

PART TWO
CHAPTER 4

Quantifying the Emissions and Health Benefits of Energy Efficiency and Renewable Energy

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ABOUT THIS CHAPTER

This chapter provides policy makers and analysts with information about a range of methods they can use to estimate the emissions and health benefits of energy efficiency and renewable energy. It first describes the methods and key considerations for selecting or using the methods. The chapter then provides case studies illustrating how the methods have been applied and lists examples of relevant tools and resources analysts can use. Building off the direct electricity impacts discussed in Chapter 2, “Estimating the Direct Electricity Impacts of Energy Efficiency and Renewable Energy,” the benefits quantified using methods discussed in this chapter can serve as inputs into subsequent economic assessments discussed in Chapter 5, “Estimating the Economic Benefits of Energy Efficiency and Renewable Energy.”

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4.1. OVERVIEW

Many state and local policy makers are exploring or implementing energy efficiency and renewable energy policies that achieve emissions and health benefits, particularly by reducing criteria air pollutants and greenhouse gas (GHG) emissions. As discussed in Part One, “The Multiple Benefits of Energy Efficiency and Renewable Energy” of this *Guide*, emissions and health benefits include improving air quality, avoiding costly illnesses and premature death, and helping to mitigate climate change.

This chapter is designed to help analysts and decision makers in states and localities understand the methods, tools, opportunities, and considerations for assessing the emissions and health benefits of energy efficiency and renewable energy policies, programs, and measures. While it focuses primarily on emissions from electricity, analysts can apply the methods and tools presented in this chapter to emissions from other sources.

The range of methods and tools described is not exhaustive and inclusion of a specific tool does not imply EPA endorsement. Also, some regulatory programs may require the use of specific tools or approaches. A state or local analyst conducting an analysis to meet federal standards, for example, should determine if the standards require use of a specific method or tool.

4.2. APPROACH

Quantifying the emissions and health benefits of energy efficiency and renewable energy initiatives involves four basic steps:

1. **Develop and project a baseline** emissions profile.
2. **Quantify the emissions reductions expected** from energy efficiency and renewable energy measures.
3. **Estimate any immediate changes in air quality** resulting from emissions reductions.
4. **Quantify the health and related economic effects** of these air quality changes.

These steps typically occur linearly, as depicted in Figure 4-1, because the output of each step feeds into the subsequent step. For example, the air quality changes quantified in “Step 3: Estimate Air Quality Changes From Reductions,” depend on any criteria air pollutant emissions reductions quantified in “Step 2: Quantify Expected Emissions Reductions.” The incidences of health effects avoided, as quantified in “Step 4: Quantify Health and Related Economic Effects,” depends on the changes in air quality. The specific steps are illustrated in more detail in Table 4-1 and in the remainder of this chapter.

Analysts may choose to estimate some or all of the benefits described in this section, depending on the types and magnitude of emissions reductions or their priorities. For example, an analyst conducting a short-term assessment may discover in “Step 2: Quantify Expected Emissions Reductions,” that the energy efficiency and renewable energy measures under consideration could reduce sizable amounts of both GHGs and criteria air pollutants. Since criteria air pollutant reductions result in direct, immediate air quality and health benefits, the analyst can choose to quantify these benefits by completing “Step 3: Estimate Air Quality Changes From Reductions” and “Step 4: Quantify Health and

Figure 4-1: Steps for Quantifying Emissions and Health Benefits



Related Economic Effects.”¹ Alternatively, for programs with measures that yield sizable GHG reductions but negligible criteria air pollutant reductions, analysts may decide that they will not gain valuable new insights by quantifying air quality and health benefits as part of a short-term assessment.

For each of the four basic steps, the remainder of this chapter describes a range of basic to sophisticated modeling methods, along with related protocols, data needs, tools, and resources that analysts can use to quantify the state and local emissions and health benefits of energy efficiency and renewable energy initiatives.

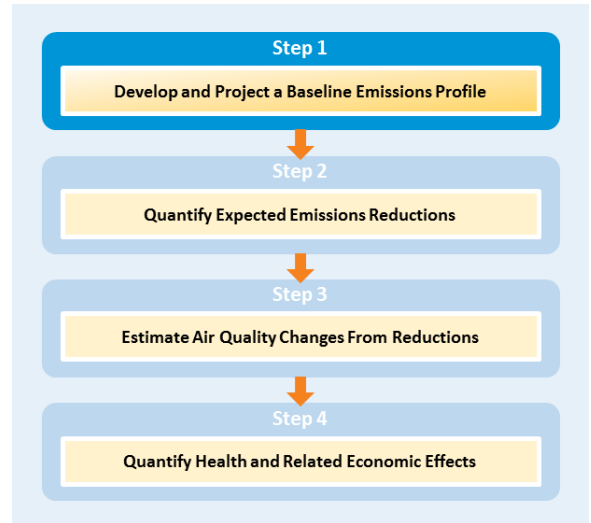
Table 4-1: Quantifying the Emissions and Health Benefits of Energy Efficiency and Renewable Energy

Step 1	Step 2	Step 3	Step 4
Develop and Project a Baseline Emissions Profile (Section 4.2.1.)	Quantify Expected Emissions Reductions (Section 4.2.2.)	Estimate Air Quality Changes From Reductions (Section 4.2.3.)	Quantify Health and Related Economic Effects (Section 4.2.4.)
Criteria Air Pollutants			
a. Determine preferred type of accounting framework and approach for developing and projecting an inventory. b. Compile criteria air pollutant emissions from available sources into inventory. c. Develop a projection using assumptions about the future and available tools.	a. Estimate criteria air pollutant reductions from energy efficiency and renewable energy using: <ul style="list-style-type: none"> ▪ Energy savings estimates and a profile of when these impacts are anticipated to occur ▪ Operating characteristics of energy efficiency or renewable energy resource (load profile) ▪ Emission factors ▪ Control technology data b. Compare against the baseline determined in Step 1.	Use criteria air pollutant data determined in Step 2 to estimate immediate changes in air quality with an air quality model.	a. Use data on air quality changes determined in Step 3 and epidemiological and population information to estimate immediate health effects. b. Apply economic values of avoided health effects to monetize benefits.
GHG Emissions			
a. Determine preferred type of accounting framework and approach for developing and projecting an inventory. b. Compile GHG emissions from available sources into inventory. c. Develop a projection using assumptions about the future and available tools.	a. Estimate GHG emissions reductions from energy efficiency or renewable energy using: <ul style="list-style-type: none"> ▪ Energy savings estimates and a profile of when these impacts are anticipated to occur ▪ Operating characteristics of energy efficiency or renewable energy resource (load profile) ▪ Emission factors ▪ Fuel data b. Compare against the baseline determined in Step 1.	<i>Assessing the longer-term air quality changes and resulting health and economic changes from GHG reductions involves a fuller assessment of the longer-term impacts of climate change, which are not covered in this Guide.</i>	

¹ While criteria air pollutant reductions result in immediate health benefits, the health benefits of GHG reductions accrue and are better analyzed over the long term.

4.2.1. Step 1: Develop and Project a Baseline Emissions Profile

The first step in estimating criteria air pollutant or GHG reductions from new energy efficiency and renewable energy policies or programs is to prepare a baseline profile of state- or local-level emissions.² The profile includes an inventory and reference case projection (or forecast) to document historical and projected emissions levels in the absence of the additional energy efficiency or renewable energy. These projected levels are also called business-as-usual (BAU) projections and will be compared to projections that include expected policy impacts. The baseline covers the years for which energy efficiency and renewable energy policy impacts are being estimated, and can include historical, current, and projected emissions data. Once developed, the baseline provides a reference case against which to measure the emissions impacts of an energy efficiency or renewable energy initiative.



Determining Which Pollutants to Include in a Baseline Emissions Inventory

Developing a baseline that includes both criteria air pollutants and GHGs serves as a comprehensive point for making well-informed policy and planning decisions about energy efficiency and renewable energy investments. Emissions inventories and projections are typically created for criteria air pollutants (to support Clean Air Act air quality attainment planning) or for GHGs (to support state or local climate change action plans) but do not typically include both criteria air pollutants *and* GHGs. Including both types of emissions, however, will facilitate a more comprehensive analysis of the emissions benefits of energy efficiency and renewable energy policies across multiple pollutants (i.e., multi-pollutant planning). For an overview of the types of sources that generate air pollution and could be affected by energy efficiency and/or renewable energy policies, see the text box below, “Sources of Air Pollution Emissions.”

An advantage of multi-pollutant planning is that it helps analysts determine whether energy efficiency and renewable energy programs that reduce GHGs also reduce criteria air pollutants, yielding health benefits (keeping in mind that some measures that reduce GHG emissions can actually increase emissions of criteria air pollutants). For example, a measure that encourages switching from electricity generated with natural gas to electricity generated by wind, an electricity source that does not cause direct emissions, will result in both criteria air pollutant benefits and GHG emissions reductions. However, a measure that encourages switching from electricity generated with natural gas to electricity generated by biomass, which may cause some types of emissions, has less certain air pollution impacts. Additional discussion on biomass is in Section 4.2.2., “Step 2: Quantify Expected Emissions Reductions.”

Typically, the state agency responsible for managing air pollution develops a criteria air pollutant inventory every 3 years as part of its responsibility to meet National Ambient Air Quality Standards (NAAQSs) established under the Clean Air Act. GHG emissions inventory practices vary depending on state or local government requirements since some emissions sources within a state or local jurisdiction are not required by federal law to inventory their GHG emissions.³ State or

² Some analysts may skip this step, particularly if they are doing a very simple analysis. For a more comprehensive analysis, however, the baseline emissions profile is instrumental when comparing the impacts of a policy to a no policy scenario.

³ While state and local governments are not required by the federal government to submit GHG inventories, some emissions sources are required to report their GHG emissions to EPA. For example, EPA’s GHGRP generally requires annual reporting of GHG emissions and other relevant information from large fuel suppliers and facilities that emit 25,000 metric tons of CO₂ or more per year. EPA also generally requires electric generating units (EGUs) subject to the Acid Rain Program and with capacity greater than 25 Megawatts (MW) to report emissions and generation data to EPA. These data can be helpful for states and local governments creating own inventories.

SOURCES OF AIR POLLUTION EMISSIONS

Air pollution emissions sources can be grouped into several categories including: point, area, on-road mobile, off-road mobile, and biogenic sources. These source categories are mutually exclusive apart from biogenic sources, which can overlap with the remaining sources. Each is described below.

