + O3 | 2.4 | 4.2 | \$35,000,000 | \$61,000,000 |
| Mortality, All Cause* | PM2.5 | 1.7 | 3.5 | \$25,000,000 | \$51,000,000 |
| Mortality, O3 Short-term Exposure | O3 | 0.03 | 0.03 | \$430,000 | \$430,000 |
| Mortality, O3 Long-term Exposure | O3 | 0.66 | 0.66 | \$9,600,000 | \$9,600,000 |
| Nonfatal Heart Attacks | PM2.5 | 1.1 | 1.1 | \$100,000 | \$100,000 |
| Infant Mortality | PM2.5 | 0.01 | 0.01 | \$140,000 | \$140,000 |
| Hospital Admits, All Respiratory | PM2.5 + O3 | 0.23 | 0.23 | \$6,000 | \$6,000 |
| Hospital Admits from PM2.5 | PM2.5 | 0.15 | 0.15 | \$4,500 | \$4,500 |
| Hospital Admits from O3 | O3 | 0.08 | 0.08 | \$1,400 | \$1,400 |
| ER Visits, Respiratory | PM2.5 + O3 | 3.1 | 3.1 | \$5,000 | \$5,000 |
| Respiratory Visits from PM2.5 | PM2.5 | 1.2 | 1.2 | \$1,900 | \$1,900 |
| Respiratory Visits from O3 | O3 | 1.9 | 1.9 | \$3,100 | \$3,100 |
| Asthma Onset | PM2.5 + O3 | 8.5 | 8.5 | \$710,000 | \$710,000 |
| Asthma Onset from PM2.5 | PM2.5 | 3.8 | 3.8 | \$320,000 | \$320,000 |
| Asthma Onset from O3 | O3 | 4.7 | 4.7 | \$390,000 | \$390,000 |
| Asthma Symptoms | PM2.5 + O3 | 1,400 | 1,400 | \$270,000 | \$270,000 |
| Albuterol Use | PM2.5 | 700 | 700 | \$440 | \$440 |
| Chest Tightness | O3 | 200 | 200 | \$75,000 | \$75,000 |
| Cough | O3 | 230 | 230 | \$89,000 | \$89,000 |
| Shortness of Breath | O3 | 100 | 100 | \$38,000 | \$38,000 |
| Wheezing | O3 | 190 | 190 | \$71,000 | \$71,000 |
| ER Visits, Asthma | O3 | 0.02 | 0.02 | \$12 | \$12 |
| Lung Cancer Incidence | PM2.5 | 0.12 | 0.12 | \$6,000 | \$6,000 |
| Hospital Admits, Cardiovascular | PM2.5 | 0.25 | 0.25 | \$7,100 | \$7,100 |
| Hospital Admits, Alzheimers | PM2.5 | 0.71 | 0.71 | \$16,000 | \$16,000 |
| Hospital Admits, Parkinsons | PM2.5 | 0.14 | 0.14 | \$3,300 | \$3,300 |
| Stroke Incidence | PM2.5 | 0.10 | 0.10 | \$6,400 | \$6,400 |
| Hay Fever/Rhinitis Incidence | PM2.5 + O3 | 54 | 54 | \$59,000 | \$59,000 |
| Hay Fever/Rhinitis from PM2.5 | PM2.5 | 24 | 24 | \$26,000 | \$26,000 |

Desktop Version

Step 3: View Results

[BUILD NEW SCENARIO](#)

A. Summary of Health Effects Results

Below is a table with the health effects results based on your scenario.

Info You are viewing results for all contiguous U.S. states. This is because changes in air quality can impact health endpoints in multiple locations due to the transportation of emissions across state and county lines.

Use the filters below to see health effects for a specific state or county.

1. Filter by state: All contiguous U.S. states 2. Filter by county: (optional) All counties

Results for: All Contiguous U.S. States

[Export: All results | Current filter](#)

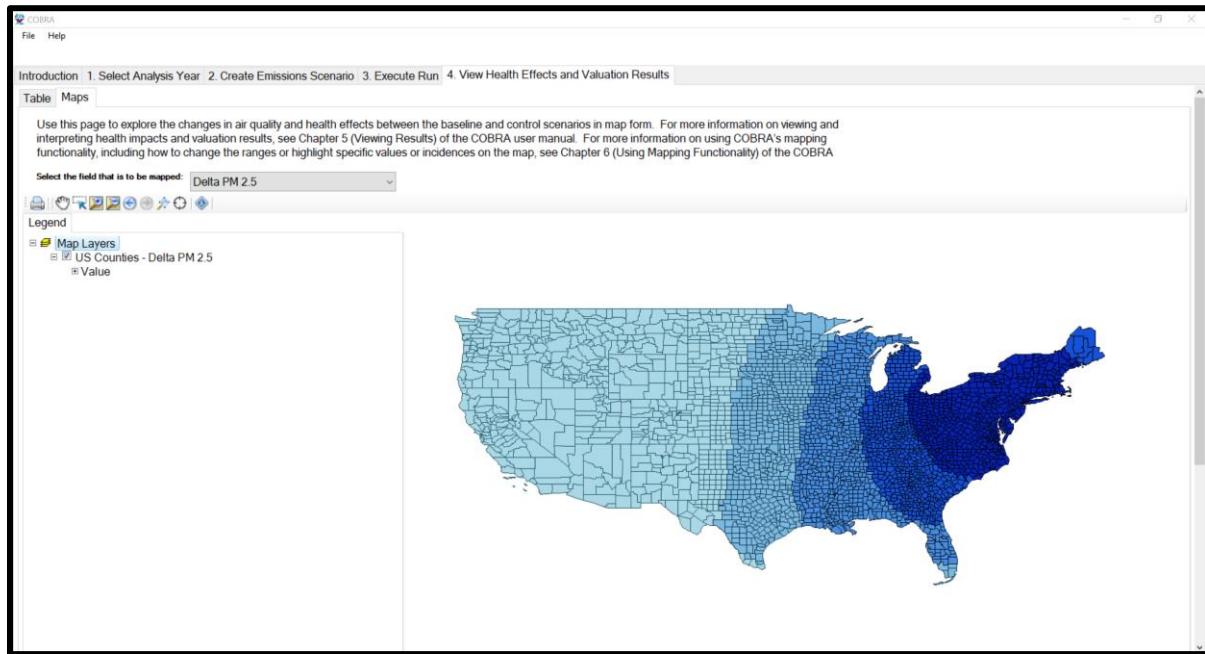
| Health Endpoint | Pollutant | Change in Incidence | | Monetary Value | |
|---|------------------------------------|---------------------|--------|------------------------|------------------------|
| | | (cases, annual) | | Low | High |
| Mortality | PM _{2.5} O ₃ | 74 | 95 | \$1,100,000,000 | \$1,400,000,000 |
| Nonfatal Heart Attacks | PM _{2.5} | 14 | 14 | \$1,300,000 | \$1,300,000 |
| Infant Mortality | PM _{2.5} | 0.16 | 0.16 | \$2,600,000 | \$2,600,000 |
| Hospital Admits, All Respiratory | PM _{2.5} O ₃ | 9.4 | 9.4 | \$190,000 | \$190,000 |
| Emergency Room Visits, Respiratory | PM _{2.5} O ₃ | 170 | 170 | \$270,000 | \$270,000 |
| Asthma Onset | PM _{2.5} O ₃ | 390 | 390 | \$33,000,000 | \$33,000,000 |
| Asthma Symptoms | PM _{2.5} O ₃ | 61,000 | 61,000 | \$20,000,000 | \$20,000,000 |
| Emergency Room Visits, Asthma | O ₃ | 0.77 | 0.77 | \$630 | \$630 |
| Lung Cancer Incidence | PM _{2.5} | 1.1 | 1.1 | \$54,000 | \$54,000 |
| Hospital Admits, Cardio-Cerebro/Peripheral Vascular Disease | PM _{2.5} | 2.4 | 2.4 | \$69,000 | \$69,000 |
| Hospital Admits, Alzheimers Disease | PM _{2.5} | 11 | 11 | \$240,000 | \$240,000 |
| Hospital Admits, Parkinsons Disease | PM _{2.5} | 0.94 | 0.94 | \$22,000 | \$22,000 |
| Stroke Incidence | PM _{2.5} | 0.96 | 0.96 | \$60,000 | \$60,000 |
| Hay Fever/Rhinitis Incidence | PM _{2.5} O ₃ | 2,500 | 2,500 | \$2,800,000 | \$2,800,000 |
| Cardiac Arrest, Out of Hospital | PM _{2.5} | 0.23 | 0.23 | \$16,000 | \$16,000 |
| Emergency Room Visits, All Cardiac | PM _{2.5} | 5.4 | 5.4 | \$11,000 | \$11,000 |
| Minor Restricted Activity Days | PM _{2.5} | 12,000 | 12,000 | \$1,500,000 | \$1,500,000 |
| School Loss Days | O ₃ | 33,000 | 33,000 | \$62,000,000 | \$62,000,000 |
| Work Loss Days | PM _{2.5} | 2,100 | 2,100 | \$640,000 | \$640,000 |
| Total Health Effects from PM_{2.5} | | | | \$250,000,000 | \$550,000,000 |
| Total Health Effects from O₃ | | | | \$950,000,000 | \$950,000,000 |
| Heart Total Health Effects | | | | \$1,200,000,000 | \$1,500,000,000 |

Note: Dollar amounts shown are based on 2022 currency values. Additionally, all values have been rounded to 2 significant figures. Please [export the results](#) in order to see values with higher precision. The Low and High values represent differences in the methods used to estimate some of the health impacts in COBRA. For example, high and low results for avoided premature mortality are based on two different epidemiological studies of the impacts of PM_{2.5} on mortality in the United States.

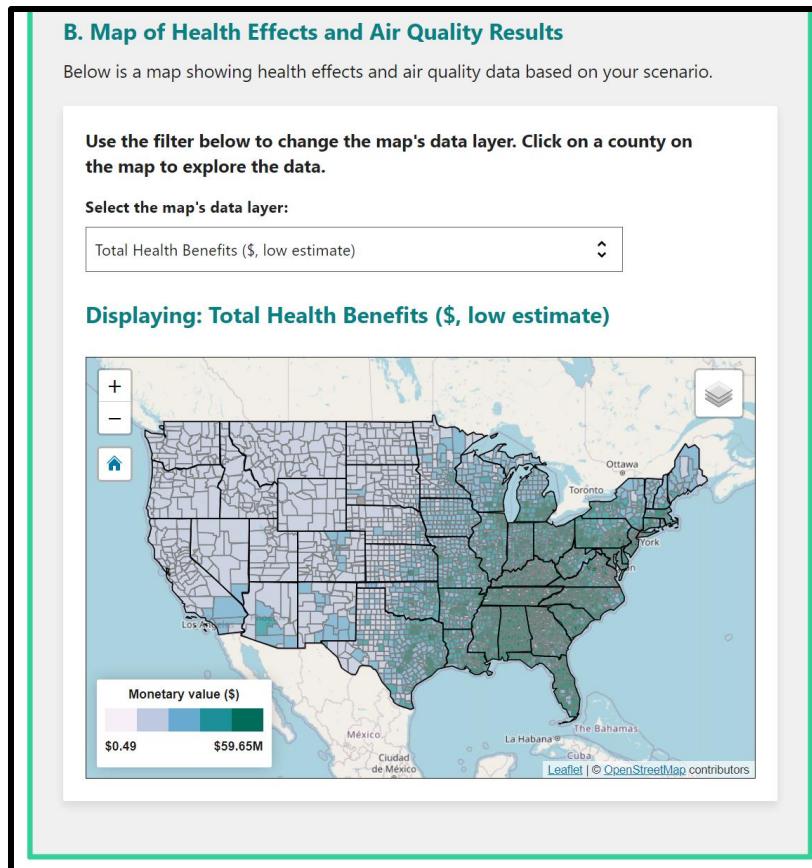
Web Version

The results table above shows health benefits and avoided health impacts for both PM_{2.5} and O₃ for Montgomery, Pennsylvania. Here, you see that the emissions scenario results in avoiding 2.4 to 4.2 adult premature deaths, which is a sum of PM_{2.5}- and O₃-related mortality.

The **Map** tab shows the results from the previous table on a map. When you click on the tab you will see a map of the United States. To display a result, select an outcome from the drop-down menu labeled ‘Select the field that is to be mapped.’ Below, the map of Delta PM_{2.5} shows the change in the particulate matter concentration between the baseline and control scenarios. The darker the shade of blue, the greater the change in concentration. As in the other results tables, a positive number indicates a *decrease* from the baseline scenario. You can also view any of the other results on the map by selecting them from the drop-down list under ‘Select the field that is to be mapped’. See Chapter 6 for more details on how to use COBRA’s mapping functionality.



Desktop Version



Web Version

Export and save your results.

You may want to look at and manipulate the results data outside of COBRA. You can export data sets into a CSV format, which can be used with spreadsheet programs.

Emissions Scenario Definition in Table Form

To save the definition of your emissions changes scenario, go to the **2. Create Emissions Scenario** tab. In the top right panel, click **Save Scenario**. In the following window, browse to the file location where you want to save your data, and select ‘CSV files’ in the ‘Save as type’ drop-down box. You can then enter a name for the file in the box above. Click **Save** and COBRA will save the file.

Results in Table Form

To export the results table, go to the **4. View Health Effects and Valuation Results** tab and then to the **Table** tab. Click the **Export Full Results to CSV** or **Export Results to Excel** button on the top right to export results to a CSV or Excel file. In the following

window, browse to the file location where you want to save your data, enter a name for the file, and click **Save**.

In the table form, you will see that the air quality variables shown are ‘Base PM 2.5’, ‘Control PM 2.5,’ ‘Delta PM 2.5,’ ‘Base O₃,’ ‘Control O₃,’ and ‘Delta O₃.’ Delta PM_{2.5} is the difference in ambient fine particulate matter (PM_{2.5}) between the baseline scenario and your new scenario (the control scenario) in the year of your analysis (in this example, 2023), in units of micrograms per cubic meter ($\mu\text{g}/\text{m}^3$). Note that positive values indicate a reduction in PM_{2.5} in the control scenario.

When you filter the table to Montgomery County, you will see that the estimated ambient PM_{2.5} concentration in the control scenario is 7.7 $\mu\text{g}/\text{m}^3$, compared to the estimated baseline concentration of 7.8 $\mu\text{g}/\text{m}^3$. The difference between the two estimated concentrations (Delta PM_{2.5}) is 0.040 $\mu\text{g}/\text{m}^3$, which is the estimated change in air quality due to the 25% reduction in emissions from fuel combustion electricity generating plants in the whole state (the change in concentration is due to decreases in emissions from plants within the county and in other counties). Note that positive changes indicate a lower concentration in the control scenario. If the value in ‘Delta PM_{2.5}’ were negative, it would indicate an increase in concentration. In this county, the emissions reduction scenario results are an estimated 2.4 to 4.2 adult premature deaths avoided (over the next 20 years), an estimated 1.1 avoided non-fatal heart attacks, and an estimated 0.010 avoided O₃-related emergency room visit for asthma (in 2023).

The table includes low and high estimates for the changes in the number of cases and the corresponding economic values for adult mortality and non-fatal heart attacks. The low and high estimates are derived using two sets of assumptions about the sensitivity of adult mortality and non-fatal heart attacks to changes in ambient PM_{2.5} and O₃ levels. Specifically, the high estimates are based on studies that estimated a larger effect of changes in ambient PM_{2.5} levels on the incidence of these health effects. For further details on the calculation of low and high estimates, see the description of the health effects table in Chapter 5 and the detailed assumptions in Appendix C.

The three health effects below demonstrate the interpretation of the change in health effects and their economic values for Montgomery County, Pennsylvania: respiratory hospital admissions, adult mortality, and non-fatal heart attacks.

- **O₃-related Emergency Room Visits for Asthma.** In COBRA, most health effects and their economic values are expected to occur in the year of analysis. For instance, this scenario results in less than one avoided emergency room visits for asthma in Montgomery County. This fraction of an avoided case and its economic value (approximately \$11) would occur in 2023.

- **Adult Mortality.** In contrast to respiratory hospital admissions, all avoided cases of adult mortality are not expected to occur in the year of analysis. Therefore, COBRA uses the 2% discount rate you selected in Step 4 to calculate the value of all avoided cases of adult mortality in present terms (in Montgomery County, a low estimate of 2.4 avoided cases of adult mortality are valued at a total of approximately \$35 million).
- **Non-fatal Heart Attacks.** Another special case is non-fatal heart attacks. All avoided cases of non-fatal heart attacks are expected to occur in the year of analysis, but the costs associated with this health effect would occur over multiple years. Thus, while this scenario results in a range of 1.1 cases of non-fatal heart attacks in 2023, all economic benefits associated with this change (\$100,000) would not accrue in that same year.

The table below relates the timing of the expected health effects and economic costs or benefits to the specific types of incidences in COBRA.

| Type of Health Incidence | All health effects occur in the year of analysis? | All economic costs or benefits occur in same year of analysis? |
|---------------------------------|---|--|
| Adult mortality | No | No, the value is discounted to present terms |
| Non-fatal heart attacks | Yes | No, the value is discounted to present terms |
| All other health impacts | Yes | Yes |

In addition, remember that although emissions were changed only in Pennsylvania, COBRA calculates changes in PM_{2.5} and O₃ for the whole country. If you would like to examine the results for any of states bordering Pennsylvania, simply filter for different states.

As described earlier, it is also important to remember COBRA does not capture dynamic effects of electricity markets – these markets determine electricity dispatch by EGUs and associated emissions levels. For example, if you assume an emission reduction among power plants in one area, it is possible that electricity generation and emissions may increase in another location unless there is an underlying change in electricity demand. Because COBRA does not capture potential electricity market effects, users should exercise care when interpreting the impacts of an emissions change in a specific location.

Results in Map Form

To save a map for use in another mapping application, navigate to the map and right-click on the ‘US counties’ data in the legend panel and then click **Data... Export Data**. In the following window, browse to the file location where you want to save your data, enter a

file name, and select ‘.shp’ in the ‘Save as type:’ drop-down menu. Click **Save** and COBRA will save the file.

To save the map as an image, click the ‘Print’ button in the toolbar. In the following window, click **File... Save**. Then browse to the file location where you want to save your data and select ‘DotSpatial Layout File’ or ‘Portable Network Graphics’ in the ‘Save as type’ drop-down box. You can then enter a name for the file in the box above (e.g., type ‘Penn Utility Reduction–2023 – 2%’). Click **Save** and COBRA will save the file.

CHAPTER 3. Baseline Data

Click on the **1. Select Analysis Year** tab to select an analysis year.

Basic Options

The COBRA model contains detailed 2016, 2023, and 2028 baseline emissions data for every county in the U.S., by state, county, tier category, and pollutant type (see Appendix A for details on the baseline data). It is recommended that new COBRA users start by using the default 2016, 2023, and 2028 baseline emissions database. To use the 2023 default emissions, go to the **Basic Options** tab, select 2023 in the “Select analysis year” drop down menu, and click **Apply selected analysis year**. COBRA will automatically use the population, baseline health incidence, baseline emissions, and health impact valuation datasets that correspond to the analysis year you select.

Advanced Options

Users can also import custom datasets for population, baseline health incidence, baseline emissions, health effect functions, and health impact valuation.

Custom Baseline Emissions

There are two ways for users to import custom emissions: (1) load a file containing only baseline emissions or (2) load a file containing emissions for both the baseline and your control scenario. It is important for input files to correspond to the same year, so if you choose to import custom baseline emissions data for a year that is not preloaded, you would also want to modify population data and incidence data to represent that same year. For example, running COBRA with a 2023 baseline emissions inventory, 2023 population data, and 2023 incidence data would result in COBRA estimating 2023 health benefits. However, running COBRA with a 2020 baseline emissions inventory and 2023 population and incidence data would result in theoretical annual health benefits that do not correspond to any calendar year. Alternatively, running COBRA with a projected emissions inventory for 2030 and the default 2023 population and incidence data would assume that population and incidence are constant from 2023 to 2030.

COBRA requires that imported baseline emission files be in a specific format. To create a properly formatted custom baseline emissions file, create a CSV file with the column headings shown in Exhibit 2. Each row of the file should correspond to a different source in a different county.

Exhibit 2. Format of Baseline Emissions File.

| Column Heading | Description of Column Headings |
|-------------------------|---|
| typeindx ¹ | Stack height associated with the emission |
| sourceindx ² | Source index, which COBRA uses in its source receptor model |
| stid | FIPS state ID (e.g., the state FIPS code for Pennsylvania is 42) |
| cyid | FIPS county ID (e.g., the county FIPS code for Swarthmore, PA is 045) |
| TIER1 ³ | Emissions category to which emissions source corresponds, at tier 1 level |
| TIER2 ³ | Emissions category to which emissions source corresponds, at tier 2 level |
| TIER3 ³ | Emissions category to which emissions source corresponds, at tier 3 level |
| NO2 | Nox emissions from each source in the baseline |
| SO2 | SO2 emissions from each source in the baseline |
| PM25 | Primary PM2.5 emissions from each source in the baseline |
| VOC | VOC emissions from each source in the baseline |

Notes:

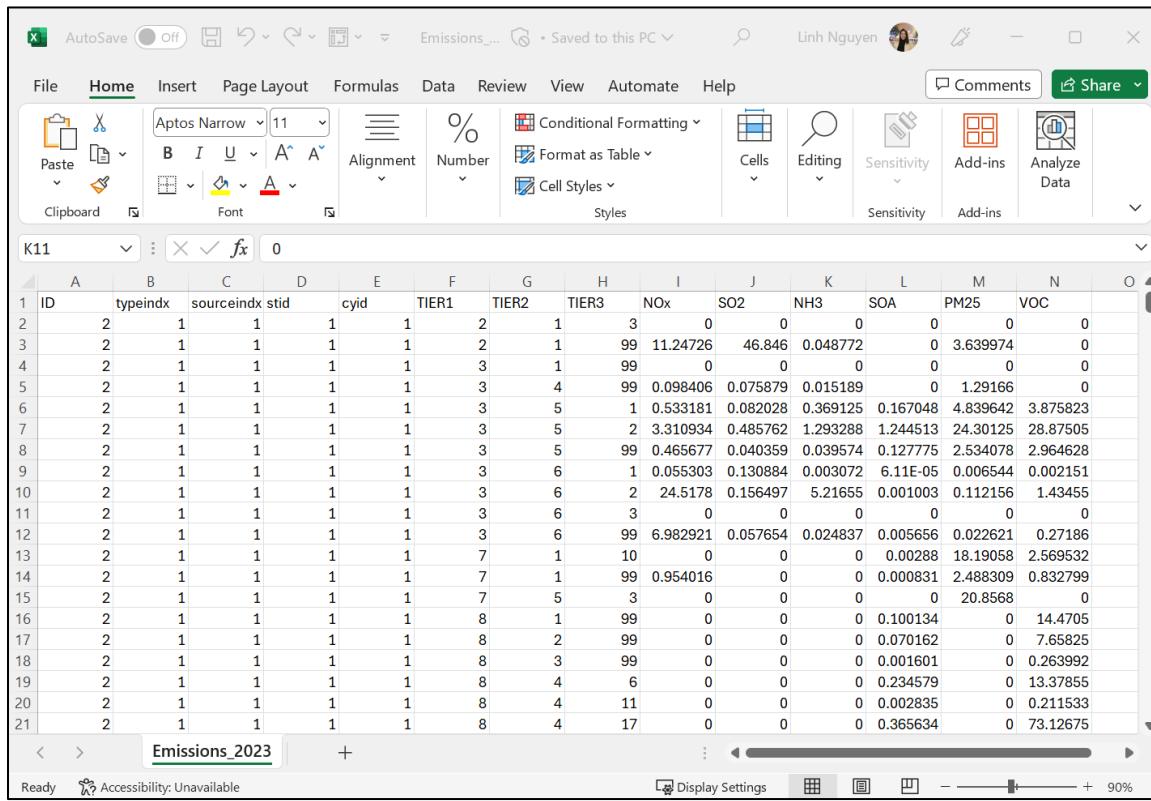
¹ A table of typeindx and name is saved on your computer after installing COBRA in the default location, in C:/Program Files/COBRA/input files/data dictionary/typeindx – stack heights.csv.

² A table of sourceindx and FIPS is saved on your computer after installing COBRA in the default location, in C:/Program Files/COBRA/input files/data dictionary/SOURCEINDX to FIPS crosswalk.csv.

³ A table of tier definitions and tier numbers is saved on your computer after installing COBRA in the default location, in C:/Program Files/COBRA/input files/data dictionary/EmissionsTier Definitions.csv.

⁴ Previous editions of COBRA included emissions of NH₃ as an input. Starting with COBRA 5.0 the source-receptor matrix no longer considers NH₃ as an input to model PM_{2.5} concentrations. However, because NH₃ could be used as an input in future versions of COBRA, it has been maintained in the tool and is required in the format of the baseline emissions file, although it is not currently used in the calculations.

To see the template for a baseline emissions file, navigate to the folder where you installed COBRA – the default location is C:/Program Files/COBRA/. From there, navigate to input files/emissions/Emissions_2023.csv. This is the default COBRA 2023 emissions baseline, so do not make any changes directly to this file.



| | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O |
|----|----|----------|------------|-----|------|-------|-------|-------|----------|----------|----------|----------|----------|----------|---|
| 1 | ID | typeindx | sourceindx | std | cyid | TIER1 | TIER2 | TIER3 | NOx | SO2 | NH3 | SOA | PM25 | VOC | |
| 2 | 2 | 1 | 1 | 1 | 1 | 2 | 1 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 3 | 2 | 1 | 1 | 1 | 1 | 2 | 1 | 99 | 11.24726 | 46.846 | 0.048772 | 0 | 3.639974 | 0 | |
| 4 | 2 | 1 | 1 | 1 | 1 | 3 | 1 | 99 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 5 | 2 | 1 | 1 | 1 | 1 | 3 | 4 | 99 | 0.098406 | 0.075879 | 0.015189 | 0 | 1.29166 | 0 | |
| 6 | 2 | 1 | 1 | 1 | 1 | 3 | 5 | 1 | 0.533181 | 0.082028 | 0.369125 | 0.167048 | 4.839642 | 3.875823 | |
| 7 | 2 | 1 | 1 | 1 | 1 | 3 | 5 | 2 | 3.310934 | 0.485762 | 1.293288 | 1.244513 | 24.30125 | 28.87505 | |
| 8 | 2 | 1 | 1 | 1 | 1 | 3 | 5 | 99 | 0.465677 | 0.040359 | 0.039574 | 0.127775 | 2.534078 | 2.964628 | |
| 9 | 2 | 1 | 1 | 1 | 1 | 3 | 6 | 1 | 0.055303 | 0.130884 | 0.003072 | 6.11E-05 | 0.006544 | 0.002151 | |
| 10 | 2 | 1 | 1 | 1 | 1 | 3 | 6 | 2 | 24.5178 | 0.156497 | 5.21655 | 0.001003 | 0.112156 | 1.43455 | |
| 11 | 2 | 1 | 1 | 1 | 1 | 3 | 6 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | |
| 12 | 2 | 1 | 1 | 1 | 1 | 3 | 6 | 99 | 6.982921 | 0.057654 | 0.024837 | 0.005656 | 0.022621 | 0.27186 | |
| 13 | 2 | 1 | 1 | 1 | 1 | 7 | 1 | 10 | 0 | 0 | 0 | 0.00288 | 18.19058 | 2.569532 | |
| 14 | 2 | 1 | 1 | 1 | 1 | 7 | 1 | 99 | 0.954016 | 0 | 0 | 0.000831 | 2.488309 | 0.832799 | |
| 15 | 2 | 1 | 1 | 1 | 1 | 7 | 5 | 3 | 0 | 0 | 0 | 0 | 20.8568 | 0 | |
| 16 | 2 | 1 | 1 | 1 | 1 | 8 | 1 | 99 | 0 | 0 | 0 | 0.100134 | 0 | 14.4705 | |
| 17 | 2 | 1 | 1 | 1 | 1 | 8 | 2 | 99 | 0 | 0 | 0 | 0.070162 | 0 | 7.65825 | |
| 18 | 2 | 1 | 1 | 1 | 1 | 8 | 3 | 99 | 0 | 0 | 0 | 0.001601 | 0 | 0.263992 | |
| 19 | 2 | 1 | 1 | 1 | 1 | 8 | 4 | 6 | 0 | 0 | 0 | 0.234579 | 0 | 13.37855 | |
| 20 | 2 | 1 | 1 | 1 | 1 | 8 | 4 | 11 | 0 | 0 | 0 | 0.002835 | 0 | 0.211533 | |
| 21 | 2 | 1 | 1 | 1 | 1 | 8 | 4 | 17 | 0 | 0 | 0 | 0.365634 | 0 | 73.12675 | |

To import custom baseline datasets, click on the **Advanced Options** tab at the top of the **1. Select Analysis Year** screen. To import a properly formatted baseline emissions file into COBRA, click **Load a Baseline Emissions CSV File**. In the pop-up window, navigate to the location of your baseline emissions CSV file, click the file, and then click **Open**. If you try to import a baseline emissions file that is incorrectly formatted, COBRA will display an error message that an “unhandled exception has occurred in your application.”