Point Source: A stationary location or fixed facility from which pollutants are discharged, such as an electric power plant or a factory smokestack.

Area Source: An air pollution source that is released over a relatively small area but cannot be classified as a point source. Area sources include small businesses and household activities, product storage and transport distribution (e.g., gasoline), light industrial/commercial sources, agriculture sources (e.g., feedlots, crop burning), and waste management sources (e.g., landfills). Emissions from area sources are generally reported by categories rather than by individual source.

On-Road Mobile Source: Highway vehicles such as cars and light trucks, heavy trucks, buses, engines, and motorcycles.

Non-Road Mobile Source: Combustion engines not associated with highway vehicles, such as farm and construction equipment, gasoline-powered lawn and garden equipment, power boats and outboard motors, and aircraft.

Biogenic Sources: Biologically based sources of emissions, from living or dead organic materials due to the natural carbon cycle (e.g., decomposition), natural disturbances (e.g., fires), or the combustion, harvest, combustion, digestion, fermentation, decomposition, or processing of these materials.

Source: U.S. EPA, 2008.

local GHG inventories are often developed by state or local environmental agencies, state energy offices, NGOs, or universities, and may be updated annually or every few years, if at all. If available, analysts can use existing inventories in their assessment of energy efficiency and renewable energy policies, rather than developing a new baseline inventory. If existing inventories are not available, analysts can develop their own inventory using the methods and tools described below. Available data sources for compiling an emissions inventory are discussed in Section 4.4., “Tools and Resources” and listed in Table 4-12.

Deciding Between Production-Based or Consumption-Based Accounting

When developing an inventory that includes electricity-related emissions, analysts will decide whether they wish to inventory electricity-related emissions using production-based (i.e., scope 1) or consumption-based (i.e., scope 2) accounting. Production-based emissions occur within the boundaries over which the entity has jurisdiction. For example, the emissions resulting from direct combustion of fossil fuels at power plants (on site) are based on production. Consumption-based emissions encompass those emissions produced by consumption within those same boundaries, regardless of the origin of those emissions. Typical sources of consumption-based emissions include purchased electricity, steam, or chilled water.

Analysts typically choose the scope based on both the purpose and the geographic scale of the inventory. For example, local governments often include scope 2 emissions if or when they do not have electric generating plants within their boundaries but still wish to evaluate the impacts of electricity use in the community. State or local policy makers may wish to evaluate emissions from generation (i.e., scope 1) if they are exploring policies related to the electricity sector, such as a renewable portfolio standard (RPS) or goal, but may wish to evaluate emissions on a consumption, or scope 2, basis if they are exploring impacts of end-use energy efficiency programs. An inventory may include both scopes, but analysts should be cautious when summing results to avoid double-counting of emissions.⁴

⁴ For more information about scopes, see the California Air Resources Board Local Government Operations Protocol for Greenhouse Gas Assessment at: <https://www.arb.ca.gov/cc/protocols/localgov/localgov.htm>.

There are two basic approaches for developing state and local emissions inventories for criteria air pollutants and/or GHGs: top-down and bottom-up. These approaches vary in their level of data and aggregation, with top-down inventory methods using higher-level, more aggregated data than bottom-up inventory methods. It is common for a single inventory to combine both top-down and bottom-up methodologies and tools, and protocols may accommodate both approaches.

In either approach, analysts can apply emission factors to convert estimates of energy consumption into estimates of emissions, as described in the text box “Emission Factor Method for Inventories.” For bottom-up baseline emissions inventories, however, analysts have another option, beyond the emission factor method, of summing emissions data directly monitored at the plant or source level.

While the inventory development process can be time- and resource-intensive, readily available data and emission factors can streamline this process, avoiding the need to use complex modeling methods if budget is not available. Furthermore, if a state or locality intends to examine energy efficiency and renewable energy impacts on only one sector (e.g., stationary energy), the emissions inventory only needs to cover that sector to look at these impacts.

When assessing power sector emissions for inventories, it is most appropriate to use a “system average” emission factor that represents the average emissions intensity of the region throughout the year. However, when assessing the emissions impact from an energy efficiency or renewable energy project, analysts can consider using a marginal emission factor or more sophisticated modeling method that represents the emission characteristics of the generation being displaced by the project. For more information about estimating emissions reductions from policies or programs, including the use of marginal emission factors, see Section 4.2.2., “Step 2: Quantify Expected Emissions Reductions.”

The rest of Section 4.2.1. presents information about each approach for developing an emissions inventory, including their strengths and limitations, appropriate applications, and data needs. It also describes methods for projecting inventories into the future. Section 4.4., “Tools and Resources,” provides relevant data sources and resources, and the tools available to states and localities for developing and projecting a baseline emissions profile.

Top-Down Inventory Development

A top-down inventory contains aggregated activity data across the state or locality, and is used to generate statewide or locality-wide estimates of criteria air pollutant or GHG emissions. For example, a top-down inventory might report emissions estimates for categories within a state or locality (e.g., different industries), but typically would not contain data on emissions from specific facilities or buildings.

When Used: Top-down approaches are often used to develop statewide estimates of criteria air pollutants, estimates of area source emission of criteria air pollutants, and inventories of statewide or city-wide GHGs.

EMISSION FACTOR METHOD FOR INVENTORIES

An emission factor is a representative value that relates the quantity of a pollutant released into the atmosphere with an associated activity on an intensity basis. Emission factors are used to calculate emissions estimates by multiplying the emission factor (e.g., pounds of NO_x per kWh produced) by the activity level (e.g., kWh produced). Emission factors can be produced based on the chemical composition of the fuels burned or determined by emissions monitors.

Emission factors for CO₂, NO_x, SO₂, and other pollutants are available from:

- EPA’s Clearinghouse for Inventories and Emissions Factors (CHIEF)
<https://www.epa.gov/chief>
- EPA’s Emissions & Generation Resource Integrated Database (eGRID)
<https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid>
- EPA’s Power Profiler
<https://www.epa.gov/energy/power-profiler>
- EPA’s U.S. Greenhouse Gas Inventory Reports
<https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks>
- Intergovernmental Panel on Climate Change Emissions Factor Database (EFDB)
<http://www.ipcc-nggip.iges.or.jp/EFDB/main.php>
- Center for Corporate Climate Leadership GHG Emission Factors Hub
<http://www.epa.gov/climateleadership>

Strengths of top-down approaches include being able to capture a more comprehensive picture of emissions in a state or locality and that data sources are more easily accessible.

Limitations include lack of in-depth sectoral emissions detail, uncertainty when using averaged emission factors, and a lack of spatial resolution.

Because the location of where criteria air pollutants are emitted is important, an ideal inventory would be bottom-up and include very detailed, source-specific data that can be used in air quality modeling. However, some sources, such as area sources (e.g., fuel use and industrial use of paints, solvents, and consumer products), cannot be easily attributed to individual sectors or sources and lend themselves more appropriately to a top-down method.⁵

While there may be circumstances in which a state agency desires significant bottom-up detail about the sources of its GHG emissions, GHG inventories generally do not require the same level of detailed spatial resolution as criteria air pollutant inventories since a ton of GHGs in one part of the state affects global climate change in the same way as a ton of the same GHGs in another part of the state. In addition, GHG emission factors are less dependent on technological differences, making larger scale calculations possible without a significant loss in accuracy. For GHG emissions, the top-down method can be most appropriate when developing statewide estimates of emissions. Refer to Section 4.4., “[Tools and Resources](#),” for relevant protocols for developing a top-down inventory.

Top-Down Data Needs

To complete a top-down statewide or community-wide emissions inventory for the energy sector, an analyst needs a variety of data, such as:

- *Statewide or community-wide electricity generation; energy consumption by sector; and coal, oil, and natural gas production and distribution.*⁶ Many of these data are available at the state level from national sources, such as the Energy Information Agency (EIA) State Energy Data System.⁷ Some city-wide data may be obtained from local utilities or from the U.S. Department of Energy’s (U.S. DOE’s) State and Local Energy Database.⁸
- *Data on economic activity and human population levels.* These data are also available from national sources such as the Bureau of Economic Analysis’ Regional Accounts and the U.S. Census Bureau Population Estimates.

Some tools, such as EPA’s State Inventory Tool, provide default values analysts can use. For a comprehensive list of available data sources and tools analysts can use to develop inventories, see Section 4.4., “[Tools and Resources](#).”

Bottom-Up Inventory Development

While top-down inventories are developed using high-level, aggregated energy and economic information, bottom-up inventories for both GHG and criteria air pollutant emissions are built from source, air pollution equipment, and activity data. Bottom-up inventory development involves collecting information on the number and type of sources from individual entities (e.g., businesses, local governments) within the state. Data collected in this manner may provide a more accurate estimate of emissions within particular sectors (e.g., state- or locally owned government buildings).

When used: Bottom-up approaches are often used for sector-specific GHG inventories and stationary source emissions estimates for criteria air pollutants.

⁵ Mobile sources are included as a separate category from area sources in typical air pollution inventories.

⁶To expand the inventory beyond energy, or in some cases to fully account for all emissions related to the energy sector (e.g., if using IPCC accounting methods as discussed on page 4–23), states would need data on sources such as agricultural crop production, animal populations, and fertilizer use; waste generation and disposal methods; industrial activity levels; forestry and land use; and wastewater treatment methods.

⁷ State-level data on energy production, consumption, prices, and expenditures are available at: <https://www.eia.gov/state/seds/>.

⁸ City-wide data on electricity generation, energy consumption by sector, and coal, oil, and natural gas production and distribution is available at: <https://apps1.eere.energy.gov/sled/#/>.

Strengths of bottom-up approaches are that they can provide more detailed or nuanced profile of emissions as well as better spatial resolution than top-down approaches. They can provide comprehensive estimates of precursor emissions and spatial and temporal details that are required for air quality modeling applications.

Limitations are that they require a large amount of highly disaggregated data, which can be difficult to obtain, and may not capture all emissions in a state or community.

Bottom-up inventories can supplement statewide or community-wide GHG and other air pollutant emissions inventories by providing additional, more detailed information. However, it cannot be automatically assumed that a bottom-up inventory is better than a top-down inventory. An emissions inventory is no better than the accuracy of the input data and the care that is used to build the inventory. Refer to Section 4.4., “[Tools and Resources](#),” for relevant tools and protocols for developing a bottom-up inventory.