To create a properly formatted file with both custom baseline and control scenario emissions, create a CSV file with the headings shown in Exhibit 3. Each row of the file should correspond to a different source in a different county.

Exhibit 3. Format of Baseline and Scenario Emissions File

| Column Heading | Description of Column Headings |
|-------------------------|---|
| typeindx ¹ | Stack height associated with the emission |
| sourceindx ² | Source index, which COBRA uses in its source receptor model |
| std | FIPS state ID (e.g., the state FIPS code for Pennsylvania is 42) |
| cyid | FIPS county ID (e.g., the county FIPS code for Swarthmore, PA is 045) |

| Column Heading | Description of Column Headings |
|-----------------------|--|
| TIER1 ³ | Emissions category to which emissions source corresponds, at tier 1 level |
| TIER2 ³ | Emissions category to which emissions source corresponds, at tier 2 level |
| TIER3 ³ | Emissions category to which emissions source corresponds, at tier 3 level |
| BASE_NOx | NO _x emissions from each source in the baseline |
| BASE_SO2 | SO ₂ emissions from each source in the baseline |
| BASE_NH3 ⁴ | NH ₃ emissions from each source in the baseline |
| BASE_PM25 | Primary PM _{2.5} emissions from each source in the baseline |
| BASE_VOC | VOC emissions from each source in the baseline |
| CTRL_NOx | NO _x emissions from each source in the control scenario |
| CTRL_SO2 | SO ₂ emissions from each source in the control scenario |
| CTRL_NH3 ⁴ | NH ₃ emissions from each source in the control scenario |
| CTRL_PM25 | Primary PM _{2.5} emissions from each source in the control scenario |
| CTRL_VOC | VOC emissions from each source in the control scenario |
| TIER1NAME | Name of emissions category to which emissions source corresponds, at tier 1 level |
| TIER2NAME | Name of emissions category to which emissions source corresponds, at tier 2 level |
| TIER3NAME | Name of emissions category to which emissions source corresponds, at tier 3 level |
| FIPS | FIPS state-county ID (e.g., the state FIPS code for Pennsylvania is 42 and the county FIPS code for Swarthmore, PA is 045, so the state-county FIPS ID is 42045) |
| STATE | State |
| COUNTY | County |
| TYPE | Type denotes the stack height associated with the emission |

Notes:

¹ A table of typeindx, type, and name is saved on your computer after installing COBRA in the default location, in C:/Program Files/COBRA/input files/data dictionary/typeindx – stack heights.csv.

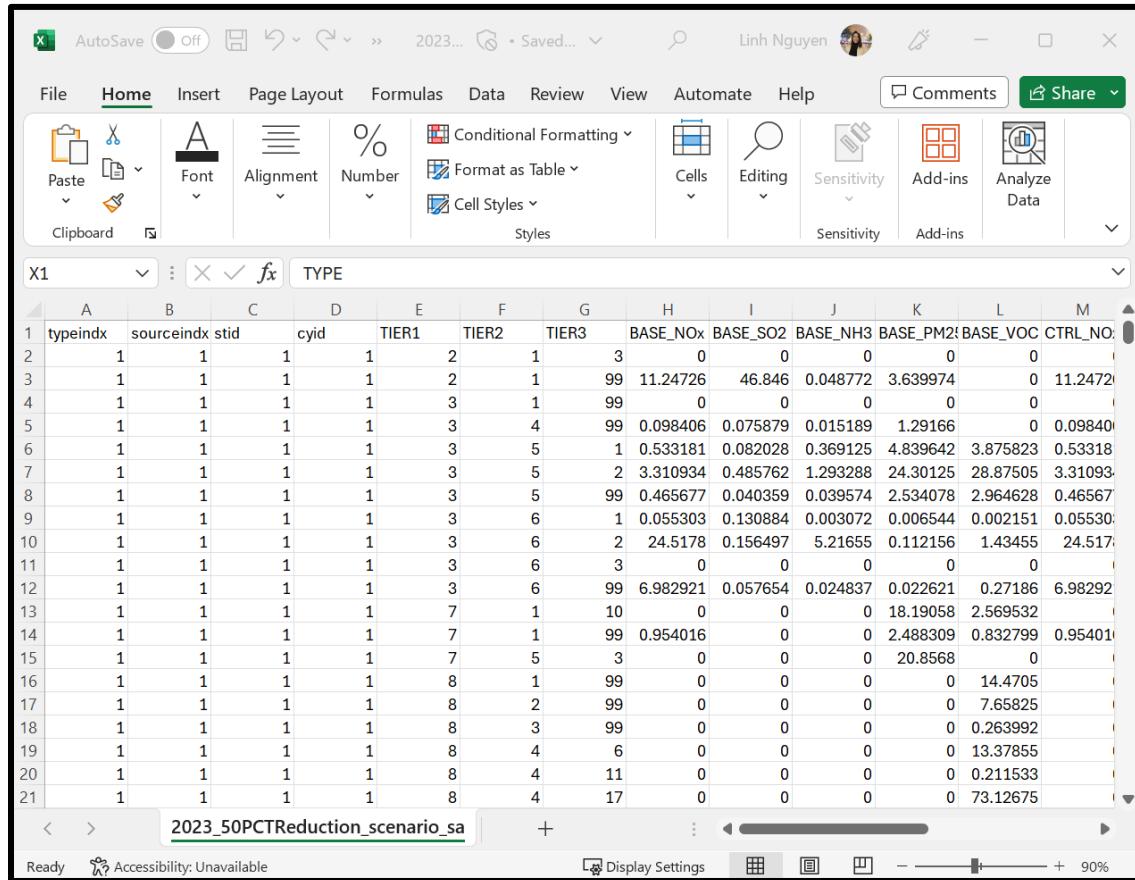
² A table of sourceindx and FIPS is saved on your computer after installing COBRA in the default location, in C:/Program Files/COBRA/input files/data dictionary/SOURCEIDX to FIPS crosswalk.csv

³ A table of tier definitions and tier numbers is saved on your computer after installing COBRA in the default location, in C:/Program Files/COBRA/input files/data dictionary/EmissionsTier Definitions.csv

⁴ Previous editions of COBRA included emissions of NH₃ as an input. Starting with COBRA 5.0 the source-receptor matrix no longer considers NH₃ as an input to model PM_{2.5} concentrations. However, because NH₃ could be used as an input in future versions of COBRA, it has been maintained in the tool and

BASE_NH3 and CTRL_NH3 are required fields in the format of the baseline and scenario emissions file, although they are not currently used in the calculations.

To see an example baseline and control scenario emissions file, navigate to your Documents folder in Windows. From there, navigate to input files/emissionsscenarios/2023_50PCTReduction_scenario_sample.csv.



The screenshot shows a Microsoft Excel spreadsheet titled "2023_50PCTReduction_scenario_sa". The data starts with a header row (row 1) and 20 data rows (rows 2-21). The columns are labeled as follows:

| | A | B | C | D | E | F | G | H | I | J | K | L | M |
|----|----------|------------|------|------|-------|-------|-------|----------|----------|----------|-----------|----------|---------|
| 1 | typeindx | sourceindx | stid | cyid | TIER1 | TIER2 | TIER3 | BASE_NOx | BASE_SO2 | BASE_NH3 | BASE_PM25 | BASE_VOC | CTRL_NO |
| 2 | 1 | 1 | 1 | 1 | 2 | 1 | 3 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 1 | 1 | 1 | 1 | 2 | 1 | 99 | 11.24726 | 46.846 | 0.048772 | 3.639974 | 0 | 11.2472 |
| 4 | 1 | 1 | 1 | 1 | 3 | 1 | 99 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 1 | 1 | 1 | 1 | 3 | 4 | 99 | 0.098406 | 0.075879 | 0.015189 | 1.29166 | 0 | 0.09840 |
| 6 | 1 | 1 | 1 | 1 | 3 | 5 | 1 | 0.533181 | 0.082028 | 0.369125 | 4.839642 | 3.875823 | 0.53318 |
| 7 | 1 | 1 | 1 | 1 | 3 | 5 | 2 | 3.310934 | 0.485762 | 1.293288 | 24.30125 | 28.87505 | 3.31093 |
| 8 | 1 | 1 | 1 | 1 | 3 | 5 | 99 | 0.465677 | 0.040359 | 0.039574 | 2.534078 | 2.964628 | 0.46567 |
| 9 | 1 | 1 | 1 | 1 | 3 | 6 | 1 | 0.055303 | 0.130884 | 0.003072 | 0.006544 | 0.002151 | 0.05530 |
| 10 | 1 | 1 | 1 | 1 | 3 | 6 | 2 | 24.5178 | 0.156497 | 5.21655 | 0.112156 | 1.43455 | 24.517 |
| 11 | 1 | 1 | 1 | 1 | 3 | 6 | 3 | 0 | 0 | 0 | 0 | 0 | 0 |
| 12 | 1 | 1 | 1 | 1 | 3 | 6 | 99 | 6.982921 | 0.057654 | 0.024837 | 0.022621 | 0.27186 | 6.98292 |
| 13 | 1 | 1 | 1 | 1 | 7 | 1 | 10 | 0 | 0 | 0 | 18.19058 | 2.569532 | |
| 14 | 1 | 1 | 1 | 1 | 7 | 1 | 99 | 0.954016 | 0 | 0 | 2.488309 | 0.832799 | 0.95401 |
| 15 | 1 | 1 | 1 | 1 | 7 | 5 | 3 | 0 | 0 | 0 | 20.8568 | 0 | |
| 16 | 1 | 1 | 1 | 1 | 8 | 1 | 99 | 0 | 0 | 0 | 0 | 14.4705 | |
| 17 | 1 | 1 | 1 | 1 | 8 | 2 | 99 | 0 | 0 | 0 | 0 | 7.65825 | |
| 18 | 1 | 1 | 1 | 1 | 8 | 3 | 99 | 0 | 0 | 0 | 0 | 0.263992 | |
| 19 | 1 | 1 | 1 | 1 | 8 | 4 | 6 | 0 | 0 | 0 | 0 | 13.37855 | |
| 20 | 1 | 1 | 1 | 1 | 8 | 4 | 11 | 0 | 0 | 0 | 0 | 0.211533 | |
| 21 | 1 | 1 | 1 | 1 | 8 | 4 | 17 | 0 | 0 | 0 | 0 | 73.12675 | |

To import a properly formatted baseline and control emissions CSV file into COBRA, click **Load a Baseline Control Scenario Emissions CSV File**. In the pop-up window, navigate to the location of your baseline emissions CSV file, click the file, and then click **Open**.

Custom Population, Incidence, and Valuation Datasets

The **Advanced Options** tab allows users to select customized input files for population data, incidence data, and valuation functions. Note that baseline emissions, population, incidence, and valuation functions vary over time. It is important for input files to correspond to the same year. For example, running COBRA with a 2023 baseline emissions inventory, 2023 population data, and 2023 incidence data would result in COBRA estimating 2023 health benefits. However, running COBRA with a 2023

baseline emissions inventory and 2020 population data would result in theoretical annual health benefits that do not correspond to any calendar year. Alternatively, running COBRA with a projected emissions inventory for 2030 and the default 2023 population and incidence data would assume that population and incidence are constant from 2023 to 2030.

COBRA requires that customized input files be in a specific format. To create a properly formatted population dataset, create a CSV file where each row is a different county and includes the columns listed in Exhibit 4.

Exhibit 4. Format of Population File

| Column Heading | Description of Column Headings |
|----------------------------|--|
| Year | Year of population data |
| DestinationID ¹ | DestinationID uses same pattern as SOURCEIDX to indicate destination locations. |
| FIPS | FIPS state-county ID (e.g., the state FIPS code for Pennsylvania is 42 and the county FIPS code for Swarthmore, PA is 045, so the state-county FIPS ID is 42045) |
| Age0 | Population at age 0 |
| ... | Population at each age |
| Age99 | Population older than or equal to 99 |

¹ See data dictionary file that is saved on your computer after installing COBRA in the default location, in C:/Program Files/COBRA/input files/data dictionary/SOURCEIDX to FIPS crosswalk.csv

To create a properly formatted incidence dataset, create a CSV file where each row is a different county and includes the columns listed in Exhibit 5.

Exhibit 5. Format of Incidence File

| Column Heading | Description of Column Headings |
|----------------------------|---|
| Year | Year of population data |
| DestinationID ¹ | DestinationID uses same pattern as SOURCEIDX to indicate destination locations. |
| FIPS | FIPS state ID (e.g., the state FIPS code for Pennsylvania is 42 and the county FIPS code for Swarthmore, PA is 045, so the state-county FIPS ID is 42045) |
| Endpoint | Written descriptor indicating health endpoint associated with the recorded incidence rate. |
| Age0 | Incidence of a specific endpoint for population at age 0 |
| ... | Incidence of a specific endpoint for population at each age |

| Column Heading | Description of Column Headings |
|-----------------------|---|
| Age99 | Incidence of a specific endpoint for population older than or equal to 99 |

¹ See data dictionary file that is saved on your computer after installing COBRA in the default location, in C:/Program Files/COBRA/input files/data dictionary/SOURCEIDX to FIPS crosswalk.csv

To create a properly formatted valuation functions dataset, create a CSV file where each row represents a concentration-response function from a single study for a specific age group and includes the columns described in Exhibit 6.

Exhibit 6. Format of Valuation Functions File.

| Column Heading | Description of Column Headings |
|-----------------------|---|
| CRFunctionID | ID for C-R functions (linked to the health effect function file) |
| Endpoint | String descriptor indicating Endpoint for the Valuation function. |
| PoolingWeight | Functions are pooled accounting to Endpoint. PoolingWeight indicates the relative weight given to this function. |
| Seasonal_Metric | Daily or Annual are allowable entries. Indicate if computed effect is for a day or an entire year. |
| Study_Author | Study Author |
| Study_Year | Study Year |
| Start_Age | Beginning of age range to which health impact function applies |
| End_Age | End of age range to which health impact function applies |
| Function | Functional form that is to be computed. (e.g., $(1-(1/(1-\text{Incidence})*\text{Exp}(\text{Beta}*\text{DETAQ})+\text{Incidence}))*\text{Incidence}*\text{POP}$) |
| Beta | Beta parameter supplied to functional form. |
| Adjusted | Not used |
| Parameter_1_Beta | Parameter_1_Beta parameter supplied to functional form. |
| A | A parameter supplied to functional form. |
| Name_A | Description of A parameter. |
| B | B parameter supplied to functional form. |
| Name_B | Description of B parameter. |
| C | C parameter supplied to functional form. |
| Name_C | Description of C parameter. |
| Cases | Not used |
| HealthEffect | Use same as IncidenceEndpoint |
| ValuationMethod | Note of valuation method used. |
| VALUE | Valuation of health endpoint using (undiscounted) |

| Column Heading | Description of Column Headings |
|-------------------|---|
| ApplyDiscount | Variable indicating whether to apply discounting. Values are “YES” or “NO”. |
| IncidenceEndpoint | Indicates Endpoint to use for lookup in Incidence data set. |

Custom Health Effect Function Datasets

The **Advanced Options** tab allows users to select customized health effect function datasets. The default health dataset in COBRA relies on an up-to-date assessment of the published scientific literature to ascertain the relationship between particulate matter and adverse human health effects, and can be used for all analysis years. Because of this, most users will not want to modify this input. If you use custom datasets to describe health effect functions, please list the sources of these datasets and any assumptions used to generate them when reporting your results.

If you do choose to import a custom health effect function dataset, COBRA requires that this file be in a specific format. To create a properly formatted health effect functions dataset, create a CSV file where each row represents a concentration-response function from a single study for a specific age group and includes the columns listed in Exhibit 7.

Exhibit 7. Format of Health Effect Functions File.

| Column Heading | Description of Column Headings |
|------------------|---|
| FunctionID | ID for C-R functions (linked to the valuation function file) |
| Endpoint | String descriptor indicating endpoint for the Health/Concentration-Response function. |
| PoolingWeight | Functions are pooled accounting to Endpoint. PoolingWeight indicates the relative weight given to this function. |
| Seasonal_Metric | Daily or Annual are allowed entries. Indicate if computed effect is for a day or an entire year. |
| Study_Author | Study Author |
| Study_Year | Study Year |
| Start_Age | Beginning of age range to which health impact function applies |
| End_Age | End of age range to which health impact function applies |
| Function | Functional form that is to be computed. (e.g., $(1-(1/(1-\text{Incidence})*\text{Exp}(\text{Beta}*\text{DETAQ})+\text{Incidence}))*\text{Incidence}*\text{POP}$) |
| Beta | Beta parameter supplied to functional form. |
| Adjusted | Not used |
| Parameter_1_Beta | Parameter_1_Beta parameter supplied to functional form. |

| Column Heading | Description of Column Headings |
|-------------------|---|
| A | A parameter supplied to functional form. |
| Name_A | Description of A parameter. |
| B | B parameter supplied to functional form. |
| Name_B | Description of B parameter. |
| C | C parameter supplied to functional form. |
| Name_C | Description of C parameter. |
| Cases | Not used |
| IncidenceEndpoint | Indicates Endpoint to use for lookup in Incidence data set. |

Exploring Baseline Emissions Data

You can explore the geographic distribution of pollutant concentrations in the baseline scenario by clicking on the **2. Create Emissions Scenario** tab and then clicking on the **View Emissions Map** tab.

At the top of this screen, you will see a drop-down menu labeled ‘Select the field that is to be mapped.’ The first five options listed (Base NH3, Base NO2, Base PM2.5, Base SO2, and Base VOC) correspond to the baseline emissions of ammonia (NH₃),¹¹ nitrogen oxides (NO_x), fine particulate matter (PM_{2.5}), sulfur dioxide (SO₂), and Volatile Organic Compounds (VOCs), respectively, from all sectors. Select any of these emissions to view a map of county-level baseline emissions. See Chapter 6 for more details on how to use COBRA’s mapping functionality.

¹¹ Note, as discussed above, NH3 is no longer used in the calculation in COBRA, but it has been maintained in the model for potential use in future versions.

CHAPTER 4. Creating a New Emissions Scenario

COBRA allows users to define new emissions scenarios and investigate the related changes in air quality and health effects. The scenario definition, results tables, and results maps can be exported for future use or archiving purposes.

The steps to creating a new scenario within the COBRA interface are simple:

Step 1. Select the Analysis Year and Baseline Data. See Chapter 3.

Step 2a. Select the Geography and Tier Level. You can specify emissions changes at the national, state, or county level from fourteen emission source categories.

Step 2b. Enter Emissions Changes. Changes can be made for each state or county, or the entire nation. You can group states and counties and make changes to them together, or make different changes to different geographic areas.

Step 3. Run the Scenario. COBRA will calculate the changes in ambient PM_{2.5} between your selected baseline scenario and the new control scenario, and calculate the associated changes in health effects and monetary impacts.

Step 4. Examine the results. See Chapter 5.

Selecting Scenario Geography

To define your scenario, click the **2. Create Emissions Scenario** tab and then the **Emissions Scenario** tab. In the top left panel you can select the geographic area(s) to which you want to apply emissions changes. Note that once your comparison is run, you will be able to see results (changes in ambient PM_{2.5} levels and health effects) for the entire country. Click on the appropriate choice in the left panel.

The geographic areas you select determine where your emissions changes are made. Your selection does not affect the geographic area for which you can view results. Regardless of the geographic area you select for emissions changes, you can view results for the entire country.

- **US.** If you wish to make emissions changes to the entire United States, select ‘US.’
- **Individual State.** If you wish to make emissions changes to just one state, click that state.
- **Individual County.** If you wish to make emissions changes to just one county, click that county.

- **Multiple Geographic Areas.** If you wish to make the same emissions changes to multiple geographic areas, click the check box next to each of those geographic areas in the ‘Tier and Location Selection’ panel. It is possible to select multiple states (e.g., all of California and Oregon), multiple counties (e.g., Dade County, Florida and Broward County, Florida), and combinations of states and counties (e.g., all of Massachusetts and Providence County, Rhode Island).

The ‘Pollutants’ panel in the top center of your screen will show the total baseline emissions for all the selected geographic areas.

When you apply an emissions change to multiple geographic areas as a percentage, your control scenario will consist of emissions in each county in the selected areas changing by that same percentage. When you apply an emissions change to multiple geographic areas in tons, your control scenario will consist of emissions in each county in the selected areas changing by different amounts that add up to the input total emissions change. COBRA divides the total emissions change across counties in proportion to their baseline emissions.

If you have decided to apply different changes to different geographic areas categories, you will need to select the geographic area, select the tier level, and define the scenario emissions separately for each geographic area.

Selecting Tier Level

Next, define the categories of emissions affected. The center panel contains a directory tree with all the tier 1, 2, and 3 source categories (see Appendix A for a list of source categories and their emissions). You can define emissions changes at any level, but each level always includes all the levels indented underneath it. Click the tier at which you would like to apply your emissions changes. A change entered for a tier category applies to all of the branches under it, but you must enter changes individually for tier categories on separate branches.

Defining Scenario Emissions

After you have selected your tier and geographic area, you can create a new emissions scenario by defining changes to the baseline emissions scenario. This can either be done manually or by uploading an AVERT emissions change data file if you have EPA AVERT model outputs you would like to use.

Manually Entering Emissions Changes

To manually enter the changes to the baseline emissions, use the boxes in the right panel for each of the five pollutants potentially emitted by sources in that category. You can enter emissions increases or decreases by percent or by tons. To the right of the boxes you will see the total emissions for your selected tier and geographic area for the baseline

and control scenarios. Click **Apply Changes** to save your changes. If your emissions scenario attempts to reduce emissions by more than exists in the baseline emissions inventory (e.g., if the SO₂ emissions baseline for Fuel Combustion: Electric Utilities in California is 4,065 tons and you try to reduce those emissions by 4,100 tons), you will get the error message “Please make sure you do not try to reduce emissions by more than actually present in the baseline” and COBRA will not allow you to enter those inputs.

Note that the input for NH₃ has been disabled starting with version 5.0 of COBRA. The new S-R matrix included in the version no longer considers emissions of NH₃ to calculate PM_{2.5} concentrations. However, because future versions of COBRA may include refinements that would require NH₃ as an input (such as the estimation of ammonium ion concentrations), the input box for NH₃ has been kept in the tool.

Once your emissions changes are entered for a given tier and location, you can go back and change them by selecting that tier and geographic location again in the directory trees. The emissions baseline and your previously saved control scenario changes will be displayed in the right panel. To overwrite your previously saved control scenario for that tier and location, enter your new emissions changes and click **Apply Changes**.

If you have decided to apply different changes to different geographic areas categories, click the **Clear Selected States or Counties** button and repeat the above steps for each geographic area. For example, if you want to decrease all California Off-Highway SO₂ emissions by 25% and all Oregon Off-Highway SO₂ emissions by 15%, you would have to enter the California emissions change, click **Apply Changes**, click **Clear Selected States or Counties**, enter the Oregon emissions change, and click **Apply Changes** again.

Importing Emissions Changes from AVERT

EPA’s AVoided Emissions and geneRation Tool ([AVERT](#)) estimates displaced emissions at electric power plants due to renewable energy or energy efficiency projects, policies, or programs. In addition, with the release of AVERT v4.0, the tool also estimates changes in emissions in the transportation sector from electric vehicles.

Like COBRA, AVERT has both a web-based version and a desktop (Excel-based) version. In the web-based version of AVERT, users can export results directly into the web-based of COBRA by clicking on the button labeled “**Submit Results to COBRA**” after running a renewable energy, energy efficiency and/or electric vehicle scenario in AVERT.

In the desktop version of AVERT, users can export results from AVERT to a text file that can be imported into COBRA. Once the AVERT output file is generated, it can be imported directly into the desktop version of COBRA by clicking the “**Load AVERT output file**” button in the **2. Create Emissions Scenario** tab in COBRA.

In both the web and desktop versions of COBRA, the emissions reductions from each county from AVERT will be loaded into COBRA in the “Fuel Combustion: Electric Utilities” and/or “Highway Vehicles” tiers.

In addition, in both the web and desktop versions of COBRA, users can manually input additional emissions changes in other counties or tiers after loading AVERT results into COBRA. In other words, you can still adjust other tiers besides the “Fuel Combustion: Electric Utilities” and “Highway Vehicles” tier, such as the “Fuel Combustion” Industrial” tier.

You can also enter emissions changes in the “Fuel Combustion: Electric Utilities” and “Highway Vehicles” tier for counties not included in the AVERT output file. However, if you manually adjust the emissions changes in the “Fuel Combustion: Electric Utilities” or “Highway Vehicles” tier for a county included in the AVERT output file, this will overwrite the emissions changes from the AVERT output.

In the desktop version, if you have entered any emissions changes in the user interface before loading an AVERT emissions scenario file, loading the AVERT file will make COBRA overwrite emissions changes in the “Fuel Combustion: Electric Utilities” and “Highway Vehicles” tiers for the counties included in the AVERT file. Other tiers and counties will be unaffected.

The screenshot shows the COBRA desktop application window. At the top, there's a menu bar with 'File' and 'Help'. Below it is a navigation bar with links: 'Introduction', '1. Select Analysis Year', '2. Create Emissions Scenario', '3. Execute Run', '4. View Health Effects and Valuation Results', 'Emissions Scenario', 'View Emissions Map', and 'View Detailed Emissions Changes'. The main area is divided into three sections: 'Select Location' (a tree view of US states), 'Select Emissions Tier' (a list of categories like Fuel Combustion, Industrial, etc.), and 'Modify Emissions' (a table where users can input percentage or tonnage changes for PM 2.5, SO2, NOx, NH3, and VOC). A red box highlights the 'Load AVERT output file' button at the bottom right of the 'Modify Emissions' section.

Desktop Version

The text file that AVERT generates is already formatted to directly import into COBRA without any modifications. If you choose to edit the AVERT output file, please make sure to maintain the original column headings and file format (example file shown

below), such that each row summarizes the emissions reductions in tons for a given county and tier 1 category.

| A | B | C | D | E | F | G | H | I |
|------|---------------|-------------------|------------------------|---------------------|---------------------|----------------------|----------------------|---------------------|
| FIPS | STATE | COUNTY | TIER1NAME | NOx_REDUCTIONS_TONS | SO2_REDUCTIONS_TONS | PM25_REDUCTIONS_TONS | VOCS_REDUCTIONS_TONS | NH3_REDUCTIONS_TONS |
| 2 | 5007 Arkansas | Benton County | FUEL COMB. ELEC. UTIL. | -5.138 | -1.537 | -0.011 | -0.094 | -0.035 |
| 3 | 5047 Arkansas | Franklin County | FUEL COMB. ELEC. UTIL. | -0.196 | -0.08 | -0.015 | -0.005 | -0.015 |
| 4 | 5057 Arkansas | Hempstead County | FUEL COMB. ELEC. UTIL. | -0.892 | -0.534 | -0.015 | -0.004 | -0.024 |
| 5 | 5143 Arkansas | Washington County | FUEL COMB. ELEC. UTIL. | -0.09 | -0.002 | -0.004 | -0.001 | -0.012 |
| 6 | 19041 Iowa | Clay County | FUEL COMB. ELEC. UTIL. | -0.047 | -0.001 | -0.025 | -0.002 | -0.004 |
| 7 | 20009 Kansas | Barton County | FUEL COMB. ELEC. UTIL. | -0.012 | 0 | -0.001 | 0 | 0 |
| 8 | 20021 Kansas | Cherokee County | FUEL COMB. ELEC. UTIL. | -0.229 | -0.005 | -0.042 | -0.002 | -0.037 |
| 9 | 20035 Kansas | Cowley County | FUEL COMB. ELEC. UTIL. | -0.076 | 0 | -0.002 | -0.001 | -0.001 |
| 10 | 20045 Kansas | Douglas County | FUEL COMB. ELEC. UTIL. | -4.703 | -1.552 | -0.129 | -0.113 | -0.003 |
| 11 | 20055 Kansas | Finney County | FUEL COMB. ELEC. UTIL. | -3.81 | -2.918 | -0.098 | -0.027 | -0.007 |
| 12 | 20057 Kansas | Ford County | FUEL COMB. ELEC. UTIL. | -0.028 | 0 | -0.001 | -0.001 | -0.001 |
| 13 | 20091 Kansas | Johnson County | FUEL COMB. ELEC. UTIL. | -0.099 | 0 | -0.023 | -0.007 | -0.023 |
| 14 | 20107 Kansas | Linn County | FUEL COMB. ELEC. UTIL. | -6.221 | -2.053 | -0.34 | -0.322 | 0 |
| 15 | 20111 Kansas | Lyon County | FUEL COMB. ELEC. UTIL. | -0.704 | -0.006 | -0.094 | -0.03 | -0.094 |
| 16 | 20113 Kansas | McPherson County | FUEL COMB. ELEC. UTIL. | -0.904 | 0 | -0.01 | -0.005 | -0.008 |
| 17 | 20121 Kansas | Miami County | FUEL COMB. ELEC. UTIL. | -0.017 | 0 | -0.004 | -0.001 | -0.004 |

Note that you can paste the results from multiple AVERT runs into a single text file and import it into the desktop version of COBRA. If there are any duplicate counties in the text file, COBRA will sum the emissions reductions before importing the file.

Because AVERT and COBRA use emissions data from different years, there are some instances where the baselines between the tools do not align. Subsequently, there may be rare cases where results from AVERT call for more emission reductions in a given county than there are emissions for that county in the “Fuel Combustion: Electric Utilities” tier in the COBRA baseline. In these cases, COBRA will accept emission reductions from AVERT that exceed the baseline, although COBRA does not allow users to manually enter emission reductions greater than what is in the baseline. While COBRA allows emission reductions greater than the baseline in this specific case, it is very unlikely to cause any adverse issues with the results for the scenario (such as negative PM_{2.5} or ozone concentrations) because of the influence of emissions from other sectors.

It is also possible to enter a custom scenario definition that is not generated by AVERT into COBRA as a CSV. See the Advanced Options section of Chapter 3 for further instructions on this scenario definition method.

Reviewing Scenario Definition

You can review your scenario definition by looking at the table in the **View Detailed Emissions Changes** tab. This will display all of your changes by state, county, and tier category. If the scenario is acceptable and you wish to save it for future reference, click on the **Emissions Scenario** tab and then click the **Save Scenario** button in the top right panel of the screen. This will export a comma-delimited file that contains the same information as shown in the **View Detailed Emissions Changes** table. Exporting this file is useful if you export any other tables from the results tabs; at a later date you will have a reference for what the results tables and maps are based on.

Running Scenario

When you have made all of your desired changes, navigate to the **3. Execute Run** tab. This tab asks you to choose a discount rate for the COBRA session. The discount rate you select is used to express future economic values in present terms. Not all health effects and associated economic values occur in the year of analysis. Therefore, COBRA accounts for the ‘time value of money’ preference (i.e., a general preference for receiving economic benefits now rather than later) by discounting benefits received later. Based on OMB Circular A-4, it is recommended that COBRA users calculate monetized health benefits using a 2 percent discount rate. However, users have the option of entering a custom discount rate. For more details on discount rates, see Appendix F.

After selecting a discount rate, click **Run using above options**.

The time to generate your results will vary, depending on the speed of your computer. COBRA may stop responding while it runs, and it may take 5 to 15 minutes to generate results. Once the results are generated, COBRA will navigate to the **4. View Health Effects and Valuation Results** tab, where you can view the results of your run (see Chapter 5).

CHAPTER 5. Viewing Results

Viewing Results in Table Form

Once you have defined your new scenario (called the control scenario) and run the comparison between the baseline and your scenario, you can view the results: changes in air quality and health effects between the baseline and control scenarios. You can view results in table form in the **Table** tab or in map form in the **Map** tab.

The **Table** tab describes the changes in air quality (i.e., PM_{2.5} and O₃ concentrations) between the baseline emissions scenario and your scenario (the control scenario), and the corresponding changes in health effects (incidence and monetized values). Note that if you have run a state-specific scenario, changes in air quality for other states will typically decrease as the distance from the state increases, since the emissions changes were only made there. You can navigate through the table data in several ways:

- **Scroll** through the data using the scroll bar on the right and bottom of the window.
- **Change the sort order** by clicking on the heading of any column. Click once to sort from smallest to largest and click twice to sort from largest to smallest.
- **Filter column variables** by clicking on the filter button at the top of any column. You can use this functionality to filter down to a specific state and county.
- **Change the column order** by clicking on the column name and dragging it to a new position. When you see a black line, you can drop the column there. Note that the sort order of the table will not change.
- **Change the width of a column** by moving your mouse to the column header and pointing to the dividing line between two columns. The mouse cursor will change to two arrows, indicating that you can drag the column line to condense or expand the column.
- **View totals** by navigating to the top or bottom of the table. If you filter the table, the totals row will adjust in real time to display the totals for all values that are currently visible. For example, if you have not filtered the table, the totals row will show total health effects for the entire United States. If you have filtered the table to only show results for a specific state, the totals row will show total health effects for that state.

For each county, the table lists the annual average PM_{2.5} and ozone season average of the maximum daily 8-hour average (MDA8) of the O₃ concentrations for the control scenario and the baseline scenario, as well as the change between the two scenarios (Delta PM_{2.5})

and O₃) in units of micrograms per cubic meter ($\mu\text{g}/\text{m}^3$) for PM_{2.5} and parts per million (ppm) for O₃. The table also displays the change in the number of cases for each health effect between the baseline emissions scenario and your scenario. These changes are derived using the health impact functions described in Appendix C. The table also displays an estimate of the economic value of the change in the number of cases for each health effect. For more information, see Appendix F. Exhibit 8 describes the health endpoints and valuations that are included in the health effects tables in COBRA.

Exhibit 8. Description of Health Effects and their Economic Values

| Health Effect | Air Pollutant | Description |
|--|-------------------|--|
| Mortality (low estimate) | PM _{2.5} | Low estimate of the number of deaths based on Wu et al. (2020) |
| \$ Mortality (low estimate) | PM _{2.5} | Low estimate of the economic value of the number of deaths, using Wu et al. (2020) and the selected discount rate |
| Mortality (high estimate) | PM _{2.5} | High estimate of the number of deaths based on Pope et al. (2019) |
| \$ Mortality (high estimate) | PM _{2.5} | High estimate of the economic value of the number of deaths, using Pope et al. (2019) and the selected discount rate |
| Infant Mortality | PM _{2.5} | Number of infant deaths based on Woodruff et al. (2008) |
| \$ Infant Mortality | PM _{2.5} | Economic value of the number of infant deaths based on Woodruff et al. (2008) |
| Nonfatal Heart Attacks | PM _{2.5} | Estimate of the number of non-fatal heart attacks based on Wei et al. (2019) |
| \$ Nonfatal Heart Attacks | PM _{2.5} | Estimate of the economic value of non-fatal heart attacks based on Wei et al. (2019) and the selected discount rate |
| Asthma Symptoms, Albuterol use | PM _{2.5} | Episodes of asthma symptoms that require Albuterol use based on Rabinovitch et al. (2006) |
| \$ Asthma Symptoms, Albuterol use | PM _{2.5} | Economic value of episodes of asthma symptoms with Albuterol use based on Rabinovitch et al. (2006) |
| Emergency Room Visits, All Cardiac Outcomes | PM _{2.5} | Number of cardiovascular-related emergency room visits based on Ostro et al. (2016) |
| \$ Emergency Room Visits, All Cardiac Outcomes | PM _{2.5} | Economic value of cardiovascular-related emergency room visits based on Ostro et al. (2016) |
| Emergency Room Visits, Respiratory | PM _{2.5} | Number of respiratory-related emergency room visits based on Krall et al. (2016) |
| \$ Emergency Room Visits, Respiratory | PM _{2.5} | Economic value of respiratory-related emergency room visits based on Krall et al. (2016) |
| Hospitalization, Cardio-, Cerebro-, and Peripheral Vascular Disease | PM _{2.5} | Number of hospitalizations as a result of cardio-, cerebro-, and peripheral vascular disease based on Bell et al. (2015) |

| Health Effect | Air Pollutant | Description |
|---|----------------------|---|
| \$ Hospitalization, Cardio-, Cerebro-, and Peripheral Vascular Disease | PM _{2.5} | Economic value of hospitalizations as a result of cardio-, cerebro-, and peripheral vascular disease based on Bell et al. (2015) |
| Hospitalization, Alzheimer's Disease | PM _{2.5} | Number of hospitalizations as a result Alzheimer's disease based on Kioumourtzoglou et al. (2016) |
| \$ Hospitalization, Alzheimer's Disease | PM _{2.5} | Economic value of hospitalizations as a result Alzheimer's disease based on Kioumourtzoglou et al. (2016) |
| Hospitalization, Parkinson's Disease | PM _{2.5} | Number of hospitalizations as a result Parkinson's disease based on Kioumourtzoglou et al. (2016) |
| \$ Hospitalization, Parkinson's Disease | PM _{2.5} | Economic value of hospitalizations as a result Parkinson's disease based on Kioumourtzoglou et al. (2016) |
| Hospitalization, All Respiratory | PM _{2.5} | Number of respiratory-related hospitalizations based on Ostro et al. (2009) and Bell et al. (2015) |
| \$ Hospitalization, All Respiratory | PM _{2.5} | Economic value of respiratory-related hospitalizations based on Ostro et al. (2009) and Bell et al. (2015) |
| Incidence, Stroke | PM _{2.5} | Number of stroke incidences based on Kloog et al. (2012) |
| \$ Incidence, Stroke | PM _{2.5} | Economic value of stroke incidences based on Kloog et al. (2012) |
| Incidence, Out of Hospital Cardiac Arrest | PM _{2.5} | Number of out of hospital cardiac arrest incidences based on Silverman et al. (2010), Rosenthal et al. (2008), and Ensor et al. (2013) |
| \$ Incidence, Out of Hospital Cardiac Arrest | PM _{2.5} | Economic value of out of hospital cardiac arrest incidences based on Silverman et al. (2010), Rosenthal et al. (2008), and Ensor et al. (2013) |
| Incidence, Lung Cancer | PM _{2.5} | Number of out of lung cancer incidences based on Gharibvand et al. (2016) |
| \$ Incidence, Lung Cancer | PM _{2.5} | Economic value of lung cancer incidences based on Gharibvand et al. (2016) |
| Incidence, Asthma | PM _{2.5} | Number of asthma incidences based on Tetreault et al. (2016) |
| \$ Incidence, Asthma | PM _{2.5} | Economic value of asthma incidences based on Tetreault et al. (2016) |
| Minor Restricted Activity Days | PM _{2.5} | Number of minor restricted activity days (days on which activity is reduced, but not severely restricted – e.g., missing work or being confined to bed is too severe to be MRAD) based on Ostro and Rothschild (1989) |
| \$ Minor Restricted Activity Days | PM _{2.5} | Economic value of minor restricted activity days based on Ostro and Rothschild (1989) |
| Work Loss Days | PM _{2.5} | Number of work days lost due to illness based on Ostro (1987) |

| Health Effect | Air Pollutant | Description |
|--|----------------------|--|
| \$ Work Loss Days | PM _{2.5} | Economic value of work days lost due to illness based on Ostro (1987) |
| School Loss Days | O ₃ | Number of school absences as a result of air pollution based on Adams et al. (1999) |
| \$ School Loss Days | O ₃ | Economic value of school absences as a result of air pollution based on Adams et al. (1999) |
| Asthma Symptoms, Cough | O ₃ | Number of cough episodes as a result of air pollution based on Lewis et al. (2013) |
| \$ Asthma Symptoms, Cough | O ₃ | Economic value of cough episodes as a result of air pollution based on Lewis et al. (2013) |
| Asthma Symptoms, Wheeze | O ₃ | Number of wheeze episodes as a result of air pollution based on Lewis et al. (2013) |
| \$ Asthma Symptoms, Wheeze | O ₃ | Economic value of wheeze episodes as a result of air pollution based on Lewis et al. (2013) |
| Asthma Symptoms, Chest Tightness | O ₃ | Number of chest tightness episodes as a result of air pollution based on Lewis et al. (2013) |
| \$ Asthma Symptoms, Chest Tightness | O ₃ | Economic value of chest tightness episodes as a result of air pollution based on Lewis et al. (2013) |
| Asthma Symptoms, Shortness of Breath | O ₃ | Number of shortness of breath episodes as a result of air pollution based on Lewis et al. (2013) |
| \$ Asthma Symptoms, Shortness of Breath | O ₃ | Economic value of shortness of breath episodes as a result of air pollution based on Lewis et al. (2013) |
| Emergency Room Visits, Asthma | O ₃ | Number of asthma-related emergency room visits Mar and Koenig (2009) |
| \$ Emergency Room Visits, Asthma | O ₃ | Economic value of asthma-related emergency room visits Mar and Koenig (2009) |

Notes: * For adult mortality and nonfatal heart attacks, COBRA contains multiple health impact functions that relate PM_{2.5} and each health effect. Therefore, there are high and low estimates of the cases avoided and their economic values for each of these health effects. More details on the underlying health impact functions are available in Appendix C. In addition, future costs are calculated using a discount rate that you selected before running the scenario.

The health effects table includes low and high estimates for the changes in the number of cases and the corresponding economic values for adult mortality and non-fatal heart attacks. The low and high estimates are derived using two sets of assumptions about the sensitivity of adult mortality and non-fatal heart attacks to changes in ambient PM_{2.5} levels. Specifically, the high estimates are based on studies that estimated a larger effect of changes in ambient PM_{2.5} levels on the incidence of these health effects. The low and high estimates for each of these values are derived as follows:

- **Adult Mortality.** EPA (2009) used two studies when analyzing proposed PM_{2.5} NAAQS; EPA presented the results separately for each study. Following EPA, COBRA reports the results of two health impact functions that relate PM_{2.5} and mortality: Wu et al. (2020) and Pope et al. (2019). In the health effects table, **Adult Mortality (Low)** and **\$ Adult Mortality (Low)** represent estimates of adult deaths avoided and their economic value, respectively, based on Wei et al. (2020). **Adult Mortality (High)** and **\$ Adult Mortality (High)** represent estimates of adult deaths avoided and their economic value, respectively, based on Pope et al. (2019).
- **Nonfatal Heart Attacks.** COBRA calculates the estimate for non-fatal heart attack cases avoided (**Nonfatal Heart Attacks**) and its economic value (**\$ Nonfatal Heart Attacks**). The estimate is based on Wei et al. (2019).

The value in each health effects column represents the total change in the number of cases of each health endpoint in a county.¹²

Interpreting positive and negative results:

In the health effects table, positive numbers indicate reductions in the number of cases of adverse health effects and the associated monetary benefits of your scenario. Negative numbers signify increases in the number of cases of health effects and the resulting costs.

All health effects are monetized. However, to prevent double-counting, the calculation of asthma exacerbations only includes asthma effects occurring in children aged 6 to 18 years. This approach follows the recommendations of EPA's Science Advisory Board Health Effects Subcommittee for valuing asthma exacerbations, as described in the benefits analysis for the 2006 Regulatory Impact Analysis for the revised PM_{2.5} NAAQS (U.S. EPA, 2006). Studies of the general population include asthmatics, so estimates based solely on the adult asthmatic population cannot be directly added to the general population numbers without double-counting. Instead, asthma exacerbations occurring in adults were assumed to be accounted for in health effects for the general population, such as Work Loss Days and Minor Restricted Activity Days (U.S. EPA, 2006). Since the health effects for the general population do not include asthma effects in children, the analysis of asthma exacerbations for children does not lead to double-counting (see Appendix C for details).

¹² A value of 3.00 in the Adult Mortality (low) column, for instance, indicates that in your scenario there would be an estimated 3 fewer cases of premature mortality compared to the baseline emissions scenario over the following 20 years. *Note, however, that a negative number signifies an increase in cases.* Therefore, - 3.00 in the Adult Mortality (low) column indicates that in your scenario there would be 3 additional cases of premature mortality over the following 20 years compared to the baseline emissions scenario.

Viewing Results in Maps Form

The **Map** tab displays the results of your scenario geographically. The left ‘Select the field that is to be mapped:’ drop-down menu allows you to change the values shown on the map. You can display the change in PM_{2.5} or O₃ between your scenario and the baseline emissions (the same values shown as ‘Delta PM_{2.5}’ or ‘Delta O₃’ in the **Table** tab), or any of the health endpoints included in the model. The values displayed for each health endpoint are the change in the number of cases (or deaths for ‘Adult Mortality (Low)’, ‘Adult Mortality (High)’, and ‘Infant Mortality’) and the economic valuation of these cases from the scenario, as displayed in the **Table** tab.

Saving Results

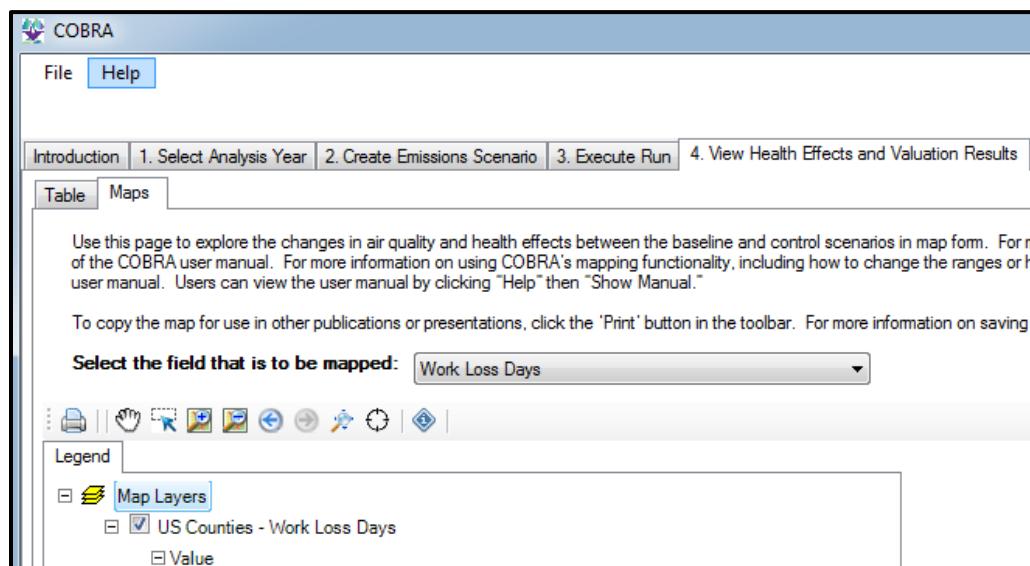
To save your results for use outside of the COBRA environment, you can export the results tables by clicking **Export to CSV** in the **Table** tab. The maps can also be customized within COBRA and then exported for use in documents and presentations (see Chapter 6).

CHAPTER 6. Using Mapping Functionality.

COBRA can create maps of baseline emissions and air quality, control scenario emissions and air quality, changes in air quality, adverse health effects avoided, and the economic value of adverse health effects avoided. To view maps of baseline or control emissions, navigate to the **2. Create Emissions Scenario** tab and click **View Emissions Map** at the top of the page. To view maps of baseline and control air quality, changes in air quality, adverse health effects avoided, and the economic value of adverse health avoided, navigate to the **4. View Health Effects and Valuation Results** tab and click on **Map** tab at the top of the page. Maps of emissions can be viewed before running COBRA, but maps of air quality and health effects can only be viewed after running COBRA.

The mapping interface works the same way in both screens. Below, we describe the major capabilities of the mapping tool and show how to use it for the Pennsylvania example described in Chapter 2. Note that most of this section is written for the desktop version of COBRA, as the web version does not have the same level of mapping functionality.

To create a map, select the variable you would like to map in the ‘Select the field that is to be mapped’ drop-down menu. For this example, you will examine avoided work loss days.



Desktop Version

B. Map of Health Effects and Air Quality Results

Below is a map showing health effects and air quality data based on your scenario.

Use the filter below to change the map's data layer. Click on a county on the map to explore the data.

Select the map's data layer:

Work Loss Days (cases)

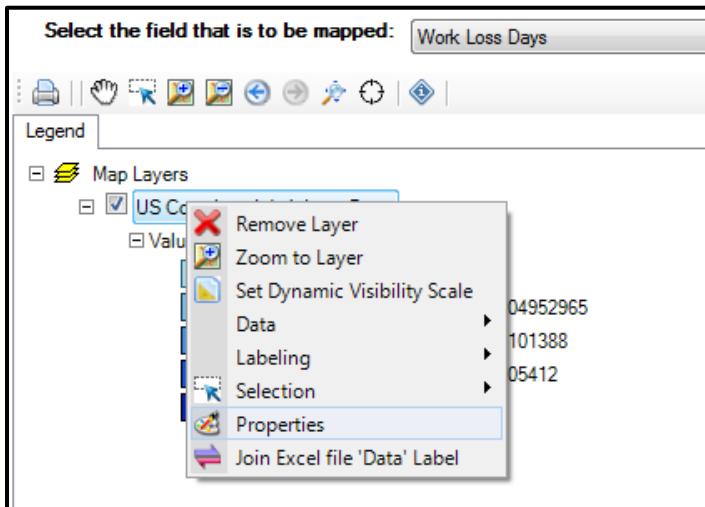


Displaying: Work Loss Days (cases)

[Web Version](#)

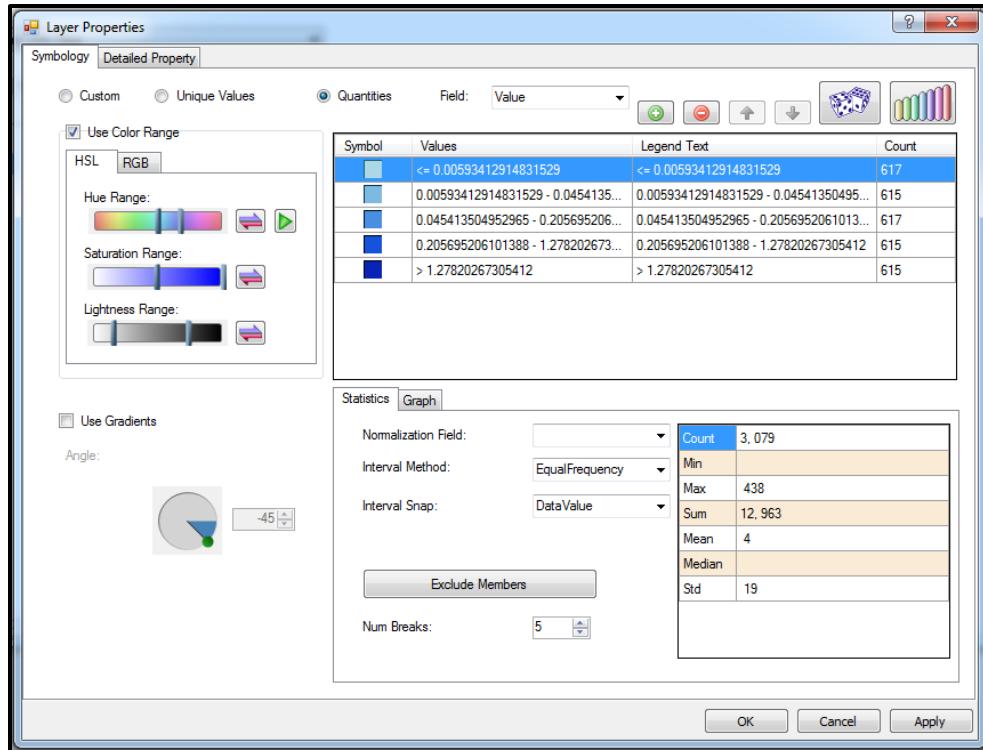
Customizing Map Appearance

To modify the color scheme of the map, right-click ‘US Counties’ in the Legend panel and then click ‘Properties.’



[Desktop Version](#)

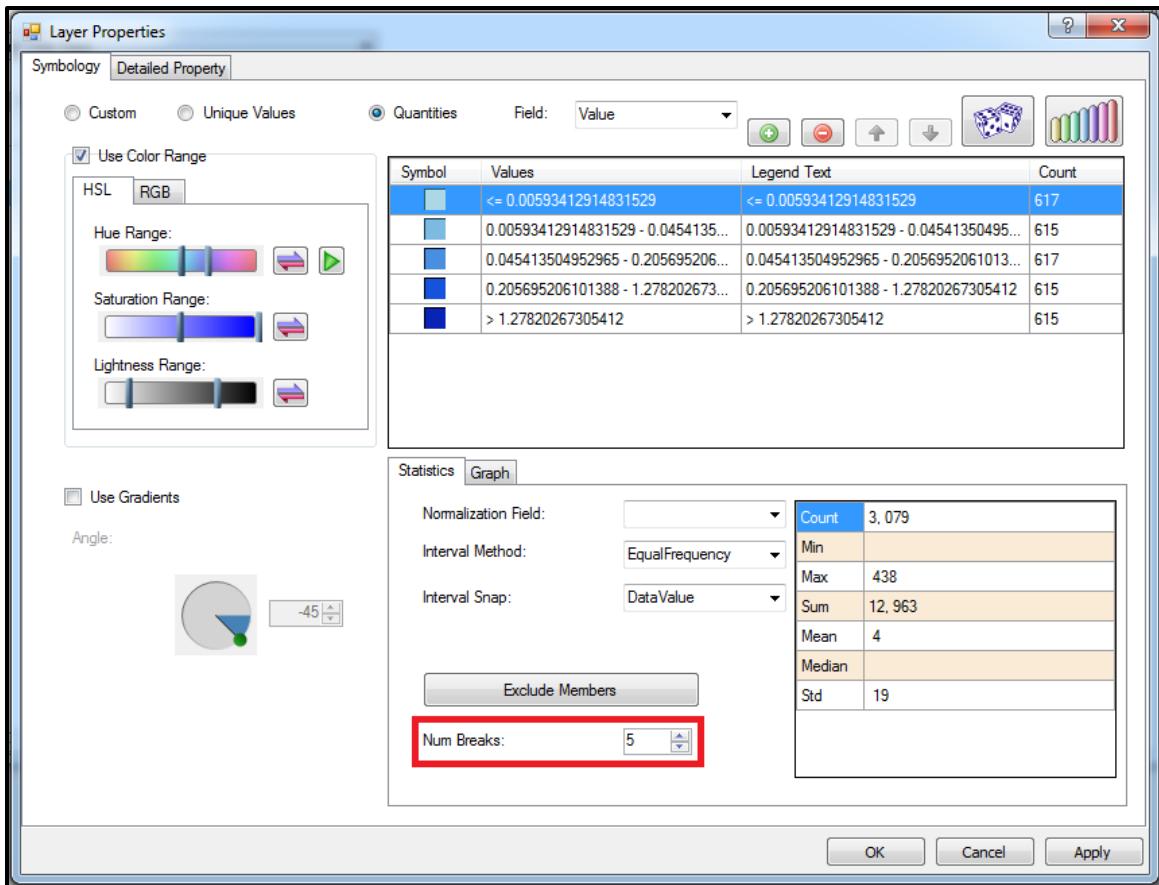
The menu that pops up has three panels. The top left panel allows you to select the overall color scheme that will define the map. The top right panel summarizes the color classification scheme (in this example, the shading that indicates larger numbers of avoided work loss days). The bottom right panel allows you to modify the ranges (or “interval breaks”) used in the color classification scheme.



Desktop Version

Defining Interval Breaks

You can adjust how color intervals are defined in the bottom right panel. In the box to the right of 'Num Breaks' (indicated in red below), enter the number of intervals you would like your map to have.