Bottom-Up Data Needs

Bottom-up inventories are data-intensive. For example, an analyst developing a bottom-up inventory would compile a list of emissions sources for each sector, and determine activity data (e.g., fuel consumption) and technology-specific emission factors or emissions monitoring data for each source on the list. Often, the required data are not as readily available from national databases as for top-down inventories. As a result, bottom-up inventories may require a significant level of effort and time expenditure for data collection. While obtaining data can be difficult, the bottom-up method can yield a more detailed or nuanced profile of emissions for a particular sector than a top-down method. For a list of available data sources and tools analysts can use to develop inventories, see Section 4.4., “[Tools and Resources](#).”

Projecting Future Emissions

Emissions projections provide a basis for:

- Demonstrating the emissions benefits of a future energy efficiency or renewable energy program
- Developing control strategies to achieve air quality standards, such as strategies included in state implementation plans (SIPs)
- Conducting air quality attainment analyses
- Identifying sectors ripe for climate change mitigation measures for state or local climate change plans and/or state climate change regulations
- Tracking progress toward meeting air quality standards or GHG reduction goals

To conduct an analysis of potential emissions reductions from a future policy, an analyst will typically develop projected estimates of both the new policy case and the BAU case that does not include the new policy.

When developing emissions projections related to the energy sector, it is important to account for as many variables as possible that are anticipated to affect both future year emissions, and the projections of fuel consumption by fuel type that underpin future year emissions for the energy sector. Where possible, it is helpful for analysts to include projections of population growth and migration, economic growth, electricity demand, fuel availability, fuel prices, technological progress, changing land-use patterns, environmental regulations, and extreme weather impacts.⁹ Analysts can project future emissions based on both historic trends and expectations about these numerous factors. The projection results will largely depend on the specific drivers included in the analysis and the projection’s time horizon and spatial scale. See Section 4.4., “[Tools and Resources](#),” for descriptions of guidance documents and tools that are available to help states

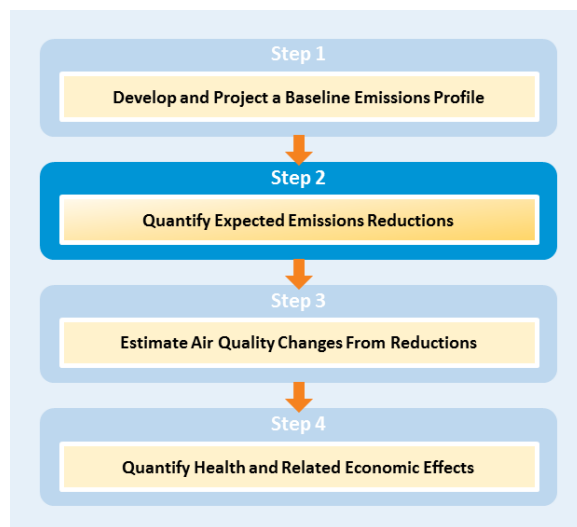
⁹ *Some of these variables are closely related, and consist of specific components that may include electricity imports and exports, power plant construction or retirement, power plant technology type, domestic vs. imported agricultural production, waste production, number of road vehicles, tons of freight transported, vehicle miles traveled, and environmental regulations.*

project future emissions. More information about forecasting energy baselines is available in Chapter 2, “Estimating the Direct Electricity Impacts of Energy Efficiency and Renewable Energy.”

4.2.2. Step 2: Quantify Expected Emissions Reductions

Once analysts have developed and projected their baseline emissions profile, they can estimate the air pollution emissions that are avoided when implementing energy efficiency and renewable energy measures. If a state agency has previously developed baseline emissions projections, analysts can examine these projections and align assumptions between the baseline projection and the emissions reduction case. For example, the original baseline projection may have assumed fuel prices or rates of economic growth that are now outdated. Using consistent assumptions will ensure that the emissions reductions from the emissions reduction case are due to the energy efficiency or renewable energy policy or program and not due to a difference in the underlying assumptions to the projections.

Analysts can use a range of methods—from basic to sophisticated—to quantify emissions reductions from energy efficiency and renewable energy measures, as shown in Table 4-2.



- **Basic methods** to quantify emissions reductions are simplified methods that often assume consistent energy savings throughout the year and assign marginal emissions rates or specific emissions rates for proxy unit types based on historical data rather than accounting for hourly load profiles for the year or considering dispatch patterns. When compared to intermediate or more sophisticated methods, they require the least amount of time and technical expertise, have transparent assumptions, normally do not require software licensing fees, and are computationally simpler than more sophisticated methods. These methods, however, can miss important system-level dynamics, such as transmission constraints, and may be less accurate than sophisticated methods. They are most appropriate for non-regulatory analyses, such as screening-level analyses, analyses of voluntary programs, or for assessing the performance of existing programs.
- **Intermediate methods** to quantify emissions reductions require some technical expertise but allow analysts flexibility to adjust the electric generating unit (EGU) fleet and reflect different energy efficiency and renewable energy assumptions and savings or load shapes. Unlike basic methods, intermediate methods can use hourly load profiles to reflect time-of-day impacts throughout the year and use EGUs’ dispatch patterns to assess impacts. Intermediate methods may be more credible than basic methods; like basic methods, though, they are based on historical data and can miss important system-level dynamics. Analysts can use these methods to compare the emissions impacts of different energy efficiency and renewable energy programs from the county to the state level depending on the tools and resources used and they can also be used when developing short-term plans for regulatory compliance (e.g., NAAQS) or energy plans.
- **Sophisticated methods** are usually more dynamic than basic-to-intermediate methods, using energy-related models that represent the interplay of future assumptions within the electricity or energy system. To calculate the effects on emissions, sophisticated methods provide detailed forecasts of regional supply and demand in relation to multiple factors—including, but not limited to, emissions controls, fuel prices, dispatch changes, and new generation resources. They can be used to compare baseline energy and emissions forecasts with scenarios based on implementation of energy efficiency and renewable energy measures. Using sophisticated models to estimate displaced emissions from energy efficiency and renewable energy measures generally results in more

rigorous estimates of emissions impacts than using basic-to-intermediate methods. However, these methods can also be more resource-intensive.

Selecting a Method for Quantifying Emissions Reductions from Energy Efficiency and Renewable Energy

When choosing a method for quantifying emissions reductions, analysts typically:

- Determine which of the available tools or methods can be used to estimate the pollutants and emissions of interest.¹⁰
- Evaluate the rigor of analysis needed (e.g., screening-level vs. regulatory impact analysis).
- Assess the energy data requirements and available energy data from the energy efficiency or renewable energy resources to assess compatibility with each potential method and/or tool.
- Consider any financial costs or technical expertise requirements of each potential method and/or tool against available resources.

There are strengths and limitations of each method for estimating emissions reductions, as summarized in Table 4-2. Analysts can use these comparisons to help determine the most appropriate method for their particular goals.

¹⁰ The SEE Action Energy Efficiency Program Impact Evaluation Guide was developed as an update to the National Action Plan for Energy Efficiency (NAPEE) guide and provides further guidance on how to quantify emissions reductions (SEE Action, 2012).

Table 4-2: Comparison of Basic, Intermediate, and Sophisticated Methods for Quantifying Air Pollutant and GHG Emissions Effects of Energy Efficiency and Renewable Energy Initiatives

Type of Method	Strengths	Limitations	When to Use This Method	Example Tools / Data Sources ^a
Basic				
<ul style="list-style-type: none"> Methods that often assume consistent energy savings throughout the year and assign marginal emissions rates or specific emissions rates for proxy unit types 	<ul style="list-style-type: none"> Transparent assumptions Easy-to-understand method Modest level of time, technical expertise, and labor required Inexpensive 	<ul style="list-style-type: none"> May be imprecise and less credible than other methods Limited ability to customize unique load characteristics of different energy efficiency and renewable programs Not applicable for long-term projections Do not typically account for imported power Do not account for myriad of factors influencing dispatch on a local scale, such as transmission constraints or reliability requirements 	<ul style="list-style-type: none"> Screening analysis Voluntary programs Evaluating existing programs 	<ul style="list-style-type: none"> AVERT (preexisting marginal emission factors) ClearPath™ eCalc eGRID (preexisting marginal emission factors) Proxy Plant method SUPR2
Intermediate				
<ul style="list-style-type: none"> Methods that can reflect time-of-day impacts throughout the year and use EGU's dispatch patterns to assess impacts of EE/RE but do not account for detailed assumptions that sophisticated approaches can (e.g., fuel prices, emissions budget trading program effects, dispatch changes) 	<ul style="list-style-type: none"> Transparent assumptions and method Allow flexibility to adjust EGU fleet and reflect different energy efficiency and renewable energy assumptions and load shapes May be more credible than basic methods 	<ul style="list-style-type: none"> Require some technical expertise Do not represent small energy efficiency and renewable energy programs well Do not typically account for imported power Do not account for myriad of factors influencing dispatch on a local scale such as transmission constraints or reliability requirements 	<ul style="list-style-type: none"> Regulatory compliance for short-term plans (e.g., NAAQS) Energy plans County-level impacts Analysis of portfolio of energy efficiency and renewable energy programs Impacts comparison of different energy efficiency and renewable energy programs 	<ul style="list-style-type: none"> AVERT custom analysis ERTAC EGU forecasting tool LEAP Time-Matched Marginal Emissions Model
Sophisticated				
<ul style="list-style-type: none"> Methods that can provide detailed forecasts of regional supply and demand impacts over time due to EE/RE policies and programs 	<ul style="list-style-type: none"> More rigorous than other methods May be perceived as more credible than other methods, especially for long-term projections Allow for sensitivity analysis May explicitly account for and quantitatively estimate imported power 	<ul style="list-style-type: none"> May be less transparent than spreadsheet methods Labor- and time-intensive Often involve high software licensing costs Require assumptions that have large impact on outputs May require significant technical expertise in energy modeling 	<ul style="list-style-type: none"> Emissions budget programs Resource planning Rate cases Financial/economic impacts projections Regulatory compliance and energy plans for short- and long-term time horizons Multi-sector analysis 	<ul style="list-style-type: none"> ENERGY 2020 e7 Capacity Expansion GE MAPS™ IPM® MARKAL/TIMES NEMS PLEXOS® PROSYM™ PROMOD IV® ReEDS RPM

^a See Section 4.4., "Tools and Resources" at the end of this chapter for more information.

Basic-to-Intermediate Methods to Quantify Emissions Reductions

Analysts can use a range of basic-to-intermediate methods to quantify the emissions reductions expected from energy efficiency and renewable energy. Basic and intermediate methods both involve:

- **Step 2a:** Establish the operating characteristics of the clean energy resource, also known as its load profile, on either an annual basis for basic methods (2a.1) or hourly basis for intermediate methods (2a.2).
- **Step 2b:** Use EPA preexisting marginal emission factors, such as those from the eGRID database or AVoided Emissions and geneRation Tool (AVERT) (2b.1), or develop custom factors based on the marginal generating units in the grid region (2b.2).¹¹
- **Step 2c:** Calculate the total emissions reductions by multiplying the avoided emission factor by the avoided electricity generation (i.e., as calculated in Chapter 2, “Estimating the Direct Electricity Impacts of Energy Efficiency and Renewable Energy”). The following equation provides an example for calculating emissions reductions:

$$\text{Total Emissions Reductions (100 tons CO}_2\text{)} = \text{Avoided Electricity Generation (200 MWh)} \times \text{Emission Factor (0.5 } \frac{\text{tons CO}_2\text{}}{\text{MWh}}\text{)}$$

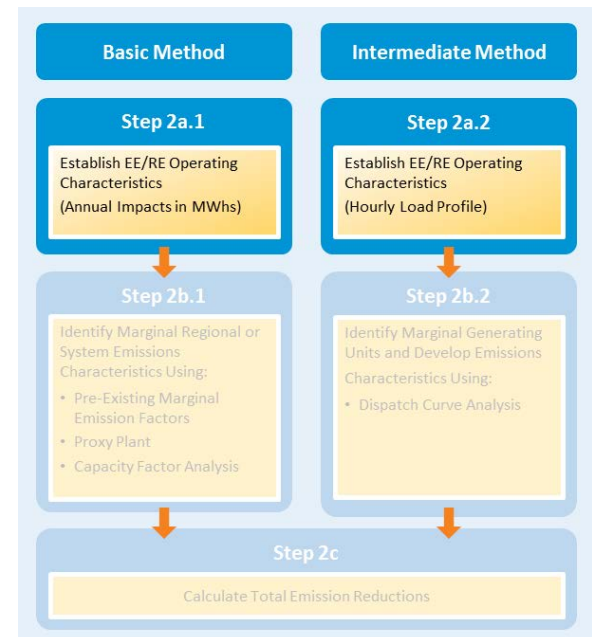
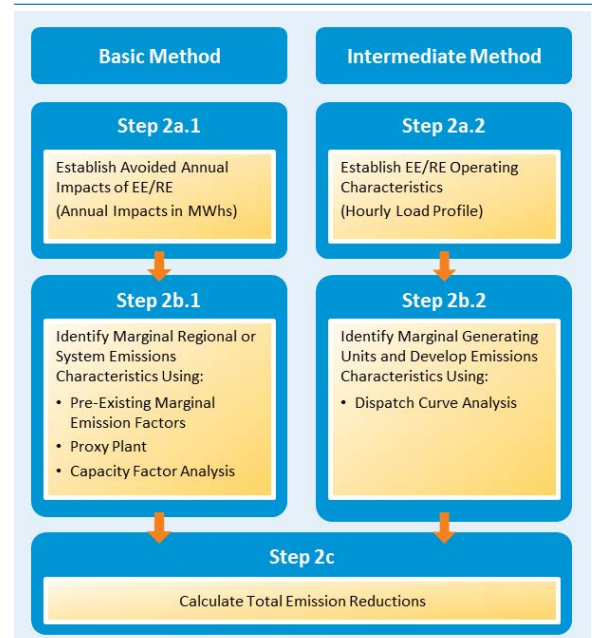
These procedures are illustrated in the flowchart in Figure 4-2 and described in greater detail below.

Step 2a: Establish Energy Efficiency and Renewable Energy Operating Characteristics

The first step to quantifying air pollutant and GHG reductions of energy efficiency and renewable energy is to estimate the amount of energy (in kilowatt-hours [kWhs]) the energy efficiency or renewable energy measure is expected to save or generate over the course of a year and the measure’s lifetime. Methods for estimating the amount of energy are described in Chapter 2, Section 2.2.2., “Step 2: Estimate Potential Direct Electricity Impacts.”

In addition to estimating annual impacts, analysts may want to estimate the timing of impacts within a year, either hourly or on some less frequent interval. The impacts of energy efficiency and renewable energy resources depend on the timing of their impact because marginal emissions rates of power plants vary depending on their merit order of dispatch, fuel type, and levels of efficiency. Therefore, measures that reduce generation requirements or add renewable energy generating capacity at the time of peak demand, will have

Figure 4-2: Basic and Intermediate Methods for Quantifying Emissions Reductions from Energy Efficiency and Renewable Energy



¹¹ Marginal emission factors from eGRID can be found at: <https://www.epa.gov/energy/emissions-generation-resource-integrated-database-eGRID>. Marginal emission factors from AVERT can be found at: <https://www.epa.gov/statelocalenergy/avoided-emission-factors-generated-avert>. See Section 4.4., “Tools and Resources” for more information.

different impacts from measures that affect the system during periods of low demand when a different mix of oil and gas steam plants or coal plants may be operating.

Step 2b: Identify the Marginal Generating Unit(s) and/or Develop Emissions Characteristics

The next step is to identify the marginal generating unit(s) and associated emissions characteristics. A marginal generating unit is the last generating unit to be dispatched in any hour, based on least-cost dispatch. This means that it is the most expensive on a variable cost basis.¹² The emissions characteristics of one unit or group of units can be expressed as an emission factor for each pollutant, and are typically expressed in pounds per Megawatt-hour (MWh). These factors represent the reduction in emissions per pound of energy generation avoided due to energy efficiency or renewable energy resources.

There are several basic-to-intermediate methods analysts can use to characterize the marginal generation source and its associated emission factor:

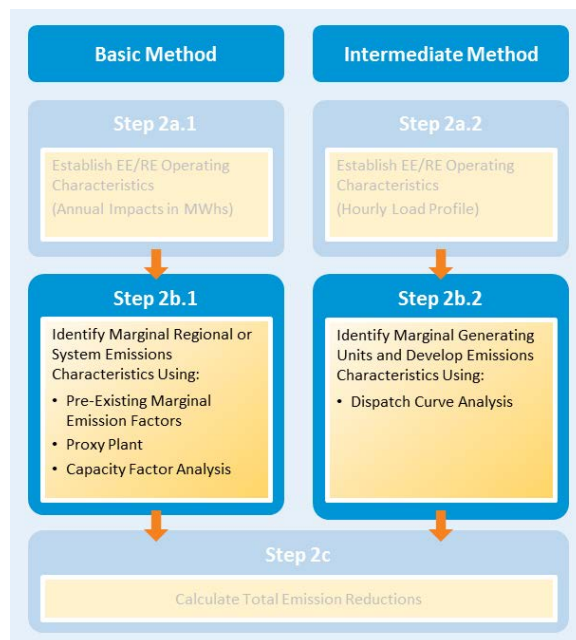
Basic Methods

- **Basic Method 1: Adopt Preexisting Marginal Emission Factor.** Options for this method include non-baseload output emissions rates from eGRID and technology-related emission factors from AVERT.
- **Basic Method 2: Proxy Plant.** This method selects one unit as a proxy for developing a marginal emission factor. Typically, this marginal unit represents emissions from a new power plant that would have been built if it was not for the overall demand reduction on the system from the energy efficiency or renewable energy resources. The proxy plant may also represent the type of power plant that is typically on the margin at the time of the day that correlates with the time of the day that the energy efficiency or renewable energy impacts would occur.
- **Basic Method 3: Capacity Factor Analysis** (also called Displacement Curve Analysis). This method builds and uses a displacement curve using factors based on a unit or power plant's capacity factor or other characteristics that correlate with the likelihood of displacement.

Intermediate Method

- **Intermediate Method: Dispatch Curve Analysis.** Typically, this method couples historical hourly generation and emissions with the hourly load reduction profiles of energy efficiency and renewable energy resources to determine hourly marginal emissions rates and hourly, monthly, and annual emissions reductions.

When determining the emission factor for the marginal generating unit(s) using any of the four basic or intermediate methods above, choose the one that best fits the rigor of analysis needed, availability of energy efficiency or renewable energy data, and electricity generating unit operating assumptions. The most accurate results will reflect the type of energy efficiency or renewable energy resource; however, the data and technical expertise requirements to make the calculations more detailed can be more complicated. For example, the accuracy of the analysis can be improved by



¹² Variable costs are those costs that vary depending on a company's production volume; they rise as production increases and fall as production decreases. Variable costs differ from fixed costs such as rent, advertising, insurance and office supplies, which tend to remain the same regardless of production output

understanding the time of day an energy efficiency measure or renewable energy resource will displace electricity generation and modifying the emission factors to reflect those temporal characteristics.

Information about the strengths, limitations, and appropriate use of each of the four methods is summarized in Table 4-3. There are tools that employ most of these methods that can aid in reducing the complication and construction of custom analysis. These tools and other relevant resources are described later in this chapter in Section 4.4., “Tools and Resources.”