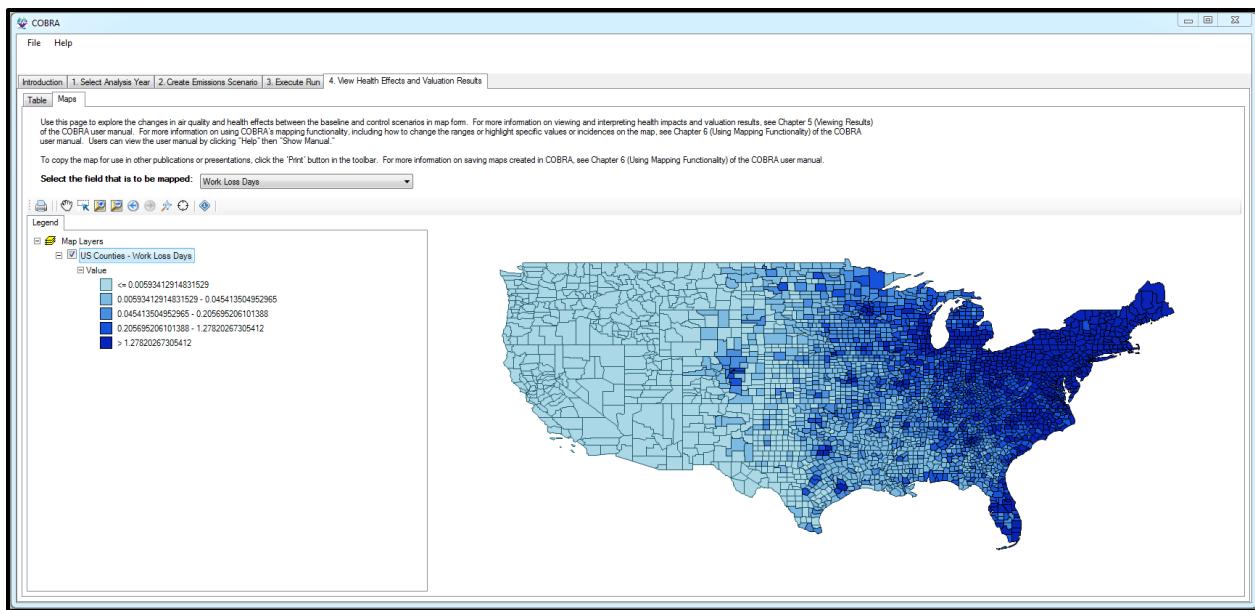


Desktop Version

If you select 1, all counties will be in the same interval and the map will be a single color. If you select 10, there will be 10 intervals that can be 10 different colors. In this example, you should select 5. Next, select how COBRA should define the intervals. There are four possible methods, described below.

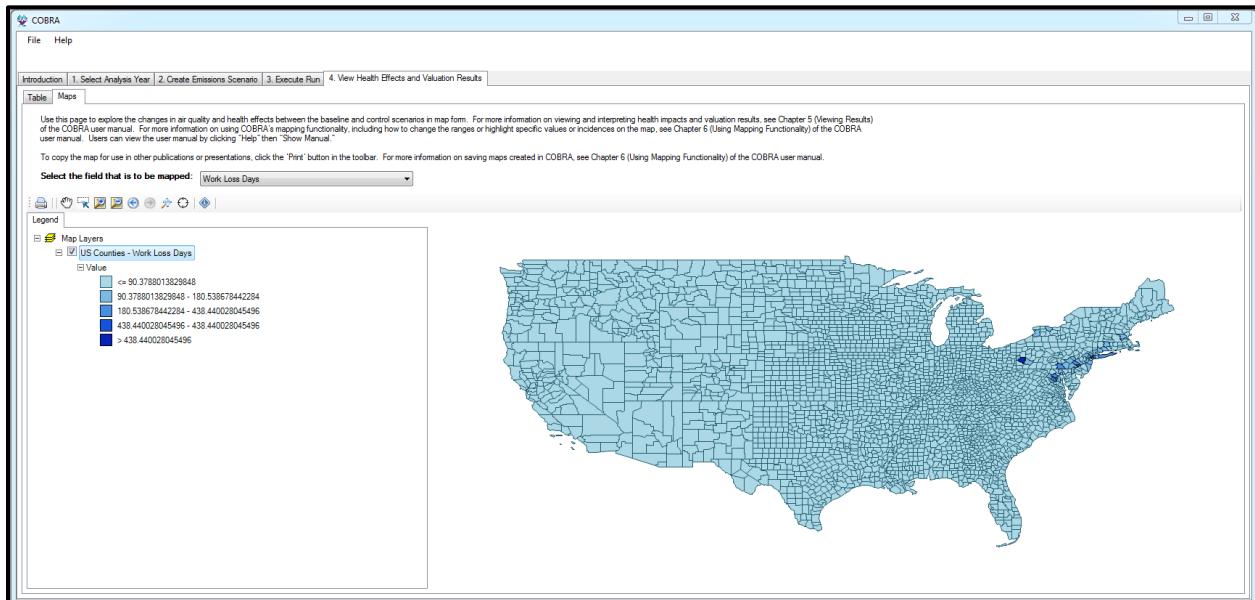
- **Equal Frequency.** This method takes the range of the values, and, using the number of breaks you selected, splits the range into intervals where each interval contains the same number of counties. Below is the map of avoided work loss days where intervals are defined using the equal frequency option. This is COBRA's default setting.

Chapter 6. Using Mapping Functionality



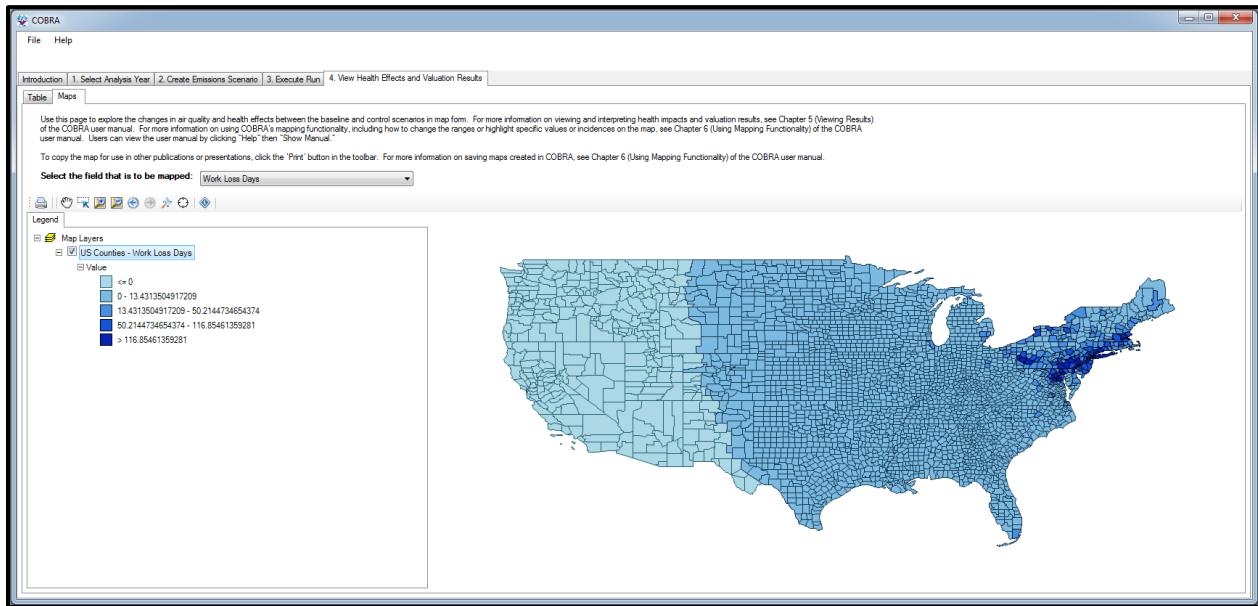
Desktop Version

- **Equal Intervals.** This method takes the range of the values for all counties in the U.S., and, using the number of breaks you selected, splits the range into equal intervals. Below is the map of avoided work loss days where intervals are defined using the equal intervals option.



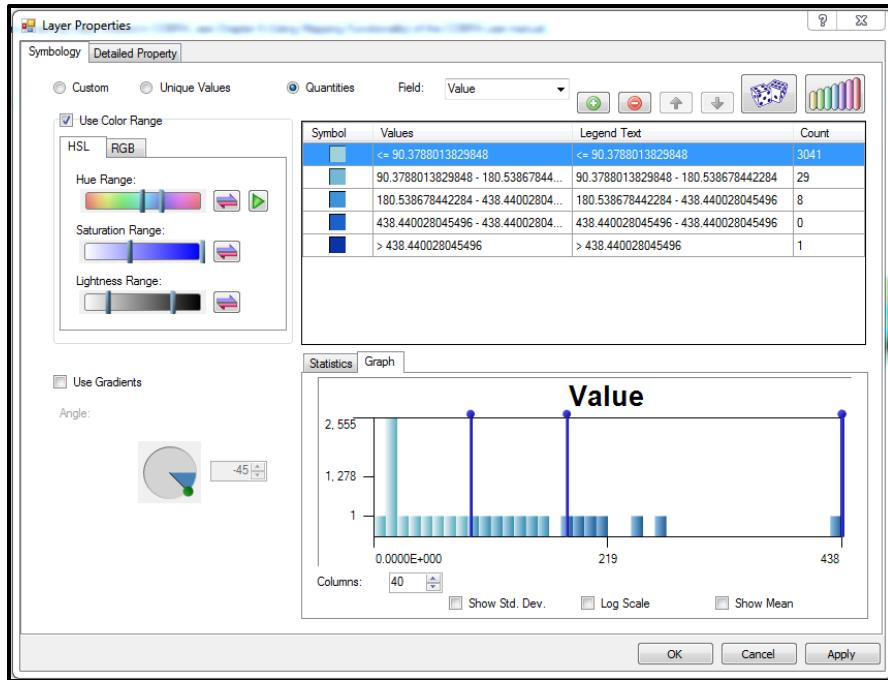
Desktop Version

- **Natural Breaks.** This method divides counties into groups where the values (e.g., for avoided work loss days) are similar within groups and less similar to counties in other groups (based on variance in the values). Below is the map of avoided work loss days where intervals are defined using the natural breaks option.



Desktop Version

Manual. This method allows you to manually enter the range of each interval. To do so, click the **Graph** tab in the bottom right panel. This displays the distribution of values across all counties in the United States in a histogram. The x-axis is the value you are mapping (in this example, work loss days avoided) and the y-axis is the number of counties. The height of each rectangle is the number of counties with avoided work loss days within the range defined by the base of that rectangle. The blue lines are the boundaries defining the intervals for your color scheme. To change these boundaries, click on one of the blue lines and drag it to the boundary you want.

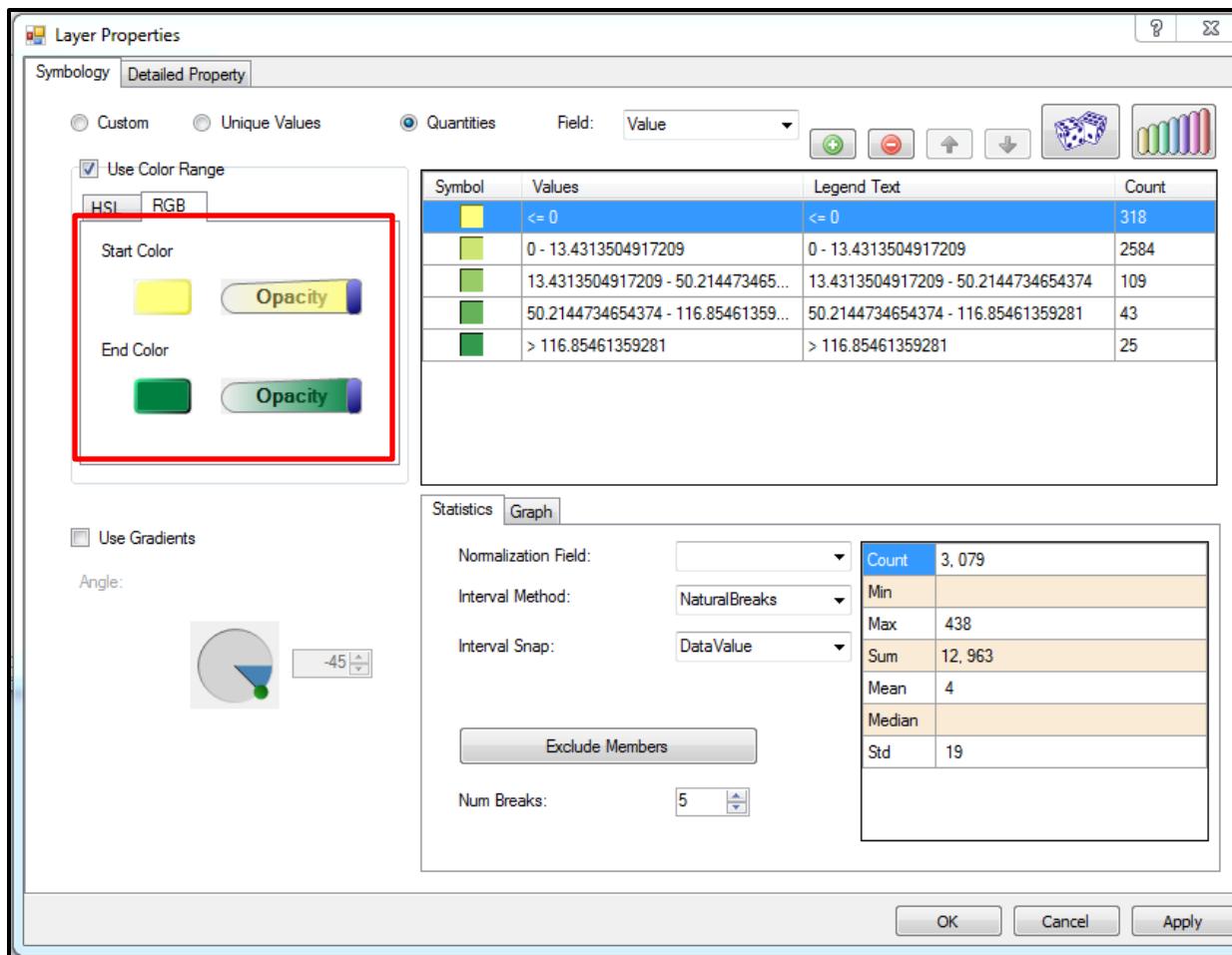


Desktop Version

The method used to define a map's interval boundaries affects the conclusions that are likely to be drawn from the map, so it is important that users exercise care in selecting interval definition schemes. In this example, you can choose to define intervals using the Natural Breaks method.

Changing Color Scheme

Navigate to the top left panel to change the map's color scheme. To create a simple spectrum that fades from one color to another color, click the **RGB** tab. Click the 'Start Color' box and select a color to represent the boxes with the smallest value. Then, click the 'End Color' box and select another color to represent the color with the largest value. In this example, choose yellow to represent counties with the smallest number of avoided work loss days and green to represent counties with the largest number of work loss days avoided.



Desktop Version

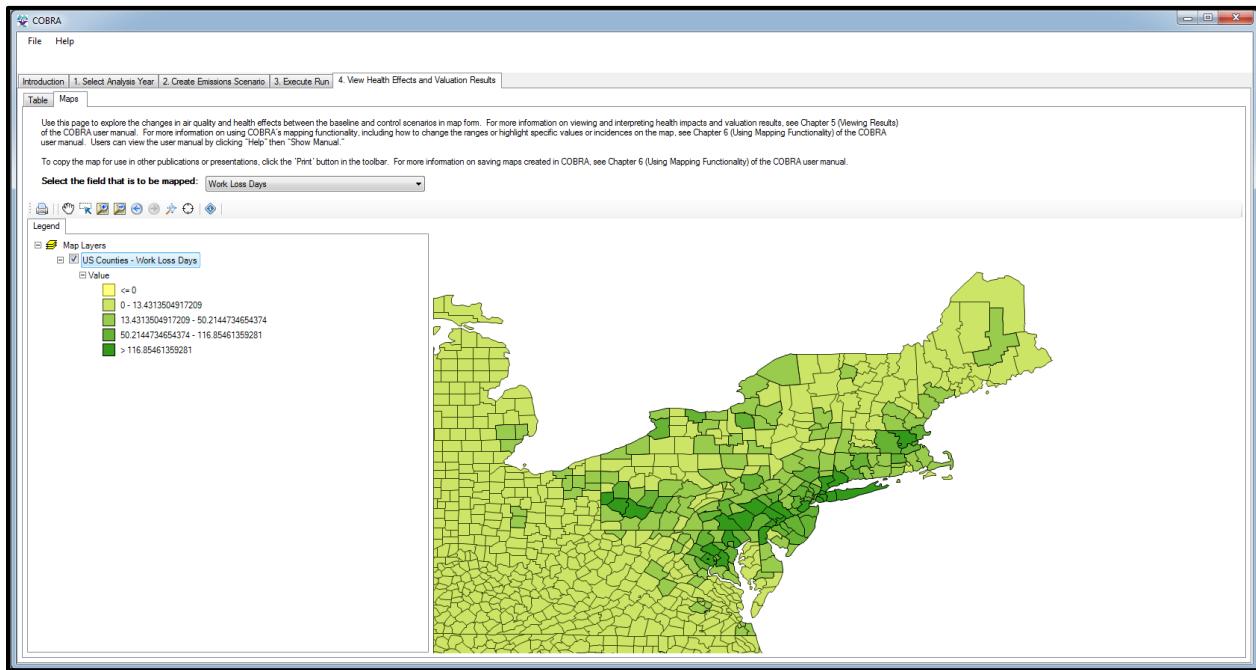
After selecting interval breaks and deciding on a color scheme, you can review your selections in the top right panel. The ‘Symbol’ column shows the color that will represent all counties within each interval. The ‘Values’ column summarizes the definition of each interval. The ‘Count’ column lists the number of counties within each interval. The ‘Legend Text’ column displays the text that will be displayed in the legend. You can modify the legend text by double-clicking on the text.

After creating the desired color scheme, click **Apply**.

Modifying Map Scale

You can zoom in or out on the map by selecting **Zoom In** (zoom in icon) or **Zoom Out** (zoom out icon) in the top left toolbar and then clicking anywhere on the map. You can also zoom in on a specific area by clicking the **Zoom In** tool and then drawing a box with left mouse button depressed. To pan, click the **Pan** button (pan icon) and then click and drag the map to the portion you wish to view. You can toggle between extents (i.e. map scales) by clicking **Zoom to Previous Extent** (previous extent icon) and **Zoom to Next Extent** (next extent icon). To zoom out to the full U.S., click **Zoom to Maximum Extents** (maximum extent icon).

). To center the map at a specific location, click **Zoom to Coordinates** (⊕) and input the relevant latitude and longitude coordinates. Because this scenario focused on emissions reductions in Pennsylvania, in this example you will zoom in to the Northeast United States.

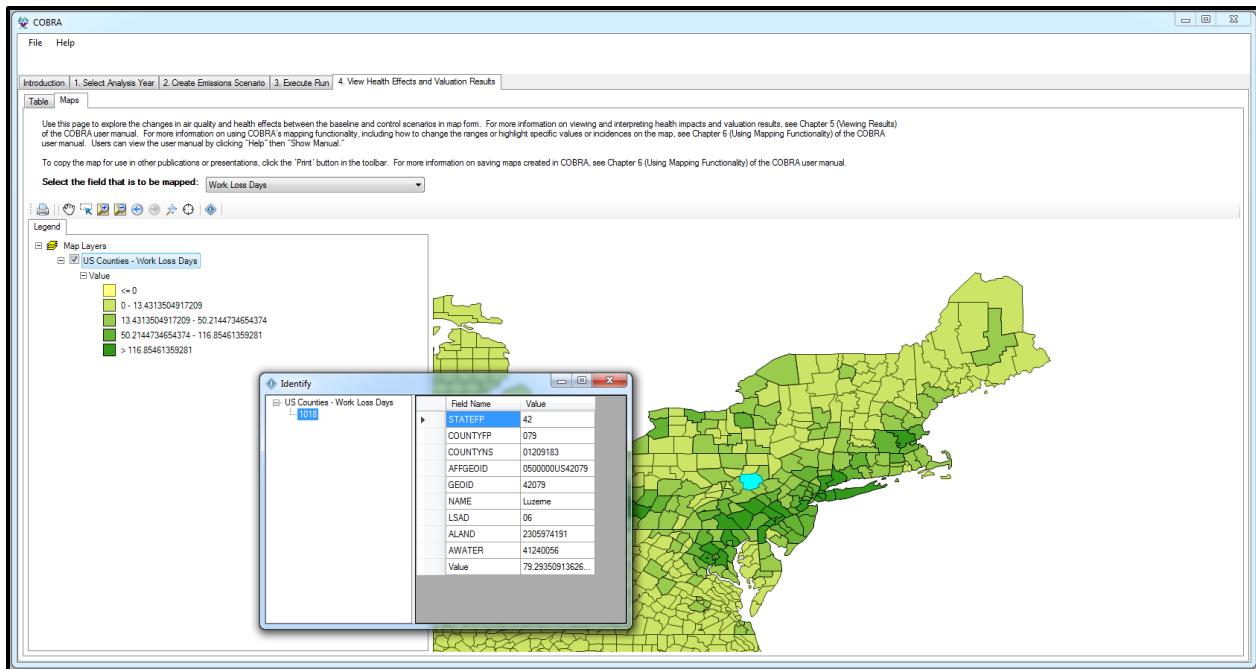


Desktop Version

Exploring Data

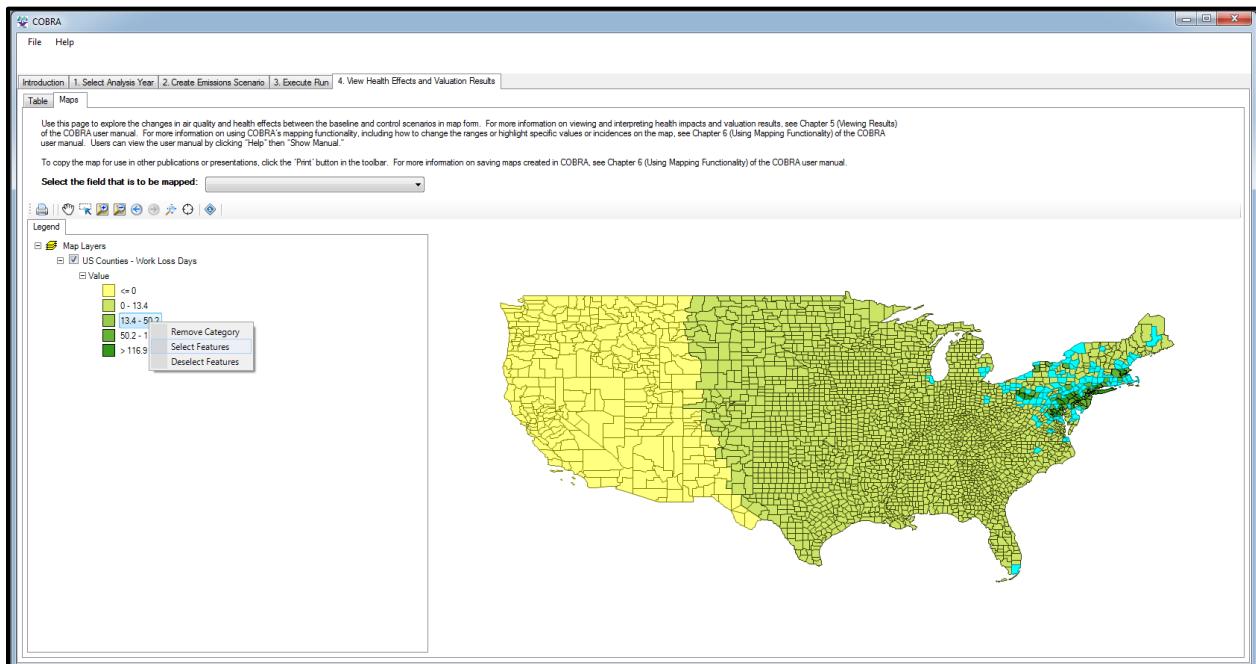
To get map information about a specific county, click the **Identifier** button (⊕) in the top left toolbar and then click the county of interest. The selected county will be highlighted in teal and a box will pop up that contains the name of the county, the estimate for the value you are mapping for this county (e.g., avoided work loss days), and other identifying information for the county. For example, if you select Berks county, Pennsylvania you will see that the emissions reduction scenario will avoid about 134 work loss days in this county.

Chapter 6. Using Mapping Functionality



Desktop Version

To select all counties that have values in a given interval (as described in the “Defining Interval Breaks” section above), right click on the interval in the Legend and then click ‘Select Features.’



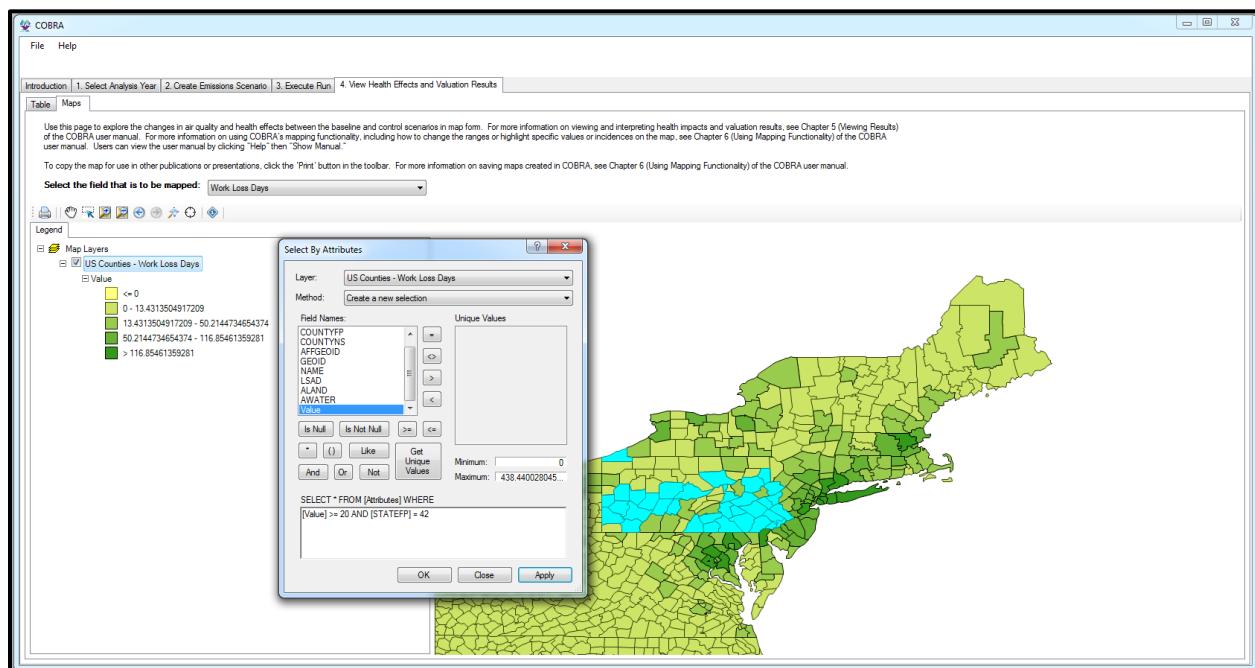
Desktop Version

To find counties that match some criterion, right click the ‘US Counties’ drop-down, then click **Selection...Select by Attributes**. You can fill the box with the criteria you are interested in. For example, if you want to see which counties have more than 20 avoided work loss days and are also located in Pennsylvania (which has a state FIPS code of 42¹³), you can make selections from the ‘Field Names’ list in the upper left of the pop up box. For this example, you would:

- First, double-click Value from the ‘Field Names’ list, click the ‘>=’ button, and then type 20. This sets the criterion for at least 20 avoided work loss days.
- You would then add the criterion for counties located in Pennsylvania as follows: click the ‘And’ button, double-click STATEFP from the ‘Field Names’ list, click the ‘=’ button, and then type 42.

Alternatively, once you are familiar with this functionality, you could simply write this equation in the box at the bottom of the window: “[Value]>=20 AND [STATEFP]=42”.

Once you have described your selection, click **Apply**. COBRA will highlight the counties that fit your criteria in teal.