Table 4-3: Comparison of Methods to Identify Marginal Unit(s) and Associated Emissions Characteristics

Method	Strengths	Limitations	When to Use This Method
Basic Method			
Adopt Preexisting Marginal Emission Factors <ul style="list-style-type: none"> Preexisting marginal emission factors based on non-baseload (eGRID) or technology-specific load characteristics (AVERT) 	<ul style="list-style-type: none"> Computationally simple Requires less labor and data than unit type or dispatch curve analysis 	<ul style="list-style-type: none"> Somewhat insensitive to dispatch process Neglects power transfers between areas History may not be good indicator of future 	<ul style="list-style-type: none"> Rough estimates of energy efficiency or renewable energy benefits for displacing emissions When lacking energy efficiency or renewable energy operating characteristics
Proxy Plant <ul style="list-style-type: none"> Select a single unit type that represents the marginal unit 	<ul style="list-style-type: none"> Computationally simple Requires less labor and data than all other methods 	<ul style="list-style-type: none"> Uses simple assumption that only a single unit type is always on the margin There may actually be more than one unit on the margin because EE/RE has regional impacts on electric grid 	<ul style="list-style-type: none"> Rough estimates of energy efficiency or renewable energy benefits for displacing emissions When evaluating the avoidance of a future power plant When only one type of unit would be running at a specific time (e.g., peak hours during summer)
Capacity Factor Analysis <ul style="list-style-type: none"> Also called displacement curve analysis Estimates an emissions rate based on the relationship of a unit type’s characteristic (e.g., capacity factor) with how often that unit type will be displaced 	<ul style="list-style-type: none"> Simpler and less labor required than dispatch curve analysis Considers generation resource characteristics 	<ul style="list-style-type: none"> Somewhat insensitive to dispatch process It may be inaccurate for baseload energy efficiency or renewable energy resources 	<ul style="list-style-type: none"> Preliminary planning and evaluation of energy efficiency and renewable energy resources, especially those that operate during peak times
Intermediate Methods			
Dispatch Curve Analysis <ul style="list-style-type: none"> Examines historical hourly dispatch data to estimate the characteristics and frequency of each generating unit on the margin 	<ul style="list-style-type: none"> More reflective to dispatch merit order than basic methods Uses actual historical dispatch data Reflects time-of-day differences in EE/RE resources 	<ul style="list-style-type: none"> Higher data requirements than basic methods Assumptions may need to be updated regularly Typically relies on sophisticated algorithms to estimate the underlying emissions rates, leading to concerns over transparency and available technical expertise 	<ul style="list-style-type: none"> Planning and regulatory studies Analyzing the impacts of energy efficiency and renewable energy programs When the load shape of the energy efficiency or renewable energy resource is known

Basic Method 1: Adopt Preexisting Marginal Emission Factors

This method involves adopting a preexisting marginal emission factor (e.g., lbs. SO₂/MWh) that is suitable for the energy efficiency or renewable energy resource. Existing marginal emission factors typically represent the emissions profile of what is expected to be on the margin in a geographical region, but marginal emission factors have also been developed to represent specific technologies or a bundle of technologies. Available factors include:

- *Non-baseload emissions rates.* Non-baseload emissions rates are available from EPA’s eGRID database, and represent an annual approximation of the weighted average emission intensity of the generators on the margin. Using eGRID, analysts can locate non-baseload emission factors by eGRID sub-region or state, and EPA developed these emissions rates using the capacity factor analysis method described below.
- *Bundled technology emissions rates.* Marginal emissions rates corresponding to a bundled suite of energy efficiency resources by region have been developed through EPA’s AVERT tool. AVERT currently provides pre-determined marginal emission factors for a general portfolio of energy efficiency resources, and energy efficiency resources that displace power equally throughout the year.
- *Technology-specific emissions rates.* Marginal emissions rates corresponding to specific technologies by region have also been developed through EPA’s AVERT tool. AVERT currently provides pre-determined marginal emission factors for wind resources, and utility-scale solar photovoltaic resources.

For a more detailed description of the AVERT and eGRID emission factors, see Section 4.4., “Tools and Resources.”

Basic Method 2: Proxy Plant

The proxy plant method recognizes that what is on the margin is a function of when the energy efficiency or renewable energy load impact occurs. Based on the expected operating characteristics of the energy efficiency or renewable energy resource (e.g., peak or off-peak hours throughout the day, or timing of impacts throughout the year on a less frequent interval), a single generating unit—or “proxy plant”—can be selected to represent the emissions characteristics of the displaced generation. This method should only be used when the energy efficiency or renewable energy resource is likely to operate during a particular time period (e.g., peak hours during the summer), since the marginal generating unit is more likely to be the same type of unit during similar time periods. Using a single proxy plant to represent avoided generation of the existing fleet is the simplest way to represent displacement, as this is equivalent to one unit being on the margin 100 percent of the time. However, this application is not recommended if other basic approaches are available. Using a proxy plant is unlikely to be more accurate than using an existing marginal emission factor, with the exception of implementing energy efficiency or renewable energy resources in a load-constrained grid where only one unit is expected to be on the margin.

An analyst could also apply a proxy plant method when assuming a large amount of energy efficiency or renewable energy resources are avoiding the installation of a new type of power plant. For instance, if a new natural gas combined-cycle plant would need to come online to meet future demand, an analyst could assume the emission factor from this avoided new plant represents a “proxy plant.” However, the proxy plant method cannot apply important factors (e.g., fuel prices, dispatch economics, and grid dynamics) that sophisticated energy modeling methods can when discerning which new plants will be built in the future.

APPLICABILITY OF SYSTEM AVERAGE EMISSION FACTORS

When selecting an emission factor for quantifying emissions reductions of energy efficiency and renewable energy, analysts should avoid selecting an emission factor that represents the average emissions rate of all units within a region. While these emission factors are appropriate for developing a GHG inventory (see “Step 1: Develop and Project a Baseline Emissions Profile”), they ignore the fact that some units have low operating costs and therefore are extremely unlikely to be displaced by energy efficiency or renewable energy resources.

For more information, see *Total, Non-baseload, eGRID Subregion, State Guidance on the Use of eGRID Output Emission Rates*, <https://www3.epa.gov/ttnchie1/conference/ei18/session5/rothschild.pdf>.

Basic Method 3: Capacity Factor Analysis (Also Called Displacement Curve Analysis)

The capacity factor¹³ analysis method uses displacement curves to estimate marginal units and their emissions characteristics. The curves used under this method reflect the likelihood of a unit being displaced, based on its expected place in the dispatch order. Compared to adopting an existing marginal emission factor, this method provides a more sophisticated way to customize the marginal emission factor based on the operating characteristics of the resource. Disaggregating the unit types as much as possible (e.g., by unit type, heat rate, and controls) makes capacity factor analysis more representative.

To implement this method, analysts develop a displacement curve to identify what generation is likely to be displaced. Some classes of units are more likely to be displaced than others by energy efficiency and renewable energy measures. For example, some coal, nuclear, and hydro plants typically provide constant baseload power, while the operating levels of higher-cost units (e.g., new gas-fired units) fluctuate, increasing their output during peak daytime hours. Older, less efficient, and more expensive coal, gas, and oil units or combustion turbines may only dispatch during the peak output periods. Due to the operating characteristics of many types of energy efficiency and renewable energy projects, the electricity produced or saved is likely to displace electricity from load-following¹⁴ and peaking units in the short term, rather than from baseload units. Analysts will need to generalize the emissions characteristics of the generating unit type that is on the margin, which may vary considerably across different control areas and time periods. Historical unit capacity factors, representing the ratio of energy generated to the maximum potential for energy generation over a period of time, are typically used to construct a dispatch curve, as is illustrated in Figure 4-3.

Estimating emission factors based on displacement curve analysis involves the following steps:

1. *Estimate the percentage of total hours* that each unit type (e.g., coal-fired steam, oil-fired steam, gas combined-cycle, gas turbine, etc.) is likely to be on the margin. When a unit is on the margin, its output will be displaced by the new energy efficiency and renewable energy resource. This step is discussed in further detail in Chapter 3, in the section “Avoided Costs of Electricity Generation or Wholesale Electricity Purchases” under “Generation Benefits: Avoided Costs.” Historical generation data for individual plants are available from EPA’s eGRID database.
2. *Determine the average emissions rate* for each unit type (in pounds of emissions per MWh output). Use public data sources such as EPA’s eGRID database or standard unit type emission factors from EPA AP-42, a compilation of air pollutant emission factors.¹⁵
3. *Calculate an emissions-contribution rate* for each unit type by multiplying the unit type average emissions (lbs./MWh) by the fraction of hours that the unit type is likely to be displaced.

¹³ Capacity factors represent the ratio of energy generated to the potential for energy generation at full power operation over a period of time. For example, if a generating unit has a maximum generating capacity of 10 MW and operates at 3 MW on average throughout the year, it would have a capacity factor of 30 percent for that year.

¹⁴ “Load-following” refers to those generating resources that are dispatched in addition to baseload generating resources to meet increased electricity demand, such as during daytime hours. In the longer term, the electricity saved from energy efficiency or produced from renewable energy projects not specific to the time of day (e.g., CHP, geothermal, not solar) can displace electricity from baseload resources.

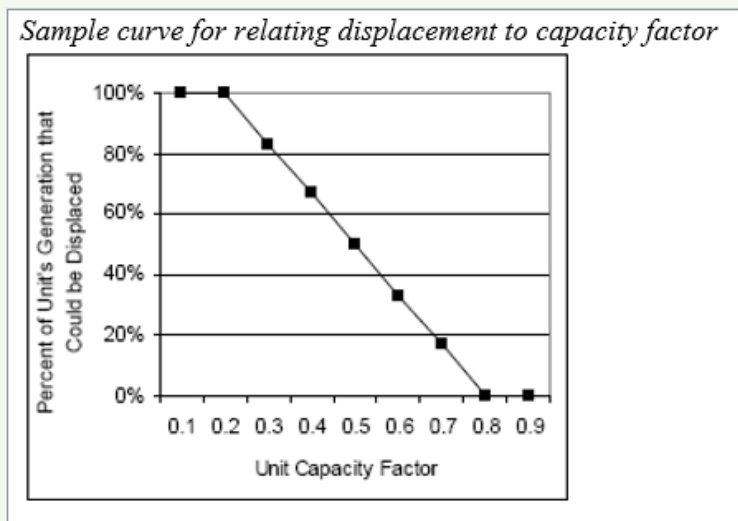
¹⁵ Note that AP-42 does not provide GHG emission factors; for GHGs, use fuel-specific emission factors from EPA’s Inventory of U.S. Greenhouse Gas Emissions and Sinks. Also note that AP-42 factors are dependent on the air pollution controls that have been installed and this information would be needed to accurately estimate emissions rates. EPA AP-42 is available at <https://www.epa.gov/air-emissions-factors-and-quantification/ap-42-compilation-air-emission-factors>.

CAPACITY FACTORS AND UNIT DISPLACEMENT FOR BASELOAD AND LOAD-FOLLOWING PLANTS

In general, baseload plants operate at all times throughout the year because their operating costs are low and because they typically are not suitable for responding to the many fluctuations in load that occur throughout the day. Thus, their capacity factors are generally very high (e.g., greater than 0.8) and they are unlikely to be affected by short-term fluctuations in load. In contrast, load-following plants that can quickly change output have much lower capacity factors (e.g., less than 0.3) and are more likely to be displaced.

As a basic method, the capacity factor of a plant can be used as an indicator for how likely the plant is to be displaced by an energy efficiency or renewable energy measure. The following graph shows an example of a simple curve that relates the likelihood that a unit's output would be displaced to its capacity factor. Baseload plants, such as nuclear units, are represented on the right side of the X-axis and are assumed to be very unlikely to be displaced. Peak load plants, such as combustion turbines, are represented on the left side of the X-axis and are much more likely to be displaced. One exception to this correlation between capacity factor and time spent on the margin is for non-dispatchable generation (e.g., solar and wind generation) that generally has a low capacity factor but rarely gets displaced.

Figure 4-3: Sample Curve for Relating Displacement to Capacity Factor



Source: Keith and Biewald, 2005.

Note: In this chart, the unit capacity factor is used as an indicator for how likely a plant is to be displaced by an energy efficiency or renewable energy measure.

These steps can be illustrated with an example where an energy efficiency program saves 1,000 MWhs in a region where multiple generating units are operating. For this example, how could analysts know which units would be displaced using the capacity factor approach? In Table 4-4, the hypothetical generating units are presented in ascending order of the number of hours each unit generates electricity during this time period, which is shown in column 1. Column 2 shows the percent displaceable for each unit based on the rule of thumb represented in the table by the capacity factor for each unit that the unit's bar intersects the line, with capacity factors being represented on the X-axis. Column 4 shows the unit's MWhs that could be displaced. Column 5 shows the percentage of the saved energy that is allocated to each unit. This is done by dividing the displaceable energy for each unit by the total available displaced energy (e.g., Unit A's displaced energy is 50,000 MWhs, which is 6.5 percent of the total 768,100 MWhs of displaceable energy) and column 6 shows the MWhs displaced at each generating unit (column 5 multiplied by 1,000 MWhs). The final step would be to multiply the MWhs displaced in column 6 with the appropriate emissions rates for each unit.

Table 4-4: Allocating Displaced Energy Using the Capacity Factor Approach

1	2	3	4	5	6
Unit	Percentage Displaceable	Historical Generation (MWh)	MWhs Displaceable	Percentage of Energy Saved Allocated to Unit	MWhs Displaced
A	100%	50,000	50,000	6.5%	65
B	82%	65,000	53,000	6.9%	69
C	79%	120,000	94,800	12%	123
D	48%	500,000	240,000	31%	312
E	22%	1,500,000	330,000	43%	430
F	0%	1,800,000	0	0%	0
G	0%	2,000,000	0	0%	0
Totals		6,035,000	768,100	100%	1,000

Source: Keith and Biewald, 2005.

Like other basic approaches, the capacity factor analysis method does not capture some aspects of electricity system operations. For example, an extended outage at a baseload unit (for scheduled maintenance or unanticipated repairs) would increase the use of load-following and peaking units, in turn affecting how much the energy efficiency or renewable energy project changes emissions. According to a capacity factor analysis method, this baseload unit would now have a lower capacity factor and therefore be more likely to be displaced even though it would rarely if ever be on the margin. Nevertheless, the detail of the capacity factor analysis method will generally produce a more credible and accurate estimate of displaced emissions than a proxy plant or existing marginal emission factor that does not account for technology-specific characteristics.

Intermediate Method: Dispatch Curve Analysis

While displacement curve analyses estimate an emissions rate based on an indicator for each type, characterizing how often that unit type will be displaced, dispatch curve analyses examine historical hourly dispatch data to estimate the characteristics and frequency of each generating unit being on the margin. Analysts use this information to determine tons of emissions avoided by an energy efficiency or renewable energy resource for a period of time in the past. In general, generating units are dispatched in a predictable order that reflects the cost and operational characteristics of each unit. These plant data can be assembled into a generation “stack,” with lowest marginal cost units on the bottom and highest on the top. A dispatch curve analysis matches each load level with the corresponding marginal supply (or type of marginal supply). Dispatch curves are also referred to as load duration curves.

The dispatch curve analysis method is commonly used in planning and regulatory studies. It has the advantage of incorporating elements of how generation is actually dispatched while retaining the simplicity and transparency associated with basic modeling methods. However, this intermediate method can become data-intensive if data for constructing the dispatch curve are not readily available.

Table 4-5 and Figure 4-4 illustrate this process for a one-week period (168 hours). There are 10 generating units in this hypothetical power system, labeled 1 through 10. The units are presented in ascending order of the number of hours each unit generates electricity during this time period, which is shown in column 3 of the table and is reflected in the bars of the figure. Column 4 shows the number of hours that each unit is on the margin; this is represented in Figure 4-4 as the number of hours for each unit that the unit’s bar intersects the line, with hours being represented on the X-axis. Column 5 shows the unit’s SO₂ emissions rate. The hours on the margin and SO₂ emissions rate columns are then combined to come up with a weighted average SO₂ emissions rate of 5.59 lbs./MWh for these units, which would be used to determine SO₂ emissions benefits for the energy efficiency or renewable energy initiative.

EPA has data that state, local, and tribal agencies can use for this method to obtain hourly generation and emissions rates for each generating unit in their region (U.S. EPA, 2012). These data can be obtained from:

<http://ampd.epa.gov/ampd/>.

Table 4-5: Hypothetical Load for One-Week Period: Hours on Margin and Emissions Rate

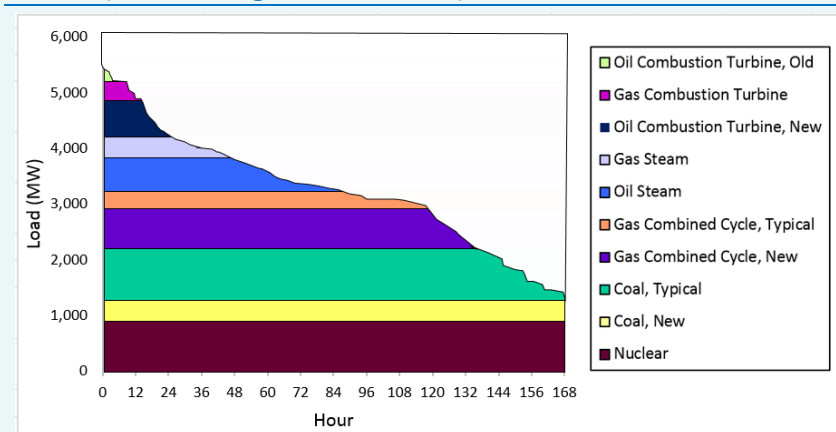
1	2	3	4	5
Unit	Unit Name	Hours of Generation	Hours on Margin	SO ₂ Emissions Rate (lbs./ MWh)
1	Oil Combustion Turbine, Old	5	5	1.00
2	Gas Combustion Turbine	15	10	0.00
3	Oil Combustion Turbine, New	24	9	1.00
4	Gas Steam	45	21	0.10
5	Oil Steam	85	40	12.00
6	Gas Combined-Cycle, Typical	117	32	0.01
7	Gas Combined-Cycle, New	134	17	0.01
8	Coal, Typical	168	34	13.00
9	Coal, New	168	0	1.00
10	Nuclear	168	0	0.00

Note: Weighted average, SO₂ emissions (lbs./MWh): 5.59.

Constructing a dispatch curve requires data on:

- Historical utilization of all generating units in the region of interest
- Operating characteristics, including costs (indicative of dispatch order) and emissions rates of the specific generating units, throughout the year
- Operating characteristics of the types of energy efficiency and renewable energy projects (e.g., load profiles)
- Hourly regional electricity demand or loads

Figure 4-4: A Hypothetical Hourly Dispatch Curve Representing 168 Hours by Generating Unit, Ranked by Load Level



Source: ICF recreated chart based on Keith and Biewald, 2005.

Note: The dispatch (i.e., load duration) curve is the curve at the top of the bars in this figure and it represents demand over a period of time. When combined with the dispatch characteristics represented under the curve, the load duration curve line also acts as a dispatch curve.

These data can be obtained from a variety of sources. Data on operating cost, historical utilization, and generator-specific emissions rates can typically be obtained from the EIA (<http://www.eia.gov/electricity/data.cfm>), or the local load balancing authority.

When generator cost data are not available, the relative dispatch order for each unit or capacity factors for traditional¹⁶ generating units can be used to approximate the relative cost of the unit (Those with the lowest cost operate more often throughout the year.) AVERT’s statistical model is one example of a source where these data can be found.

If unit-level cost data are available, calculating the weighted average of each unit’s emissions rate, as shown in Figure 4-4, is preferable to aggregating plants, especially when there is considerable variation in the emissions rates within each unit type.

DISPATCH CURVE ANALYSIS TO ESTIMATE THE EMISSIONS REDUCTIONS OF WIND ENERGY IN THE UNITED STATES

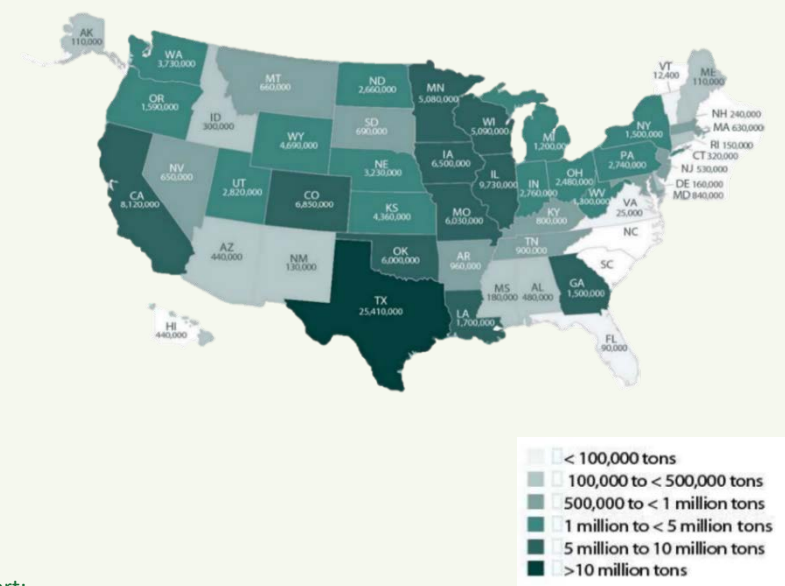
In May 2014, the American Wind Energy Association (AWEA) released a report detailing the state-by-state emissions benefits of deploying wind power throughout the country. To calculate the avoided NO_x, SO₂, and CO₂ emissions from wind generation, AWEA used EPA’s AVERT tool. AWEA collected state-by-state wind electricity generation from DOE’s Energy Information Agency (EIA) for the year 2013. AWEA then incorporated these data into AVERT and apportioned wind generation to the states. Since AVERT does not model Hawaii and Alaska, emissions benefits for these states were calculated independently using EIA fuel mix and generation data.