Desktop Version

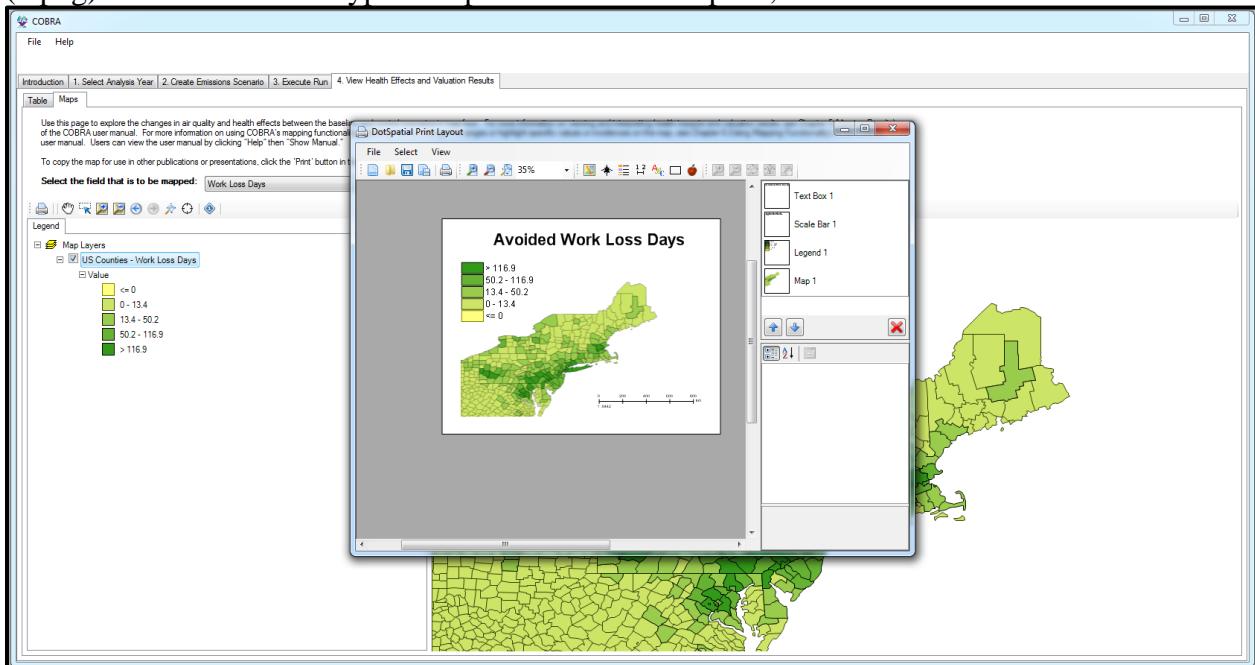
¹³ FIPS codes uniquely identify United States counties and states. Codes can be accessed at: <https://www.census.gov/geo/reference/codes/cou.html>.

Exporting Map

Printing or Exporting Map as Image

To print the map or export a map as an image, click the **Print** button (🖨) in the toolbar. To modify how much space the map takes up on the page, click the map, then click the bottom right corner of the map and drag the rectangle. You can also click the center of the map and move it elsewhere on the page. You can zoom in and out and pan using the tools in the right hand side of the screen. To change the orientation of the page, click **File...Page Setup** then click Landscape. You can also add a compass, legend, scale bar, or text box from the toolbar. To edit the text box, click the text box and then edit the “Text” row in the bottom right panel. For example, you can add a title to the map “Avoided Work Loss Days” in a text box.

To save the map as an image, click **File...Save As** and then click Portable Network Graphics (*.png) from the ‘Save as type:’ drop-down menu. To print, click **File...Print**.

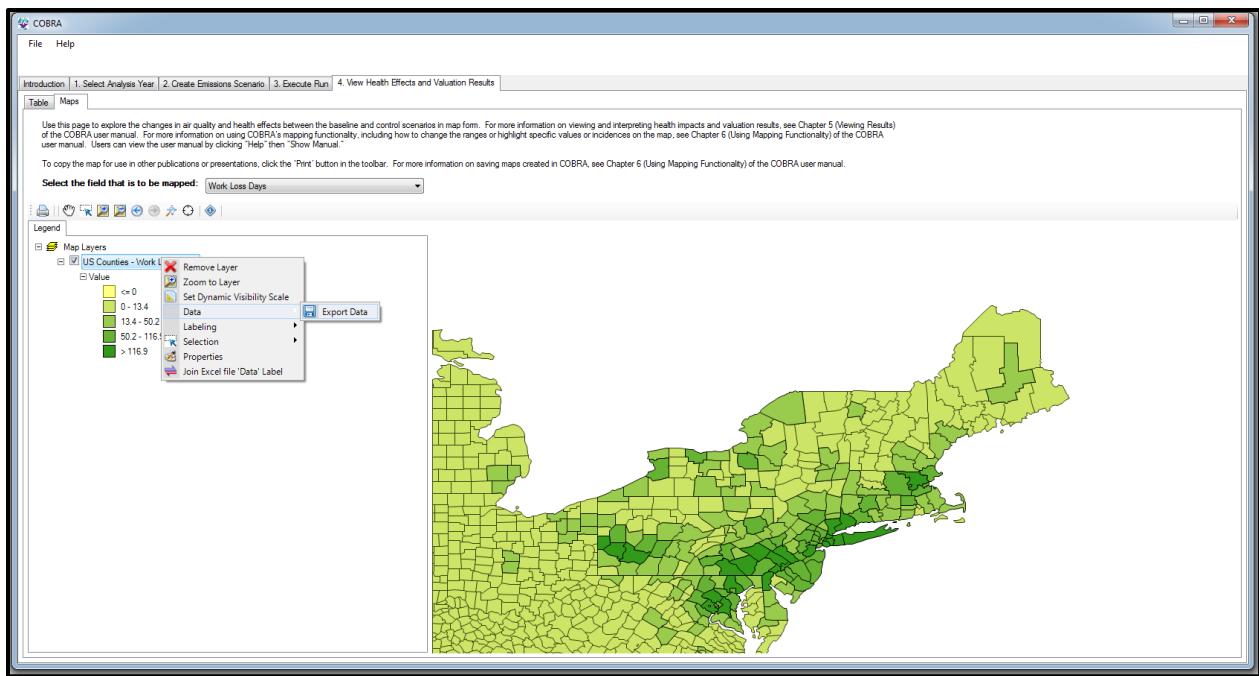


Desktop Version

Exporting Map for Use in Other Mapping Software

To export the map as a shapefile, right click ‘US Counties’ in the Legend tab. Then click **Data...Export Data**. Click the folder icon to navigate to the folder where you would like to save the map, and select ‘DotSpatial.Shapefile – Shapefiles (*.shp)’ from the ‘Save as type:’ drop-down menu. Click **Save**.

Chapter 6. Using Mapping Functionality



Desktop Version

Glossary

Baseline emissions scenario: The emissions estimates for a given year in absence of a policy, ambient pollution levels and health impacts for that year. The baseline emissions scenario is compared to the control scenario when running COBRA.

Control scenario: A hypothetical scenario that factors in user-specified emissions changes (to ‘control’ emissions). In COBRA, the control scenario is compared to the baseline scenario.

Delta PM_{2.5}: The difference in ambient concentrations of particulate matter that is less than or equal to 2.5 microns in diameter.

Delta O₃: The difference in concentrations of ground level ozone.

Federal Information Processing Standards (FIPS) geographic codes: codes which uniquely identify United States counties and states. Codes can be accessed at <https://www.census.gov/geo/reference/codes/cou.html>.

Health impact function: An equation that calculates the change in adverse health effects associated with a change in exposure to air population. A typical health impact function has inputs specifying the change in the air pollutant, an effect coefficient (specifying the percent change in an adverse health effect per unit change of a pollutant), the age of the population affected, and the incidence rate of the adverse health effect.

Scenario definition: A table of all edits made to the baseline emissions when defining a control scenario. The table can be viewed within COBRA or can be exported for future reference.

Sensitivity analyses: Comparison of analyses performed with varied assumptions or decisions to determine whether the assumptions/decisions have a major effect on the results of the analysis.

Source-receptor matrix: An air quality model built into COBRA that calculates the change in PM_{2.5} levels for any given change in emissions. Appendix A discusses this model in more detail.

Tier category: Classification used by EPA for emission inventories.

APPENDICES

Appendix A: Dispersion Modeling in COBRA

COBRA estimates particulate matter and ozone levels using a Source-Receptor (S-R) Matrix developed by EPA (Baker et al., 2023). The S-R Matrix consists of fixed transfer coefficients that reflect the relationship between emissions of air pollutants (primary PM_{2.5}, NO_x, SO₂, and VOC) at source counties and concentrations of particulate matter and ozone in receptor counties. This S-R Matrix replaces a previous version that had been used in COBRA up through version 4.1.

The current S-R Matrix used in COBRA was developed using the Comprehensive Air Quality Model with Extensions (CAMx),¹⁴ specifically by using the source apportionment feature, which tracks the contribution of air pollutant emissions at sources to concentrations at receptors.

Baker et al. conducted two validations of the S-R Matrix, comparing the resulting particulate matter and ozone concentrations from the matrix against those developed by EPA using more sophisticated photochemical models, including an analysis of emission reductions in the highway vehicles sector and the electric power section using CAMx and the Community Multiscale Air Quality model (CMAQ). In both cases, the S-R Matrix compared well with the photochemical model predictions ($r=0.94$ for the highway vehicles scenario and $r=0.92$ for the electric power sector scenario). Furthermore, in both cases, the current S-R Matrix more closely matched the photochemical model predictions than the previous S-R Matrix.

While the current S-R Matrix performed well in the evaluations, EPA still recommends that COBRA be treated as a screening tool that provides an estimate of the likely impact of a change in emissions on ambient PM_{2.5} and ozone levels. More sophisticated atmospheric dispersion models should be used if detailed estimates of ambient air quality changes are required.

The sections below summarize the details of how the S-R matrix is used in COBRA in order to derive the changes in air quality resulting from changes in emissions, as well as the methods used to develop the emissions baseline.

Details of S-R Matrix Implementation in COBRA

To calculate the ambient annual PM_{2.5} concentrations and the ozone season maximum daily 8-hour average (MDA8) ozone concentrations, COBRA multiplies the emissions of air pollutants in source counties by the transfer coefficients in the S-R Matrix developed by Baker et al. (2023) to model concentrations in receptor counties.

¹⁴ <https://www.camx.com/>

The matrix includes transfer coefficients with relationships between all counties. For example, the matrix includes coefficients to estimate how emissions of primary PM_{2.5} impact ambient PM_{2.5} concentrations in all other counties in the United States.

The matrix includes transfer coefficients for three components of PM_{2.5} and two components of ozone. For PM_{2.5} the matrix has separate coefficients for primary (directly emitted) PM_{2.5}, as well as PM nitrate ion and PM sulfate ion. To calculate PM_{2.5} concentrations, COBRA multiplies county-level PM_{2.5} emissions by the coefficient for PM_{2.5}, NO_x emissions by the coefficient for PM nitrate ion, and SO₂ emissions by the coefficient for PM sulfate ion. COBRA then sums the contributions from each source county and across the three PM_{2.5} components (primary PM_{2.5}, PM nitrate, and PM sulfate) to estimate a total value for PM_{2.5} concentrations in each receptor county. This is done using both the baseline emissions and the emissions under the policy scenario to calculate the differences (delta) in the concentrations.

Note that this approach calculates a subset of the components of total particulate matter concentrations, and it does not include calculations for components such as secondary organic aerosols or ammonium ion. Therefore, the results of this matrix for PM_{2.5} concentrations could be considered conservative.

For ozone, the matrix has separate coefficients for NO_x and VOC. Similar to the PM_{2.5} calculations, the ozone calculations involve multiplying the NO_x and VOC emissions from each source county by their respective transfer coefficients to estimate ozone concentrations in each receptor county. COBRA then sums the contributions from each source county and the NO_x and VOC components to model a total ozone concentration in each county. This is done using both the baseline emissions and the emissions under the policy scenario to calculate the differences (delta) in the concentrations.

As with the PM_{2.5} calculations, there are components of total ambient ozone concentrations that are not included in COBRA, such as transport of ozone from outside the United States.

Therefore, the ozone concentrations reported by COBRA are not necessarily indicative of the total ozone concentrations in each county. However, the delta concentrations between the baseline and policy cases—and the resulting health impacts—are indicative of the change in emissions between the baseline and policy cases.

Emissions Data

We use emissions data from EPA's 2016v1 Air Emissions Modeling Platform (2016v1 platform) to forecast ambient 2016, 2023, and 2028 PM_{2.5} levels in COBRA.¹⁵ The 2016, 2023, and 2028 emissions inventories contain predicted emissions that reflect federal and state measures

¹⁵ Note that 2016 county-level biogenic emissions (from plants and soil) were estimated using the county total annual emissions by sector (available for download at <ftp://ftp.epa.gov/EmisInventory/2011v6/v2platform/reports/>) for EPA's 2011 Version 6.2 Air Emissions Modeling Platform.

(promulgated or under reconsideration) as of May 2018.¹⁶ The 2016, 2023, and 2028 base cases include:

- electrical generating unit emissions (reflecting the implementation of the Cross State Air Pollution Rule Update),
- the Mercury and Air Toxics Rule,
- the Standards of Performance for Greenhouse Gas Emissions from New, Modified, and Reconstructed Stationary Sources,
- mobile emissions (reflecting changes in activity data and the impacts the Tier 3 Motor Vehicle Emission and Fuel Standards Rule and local inspection and maintenance programs), and
- base year-specific fire data for 2016.

In addition, we used the 2016 base case emissions inventory to help develop calibration factors (discussed in more detail in a later section). Exhibit A-2a, Exhibit A-2b, and Exhibit A-2c summarize the 2016, 2023, and 2028 emissions data for the continental U.S. that we used.

¹⁶ More details about the development of the 2016, 2023, and 2028 baseline emissions case are available in the supporting information for the 2016v1 Emissions Modeling Platform, available here: <https://www.epa.gov/air-emissions-modeling/2016v1-platform>

Exhibit A-2a. 2016 Emissions Inventory Summary, by Tier 1 (tons/year)

| Tier 1 | NO_x | SO₂ | PM_{2.5} | VOC |
|------------------------------------|-----------------------|-----------------------|-------------------------|-------------------|
| Fuel Combustion Electric Utilities | 1,213,176 | 1,509,524 | 123,023 | 33,346 |
| Fuel Combustion Industrial | 962,831 | 367,909 | 179,510 | 105,988 |
| Fuel Combustion Other | 521,545 | 85,937 | 346,201 | 373,681 |
| Chemical & Allied Product Manuf. | 41,867 | 111,625 | 14,476 | 79,541 |
| Metals Processing | 60,542 | 85,099 | 34,984 | 22,838 |
| Petroleum & Related Industries | 593,419 | 80,056 | 25,818 | 2,873,249 |
| Other Industrial Processes | 319,965 | 138,608 | 260,264 | 336,096 |
| Solvent Utilization | 1,248 | 65 | 3,745 | 3,035,948 |
| Storage & Transport | 2,960 | 818 | 15,426 | 661,600 |
| Waste Disposal & Recycling | 109,378 | 30,976 | 225,040 | 229,311 |
| Highway Vehicles | 3,630,548 | 27,559 | 117,758 | 1,852,260 |
| Off-Highway Vehicles | 2,173,402 | 33,326 | 136,316 | 1,258,667 |
| Natural Sources | 965,761 | 0 | 0 | 42,133,700 |
| Miscellaneous | 239,994 | 115,256 | 3,723,122 | 3,324,005 |
| Total | 10,836,636 | 2,586,758 | 5,205,683 | 56,320,230 |

Exhibit A-2b. 2023 Emissions Inventory Summary, by Tier 1 (tons/year)

| Tier 1 | NO_x | SO₂ | PM_{2.5} | VOC |
|------------------------------------|-----------------------|-----------------------|-------------------------|-------------------|
| Fuel Combustion Electric Utilities | 784,566 | 790,808 | 122,222 | 37,822 |
| Fuel Combustion Industrial | 929,186 | 280,440 | 178,905 | 115,012 |
| Fuel Combustion Other | 516,645 | 48,594 | 332,817 | 362,513 |
| Chemical & Allied Product Manuf. | 40,321 | 103,924 | 14,802 | 82,224 |
| Metals Processing | 54,640 | 67,825 | 35,047 | 22,970 |
| Petroleum & Related Industries | 607,132 | 92,748 | 28,081 | 3,291,678 |
| Other Industrial Processes | 312,538 | 129,497 | 268,509 | 345,611 |
| Solvent Utilization | 1,249 | 65 | 3,754 | 3,139,345 |
| Storage & Transport | 2,648 | 847 | 15,411 | 619,369 |
| Waste Disposal & Recycling | 106,723 | 32,391 | 225,221 | 229,983 |
| Highway Vehicles | 1,750,937 | 12,484 | 72,468 | 1,098,966 |
| Off-Highway Vehicles | 1,694,745 | 38,165 | 96,121 | 987,588 |
| Natural Sources | 965,761 | 0 | 0 | 42,133,700 |
| Miscellaneous | 240,053 | 115,265 | 3,750,534 | 3,334,678 |
| Total | 8,007,144 | 1,713,053 | 5,143,892 | 55,801,459 |

Exhibit A-2c. 2028 Emissions Inventory Summary, by Tier 1 (tons/year)

| Tier 1 | NO_x | SO₂ | PM_{2.5} | VOC |
|------------------------------------|-----------------------|-----------------------|-------------------------|-------------------|
| Fuel Combustion Electric Utilities | 766,652 | 808,476 | 121,562 | 37,971 |
| Fuel Combustion Industrial | 929,420 | 285,579 | 188,424 | 117,610 |
| Fuel Combustion Other | 508,511 | 47,450 | 328,496 | 358,818 |
| Chemical & Allied Product Manuf. | 45,755 | 103,938 | 15,125 | 82,776 |
| Metals Processing | 54,690 | 68,071 | 35,099 | 23,018 |
| Petroleum & Related Industries | 582,205 | 95,879 | 28,339 | 3,420,707 |
| Other Industrial Processes | 313,274 | 129,739 | 273,239 | 347,825 |
| Solvent Utilization | 1,252 | 65 | 3,764 | 3,229,409 |
| Storage & Transport | 2,651 | 849 | 15,426 | 570,872 |
| Waste Disposal & Recycling | 106,354 | 32,379 | 225,214 | 230,322 |
| Highway Vehicles | 1,246,019 | 11,703 | 58,925 | 836,112 |
| Off-Highway Vehicles | 1,524,774 | 42,668 | 81,990 | 938,552 |
| Natural Sources | 965,761 | 0 | 0 | 42,133,700 |
| Miscellaneous | 240,101 | 115,272 | 3,763,155 | 3,336,351 |
| Total | 7,287,419 | 1,742,068 | 5,138,758 | 55,664,043 |

When modeling emission sources, we categorized them into elevated point sources and area/mobile sources. For each, we calculate an “effective stack” height, which takes into account the actual stack height, gas temperature and velocity, stack diameter, and other factors. The effective stack height is important as it is one of the greatest determinants¹⁷ of how far emissions will disperse – generally the taller the effective stack the further the emissions might travel from the source. In calculating effective stack height, we assume an average wind speed of 5 meters per second using the plume rise algorithm from ISCST3 (U.S. EPA, 1995).

We group stationary point source emissions for each county into three groups based on effective stack height: (1) less than 250 meters, (2) 250 to 500 meters, and (3) greater than 500 meters.¹⁸ We assume that emissions from the two groups less than 500 meters originate from the center of the county in which they are located. For point sources with effective stack heights greater than

¹⁷ The other determinants include wind speed and direction as well as atmospheric chemistry.

¹⁸ In a very small number of cases (0.32% of records in the emissions baseline), there are point source emissions in multiple stack height groups for the same Tier 3 emission category in the same county. When emissions changes are entered in the COBRA model for these cases, the changes are apportioned to stack height groups in proportion to the baseline scenario emissions.

500 meters, we use their true latitude and longitude coordinates when modeling the dispersion of emissions.¹⁹

Emissions from both ground-level mobile and area sources in the contiguous U.S. are combined at the county-level and modeled as emissions from stacks with an effective stack height of zero located at the source county centroid. Exhibit A-3 summarizes these emission categories.

Exhibit A-3. Emissions Categories for the S-R Matrix

| Emissions Category | Effective Stack Height | Modeled Location |
|--------------------------------|------------------------|------------------|
| U.S. area and mobile emissions | 0 m | County center |
| U.S. elevated point emissions | 0-250 m | County center |
| U.S. elevated point emissions | 250-500 m | County center |
| U.S. elevated point emissions | >500 m | True location |

¹⁹ For some counties, the emissions inventory contained more than one emission source with stack height greater than 500m. These emission sources normally have different locations and stack heights. To create a composite county-level emissions source with stack height greater than 500m, we used the latitude and longitude of the source with the tallest stack, whereas the composite stack height was an emissions-weighted average.

Appendix B: Derivation of Health Impact Functions

This Appendix reviews the derivation of health impact functions. The derivations described below were computed for EPA's BenMAP tool, and the resulting functions were also then used in COBRA. The steps discussed below were performed to take models from epidemiological studies and convert them into health impact functions for use in BenMAP to quantify the change in adverse health effects due to a change in air pollution exposure. The most common functional forms the log-linear and logistic, with a linear model used in some cases. All three derivations are discussed below to provide background.

Note that the log-linear and logistic generally produce comparable results, so the fact that some health impacts are estimated with a logistic function and others with a log-linear function is not a cause for concern. Indeed, in some circumstances, such as for small changes in air pollution, the logistic and log-linear produce essentially the same result.

The Linear Model

A linear model between the adverse health effect, y , and the pollutant concentration, x , is of the form

$$y = \alpha + \beta \cdot x$$

A linear model includes the factors that are believed to affect the incidence of the health effect, of which the pollutant would be one. So, the variable “ α ” in the linear function consists of all the other independent variables in the regression, typically evaluated at their mean values, times their respective coefficients.

The function describing the relationship between a change in x and the corresponding change in incidence (rate) of the health effect from the baseline level (y_b) to the post-control level (y_c) is then:

$$\Delta y = y_b - y_c = \beta \cdot (x_b - x_c) = \beta \cdot \Delta x$$

If y denotes an incidence rate, then Δy denotes the change in the incidence rate. If y denotes an incidence count, then the β is first divided the baseline study population to generate an incidence rate. Δx is the difference between the baseline level of the pollutant concentration and the control level of the pollutant concentration: $x_b - x_c$. (Note that typically a control strategy is intended to decrease the pollutant levels, so Δx is expected to be positive.) The expected number of cases avoided would then be calculated by multiplying Δy by the relevant population:

$$\text{Cases Avoided} = \beta \cdot \Delta x \cdot \text{population}$$

The coefficient, β , and standard error of β (σ_β) are reported directly in studies presenting results from linear regression models.

The Log-linear Model

The most commonly used functional form for criteria air pollutant concentration-response functions is the log-linear model. It defines the relationship between x and y to be of the form:

$$y = B \cdot \exp(\beta \cdot x)$$

or, equivalently,

$$\ln(y) = \alpha + \beta \cdot x,$$

where the parameter B is the incidence (rate) corresponding to the zero pollutant concentration ($x = 0$); the coefficient β is the effect of pollutant x on the natural logarithm of the incidence (rate) $y - \ln(y)$; and $\alpha = \ln(B)$.²⁰

Estimating Avoided Cases

The relationship between Δx and Δy is:

$$\Delta y = y_b - y_c = B(\exp(\beta x_b) - \exp(\beta x_c))$$

This may be rewritten as:

$$\Delta y = y_b \cdot \left(1 - \frac{1}{\exp(\beta \cdot \Delta x)}\right)$$

where y_b is the baseline incidence (rate) of the health effect – i.e., the incidence (rate) before the change in x . If y is incidence rate rather than incidence count, then the change in incidence rate, Δy , must be multiplied by the relevant population to get the expected number of cases avoided. For example, if y denotes the annual number of cases of the adverse health effect per 100,000 population then the expected number of cases avoided is calculated as:

$$\text{Cases Avoided} = \frac{y_b}{100,000} \cdot \text{population} \cdot \left(1 - \frac{1}{\exp(\beta \cdot \Delta x)}\right)$$

Estimating the Coefficient (β)

Epidemiological studies that estimate log-linear concentration-response functions often report a relative risk for a specific Δx , rather than the coefficient, β , in the function itself. The relative risk (RR) is simply the ratio of two risks corresponding to two levels of pollutant concentration –

²⁰ Other covariates besides pollution clearly affect mortality. The parameter B might be thought of as containing these other covariates, for example, evaluated at their means. That is, $B = B_0 \exp\{\beta_1 x_1 + \dots + \beta_n x_n\}$, where B_0 is the incidence of y when all covariates in the model are zero, and x_1, \dots, x_n are the other covariates evaluated at their mean values. The parameter B drops out of the model, however, when changes in y are calculated, and is therefore not important.

the “high” risk y_{high} (corresponding to the higher pollutant level, $x = x_{high}$) and the lower risk y_{low} (corresponding to the lower pollutant level, $x = x_{low}$):

$$RR = \frac{y_{high}}{y_{low}}$$

Using the original log-linear function above, it can be shown that the relative risk associated with a specific change in pollutant concentration of $\Delta x^* = x_{high} - x_{low}$ can be written as

$$RR|_{\Delta x^*} = \frac{y_{high}}{y_{low}} = \exp(\beta \cdot \Delta x^*)$$

Taking the natural log of both sides, the coefficient in the function underlying the relative risk can be derived as:

$$\beta = \frac{\ln(RR)}{\Delta x^*}$$

Once the pollutant coefficient, β , has been calculated, the change in incidence (rate), Δy , corresponding to any change in pollutant concentration, Δx , can be calculated, using the relationship between Δx and Δy given above, the baseline incidence (rate) and assessment population.

There are instances when epidemiological studies report percent increase in the relative risk, rather than relative risk itself. Given a reported x percent increase in the relative risk, the relative risk was back-calculated as $RR = 1 + x/100$. Then β is calculated as described above. Note that some epidemiological studies (see, e.g., Moolgavkar [2003]) further define x to be $\log(RR) \times 100$. In these cases, our approach to computing the RR is an approximation, although the error introduced is small. This approximation is consistent with approach implemented in EPA’s BenMAP-CE.

Estimating the Standard Error of β (σ_β)

The standard error of β (σ_β) is not often directly reported in studies presenting results from log-linear regression models. Results are most commonly presented as a relative risk and 95% confidence interval. The 95% confidence interval is defined as follows:

$$CI_{95\%} = \exp(\beta \cdot \Delta x \pm 1.96 \cdot \sigma_\beta \Delta x)$$

Based on this equation, the standard error of β (σ_β) can be estimated from the relative risk (RR), upper limit of the 95% confidence interval (UL), and lower limit of the 95% confidence interval (LL), as follows:

$$\sigma_{\beta,high} = \frac{\beta_{high} - \beta}{1.96} = \frac{(\ln(UL)/\Delta x - \ln(RR)/\Delta x)}{1.96} \quad \text{and} \quad \sigma_{\beta,low} = \frac{\beta - \beta_{low}}{1.96} = \frac{(\ln(RR)/\Delta x - \ln(LL)/\Delta x)}{1.96}$$

$$\sigma_\beta \cong \frac{\sigma_{\beta,high} + \sigma_{\beta,low}}{2} \quad \text{or} \quad \sigma_\beta \cong \frac{\beta_{high} - \beta_{low}}{3.92}$$

Some studies report only a central effect estimate and t -statistic. The t -statistic describes the strength of the observed pollutant-health effect association. It is defined as the ratio of the coefficient, β , to the standard error of β (σ_β). The standard error of β (σ_β) can, therefore, be estimated from the t -statistic as follows:

$$\sigma_\beta = \frac{\beta}{t}$$

The Logistic Model

In some epidemiological studies, a logistic model is used to estimate the probability of an occurrence of an adverse health effect. Given a pollutant level, x , and a vector of other explanatory variables, Z , the logistic model assumes the probability of an occurrence is:

$$y = P(occurrence | \beta \cdot x, \alpha \cdot Z) = \frac{\exp(\beta \cdot x) \exp(\alpha \cdot Z)}{1 + \exp(\beta \cdot x) \exp(\alpha \cdot Z)},$$

where β is the coefficient of the pollutant concentration, x , and α is a vector of coefficients of the variables in the vector Z .²

Estimating Avoided Cases

The change in the probability of an occurrence (Δy) corresponding to a change in the level of the pollutant from x_b to x_c ($= \Delta x$), all other covariates held constant, may be derived from the original C-R function above:

$$\Delta y = y_b - y_c = y_b \left(1 - \frac{1}{(1 - y_b) \cdot \exp(\beta \cdot \Delta x) + y_b} \right)$$

² Greene (1997, Chapter 19) presents models with discrete dependent variables; in particular, page 874 presents the logit model. See also Judge et al. (1985, p. 763).

Once again, to calculate the expected number of avoided cases of the adverse effect, it is necessary to multiply by the population:³

$$Cases\ Avoided = y_b \left(1 - \frac{1}{(1-y_b) \cdot \exp(\beta \cdot \Delta x) + y_b} \right) \cdot population$$

Estimating the Coefficient (β)

The estimated pollutant coefficient, β , in the original function is typically not reported in studies that use the logistic model. Instead, the odds ratio (OR) corresponding to a specific change in x is reported.

The odds of an occurrence is defined as:

$$Odds = \frac{y}{1-y}$$

It can be shown that:

$$Odds = \frac{y}{1-y} = \exp(\beta \cdot x) \exp(\alpha \cdot Z)$$

The odds ratio is just the ratio of the odds when the pollutant is at a specified higher level, x_{high} , to the odds when the pollutant is at a specified lower level, x_{low} :

$$OR = \frac{\exp(\beta \cdot x_{high}) \exp(\alpha \cdot Z)}{\exp(\beta \cdot x_{low}) \exp(\alpha \cdot Z)} = \frac{\exp(\beta \cdot x_{high})}{\exp(\beta \cdot x_{low})} = \exp(\beta \cdot \Delta x)$$

Often the odds ratio corresponding to a specified change in x , call it Δx^* , is the only measure of the effect of x reported from a study using a logistic model (just as the relative risk corresponding to a specified change in x is often the only measure of the effect of x reported from a study using a log-linear model). However, it is easy to calculate the underlying pollutant coefficient, β , from the odds ratio as follows:

$$OR|_{\Delta x^*} = \exp(\beta \cdot \Delta x^*) \rightarrow \ln(OR) = \beta \cdot \Delta x^* \rightarrow \beta = \frac{\ln(OR)}{\Delta x^*}$$

Given the pollutant coefficient, β , and the baseline probability of occurrence, y_b , the change in the probability, Δy , associated with any change in pollutant concentration, Δx , can be derived using the equation for Δy above. The expected number of avoided cases of the adverse effect is then obtained by multiplying by the population.

³ Note that because Δy here is a change in probability of occurrence (rather than a change in the rate per 100,000 population), it is necessary to multiply by the population rather than by the population/100,000.

Estimating the Standard Error of β (σ_β)

The standard error of β (σ_β) is not often directly reported in studies presenting results from logistic regression models. Results are most commonly presented as an odds ratio and 95% confidence interval. The 95% confidence interval is defined as follows:

$$CI_{95\%} = \exp(\beta \cdot \Delta x \pm 1.96 \cdot \sigma_\beta \Delta x)$$

Based on this equation, the standard error of β (σ_β) can be estimated from the odds ratio (OR), upper limit of the 95% confidence interval (UL), and lower limit of the 95% confidence interval (LL), as follows:

$$\sigma_{\beta,high} = \frac{\beta_{high} - \beta}{1.96} = \frac{(\ln(UL)/\Delta x - \ln(OR)/\Delta x)}{1.96} \quad \text{and} \quad \sigma_{\beta,low} = \frac{\beta - \beta_{low}}{1.96} = \frac{(\ln(OR)/\Delta x - \ln(LL)/\Delta x)}{1.96}$$

$$\sigma_\beta \cong \frac{\sigma_{\beta,high} + \sigma_{\beta,low}}{2} \quad \text{or} \quad \sigma_\beta \cong \frac{\beta_{high} - \beta_{low}}{3.92}$$

Some studies report only a central effect estimate and t -statistic. The t -statistic describes the strength of the observed pollutant-health effect association. It is defined as the ratio of the coefficient, β , to the standard error of β (σ_β). The standard error of β (σ_β) can, therefore, be estimated from the t -statistic as follows:

$$\sigma_\beta = \frac{\beta}{t}$$

Appendix C: Health Impact Functions

A reduction in ambient PM_{2.5} and O₃ levels is associated with reductions in a number of adverse health effects, or “endpoints.” This Appendix discusses the calculation of avoided adverse health effects, which was computed for use in EPA’s BenMAP tool and was subsequently taken for use in COBRA. The health impact functions in the COBRA model rely on an up-to-date assessment of the published scientific literature to ascertain the relationship between particulate matter and ozone and adverse human health effects. Studies were evaluated using a variety of selection criteria, including: study location and design, the characteristics of the study population, and whether the study was peer-reviewed (Exhibit C-1).

Exhibit C-1. Summary of Considerations Used in Selecting Studies

| Consideration | Comments |
|--------------------------------------|---|
| Peer reviewed research | Peer reviewed research is preferred to research that has not undergone the peer review process. |
| Study type | Among studies that consider chronic exposure (e.g., over a year or longer) prospective cohort studies are preferred over cross-sectional studies because they control for important individual-level confounding variables that cannot be controlled for in cross-sectional studies. |
| Study period | Studies examining a relatively longer period of time (and therefore having more data) are preferred, because they have greater statistical power to detect effects. More recent studies are also preferred because of possible changes in pollution mixes, medical care, and life style over time. |
| Study size | Studies examining a relatively large sample are preferred because they generally have more statistical power to detect small magnitude effects. A large sample can be obtained in several ways, either through a large population, or through repeated observations on a smaller population, e.g. through a symptom diary recorded for a panel of asthmatic children. |
| Study location | U.S. studies are more desirable than non-U.S. studies because of potential differences in pollution characteristics, exposure patterns, medical care system, population behavior and life style. |
| Measure of PM | For this analysis, C-R functions based on PM _{2.5} are preferred to those based on PM ₁₀ (particulate matter less than 10 microns in aerodynamic diameter) because reductions in emissions from diesel engines are expected to reduce fine particles and not have much impact on coarse particles. |
| Economically valuable health effects | Some health effects, such as changes in forced expiratory volume and other technical measurements of lung function, are difficult to value in monetary terms. These health effects are therefore not quantified in this analysis. |
| Non-overlapping endpoints | Although the benefits associated with each individual health endpoint may be analyzed separately, care must be exercised in selecting health endpoints to include in the overall benefits analysis because of the possibility of double counting of benefits. Including emergency room visits in a benefits analysis that already considers hospital admissions, for example, will result in double counting of some benefits if the category "hospital admissions" includes emergency room visits. |

Model Selection

In many epidemiological studies of air pollution and health, researchers estimate and present numerous single pollutant and multi-pollutant models for the same pollutant and health endpoint.

These models may differ from each other in a number of characteristics, including: the functional form of the model, the covariates included in the model, the pollutant exposure metric, the lag structure, and the study population.

For the purposes of estimating health benefits associated with pollutant changes, it is neither realistic nor advantageous to include every model presented in each study. However, it is important that a relatively objective process be used to select from among models. Described below are the criteria that were used as guidance in the selection of a particular model from among several models presented in a study. It is not possible in all cases to select a model using a completely objective and mechanical process. In many cases, professional judgment and an understanding of the study context are necessary as well to select the most appropriate models. Exhibit C-2 summarizes the selection criteria that was used.

Exhibit C-2. Description of Selection Criteria

| Selection Criteria | Description |
|------------------------------------|---|
| Goodness-of-fit statistics | If an appropriate measure of goodness of fit (i.e., how well the model fit the data) is reported for each of several models in a study, then this measure may be used as the basis on which to select a model. |
| Best captures distributed lag | Select the model that appears to best capture a distributed lag effect, as described below. If multiple single-lag models and/or moving average models are specified, select the model with the largest effect estimate, all else equal. |
| Best set of control variables | Select the model which includes temporal variables (i.e. season, weather patterns, day of the week) and other known non-pollutant confounders, all else equal. Select the model which uses the most sophisticated methods of capturing the relationship between these variables and the dependent variable (e.g., affords the most flexibility in fitting possible nonlinear trends). |
| Useful for health effects modeling | The model must be in a form that is useful for health effects modeling (e.g., the pollutant variable should be a continuous variable rather than a categorical variable). |
| Sample size | Select the model estimated with the larger sample size, all else equal. |

Distributed Lag Effect

The question of lags and the problems of correctly specifying the lag structure in a model has been discussed extensively (U.S. EPA, 2002, Section 8.4.4). In many time-series studies, after the basic model is fit (before considering the pollutant of interest), several different lags are typically fit in separate single-lag models and the most significant lag is chosen. The 2002 draft PM_{2.5} CD notes that “while this practice may bias the chance of finding a significant association, without a firm biological reason to establish a fixed pre-determined lag, it appears reasonable” (U.S. EPA, 2002, p. 8-237).

There is recent evidence (Schwartz, 2000) that the relationship between PM_{2.5} and health effects may best be described by a distributed lag (i.e., the incidence of the health effect on day n is influenced by PM_{2.5} concentrations on day n, day n-1, day n-2 and so on). If this is the case, a model that includes only a single lag (e.g., a 0-day lag or a 1-day lag) is likely to underestimate the

total impact of PM_{2.5}. The 2002 draft PM_{2.5} CD makes this point, noting that “if one chooses the most significant single lag day only, and if more than one lag day shows positive (significant or otherwise) associations with mortality, then reporting a RR [relative risk] for only one lag would also underestimate the pollution effects” (U.S. EPA, 2002, p. 8-241). The same may hold true for other pollutants that have been associated with various health effects.

Several studies report similar models with different lag structures. For example, Moolgavkar (2000a) studied the relationship between air pollution and respiratory hospital admissions in three U.S. metropolitan areas. The author reports models with PM_{2.5} lagged from zero to five days. Since the lagging of PM_{2.5} was the only difference in the models and the relationship is probably best described using a distributed lag model, any of single-lag effect estimates are likely to underestimate the full effect. Therefore, the model with the largest effect estimate was selected.

Pooling

There is often more than one study that has estimated a health impact function for a given pollutant-health endpoint combination. Each study provides an estimate of the pollutant coefficient, β , along with a measure of the uncertainty of the estimate. Because uncertainty decreases as sample size increases, combining data sets is expected to yield more reliable estimates of β , and therefore more reliable estimates of the incidence change predicted using β . Combining data from several comparable studies in order to analyze them together is often referred to as meta-analysis.

For a number of reasons, including data confidentiality, it is often impractical or impossible to combine the original data sets. Combining the results of studies in order to produce better estimates of β provides a second-best but still valuable way to synthesize information. This is referred to as pooling. Pooling β 's requires that all of the studies contributing estimates of β use the same functional form for the health impact function. That is, the β 's must be measuring the same thing.

To be consistent with the recent EPA benefits analyses, COBRA uses a random-/ fixed- effects pooling procedure (see U.S. EPA, 2009, p. 5-18), which is a method for weighting estimates involving using their variances. Variance takes into account both the consistency of data and the sample size used to obtain the estimate, two key factors that influence the reliability of results. The method is based on DerSimonian and Laird (1986).

Fixed Effect Weights

The fixed effects model assumes that there is a single true concentration-response relationship and therefore a single true value for the parameter β that applies everywhere. Differences among β 's reported by different studies are therefore simply the result of sampling error. That is, each reported β is an estimate of the same underlying parameter. The certainty of an estimate is reflected in its variance (the larger the variance, the less certain the estimate). Fixed effects pooling therefore weights each estimate under consideration in proportion to the inverse of its variance:

$$\beta_{fe} = \frac{\sum_{n=1}^N \beta_n}{\sum_{n=1}^N v_n}$$

Where

N – number of studies;

β_n – estimate provided by study n ;

v_n – variance of the estimate provided by study n ;

β_{fe} – pooled fixed effects estimate.

Random- / Fixed- Effect Weights

An alternative to the fixed effects model is the random effects model, which allows the possibility that the estimates β_n from the different studies may in fact be estimates of different parameters, rather than just different estimates of a single underlying parameter. In studies of the effects of PM_{2.5} on hospitalizations for COPD, for example, if the composition of PM_{2.5} varies among study locations the underlying relationship between the frequency of hospitalizations for COPD and PM_{2.5} may be different from one study location to another. This would violate the assumption of the fixed effects model.

It is possible to test whether it is appropriate to base the pooling on the random effects model (vs. the fixed effects model). A test statistic, Q_w , the weighted sum of squared differences of the separate study estimates from the pooled estimate based on the fixed effects model β_{fe} , is calculated as:

$$Q_w = \sum_{n=1}^N \frac{(\beta_n - \beta_{fe})^2}{v_n}$$

Under the null hypothesis that there is a single underlying parameter, β , of which all the β_n 's are estimates, Q_w has a chi-squared distribution with $N-1$ degrees of freedom. (Recall that N is the number of studies in the meta-analysis.) If Q_w is greater than the critical value corresponding to the desired confidence level, the null hypothesis is rejected. That is, in this case the evidence does not support the fixed effects model, and the random effects model is assumed, allowing the possibility that each study is estimating a different β . A five percent one-tailed test was used.

The random effect model-based pooling must take into account not only the within-study variances (used in a meta-analysis based on the fixed effects model) but the between-study variance as well. The between-study variance, η^2 , is given by:

$$\eta^2 = \frac{Q_w - (N-1)}{\sum_{n=1}^N 1/v_n - \frac{\sum_{n=1}^N 1/v_n^2}{\sum_{n=1}^N 1/v_n}}$$

(i.e., if $Q_w < N-1$), then η^2 is a negative number, and it is not possible to calculate a random effects estimate. In this case, however, the small value of Q_w would presumably have led to accepting the null hypothesis described above, and the meta-analysis would be based on the fixed effects model. The remaining discussion therefore assumes that η^2 is positive.

Given a value for η^2 , the random effects estimate is calculated in almost the same way as the fixed effects estimate. However, the pooled estimate now incorporates both the within-study variance (v_n) and the between-study variance (η^2):

$$\beta_{re} = \frac{\sum_{n=1}^N \frac{\beta_n}{\eta^2 + v_n}}{\sum_{n=1}^N \frac{1}{\eta^2 + v_n}}$$

Where

N – number of studies;

β_n – estimate provided by study n ;

v_n – variance of the estimate provided by study n ;

η^2 – within-study variance;

β_{re} – pooled random effects estimate.

The weighting scheme used in a pooling based on the random effects model is basically the same as that used if a fixed effects model is assumed, but the variances used in the calculations are different. This is because a fixed effects model assumes that the variability among the estimates from different studies is due only to sampling error (i.e., each study is thought of as representing just another sample from the same underlying population), while the random effects model assumes that there is not only sampling error associated with each study, but that there is also between-study variability – each study is estimating a different underlying β . Therefore, the sum of the within-study variance and the between-study variance yields an overall variance estimate.

Thresholds

Health impact functions have been developed with and without explicit thresholds. A threshold means that air pollution levels below the specified threshold have no adverse health effects. In some prior regulatory impact assessments (e.g., U.S. EPA, 2006) assumed a threshold of 10 $\mu\text{g}/\text{m}^3$ for $\text{PM}_{2.5}$. However, EPA's most current understanding of the scientific literature is that there is no threshold in the relationship between $\text{PM}_{2.5}$ and adverse health impacts. In its recent analysis of proposed NO_2 NAAQS, U.S. EPA (2009) used a no-threshold model to calculate $\text{PM}_{2.5}$ co-benefits down to the lowest modeled $\text{PM}_{2.5}$ air quality levels.

Following EPA's updated methodology, it is also assumed there is no threshold for modeling $\text{PM}_{2.5}$ -related health effects. This is supported by the National Research Council (2002) in its review of methods for estimating the public health benefits of air pollution regulations. They concluded that there is no evidence for any departure from linearity in the observed range of

exposure to PM₁₀ or PM_{2.5}, nor is there any indication of a threshold. They cite the weight of evidence available from both short- and long-term exposure models and the similar effects found in cities with low and high ambient concentrations of PM_{2.5}. More recently, Schwartz et al (2008) reached the same conclusion, finding a linear relationship between PM_{2.5} and premature mortality with no evidence of a threshold.

In addition, U.S. EPA completed an “expert elicitation” analysis in which it elicited opinions from 12 experts (in epidemiology, toxicology, and medicine) on the nature of this relationship (see: Industrial Economics Incorporated, 2006). The experts were asked how likely they thought it is that the relationship between PM_{2.5} and mortality is causal, and if it is causal, what is the functional form of the C-R relationship, including whether there is a threshold. Eleven of the twelve experts thought that, although each individual may have a threshold, there is insufficient empirical evidence for a threshold for the population, which is the entity of interest in a C-R function. Only one expert did include the possibility of a population threshold, assigning a probability of 50% to there being a threshold and, if there is a threshold, an 80% chance that it is less than or equal to 5 µg/m³ (which is below the level of PM_{2.5} observed in epidemiological studies), and a 20% chance that it is between 5 and 10 µg/m³.

Summary of Health Impact Functions Used in COBRA

In this Appendix, the health impact functions used to estimate PM_{2.5} and O₃-related adverse health effects are presented. Exhibit C-3 summarizes the epidemiological studies in COBRA used to estimate adverse health impacts of PM_{2.5} and O₃. Each sub-section has an exhibit with a brief description of the health impact function and the underlying parameters. Following each exhibit, a brief summary of each study and any information that is unique to that study is provided.

Exhibit C-3. Epidemiological Studies Used to Estimate Adverse Health Impacts of PM_{2.5} and O₃

| Endpoint | Air Pollutant | Metric | Author (Year) | Age | Beta |
|--|-------------------|-----------|-------------------------------|-------|-------------|
| Mortality, All Cause (high estimate) | PM _{2.5} | Annual | Pope et al. (2019) | 18-99 | 0.011330 |
| Mortality, All Cause (low estimate) | PM _{2.5} | Annual | Wu et al. (2020) | 65-99 | 0.006390 |
| Acute Myocardial Infarction, Nonfatal | PM _{2.5} | Daily | Wei et al. (2019) | 65-99 | 0.024121 |
| Asthma Symptoms, Albuterol Use | PM _{2.5} | Daily | Rabinovitch et al. (2006) | 6-17 | 0.001996 |
| Minor Restricted Activity Days | PM _{2.5} | Daily | Ostro and Rothschild (1989) | 18-64 | 0.007410 |
| Emergency Room Visits, All Cardiac Outcomes | PM _{2.5} | Daily | Ostro et al. (2016) | 0-99 | 0.000611 |
| Emergency Room Visits, Respiratory | PM _{2.5} | Daily | Krall et al. (2016) | 0-99 | 0.000545 |
| Hospitalization, Cardio-, Cerebro- and Peripheral Vascular Disease | PM _{2.5} | Daily | Bell et al. (2015) | 65-99 | 0.000648 |
| Hospitalization, Alzheimer's Disease | PM _{2.5} | Annual | Kioumourtzoglou et al. (2016) | 65-99 | 0.139762 |
| Hospitalization, Parkinson's Disease | PM _{2.5} | Annual | Kioumourtzoglou et al. (2016) | 65-99 | 0.076961 |
| Hospitalization, All Respiratory | PM _{2.5} | Daily | Bell et al. (2015) | 65-99 | 0.000250 |
| Hospitalization, All Respiratory | PM _{2.5} | Daily | Ostro et al. (2009) | 0-18 | 0.002752 |
| Incidence, Stroke | PM _{2.5} | Annual | Kloog et al. (2012) | 65-99 | 0.003430 |
| Incidence, Out of Hospital Cardiac Arrest | PM _{2.5} | Daily | Silverman et al. (2010) | 0-99 | 0.003922 |
| Incidence, Out of Hospital Cardiac Arrest | PM _{2.5} | Daily | Rosenthal et al. (2008) | 0-99 | 0.001980 |
| Incidence, Out of Hospital Cardiac Arrest | PM _{2.5} | Daily | Ensor et al. (2013) | 18-99 | 0.006376 |
| Incidence, Lung Cancer | PM _{2.5} | Annual | Gharibvand et al. (2016) | 30-99 | 0.037844 |
| Incidence, Hay Fever/Rhinitis | PM _{2.5} | Annual | Parker et al. (2009) | 3-17 | 0.025464 |
| Incidence, Asthma | PM _{2.5} | Annual | Tetreault et al. (2016) | 0-17 | 0.043672 |
| Infant Mortality | PM _{2.5} | Annual | Woodruff et al. (2008) | 0 | 0.005603 |
| Work Loss Days | PM _{2.5} | Daily | Ostro (1987) | 18-64 | 0.004600 |
| School Loss Days | O ₃ | Daily | Gilliland et al. (2001) | 5-17 | 0.007824 |
| Asthma Symptoms, Cough | O ₃ | D8HourMax | Lewis et al. (2013) | 5-12 | 0.007083 |
| Asthma Symptoms, Shortness of Breath | O ₃ | D8HourMax | Lewis et al. (2013) | 5-12 | 0.004228 |
| Asthma Symptoms, Chest Tightness | O ₃ | D8HourMax | Lewis et al. (2013) | 5-12 | 0.011395 |
| Asthma Symptoms, Wheeze | O ₃ | D8HourMax | Lewis et al. (2013) | 5-12 | 0.007638 |
| Emergency Room Visits, Asthma | O ₃ | D8HourMax | Mar and Koenig (2009) | 0-17 | 0.010436 |
| Emergency Room Visits, Asthma | O ₃ | D8HourMax | Mar and Koenig (2009) | 18-99 | 0.003922 |
| Mortality, long-term exposure | O ₃ | D8HourMax | Turner et al. (2016) | 30-99 | 0.000618 |
| Mortality, short-term exposure | O ₃ | D8HourMax | Katsouyanni et al. (2009) | 0-99 | 0.000727348 |
| Mortality, short-term exposure | O ₃ | D8HourMax | Zanobetti and Schwartz (2008) | 0-99 | 0.000826574 |

Note that Appendix B mathematically derives some of the standard types of health impact functions that exist in the epidemiological literature, such as, log-linear, logistic and linear, so only the type of functional form is noted here in Appendix C. Appendix D presents a description of the sources for the incidence and prevalence data used in these health impact functions.

Appendix D: Baseline Incidence Rates for Adverse Health Effects

Health impact functions developed from log-linear or logistic models estimate the percent change in an adverse health effect associated with a given pollutant change. In order to estimate the absolute change in incidence using these functions, the baseline incidence rate of the adverse health effect is needed. For certain health effects, such as asthma exacerbation, a prevalence rate is required, which estimates the percentage of the general population with a given ailment like asthma. This Appendix describes the data used to estimate baseline incidence rates and prevalence rates for the health effects considered in this analysis. The steps outlined in this section were completed for EPA's BenMAP tool, and the resulting incidence and prevalence rates were then taken for use in COBRA.

Mortality

This section describes how county mortality rates were developed for the years 2015 through 2050 to use in BenMAP. First, the source of 2012-2014 baseline mortality data and how county-level mortality rates were calculated is described. Then, the use of national-level Census mortality rate projections to develop county-level mortality rate projections for years 2015-2060 is discussed.

Mortality Data for 2012-2014

County-level mortality and population data from 2012-2014 were obtained for 11 causes for the contiguous United States by downloading the data from the Centers for Disease Control (CDC) WONDER database (<http://wonder.cdc.gov>).

Since the detailed mortality data obtained from CDC do not include population, the data was combined with U.S. Census Bureau population estimates exported from BenMAP. Age-, cause-, and county-specific mortality rates were then generated using the following formula:

$$RR_{i,j,k} = \frac{OO_{i,j,k}(2012) + OO_{i,j,k}(2013) + OO_{i,j,k}(2014)}{PP_{i,k}(2012) + PP_{i,k}(2013) + PP_{i,k}(2014)}$$

where $R_{i,j,k}$ is the mortality rate for age group i , cause j , and county k ; D is the death count; and P is the population.

For county-age group cells with fewer than 10 deaths, CDC WONDER suppresses the exact death count. For these observations, a mortality rate cannot be calculated. For each combination

of age group and mortality cause, the following procedure was used to deal with suppressed counts.

For each combination of state, age group and mortality cause, counties with unsuppressed mortality figures were grouped and their reported death counts were summed. These unsuppressed deaths were then subtracted from the state-level age- and cause-specific death count, which includes suppressed deaths. The resulting state-wide death count in suppressed counties were divided by the age-specific populations in those counties.

This calculation resulted in an age- and cause- specific average mortality rate for suppressed counties;

$$RR_{mm,mm,jj} = \frac{DD_{TT,mm,jj} - DD_{ll,mm,jj}}{PP_{mm,mm,jj}}$$

Where $R_{s,i,j}$ is the state average suppressed mortality rate for age group i and cause j ; $DT_{i,j}$ is the total state death count for age group i and cause j ; $Du_{i,j}$ is the aggregated state-level unsuppressed death count for age group i and cause j ; and $P_{s,i,j}$ is the aggregated population for age group i and cause j in suppressed counties.

In some instances, age- and cause-specific death counts were suppressed at both the county and state level. In these cases, national-level age- and cause- specific mortality rates were substituted for the respective missing county mortality rates.

Following CDC WONDER (<http://wonder.cdc.gov>), mortality rates were treated as “unreliable” when the death count was less than 20. For each combination of age group and mortality cause, the following procedure to deal with the problem of “unreliable” rates was used:

- For a given state, the counties where the death count was less than 20 were grouped and those death counts across those counties were summed. If the sum of deaths was greater than or equal to 20, then the populations in those counties were summed, and a single rate for the “state collection of counties” was calculated by dividing the sum of deaths by the sum of populations in those counties. This rate was then applied to each of those “unreliable” counties.
- If the sum of deaths calculated in the above step was still less than 20, the counties in the “state collection of counties” were not assigned the single rate from the above step. Instead, the regional level was proceeded to, according to the regional definitions shown below in Table D-1. In each region, all counties whose death counts were less than 20

were identified (excluding any such counties that were assigned a rate in the previous step). The death counts in those counties were summed. If the sum of deaths was greater than or equal to 20, then the populations in those counties were summed, and a single rate for the “regional collection of counties” was calculated by dividing the sum of deaths by the sum of populations in those counties. This rate was then applied to each of those counties in the “regional collection of counties.”

Exhibit D-1. Regional Definitions from U.S. Census

| Region | States Included |
|-----------|--|
| Northeast | Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut, New York, New Jersey, Pennsylvania |
| Midwest | Ohio, Indiana, Illinois, Michigan, Wisconsin, Minnesota, Iowa, Missouri, North Dakota, South Dakota, Nebraska, Kansas |
| South | Delaware, Maryland, District of Columbia, Virginia, West Virginia, North Carolina, South Carolina, Georgia, Florida, Kentucky, Tennessee, Alabama, Mississippi, Arkansas, Louisiana, Oklahoma, Texas |
| West | Montana, Idaho, Wyoming, Colorado, New Mexico, Arizona, Utah, Nevada, Washington, Oregon, California, Alaska, Hawaii |

If the sum of deaths calculated in the previous (regional) step was still less than 20, the counties in the “regional collection of counties” were not assigned the single rate from the above step. Instead, the national level was proceeded to, identifying all counties in the nation whose death counts were less than 20 (excluding any such counties that were assigned a rate in the previous steps). The death counts in those counties were then summed and divided by the sum of the populations in those counties to derive a single rate for the “national collection of counties.” This rate was then applied to each of those counties in the “national collection of counties.” In these cases where national adjustment still did not yield a death count greater than 20, a single rate was calculated for the “national collection of counties”, even though it was “unreliable,” and assigned it to those counties in the “national collection of counties.”

Exhibit D-2 shows the resulting national average all-cause mortality rates.

Exhibit D-2. National All-Cause Mortality Rates (per 100 people per year) by Age Group

| Mortality Category | Infant * | 1--17 | 18--24 | 25--34 | 35--44 | 45--54 | 55--64 | 65--74 | 75--84 | 85+ |
|----------------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|--------------|
| Mortality, All Cause | 0.5939 6 | 0.0195 1 | 0.0780 4 | 0.1066 5 | 0.1726 4 | 0.4054 2 | 0.8616 2 | 1.7967 0 | 4.6283 7 | 13.5803 4 |

* Post-neonatal mortality (deaths after the first month) for infants was estimated because the health impact function (see Appendix C) estimates post-neonatal mortality.