The study found that the 167.7 million MWh of wind generation in 2013 resulted in reductions of:

- 126.8 million short tons of CO₂ (5 percent of power sector emissions)
- 347 million pounds of SO₂
- 214 million pounds of NO_x

For more information on the AWEA study, view the report: http://awea.files.cms-plus.com/FileDownloads/pdfs/AWEA_Clean_Air_Benefits_WhitePaper%20Final

Figure 4-5: Wind Energy's 2013 Carbon Dioxide Emissions Reductions by State Using EPA's AVERT Tool



Source: AWEA, 2014.

While not required, analysts can obtain data on energy transfers between the control areas of the region and outside the region of interest to address complications from the shifting of displaced generation among existing generating units from one area to another (i.e., leakage) due to energy efficiency and renewable energy programs. Depending on the region, operational data (or simplifying assumptions) regarding energy transfers between the control areas of the region and outside the region of interest, and hourly regional loads can be obtained from the ISO or other load balancing authorities within the state’s region.¹⁷

¹⁶ As an exception, variable power resources such as solar, wind, and hydropower are not available at all times of the day throughout the year but are assumed to have lower costs than fossil fuel or nuclear units.

¹⁷ Many ISOs provide these data. To determine if an ISO does, check its market or operational data web page for regional load data (also described as zonal load data) and for energy transfers between ISOs (sometimes referred to as interface flows). NYISO is one example of where hourly regional load data, and transfer data between ISOs, can be found (http://www.nyiso.com/public/markets_operations/market_data/load_data/index.jsp).

Step 2c: Calculate Total Emissions Reductions

Total emissions reductions are calculated by applying the emission factor developed during Step 2b to the energy efficiency or renewable energy resource's level of activity, determined during Step 2a.

In the final analysis of net emissions reduction estimates, it is important for analysts to consider any GHG or criteria air pollution emissions that might be produced during the production or generation, and use of, renewable fuels (e.g., landfill gas, biomass generation). For example, how biomass is produced, harvested, and consumed will determine the net biogenic CO₂ emissions associated with its use for energy. For more information on biomass, see the text box "Accounting for Biomass Emissions" on the next page.

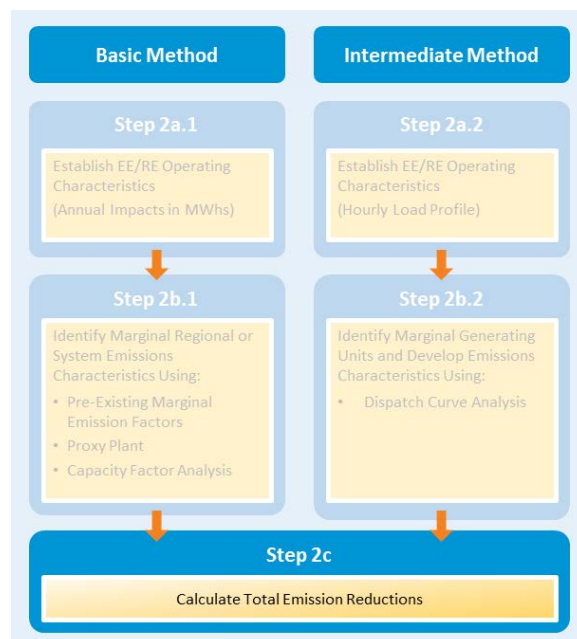
Limitations of Basic-to-Intermediate Methods

Basic-to-intermediate methods for quantifying displaced emissions are analytically simple and use data that are readily available.

However, they are less rigorous than sophisticated modeling methods. Basic methods are most appropriate for screening-level analyses. Meanwhile, policy-making and regulatory decisions can be informed by a basic screening-level analysis initially but typically require more rigorous analysis that is better suited to sophisticated modeling. The limitations of basic-to-intermediate methods include the following:

- *They are best suited for estimating potential emissions reduction benefits in a relatively short time frame (e.g., zero to 5 years).* Longer-term analyses would require emission factors that account for the addition and retirement of energy sources over time and changes in market conditions including environmental requirements.
- *They do not typically account for imported power,* which may come from generating units with very different emissions characteristics than the units within the region or system. Basic-to-intermediate methods also do not account for future changes in electricity import and export patterns, which may change the marginal energy sources during operation of the energy efficiency or renewable energy measure.
- *They do not account for the numerous factors that influence dispatch on a local scale.* For example, the existence of transmission constraints on an area where an energy efficiency or renewable energy resource is deployed can affect which resources are dispatched. When the existing electricity system is not able to provide service in load pockets¹⁸ that are served by local generators (typically due to transmission constraints), higher-cost units must be dispatched because energy cannot be imported from lower-cost units outside of the area. Reducing demand in these areas could reduce the need for these higher-cost units.

For these reasons, use of basic-to-intermediate methods is best for providing preliminary estimates of emissions reductions, reporting approximate program impacts data for annual project reports, and program evaluations that do



¹⁸ A load pocket is an area where there is insufficient transmission capability to reliably supply 100 percent of the electric load without relying on generation capacity that is physically located within that area. It is the result of high concentrations of intensive power use inevitable in a big city and limits the ability of load to be served by generating resources located remotely.

not involve regulatory compliance.¹⁹ When using basic-to-intermediate methods, it is important for analysts to remember that the more detailed the representation of the study area, the more precise and reliable the emissions estimates.

ACCOUNTING FOR BIOMASS EMISSIONS

Biomass is a fuel derived from organic matter, including, but not limited to, woody and agricultural crops and residues, or biogas (e.g., from landfills). These organic materials originate as part of the natural carbon cycle, meaning they sequester CO₂ and store it as carbon during growth and release it during decomposition, combustion, or other forms of conversion. To generate the same amount of energy, burning biomass for energy releases about the same amount of CO₂ or more as burning fossil fuels, largely due to the lower energy content of biomass and, in some cases, its moisture content. However, when considering the natural cycling of carbon in how the feedstock was produced, harvested, and used, some forms of biomass used for energy may have minimal net GHG emissions. Some programs and reporting tools may require biogenic CO₂ emissions to be reported, but not account for them in overall emissions totals, whereas others may not require biogenic emissions to be reported. When reporting and accounting for biomass emissions, analysts can follow state and/or other regulatory requirements or guidelines (see the description of the SEE Action Energy Efficiency Program Impact Evaluation Guide in the Section 4.3., “Tools and Resources,” for an example guidance document). It is important to avoid double counting biomass emissions when conducting an economy-wide GHG emissions inventory (meaning it includes emissions across all sectors). In the IPCC inventory guidelines, carbon sequestration and CO₂ emissions within biological systems, including the growth and harvest of terrestrial biomass, are assigned to the Land Use, Land Use Change, and Forestry sector. Therefore, when biomass is burned for energy, the related biogenic CO₂ emissions are accounted for in the Land Use, Land Use Change, and Forestry sector—where the carbon was stored and initially emitted via harvest—not the Energy sector (IPCC, 2006).

For more information about assessing biogenic CO₂ emissions associated with the use of biomass for energy production, please see <https://archive.epa.gov/epa/climatechange/carbon-dioxide-emissions-associated-bioenergy-and-other-biogenic-sources.html>.

Sophisticated Methods to Quantify Emissions Reductions

The two types of sophisticated models used to estimate emissions are economic dispatch models (also commonly referred to as “production costing” models) and capacity expansion models (also referred to as system planning or planning models).

Economic Dispatch Models

Economic dispatch models determine the optimal output of the EGUs over a given timeframe for a given time resolution (sub-hourly to hourly). These models generally include a high level of detail on the unit commitment and economic dispatch of EGUs, as well as on their physical operating limitations.

- **Key uses:** An economic dispatch model typically answers the question: How will this energy efficiency or renewable energy measure affect the operations of *existing* power plants? Economic dispatch models quantify the emissions reductions that occur in the short term (0–5 years).

Capacity Expansion Models

Capacity expansion models determine the optimal generation capacity and/or transmission network expansion to meet an expected future demand level and comply with a set of national, regional, or state specifications.

- **Key uses:** A capacity expansion model answers the question: How will this energy efficiency or renewable energy measure affect the composition of the fleet of plants in the future? A capacity expansion model typically takes a long-term view (5–40 years) and can estimate emissions reductions from changes to the electricity grid including the addition and retirement of power plants, rather than changes in how a set of individual power plants is dispatched. Some capacity expansion models include dispatch modeling capability, although typically on a more

¹⁹ An exception to this observation is AVERT, which can be used for short-term projections for NAAQS SIPs and can project 5–6 years out from the base year.

aggregated time scale than dedicated hourly dispatch models. Capacity expansion models that also include dispatch modeling capabilities can be used to address both the short and long-term implications of energy efficiency and renewable energy initiatives.

Both economic dispatch and capacity expansion models are summarized in Table 4-6 and are described in more detail in Chapter 3, “Assessing the Electricity System Benefits of Energy Efficiency and Renewable Energy.”