Mortality Rate Projections to 2015-2060

To estimate age- and county-specific mortality rates in years 2015 through 2060, annual adjustment factors were calculated, based on a series of Census Bureau projected national mortality rates (for all- cause mortality), to adjust the age- and county-specific mortality rates calculated using 2012-2014 data as described above. The following procedure was used:

- For each age group, the series of projected national mortality rates from 2013 to 2050 were obtained (see the 2013 rate in Table D-3) based on Census Bureau projected life tables.
- The ratio of Census Bureau national mortality rate in year Y ($Y = 2014, 2015, \dots, 2060$) to the 2013 rate was then calculated separately for each age group. These ratios are shown for selected years in Table D-4.
- Finally, to estimate mortality rates in year Y ($Y = 2015, 2020, \dots, 2060$) that are both age-group-specific and county-specific, the county- and age-group-specific mortality rates for 2012-2014 were multiplied by the appropriate ratio calculated in the previous step. For example, to estimate the projected mortality rate in 2015 among ages 18-24 in Wayne County, MI, the mortality rate for ages 18-24 in Wayne County in 2012-2014 were multiplied by the ratio of Census Bureau projected national mortality rate in 2015 for ages 18-24 to Census Bureau national mortality rate in 2013 for ages 18-24.

Exhibit D-3. All-Cause Mortality Rate (per 100 people per year), by Source, Year, and Age Group

| Source & Year | Infant* | 1-17 | 18-24 | 25-34 | 35-44 | 45-54 | 55-64 | 65-74 | 75-84 | 85+ |
|---------------------------------|---------|-------|-------|-------|-------|-------|-------|-------|-------|--------|
| Calculated CDC 2012- 2014 | 0.193* | 0.020 | 0.078 | 0.107 | 0.173 | 0.405 | 0.862 | 1.797 | 4.628 | 13.580 |
| Census Bureau 2013** | 0.654 | 0.029 | 0.088 | 0.102 | 0.183 | 0.387 | 0.930 | 2.292 | 5.409 | 13.091 |

* The Census Bureau estimate is for all deaths in the first year of life. BenMAP uses post-neonatal mortality (deaths after the first month, i.e., 0.23 per 100 people) because the health impact function (see Appendix E) estimates post- neonatal mortality. For comparison purpose, the rate for all deaths in the first year was also calculated, which is 0.684 per 100 people).

**For a detailed description of the model, the assumptions, and the data used to create Census Bureau projections, see the working paper, “Methodology and Assumptions for the 2012 National Projections,” which is available on <http://www.census.gov/population/projections/files/methodology/methodstatement12.pdf>

**Exhibit D-4. Ratio of 2025 and 2020 All-Cause Mortality Rate to 2013 Estimated All-Cause Mortality Rate,
by Age Group**

| Year | Infant | 1-17 | 18-24 | 25-34 | 35-44 | 45-54 | 55-64 | 65-74 | 75-84 | 85+ |
|------|--------|------|-------|-------|-------|-------|-------|-------|-------|------|
| 2015 | 0.93 | 0.93 | 0.96 | 1.02 | 0.96 | 0.96 | 1.01 | 1.02 | 1.03 | 1.00 |
| 2020 | 0.94 | 0.94 | 0.98 | 1.04 | 0.97 | 0.98 | 1.02 | 1.03 | 1.03 | 1.00 |
| 2025 | 0.85 | 0.81 | 0.74 | 0.80 | 0.75 | 0.77 | 0.85 | 0.91 | 0.93 | 0.97 |
| 2030 | 0.81 | 0.75 | 0.66 | 0.70 | 0.67 | 0.69 | 0.78 | 0.86 | 0.89 | 0.92 |
| 2035 | 0.76 | 0.70 | 0.58 | 0.62 | 0.60 | 0.62 | 0.71 | 0.81 | 0.87 | 0.87 |
| 2040 | 0.73 | 0.65 | 0.51 | 0.53 | 0.53 | 0.56 | 0.64 | 0.76 | 0.84 | 0.86 |
| 2045 | 0.70 | 0.60 | 0.45 | 0.46 | 0.46 | 0.50 | 0.58 | 0.71 | 0.80 | 0.86 |
| 2050 | 0.67 | 0.56 | 0.39 | 0.40 | 0.40 | 0.44 | 0.53 | 0.66 | 0.77 | 0.87 |
| 2055 | 0.64 | 0.52 | 0.34 | 0.35 | 0.35 | 0.39 | 0.48 | 0.62 | 0.73 | 0.88 |
| 2060 | 0.61 | 0.48 | 0.30 | 0.30 | 0.31 | 0.34 | 0.43 | 0.58 | 0.70 | 0.87 |

| Year | Infant | 1-17 | 18-24 | 25-34 | 35-44 | 45-54 | 55-64 | 65-74 | 75-84 | 85+ |
|------|--------|------|-------|-------|-------|-------|-------|-------|-------|------|
| 2015 | 0.93 | 0.93 | 0.96 | 1.02 | 0.96 | 0.96 | 1.01 | 1.02 | 1.03 | 1.00 |
| 2020 | 0.94 | 0.94 | 0.98 | 1.04 | 0.97 | 0.98 | 1.02 | 1.03 | 1.03 | 1.00 |
| 2025 | 0.85 | 0.81 | 0.74 | 0.80 | 0.75 | 0.77 | 0.85 | 0.91 | 0.93 | 0.97 |
| 2030 | 0.81 | 0.75 | 0.66 | 0.70 | 0.67 | 0.69 | 0.78 | 0.86 | 0.89 | 0.92 |
| 2035 | 0.76 | 0.70 | 0.58 | 0.62 | 0.60 | 0.62 | 0.71 | 0.81 | 0.87 | 0.87 |
| 2040 | 0.73 | 0.65 | 0.51 | 0.53 | 0.53 | 0.56 | 0.64 | 0.76 | 0.84 | 0.86 |
| 2045 | 0.70 | 0.60 | 0.45 | 0.46 | 0.46 | 0.50 | 0.58 | 0.71 | 0.80 | 0.86 |
| 2050 | 0.67 | 0.56 | 0.39 | 0.40 | 0.40 | 0.44 | 0.53 | 0.66 | 0.77 | 0.87 |
| 2055 | 0.64 | 0.52 | 0.34 | 0.35 | 0.35 | 0.39 | 0.48 | 0.62 | 0.73 | 0.88 |
| 2060 | 0.61 | 0.48 | 0.30 | 0.30 | 0.31 | 0.34 | 0.43 | 0.58 | 0.70 | 0.87 |

Hospitalizations

Hospitalization rates were calculated using data from the Healthcare Cost and Utilization Project (HCUP). HCUP is a family of health care databases developed through a Federal-State-Industry partnership and sponsored by the Agency for Healthcare Research and Quality (AHRQ). HCUP products include the State Inpatient Databases (SID), the State Emergency Department Databases (SEDD), the Nationwide Inpatient Sample (NIS), and the Nationwide Emergency Department Sample (NEDS). HCUP databases can be obtained from the following data services:

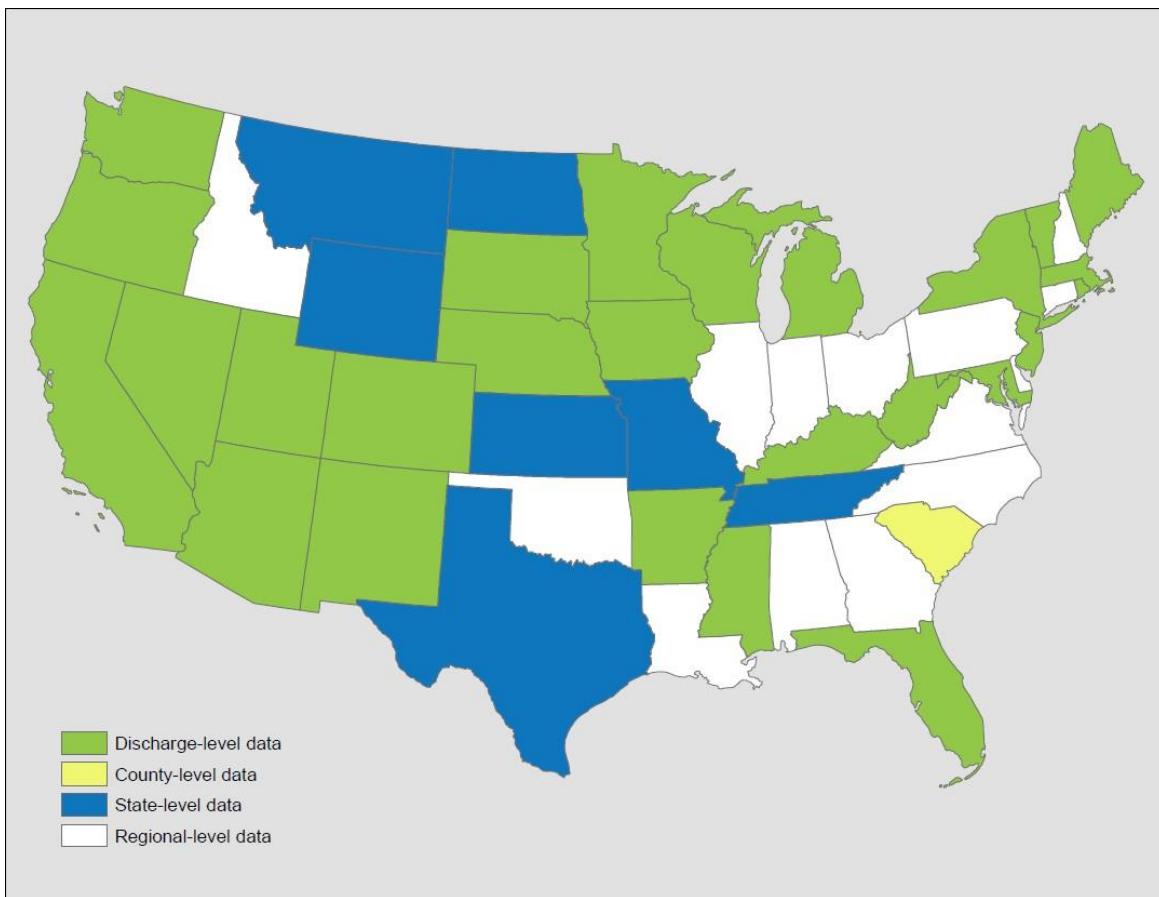
- **HCUP Central Distributor:** Many of the HCUP databases are available for purchase through the HCUP Central Distributor. The databases include detailed information for individual discharges, such as primary diagnosis (in ICD-9 codes), patient's age and residence county. HCUP categorizes hospital admissions in various ways. Hospitalization admissions are reported as emergency (admitted from the emergency department), urgent (admitted from another hospital), elective (admitted from another health facility),

including long-term care), newborn (admitted for delivery), trauma (not used by all states), or other/missing/invalid. While a substantial subset of the ISA- identified literature evaluating respiratory hospitalizations restricted analyses to emergency hospital admissions (EHAs), all hospital admission baseline incidence data within BenMAP reflects total hospital admissions due to time constraints limiting the ability to stratify incidence by admission type. In general, the vast majority of respiratory and cardiovascular hospitalizations appear to be emergency or urgent admissions. As such, the total hospital admissions rates in BenMAP should largely align with analogous EHA rates (albeit biased upward due to the small share of hospitalizations that are elective).

- **HCUP State Partners:** Some HCUP participating states do not release their data to the Central Distributor; however, the data may be obtained through contacting the State Partners. South Carolina provided county-level data.
- **HCUPnet:** This is a free, on-line query system based on data from HCUP. It provides access to summary statistics at the state, regional and national levels.

Figure D-1 shows the level of hospitalization data (e.g., discharge-level or state-level) for each state. Note that for some states neither discharge-level, county-level nor state- level data were available. In such cases, regional statistics from HCUPnet were used to estimate hospitalization rates for those states. The data year for states using HCUPnet data is 2014. For discharge-level data, the data year for most states is 2014; however, some states provided data for 2011 (CA, MS); 2012 (ME); and 2013 (AR, MA, MD, NV, SD, UT). Hospitalization rates are assumed to be reasonably constant from 2011-2014 and all are considered as 2014 rates.

Exhibit D-5. Hospitalization Data from HCUP



More information about HCUP can be found at <http://www.hcup-us.ahrq.gov/>

The procedures for calculating hospitalization rates are summarized as follows:²¹

- For states with discharge-level data:
 - Age-, health endpoint-, and county-specific hospitalization counts were calculated. South Carolina was the only state that, while not providing discharge- level data, did provide county-level data for each age group-endpoint combination.
 - The above calculation excluded hospitalizations with missing patient age or county FIPS, which may lead to

²¹ The data year for most states is 2007; the exception is MA, for which the data year is 2006. Hospitalization rates are assumed to be reasonably constant from 2006-2007 and all are considered as 2007 rates.

underestimation of rates. Therefore, the previously calculated age-, endpoint-, and county-specific counts were scaled up using an adjustment factor obtained as follows:

- The number of discharges for a specific endpoint in the state, including those discharges with missing age or county FIPS, were counted.
- The number of discharges for the endpoint in the state, excluding those records with missing age or county FIPS, were then counted.
- The adjustment factor is the ratio of the two counts.
- For California and West Virginia, patient county was unavailable for all observations. For these two states, hospital county was used in place of patient county.
- Hospitalization rates were calculated for each county by dividing the adjusted county-level hospitalization counts by the Census estimated county-level population for the corresponding year (2011 - 2014). Following CDC Wonder, rates were treated as “unreliable” when the hospitalization count was less than 20, using the same procedure used for mortality rates (see Section D.1.1).

For states with summarized state statistics (from HCUPnet) the state-, age-, endpoint-specific hospitalization rates were calculated and applied to each county in the state. The previously described procedure to adjust the “unreliable” rates was used.

- For states without discharge-level or state-level data:
 - The endpoint-specific hospitalization counts in each region were obtained from HCUPnet/NIS (this count for the i th endpoint in the j th region is referred to as “TOTAL ij ”)
 - For those states in the j th region that do have discharge-level or state-level data, the hospital admissions by endpoint were summed (this count for the i th endpoint in the j th region is referred to as “SUB ij ”).
 - The hospitalization count was then estimated for states without discharge or state data for the i th endpoint in the j th region as TOTAL ij - SUB ij . Note that while this count is endpoint- and

region-specific, it is not age-specific. The distribution of hospital admission counts across age groups were obtained based on the Central Distributor data and the same distribution for the HCUPnet hospitalizations was assumed. This distribution was then applied to the estimated hospital counts (i.e., $TOTAL_{ij} - SUB_{ij}$) to obtain endpoint-, region-, and age-specific counts.

- Using the corresponding age- and region-specific populations in BenMAP-CE from Woods and Poole (2015), age-specific hospitalization rates for the i th endpoint in the j th region were calculated and applied to the counties in the region that didn't have discharge-level or state-level data.

Exhibit D-6 shows the resulting average national hospitalization rates by health endpoint and age group.

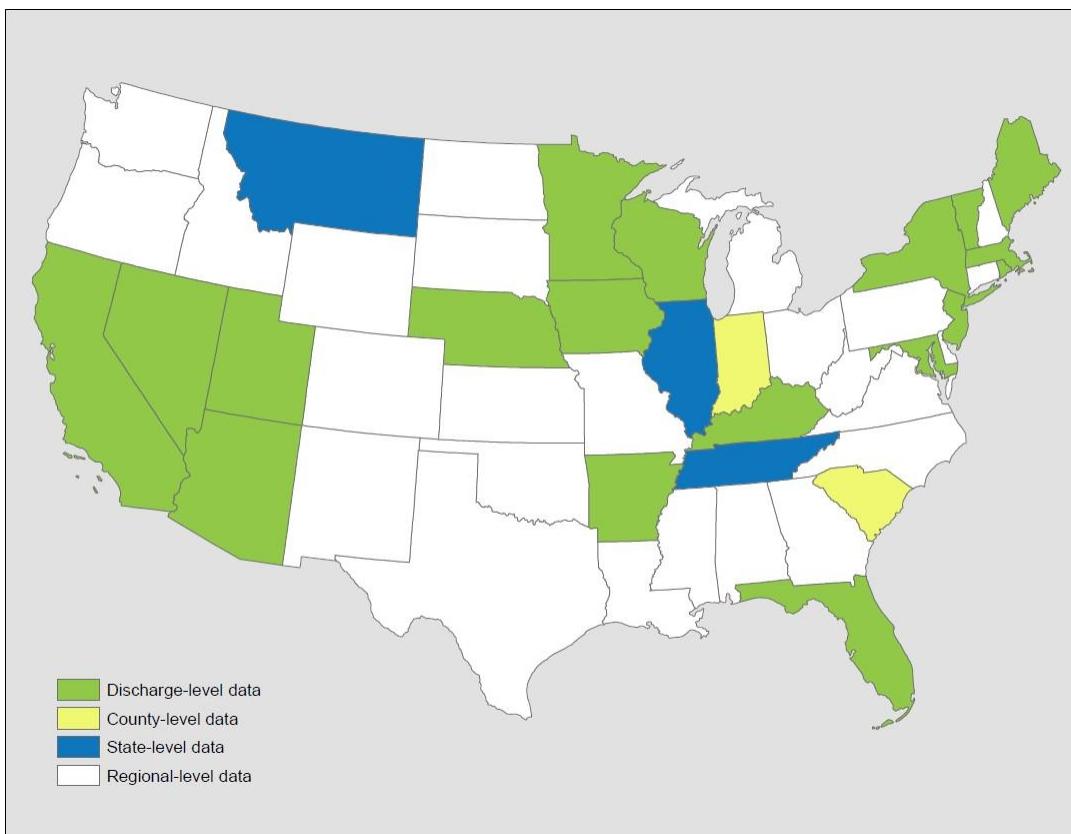
Exhibit D-6. National Hospitalization Rates, by Health Endpoint and Age Group

| Hospitalization Category | ICD-9 Code | Age 0-1 | 2-17 | 18-24 | 25-34 | 35-44 | 45-54 | 55-64 | 65-74 | 75-84 | 85+ |
|---------------------------------------|------------|---------|-------|---------|-------|-------|--------|--------|-------|-------|-------|
| <i>Respiratory</i> | | | | | | | | | | | |
| All Respiratory | 460-519 | 2.387 | 0.363 | 0.166 | 0.212 | 0.340 | 0.737 | 1.297 | 2.292 | 4.151 | 6.343 |
| Pneumonia | 480-486 | 0.477 | 0.101 | 0.039 | 0.063 | 0.103 | 0.196 | 0.336 | 0.640 | 1.426 | 2.660 |
| Chronic Lung Disease | 490-496 | 0.226 | 0.151 | 0.041 | 0.056 | 0.105 | 0.281 | 0.496 | 0.837 | 1.276 | 1.306 |
| Asthma | 493 | 0.217 | 0.147 | 0.036 | 0.048 | 0.076 | 0.123 | 0.136 | 0.157 | 0.218 | 0.243 |
| <i>Cardiovascular</i> | | | | | | | | | | | |
| All Cardiovascular | 390-429 | 0.044 | 0.017 | 0.061 | 0.138 | 0.377 | 0.914 | 1.747 | 3.131 | 5.886 | 8.832 |
| Acute Myocardial Infarction, Nonfatal | 410 | 0.000 | 0.000 | 0.002 | 0.010 | 0.068 | 0.202 | 0.380 | 0.575 | 0.921 | 1.332 |
| Ischemic Heart Disease | 410-414 | 0.000 | 0.000 | 0.002 | 0.014 | 0.105 | 0.350 | 0.689 | 1.090 | 1.570 | 1.734 |
| Dysrhythmia | 427 | 0.016 | 0.005 | 0.014 | 0.025 | 0.057 | 0.145 | 0.319 | 0.684 | 1.357 | 1.917 |
| Congestive Heart Failure | 428 | 0.010 | 0.001 | 0.005 | 0.021 | 0.061 | 0.165 | 0.344 | 0.700 | 1.727 | 3.513 |
| Stroke | 431-437 | 0.009 | 0.003 | 0.007 | 0.021 | 0.070 | 0.199 | 0.417 | 0.816 | 1.639 | 2.488 |
| <i>Neurological</i> | | | | | | | | | | | |
| Alzheimer's Disease | 331.0 | 0.000 | 0.000 | 0.00 | 0.00 | 0.00 | 0.0004 | 0.0035 | 0.027 | 0.129 | 0.248 |
| Parkinson's Disease | 332 | 0.000 | 0.000 | 0.00011 | | | 0.0037 | | 0.020 | | 0.025 |

Emergency Room Visits for Asthma

The data source for emergency department/room (ED or ER) visits is also HCUP, i.e., SID, SEDD, and NEDS. The types of data providers are also the same as those described above for hospitalizations. Exhibit D-7 shows the emergency department data in each state.

Exhibit D- 7. Emergency Department Data from HCUP



The calculation of ER visit rates is also similar to the calculation of hospitalization rates, except for the following differences:

- The SEDD databases include only those ER visits that ended with discharge. To identify the ER visits that ended in hospitalization, a variable called “admission source” was used in the SID databases. Admission source identified as “emergency room” indicates that the hospital admission came from the ER – i.e., the ER visit ended in hospitalization. For each combination of age group, endpoint and county, the ER visits that ended with discharge and those that resulted in hospitalization were summed.

- The data year varies across the states from 2011 to 2014 (see Exhibit D-7); ER visit rates are assumed to have been reasonably constant across these three years and they are considered as 2014 rates.
- Instead of using HCUPnet/NIS and NHDS in the last step as described for hospitalizations, HCUPnet/NEDS and the National Ambulatory Medical Care Survey (NAMCS) were used to calculate ER visit rates for states without discharge level or state level data.

Exhibit D-8 shows the resulting average national rates of asthma emergency room visits by age group.

Exhibit D-8. National Emergency Room Visit Rates for Asthma, by Age Group

| ER Category | ICD-9 Codes | ER Visit Rate (visits per 100 people per year) | | | | | | | | |
|-------------|-------------|--|-------|-------|-------|-------|-------|-------|-------|-------|
| | | Age 0-17 | 18-24 | 25-34 | 35-44 | 45-54 | 55-64 | 65-74 | 75-84 | 85+ |
| Asthma | 493 | 0.959 | 0.601 | 0.556 | 0.538 | 0.552 | 0.408 | 0.331 | 0.368 | 0.350 |

Nonfatal Heart Attacks

The relationship between short-term particulate matter exposure and heart attacks was quantified in case-crossover analyses by Peters et al (2001). The study population was selected from heart attack survivors in a medical clinic. Therefore, the applicable population to apply to the C-R function is all individuals surviving a heart attack in a given year. Several data sources are available to estimate the number of heart attacks per year. For example, several cohort studies have reported estimates of heart attack incidence rates in the specific populations under study. However, these rates depend on the specific characteristics of the populations under study and may not be the best data to extrapolate nationally. The American Heart Association reports approximately 785,000 new heart attacks per year (Roger et al., 2012). Exclusion of heart attack deaths reported by CDC Wonder yields approximately 575,000 nonfatal cases per year.

An alternative approach to the estimation of heart attack rates is to use data from the HCUP, assuming that all heart attacks that are not instantly fatal will result in a hospitalization. According to the HCUPnet, in 2014 there were approximately 608,795 hospitalizations due to heart attacks (acute myocardial infarction: ICD-9 code of 410, primary diagnosis).²² County-level hospitalization rates were used over estimates extrapolated from cohort studies because the

²² Source: Online query on HCUPnet website (AHRQ 2012), accessed 1-13-2012
<http://hcupnet.ahrq.gov/HCUPnet.app/HCUPnet.jsp?Id=53F290DC050F1296&Form=SelLAY&GoTo=MAINSEL&JS=Y>

former is part of a nationally representative survey with a larger sample size, which is intended to provide reliable national estimates. The hospitalization section above describes the detailed procedure for developing the incidence rates for hospitalization of AMI. As additional information is provided regarding the American Heart Association methodology, the usefulness of this estimate of heart attack incidence will be evaluated.

Rosamond et al. (1999) reported that approximately 6% of male and 8% of female hospitalized heart attack patients die within 28 days (either in or outside of the hospital). Therefore, a factor of 0.93 was applied to the count of hospitalizations to estimate the number of nonfatal heart attacks per year. Note that there was not an adjustment for fatal AMIs in the incidence rate estimation, due to the way that the epidemiological studies are designed. Those studies consider total admissions for AMIs, which includes individuals living at the time the studies were conducted. Therefore, the definition of AMI that matches the definition in the epidemiological studies was used.

School Loss Days

Epidemiological studies have examined the relationship between air pollution and a variety of measures of school absence. These measures include: school loss days for all causes, illness-related, and respiratory illness-related. There are two sources of information. The first is the National Center for Education Statistics, which provided an estimate of all-cause school loss days, and the other is the National Health Interview Survey (Adams et al., 1999, Table 47), which has data on different categories of acute school loss days. Table D-12 presents the estimated school loss day rates. Further detail is provided below on these rates.

Exhibit D-9. School Loss Day Rates (per student per year)

| Type | Northeast | Midwest | South | West |
|--------------------------------------|-----------|---------|-------|------|
| Respiratory illness-related absences | 1.3 | 1.7 | 1.1 | 2.2 |
| Illness-related absences | 2.4 | 2.6 | 2.6 | 3.7 |
| All-cause | 9.9 | 9.9 | 9.9 | 9.9 |

* Illness-related school loss day rates were based on data from the 1996 NHIS and an estimate of 180 school days per year. This excludes school loss days due to injuries. The all-cause school loss day rate was based on data from the National Center for Education Statistics.

All-Cause School Loss Day Rate

Based on data from the U.S. Department of Education (1996, Table 42-1), the National Center for Education Statistics estimates that for the 1993-1994 school year, 5.5 percent of students are absent from school on a given day. This estimate is comparable to study-specific estimates from Chen et al. (2000) and Ransom and Pope (1992), which ranged from 4.5 to 5.1 percent.

Illness-Related School Loss Day Rate

The National Health Interview Survey (NHIS) has regional estimates of school loss days due to a variety of acute conditions (Adams et al., 1999). NHIS is a nationwide sample-based survey of the health of the noninstitutionalized, civilian population, conducted by NCHS. The survey collects data on acute conditions, prevalence of chronic conditions, episodes of injury, activity limitations, and self-reported health status. However, it does not provide an estimate of all-cause school loss days.

In estimating illness-related school loss days, lost days due to injuries were subtracted from school loss days due to acute problems (Adams et al., 1999, Table 47), in order to match the definition of the study used in the C-R function to estimate illness-related school absences (Gilliland et al., 2001). The total was then divided by 180 school days per year to estimate illness-related school absence rates per school day. Similarly, when estimating respiratory illness-related school loss days, data from Adams et al. (1999, Table 47) was used. Note that 180 school days in a year was estimated to calculate respiratory illness-related school absence rates per year.

Other Acute Effects

For many of the minor effect studies, baseline rates from a single study are often the only source of information, and it is assumed that these rates hold for locations in the U.S. The use of study-specific estimates is likely to increase the uncertainty around the estimate because they are often estimated from a single location using a relatively small sample. These endpoints include: acute bronchitis, upper respiratory symptoms, and lower respiratory symptoms. Exhibit D-10 presents a summary of these baseline rates.

Exhibit D-10. Selected Acute Incidence (Cases / Person-Year)

| Endpoint | Age | Parameter | Rate | Source |
|---------------------------------------|-------|-----------|-------|--|
| Acute Bronchitis | 8-12 | Incidence | 0.043 | (American Lung Association, 2002, Table 11) |
| Minor Restricted Activity Days (MRAD) | 18-64 | Incidence | 7.8 | (Ostro & Rothschild, 1989, p. 243) |
| Work Loss Day (WLD) | 18-64 | Incidence | 2.172 | (Adams, Hendershot, & Marano, 1999, Table 41; U.S. Bureau of the Census, 1997) |

Acute Bronchitis

The annual rate of acute bronchitis for children ages 5 to 17 was obtained from the American Lung Association (2002). The authors reported an annual incidence rate per person of 0.043, derived from the 1996 National Health Interview Survey.

Minor Restricted Activity Days (MRAD)

Ostro and Rothschild (1989, p. 243) provide an estimate of the annual incidence rate of MRADs (7.8). This estimate was multiplied by 100 to get an annual rate per 100 people.

Work Loss Days

The yearly work-loss-day incidence rate per 100 people is based on estimates from the 1996 National Health Interview Survey (Adams et al., 1999, Table 41). They reported a total annual work loss days of 352 million for individuals ages 18 to 65. The total population of individuals of this age group in 1996 (162 million) was obtained from (U.S. Bureau of the Census, 1997). The average annual rate of work loss days per individual (2.17) was multiplied by 100 to obtain the average yearly work-loss-day rate of 217 per 100 people.

Asthma-Related Health Effects

Several studies have examined the impact of air pollution on asthma development or exacerbation in the asthmatic population. Many of the baseline incidence rates used in the C-R functions are based on study-specific estimates. The baseline rates for the various endpoints are described below and summarized in Exhibit D-11.

Exhibit D-11. Asthma-Related Health Effects Rates

| Endpoint | Age | Parameter | Rate | Source |
|--|------|------------|--------|------------------------------------|
| Asthma Symptoms, Shortness of Breath | 5-12 | Prevalence | 18.50% | Lewis et al. (2013, p. 51) |
| Asthma Symptoms, Wheeze | 5-12 | Prevalence | 19.40% | |
| Asthma Symptoms, Cough | 5-12 | Prevalence | 30.10% | |
| Asthma Symptoms, Chest Tightness | 5-12 | Prevalence | 12.70% | |
| Asthma Symptoms (Albuterol Use), Albuterol Use | 6-13 | Incidence | 2.2 | Rabinovitch et al. (2006, Table 1) |
| Upper Respiratory Symptoms (URS) | 9-11 | Incidence | 124.79 | Pope et al. (1991, Table 2) |

Appendix E: Population Forecasts

To estimate the change in population exposure to air pollution, we use projections based on US Census of Population and Housing 2010 and forecasting models developed by Woods & Poole (2015), which are taken from BenMAP for use in COBRA. The Woods and Poole (WP) database contains county-level projections of population by age, sex, ethnicity, and race out to 2050. Projections in each county are determined simultaneously with every other county in the United States to take into account patterns of economic growth and migration. The sum of growth in county-level populations is constrained to equal a previously determined national population growth, based on Bureau of Census estimates. The projection years used for COBRA are 2016, 2023, and 2028.

According to WP, linking county-level growth projections together and constraining to a national-level total growth avoids potential errors introduced by forecasting each county independently. County projections are developed in a four-stage process. First, national-level variables such as income, employment, and populations are forecasted. Second, employment projections are made for 172 economic areas defined by the Bureau of Economic Analysis, using an “export-base” approach, which relies on linking industrial sector production of non-locally consumed production items, such as outputs from mining, agriculture, and manufacturing with the national economy. The export-based approach requires estimation of demand equations or calculation of historical growth rates for output and employment by sector. Third, population is projected for each economic area based on net migration rates derived from employment opportunities and following a cohort component method based on fertility and mortality in each area. Fourth, employment and population projections are repeated for counties, using the economic region totals as bounds. The age, sex, ethnicity, and race distributions for each region or county are determined by aging the population by single year of age by sex and race for each year through 2050 based on historical rates of mortality, fertility, and migration.

Appendix F: Economic Value of Health Effects

This Appendix presents the mean estimate of the unit values used in this analysis. Exhibit F-1 lists these unit values for 2028, Exhibit F-2 lists these unit values for 2023 and Exhibit F-3 lists these unit values for 2016.

Exhibit F-1. Unit Values for Economic Valuation of Health Endpoints in 2028 (2023 \$)

| Health Endpoint | Air Pollutant | Age Range | Unit Value (2028 Income Level) |
|--|-------------------|-----------|--------------------------------|
| Mortality, All Cause ^a | PM _{2.5} | 0-99 | \$15,133,044.54 |
| Acute Myocardial Infarction, Nonfatal | PM _{2.5} | 65-99 | \$89,146.68 |
| Asthma Symptoms, Albuterol Use | PM _{2.5} | 6-17 | \$0.63 |
| Minor Restricted Activity Days | PM _{2.5} | 18-64 | \$120.96 |
| Emergency Room Visits, All Cardiac Outcomes | PM _{2.5} | 0-99 | \$2,120.90 |
| Emergency Room Visits, Respiratory | PM _{2.5} | 0-99 | \$1,597.78 |
| Hospitalization, Cardio-, Cerebro- and Peripheral Vascular Disease | PM _{2.5} | 65-99 | \$28,273.07 |
| Hospitalization, Alzheimer's Disease | PM _{2.5} | 65-99 | \$21,983.68 |
| Hospitalization, Parkinson's Disease | PM _{2.5} | 65-99 | \$23,447.29 |
| Hospitalization, All Respiratory ^b | PM _{2.5} | 65-99 | \$66,539.75 |
| Hospitalization, All Respiratory ^c | PM _{2.5} | 0-18 | \$17,653.30 |
| Incidence, Stroke | PM _{2.5} | 65-99 | \$62,046.06 |
| Incidence, Out of Hospital Cardiac Arrest | PM _{2.5} | 35-99 | \$65,318.08 |
| Incidence, Lung Cancer | PM _{2.5} | 85-99 | \$56,623.86 |
| Incidence, Lung Cancer | PM _{2.5} | 30-34 | \$21,635.86 |
| Incidence, Lung Cancer | PM _{2.5} | 35-44 | \$26,410.78 |
| Incidence, Lung Cancer | PM _{2.5} | 45-54 | \$34,184.32 |
| Incidence, Lung Cancer | PM _{2.5} | 55-64 | \$41,729.36 |
| Incidence, Lung Cancer | PM _{2.5} | 65-74 | \$47,872.31 |
| Incidence, Lung Cancer | PM _{2.5} | 75-84 | \$52,116.05 |
| Incidence, Hay Fever/Rhinitis | PM _{2.5} | 3-17 | \$1,095.99 |
| Incidence, Asthma | PM _{2.5} | 0-17 | \$80,211.96 |
| Infant Mortality | PM _{2.5} | 0 | \$15,133,044.54 |
| Work Loss Days | PM _{2.5} | 18-64 | \$307.11 |
| School Loss Days | O ₃ | 5-17 | \$1,776.84 |
| Asthma Symptoms, Chest Tightness | O ₃ | 0-17 | \$371.19 |
| Asthma Symptoms, Chest Tightness | O ₃ | 18-99 | \$194.29 |
| Asthma Symptoms, Cough | O ₃ | 0-17 | \$371.19 |
| Asthma Symptoms, Cough | O ₃ | 18-99 | \$194.29 |
| Asthma Symptoms, Shortness of Breath | O ₃ | 0-17 | \$371.19 |
| Asthma Symptoms, Shortness of Breath | O ₃ | 18-99 | \$194.29 |
| Asthma Symptoms, Wheeze | O ₃ | 0-17 | \$371.19 |
| Asthma Symptoms, Wheeze | O ₃ | 18-99 | \$194.29 |
| Emergency Room Visits, Asthma | O ₃ | 0-99 | \$815.77 |
| Mortality, Long-term exposure | O ₃ | 30-99 | \$15,133,044.54 |
| Mortality, Short-term exposure | O ₃ | 0-99 | \$15,133,044.54 |
| Mortality, Short-term exposure | O ₃ | 0-99 | \$15,133,044.54 |

NOTE: ^a Based on Wu et al. (2020); ^b Based on Bell et al. (2015); ^c Based on Ostro et al. (2009)

Exhibit F-2. Unit Values for Economic Valuation of Health Endpoints in 2023 (2023 \$)

| Health Endpoint | Air Pollutant | Age Range | Unit Value (2023 Income Level) |
|--|-------------------|-----------|--------------------------------|
| Mortality, All Cause ^a | PM _{2.5} | 0-99 | \$14,012,045.11 |
| Acute Myocardial Infarction, Nonfatal | PM _{2.5} | 65-99 | \$80,737.90 |
| Asthma Symptoms, Albuterol Use | PM _{2.5} | 6-17 | \$0.57 |
| Minor Restricted Activity Days | PM _{2.5} | 18-64 | \$112.00 |
| Emergency Room Visits, All Cardiac Outcomes | PM _{2.5} | 0-99 | \$1,920.85 |
| Emergency Room Visits, Respiratory | PM _{2.5} | 0-99 | \$1,447.06 |
| Hospitalization, Cardio-, Cerebro- and Peripheral Vascular Disease | PM _{2.5} | 65-99 | \$25,623.84 |
| Hospitalization, Alzheimer's Disease | PM _{2.5} | 65-99 | \$19,939.13 |
| Hospitalization, Parkinson's Disease | PM _{2.5} | 65-99 | \$21,249.62 |
| Hospitalization, All Respiratory ^b | PM _{2.5} | 65-99 | \$60,285.54 |
| Hospitalization, All Respiratory ^c | PM _{2.5} | 0-18 | \$16,000.92 |
| Incidence, Stroke | PM _{2.5} | 65-99 | \$56,193.55 |
| Incidence, Out of Hospital Cardiac Arrest | PM _{2.5} | 35-99 | \$59,156.94 |
| Incidence, Lung Cancer | PM _{2.5} | 85-99 | \$51,282.80 |
| Incidence, Lung Cancer | PM _{2.5} | 30-34 | \$19,595.06 |
| Incidence, Lung Cancer | PM _{2.5} | 35-44 | \$23,919.58 |
| Incidence, Lung Cancer | PM _{2.5} | 45-54 | \$30,959.88 |
| Incidence, Lung Cancer | PM _{2.5} | 55-64 | \$37,793.23 |
| Incidence, Lung Cancer | PM _{2.5} | 65-74 | \$43,356.74 |
| Incidence, Lung Cancer | PM _{2.5} | 75-84 | \$47,200.19 |
| Incidence, Hay Fever/Rhinitis | PM _{2.5} | 3-17 | \$992.61 |
| Incidence, Asthma | PM _{2.5} | 0-17 | \$73,225.83 |
| Infant Mortality | PM _{2.5} | 0 | \$14,012,045.11 |
| Work Loss Days | PM _{2.5} | 18-64 | \$281.80 |
| School Loss Days | O ₃ | 5-17 | \$1,630.38 |
| Asthma Symptoms, Chest Tightness | O ₃ | 0-17 | \$343.69 |
| Asthma Symptoms, Chest Tightness | O ₃ | 18-99 | \$179.90 |
| Asthma Symptoms, Cough | O ₃ | 0-17 | \$343.69 |
| Asthma Symptoms, Cough | O ₃ | 18-99 | \$179.90 |
| Asthma Symptoms, Shortness of Breath | O ₃ | 0-17 | \$343.69 |
| Asthma Symptoms, Shortness of Breath | O ₃ | 18-99 | \$179.90 |
| Asthma Symptoms, Wheeze | O ₃ | 0-17 | \$343.69 |
| Asthma Symptoms, Wheeze | O ₃ | 18-99 | \$179.90 |
| Emergency Room Visits, Asthma | O ₃ | 0-99 | \$738.82 |
| Mortality, Long-term exposure | O ₃ | 30-99 | \$14,012,045.11 |
| Mortality, Short-term exposure | O ₃ | 0-99 | \$14,012,045.11 |
| Mortality, Short-term exposure | O ₃ | 0-99 | \$14,012,045.11 |

NOTE: ^a Based on Wu et al. (2020); ^b Based on Bell et al. (2015); ^c Based on Ostro et al. (2009)

Exhibit F-3. Unit Values for Economic Valuation of Health Endpoints in 2016 (2023 \$)

| Health Endpoint | Air Pollutant | Age Range | Unit Value (2016 Income Level) |
|--|-------------------|-----------|--------------------------------|
| Mortality, All Cause ^a | PM _{2.5} | 0-99 | \$12,252,752.71 |
| Acute Myocardial Infarction, Nonfatal | PM _{2.5} | 65-99 | \$70,395.71 |
| Asthma Symptoms, Albuterol Use | PM _{2.5} | 6-17 | \$0.50 |
| Minor Restricted Activity Days | PM _{2.5} | 18-64 | \$97.94 |
| Emergency Room Visits, All Cardiac Outcomes | PM _{2.5} | 0-99 | \$1,674.80 |
| Emergency Room Visits, Respiratory | PM _{2.5} | 0-99 | \$1,261.70 |
| Hospitalization, Cardio-, Cerebro- and Peripheral Vascular Disease | PM _{2.5} | 65-99 | \$22,340.06 |
| Hospitalization, Alzheimer's Disease | PM _{2.5} | 65-99 | \$17,382.58 |
| Hospitalization, Parkinson's Disease | PM _{2.5} | 65-99 | \$18,526.46 |
| Hospitalization, All Respiratory ^b | PM _{2.5} | 65-99 | \$52,561.36 |
| Hospitalization, All Respiratory ^c | PM _{2.5} | 0-18 | \$13,950.20 |
| Incidence, Stroke | PM _{2.5} | 65-99 | \$48,995.39 |
| Incidence, Out of Hospital Cardiac Arrest | PM _{2.5} | 35-99 | \$51,579.18 |
| Incidence, Lung Cancer | PM _{2.5} | 85-99 | \$44,713.69 |
| Incidence, Lung Cancer | PM _{2.5} | 30-34 | \$17,085.01 |
| Incidence, Lung Cancer | PM _{2.5} | 35-44 | \$20,855.58 |
| Incidence, Lung Cancer | PM _{2.5} | 45-54 | \$26,994.05 |
| Incidence, Lung Cancer | PM _{2.5} | 55-64 | \$32,952.08 |
| Incidence, Lung Cancer | PM _{2.5} | 65-74 | \$37,802.92 |
| Incidence, Lung Cancer | PM _{2.5} | 75-84 | \$41,154.04 |
| Incidence, Hay Fever/Rhinitis | PM _{2.5} | 3-17 | \$865.46 |
| Incidence, Asthma | PM _{2.5} | 0-17 | \$63,797.29 |
| Infant Mortality | PM _{2.5} | 0 | \$12,252,752.71 |
| Work Loss Days | PM _{2.5} | 18-64 | \$245.40 |
| School Loss Days | O ₃ | 5-17 | \$1,419.77 |
| Asthma Symptoms, Chest Tightness | O ₃ | 0-17 | \$300.54 |
| Asthma Symptoms, Chest Tightness | O ₃ | 18-99 | \$157.31 |
| Asthma Symptoms, Cough | O ₃ | 0-17 | \$300.54 |
| Asthma Symptoms, Cough | O ₃ | 18-99 | \$157.31 |
| Asthma Symptoms, Shortness of Breath | O ₃ | 0-17 | \$300.54 |
| Asthma Symptoms, Shortness of Breath | O ₃ | 18-99 | \$157.31 |
| Asthma Symptoms, Wheeze | O ₃ | 0-17 | \$300.54 |
| Asthma Symptoms, Wheeze | O ₃ | 18-99 | \$157.31 |
| Emergency Room Visits, Asthma | O ₃ | 0-99 | \$644.18 |
| Mortality, Long-term exposure | O ₃ | 30-99 | \$12,252,752.71 |
| Mortality, Short-term exposure | O ₃ | 0-99 | \$12,252,752.71 |
| Mortality, Short-term exposure | O ₃ | 0-99 | \$12,252,752.71 |

NOTE: ^a Based on Wu et al. (2020); ^b Based on Bell et al. (2015); ^c Based on Ostro et al. (2009)

Appendix G: Instructions for Running COBRA Using Batch Files

Batch files can be used to submit emissions data representing multiple years or scenarios, so that the scenarios will run in succession without additional input from the user. This feature enables analysis of multiple years or scenarios in a single modeling step.

Running COBRA using batch files requires that users have some baseline understanding of what batch files are and how they function. Below, we describe how to (1) format emissions, population, incidence, and valuation files for use in COBRA, (2) write a Windows command to conduct a single COBRA run, and (3) create and run a batch script for multiple COBRA runs.

(1) Formatting emissions, population, incidence, and valuation files for use in COBRA

COBRA requires separate baseline and scenario emissions files in a specific format. To create properly formatted custom baseline and scenario emissions files, create a CSV file with the headings shown in Exhibit H-1. Each row of the file should correspond to a different source in a different county. Make sure to include all counties and emissions tiers in your baseline and scenario emissions files, and not just the counties and tiers where you have emissions changes.

Exhibit H-1. Format of Baseline and Scenario Emissions Files

| Column Heading | Description of Column Headings |
|-------------------------|---|
| typeindx ¹ | Stack height associated with the emission |
| sourceindx ² | Source index, which COBRA uses in its source receptor model |
| std | FIPS state ID (e.g., the state FIPS code for Pennsylvania is 42) |
| cyid | FIPS county ID (e.g., the county FIPS code for Swarthmore, PA is 045) |
| TIER1 ³ | Emissions category to which emissions source corresponds, at tier 1 level |
| TIER2 ³ | Emissions category to which emissions source corresponds, at tier 2 level |
| TIER3 ³ | Emissions category to which emissions source corresponds, at tier 3 level |
| NO2 | NO _x emissions from each source in the baseline |
| SO2 | SO ₂ emissions from each source in the baseline |
| NH3 ⁴ | NH ₃ emissions from each source in the baseline |
| PM25 | Primary PM _{2.5} emissions from each source in the baseline |
| VOC | VOC emissions from each source in the baseline |

Notes:

¹ A table of typeindx and name is saved on your computer after installing COBRA in the default location, C:/Program Files/COBRA/input files/data dictionary/typeindx – stack heights.csv.

² A table of sourceindx and FIPS is saved on your computer after installing COBRA in the default location, C:/Program Files/COBRA/input files/data dictionary/SOURCEINDEX to FIPS crosswalk.csv

³ A table of tier definitions and tier numbers is saved on your computer after installing COBRA in the default location, C:/Program Files/COBRA/input files/data dictionary/EmissionsTier Definitions.csv

⁴ Previous editions of COBRA included emissions of NH₃ as an input. Starting with COBRA 5.0 the source-receptor matrix no longer considers NH₃ as an input to model PM_{2.5} concentrations. However, because NH₃ could be used as an input in future versions of COBRA, it has been maintained in the tool and is required in the format of the baseline emissions file, although it is not currently used in the calculations.

In addition to the baseline and scenario emissions files, COBRA also requires CSV files on population, baseline health incidence, and valuation. The formats for population, baseline health incidence, and valuation files are shown in Exhibits H-2, H-3, and H-4. Sample population, health incidence, and valuation files are saved on your computer after installing COBRA in the default location: C:/Program Files/COBRA/input files/default data

Exhibit H-2. Format of Population File

| Column Heading | Description of Column Headings |
|----------------------------|--|
| Year | Year of population data |
| DestinationID ¹ | DestinationID uses same pattern as SOURCEIDX to indicate destination locations. |
| FIPS | FIPS state-county ID (e.g., the state FIPS code for Pennsylvania is 42 and the county FIPS code for Swarthmore, PA is 045, so the state-county FIPS ID is 42045) |
| Age0 | Population at age 0 |
| ... | Population at each age |
| Age99 | Population older than or equal to 99 |

¹ See data dictionary file that is saved on your computer after installing COBRA in the default location, in C:/Program Files/COBRA/input files/data dictionary/SOURCEIDX to FIPS crosswalk.csv

Exhibit H-3. Format of Incidence File

| Column Heading | Description of Column Headings |
|----------------------------|---|
| Year | Year of population data |
| DestinationID ¹ | DestinationID uses same pattern as SOURCEIDX to indicate destination locations. |
| FIPS | FIPS state ID (e.g., the state FIPS code for Pennsylvania is 42 and the county FIPS code for Swarthmore, PA is 045, so the state-county FIPS ID is 42045) |
| Endpoint | Written descriptor indicating health endpoint associated with the recorded incidence rate. |
| Age0 | Incidence of a specific endpoint for population at age 0 |
| ... | Incidence of a specific endpoint for population at each age |
| Age99 | Incidence of a specific endpoint for population older than or equal to 99 |

¹ See data dictionary file that is saved on your computer after installing COBRA in the default location, in C:/Program Files/COBRA/input files/data dictionary/SOURCEIDX to FIPS crosswalk.csv

Exhibit H-4. Format of Valuation Functions File.

| Column Heading | Description of Column Headings |
|-----------------------|--|
| CRFunctionID | ID for C-R functions (linked to the health effect function file) |
| Endpoint | String descriptor indicating Endpoint for the Valuation function. |
| PoolingWeight | Functions are pooled accounting to Endpoint. PoolingWeight indicates the relative weight given to this function. |
| Seasonal_Metric | Daily or Annual are allowable entries. Indicate if computed effect is for a day or an entire year. |
| Study_Author | Study Author |
| Study_Year | Study Year |
| Start_Age | Beginning of age range to which health impact function applies |
| End_Age | End of age range to which health impact function applies |
| Function | Functional form that is to be computed. (e.g., (1-(1/((1-Incidence)*Exp(Beta*DETAQ)+Incidence)))*Incidence*POP) |
| Beta | Beta parameter supplied to functional form. |
| Adjusted | Not used |
| Parameter_1_Beta | Parameter_1_Beta parameter supplied to functional form. |
| A | A parameter supplied to functional form. |
| Name_A | Description of A parameter. |
| B | B parameter supplied to functional form. |
| Name_B | Description of B parameter. |
| C | C parameter supplied to functional form. |
| Name_C | Description of C parameter. |
| Cases | Not used |
| HealthEffect | Use same as IncidenceEndpoint |
| ValuationMethod | Note of valuation method used. |
| VALUE | Valuation of health endpoint using (undiscounted) |
| ApplyDiscount | Variable indicating whether to apply discounting. Values are “YES” or “NO”. |
| IncidenceEndpoint | Indicates Endpoint to use for lookup in Incidence data set. |

(2) Writing a Windows COBRA command to conduct a single COBRA run

After formatting the baseline emission and scenario emission files, advanced users can run COBRA from the Windows command prompt using the following syntax:

```
"C:\Program Files\COBRA\cobra_console.exe" -d "C:\Program Files\COBRA\data\cobra.db" -b A -c B -p C -i D -v E -o F --discountrate G
```

where:

- A** is the file path for the emissions baseline in a CSV file
- B** is the file path for the emissions control scenario in a CSV file, formatted in the same way as the emissions baseline
- C** is the file path for the population CSV file
- D** is the file path for the baseline incidence CSV file
- E** is the file path for the valuation CSV file
- F** is the file path for where you would like the results CSV to be saved
- G** is the discount rate you want to run. For example, if you want to run a 2% discount rate, type 2.

The letters with dashes (e.g., -d, -b, etc.) need to be included in the syntax as written.

Below, we illustrate how one could use this syntax to run COBRA for a single scenario, named Test 1, where **A** = "C:\Program Files\COBRA\COBRA Tests\Test 1\Test1_Baseline.csv", **B** = "C:\Program Files\COBRA\COBRA Tests\Test 1\Test1_Scenario.csv", **C** = "C:\Program Files\COBRA\COBRA Tests\Test 1\Test1_Population.csv" **D** = "C:\Program Files\COBRA\COBRA Tests\Test 1\Test1_Incidence.csv", **E** = "C:\Program Files\COBRA\COBRA Tests\Test 1\Test1_Valuation.csv", **F** = "C:\Program Files\COBRA\COBRA Tests\Test 1\Test1_Results2pct.csv", and the user wants to run COBRA with a 2% discount rate.

```
"C:\Program Files\COBRA\cobra_console.exe" -d "C:\Program Files\COBRA\data\cobra.db" -b "C:\Program Files\COBRA\COBRA Tests\Test 1\Test1_Baseline.csv" -c "C:\Program Files\COBRA\COBRA Tests\Test 1\Test1_Scenario.csv" -p "C:\Program Files\COBRA\COBRA Tests\Test 1\Test1_Population.csv" -i "C:\Program Files\COBRA\COBRA Tests\Test 1\Test1_Incidence.csv" -v "C:\Program Files\COBRA\COBRA Tests\Test 1\Test1_Valuation.csv" -o "C:\Program Files\COBRA\COBRA Tests\Test 1\Test1_Results2pct.csv" --discountrate 2
```

(3) Creating a batch script for multiple COBRA runs

Users can run multiple scenarios in succession without any additional input by creating batch files that contain Windows commands for multiple COBRA runs. Below, we demonstrate how a user could use a batch file to run COBRA four times (1) “Test 1” with a 2% discount rate, (2) “Test 1” with a 7% discount rate, (3) “Test 2” with a 2% discount rate, and (4) “Test 2” with a 7% discount rate. First, the user would create the properly formatted baseline and scenario emissions files, as described above. For this example, we assume that the following file paths are used:

- "C:\Program Files\COBRA\COBRA Tests\Test 1\Test1_Baseline.csv" = file path for the emissions baseline for Test 1
- "C:\Program Files\COBRA\COBRA Tests\Test 1\Test1_Scenario.csv" = file path for the emissions scenario for Test 1
- "C:\Program Files\COBRA\COBRA Tests\Test 1\Test2_Baseline.csv" = file path for the emissions baseline for Test 2
- "C:\Program Files\COBRA\COBRA Tests\Test 1\Test2_Scenario.csv" = file path for the emissions scenario for Test 2

Then, the user would open a simple text editor (e.g. Notepad) and write the series of Windows COBRA commands that describe which baseline emissions, scenario emissions, and discount rate to use for each run, using the syntax described in (2).

```
"C:\Program Files\COBRA\cobra_console.exe" -d "C:\Program Files\COBRA\data\cobra.db" -b "C:\Program Files\COBRA\COBRA Tests\Test 1\Test1_Baseline.csv" -c "C:\Program Files\COBRA\COBRA Tests\Test 1\Test1_Scenario.csv" -p "C:\Program Files\COBRA\COBRA Tests\Test 1\Test1_Population.csv" -i "C:\Program Files\COBRA\COBRA Tests\Test 1\Test1_Incidence.csv" -v "C:\Program Files\COBRA\COBRA Tests\Test 1\Test1_Valuation.csv" -o "C:\Program Files\COBRA\COBRA Tests\Test 1\Test1_Results2pct.csv" --discountrate 2

"C:\Program Files\COBRA\cobra_console.exe" -d "C:\Program Files\COBRA\data\cobra.db" -b "C:\Program Files\COBRA\COBRA Tests\Test 1\Test1_Baseline.csv" -c "C:\Program Files\COBRA\COBRA Tests\Test 1\Test1_Scenario.csv" -p "C:\Program Files\COBRA\COBRA Tests\Test 1\Test1_Population.csv" -i "C:\Program Files\COBRA\COBRA Tests\Test 1\Test1_Incidence.csv" -v "C:\Program Files\COBRA\COBRA Tests\Test 1\Test1_Valuation.csv" -o "C:\Program Files\COBRA\COBRA Tests\Test 1\Test1_Results7pct.csv" --discountrate 7

"C:\Program Files\COBRA\cobra_console.exe" -d "C:\Program Files\COBRA\data\cobra.db" -b "C:\Program Files\COBRA\COBRA Tests\Test 2\Test2_Baseline.csv" -c "C:\Program Files\COBRA\COBRA Tests\Test 2\Test2_Scenario.csv" -p "C:\Program Files\COBRA\COBRA Tests\Test 2\Test2_Population.csv" -i "C:\Program Files\COBRA\COBRA Tests\Test 2\Test2_Incidence.csv" -v "C:\Program Files\COBRA\COBRA Tests\Test 2\Test2_Valuation.csv" -o "C:\Program Files\COBRA\COBRA Tests\Test 2\Test2_Results2pct.csv" --discountrate 2

"C:\Program Files\COBRA\cobra_console.exe" -d "C:\Program Files\COBRA\data\cobra.db" -b "C:\Program Files\COBRA\COBRA Tests\Test 2\Test2_Baseline.csv" -c "C:\Program Files\COBRA\COBRA Tests\Test 2\Test2_Scenario.csv" -p "C:\Program Files\COBRA\COBRA Tests\Test 2\Test2_Population.csv" -i "C:\Program Files\COBRA\COBRA Tests\Test 2\Test2_Incidence.csv" -v "C:\Program Files\COBRA\COBRA Tests\Test 2\Test2_Valuation.csv" -o "C:\Program Files\COBRA\COBRA Tests\Test 2\Test2_Results7pct.csv" --discountrate 7
```

Then, the user would save this file a batch file (.bat). To run the batch file, the user would double click the appropriate “.bat” file and the COBRA commands will automatically run each of the scenarios sequentially in the command prompt. When the COBRA runs are complete, the command prompt window will close and the output files will be saved in the locations indicated in the batch file.

Appendix H: References

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