Table 4-6: Comparison of Sophisticated Modeling Methods for Quantifying Air and GHG Emissions Effects of Energy Efficiency and Renewable Energy Initiatives

Strengths	Limitations	When to Use This Method	Examples of Models ^a
Economic Dispatch			
<ul style="list-style-type: none"> Provides very detailed estimations about specific plant and plant-type effects within the electric sector Provides highly detailed, geographically specific, hourly data Ideal for estimating wholesale electric prices and hours of operation and production 	<ul style="list-style-type: none"> Often lacks transparency Requires technical experience to apply May be labor-, data-, and time-intensive Often involves high labor and software licensing costs Requires establishment of a specific operational profile for the energy efficiency or renewable energy resource Cannot estimate avoided capacity costs from energy efficiency and renewable 	Often used for evaluating: <ul style="list-style-type: none"> Specific projects in small geographic areas Short-term planning (0–5 years) and regulatory proceedings 	<ul style="list-style-type: none"> GE MAPS™ IPM® PLEXOS® PROMOD IV® PROSYM™
Capacity Expansion or Planning			
<ul style="list-style-type: none"> Selects optimal changes to the resource mix based on energy system infrastructure over the long term (5–30 years) May capture the complex interactions and feedbacks that occur within the entire energy system Provides estimates of emissions reductions from changes to the electricity production and/or capacity mix May provide plant-specific detail and perform dispatch simultaneously (IPM) Designed specifically for resource planning Can estimate avoided capacity costs 	<ul style="list-style-type: none"> Often lacks transparency due to complexity Requires significant technical experience to apply May be labor- and time-intensive Often involves high labor and software licensing costs Requires assumptions that have a large impact on outputs (e.g., future fuel costs) 	Used for long-term studies (5–25 years) over large geographical areas such as: <ul style="list-style-type: none"> SIPs Late-stage resource planning Statewide energy plans GHG mitigation plans 	<ul style="list-style-type: none"> AURORA DOE’s NEMS EGEAS e7 Capacity Expansion e7 Portfolio Optimization ENERGY 2020 IPM® LEAP MARKAL, TIMES^b NREL’s ReEDS NREL’s RPM

^a For more information about individual tools, see Section 4.4., “Tools and Resources.”

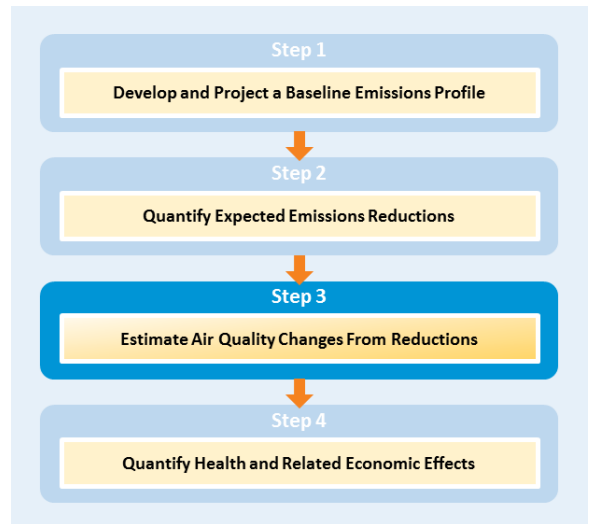
^b MARKAL model and the TIMES model are represented as multipurpose energy planning models, <https://iea-etsap.org/index.php/etsap-tools/model-generators/markal>

4.2.3. Step 3: Estimate Air Quality Changes From Reductions

Energy efficiency and renewable energy measures can reduce air pollutants—both those directly emitted and those that form in the atmosphere—and improve air quality.²⁰ Under Step 3, analysts can quantify the air quality impacts of emissions reductions using existing methods presented in this *Guide*.

Ambient air concentration levels of pollutants that people breathe are the key measures of air quality. Ambient air concentration levels are based on the monitored amount of a pollutant in the air (e.g., in units of micrograms per cubic meter [$\mu\text{g}/\text{m}^3$] or parts per million [ppm]). As noted under “Step 2: Quantify Expected Emissions Reductions,” emissions levels are based on the amount of a pollutant released to the air (e.g., in units of tons) from various sources, such as vehicles and factories. Some emissions travel far from their source to be deposited on distant land and water; others dissipate rapidly over time and distance and/or are transformed into secondary pollutants through chemical reactions in the atmosphere. The health-based standards (NAAQSs) for criteria air pollutants are based on ambient air concentration levels and in some cases an averaging time period (e.g., there are both 24-hour and annual standards for particulate matter). The pollutant concentration to which a person is exposed is just one of the factors that determines if human health will be affected—and the severity of effects if they do occur (U.S. EPA, 2009).

Modeling ambient air quality impacts can be complex, usually requiring sophisticated air quality models and extensive data inputs (e.g., meteorology). Many state and local government air program offices use rigorous air quality modeling methods for their SIPs, as required by the Clean Air Act. Some analysts use reduced-form or basic methods to quickly assess the air quality effects of changes in air pollution. These methods, summarized below, can also be used when evaluating energy efficiency and renewable energy benefits.



Methods for Quantifying Air Quality Changes

Basic Methods

Model developers have created methods for using the output of sophisticated models to produce screening tools that can be used to quickly evaluate expected air quality responses to emissions changes. These “reduced-form” screening tools use information from a series of model simulations in which precursor emissions are reduced by specified amounts (e.g., 10 percent reduction in NO_x , 20 percent reduction in NO_x , 10 percent reduction in volatile organic compounds [VOCs], 20 percent reduction in VOCs, etc.) and assess the responses by various pollutants (e.g., ozone) for each simulation to estimate a general relationship between emissions reductions and ambient pollution concentrations for a given area. The reduced-form method provides scalable multipliers to estimate the change in the ambient concentration of a pollutant due to any change in emissions from precursor pollutants. For example, if a modeled 10 percent reduction in NO_x emissions provided a 5 percent reduction in ozone, and a modeled 20 percent reduction in NO_x provided a 10 percent reduction in ozone, then the reduced-form method might show a 7.5 percent reduction in ozone from a 15 percent reduction in NO_x .

²⁰ Primary pollutants are those emitted directly into the atmosphere whereas secondary pollutants are formed in the atmosphere from chemical reactions involving primary gaseous emissions. For example, primary $\text{PM}_{2.5}$ can be directly emitted while secondary $\text{PM}_{2.5}$ is created through the chemical reactions between sulfur dioxide and nitrogen oxides in the atmosphere.

Once a series of simulations has been completed for a particular region, users can use a reduced-form method to identify the emissions reduction options or scenarios that seem most promising relative to their goals. For those scenarios identified by the screening tool as potentially effective, the user can apply a more sophisticated method to the identified scenarios to more accurately evaluate the spatial and temporal aspects of the expected response.

Strengths of reduced-form methods are that they provide a quick and low-cost way of evaluating the expected response for a variety of scenarios. **Limitations** of reduced-form methods are that they require time and resources to develop the initial general relationship between emissions reductions and ambient concentrations for each pollutant and each given area of interest. Examples of air quality screening tools, such as EPA’s Response Surface Modeling or Source-Receptor Matrix, are described in Section 4.4., “[Tools and Resources](#).”

Sophisticated Methods

Sophisticated computer models are often needed to prepare detailed estimates of the impact of emissions reductions from energy efficiency and renewable energy initiatives on regional concentrations of air pollutants. Three types of relevant air quality models are described below: dispersion models, photochemical models, and receptor models. These models require information on the location of emissions and characteristics of each emissions source, although they may represent photochemistry, geographic resolution, and other factors to very different degrees.

- *Dispersion models.* Dispersion models rely on emissions data, source and site characteristics (e.g., stack height, topography), and meteorological inputs to predict the dispersion of air emissions over time and distance and the impact on air concentrations at selected downwind locations. Although dispersion models can represent simple chemical degradation, these models do not include analysis of complex chemical transformations that occur in the atmosphere, and thus cannot assess the impacts of emissions changes on secondarily formed PM_{2.5} and ozone. These models can be used for directly emitted particles (such as from diesel engines) and air toxics. EPA-recommended models and numerous other dispersion models are available as alternatives or for use in a screening analysis as described. <https://www.epa.gov/scram/air-quality-dispersion-modeling-preferred-and-recommended-models>
- *Photochemical models.* Photochemical models capture many of the complex physical and chemical processes that occur in the atmosphere as gaseous emissions of different chemicals react and form secondary PM_{2.5} and ozone. These models perform complex computer simulations, and can be applied at a variety of scales from the local to the global level. A range of photochemical-type air quality tools are also available for use in assessing control strategies. They may not be air quality models per se, but they combine results from complex models with monitor data to calculate design values. <http://www3.epa.gov/scram001/photochemicalindex.htm>
- *Receptor models.* Receptor models can identify and quantify the sources of air pollutants at a specific location, called the “receptor” location. Unlike photochemical and dispersion air quality models, receptor models do not use pollutant emissions, meteorological data, and chemical transformation mechanisms to estimate the contribution of sources to receptor concentrations. Instead, receptor models use the chemical and physical characteristics of gases and particles measured at the source and receptor to identify source contributions to receptor concentrations. These models are a natural complement to other air quality models and are used as part of SIPs for identifying sources contributing to air quality problems. <http://www3.epa.gov/scram001/receptorindex.htm>

Examples of all three of these types of models are summarized in Section 4.4., “[Tools and Resources](#).”

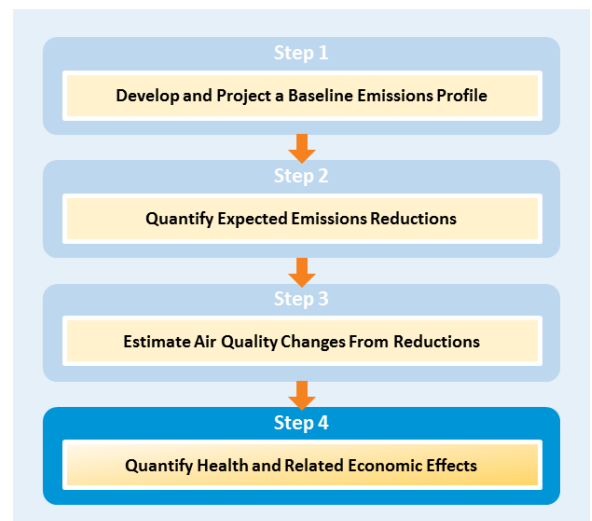
Key Considerations When Selecting a Method to Assess Air Quality Impacts

Air quality impact analysis enables energy efficiency and renewable energy policy analysts to quantify current and future changes in the concentration of ambient air pollutants that affect human health. When selecting an air quality model that will comprehensively model either short- or long-term changes in air quality, particularly in urban regions, there are a number of modeling inputs and other factors to consider, as described below.

- *The pollutants for analysis.* Deciding what pollutants to model is a critical decision when selecting a model. Directly emitted primary pollutants—such as CO₂, SO₂, primary particulate matter (PM), and many air toxics—require models capable of modeling dispersion and transport (i.e., dispersion models). Secondary pollutants, such as ozone and most PM_{2.5}, are formed by chemical reactions occurring in the atmosphere among other pollutants. Secondary pollutants are considerably more difficult to model, requiring a model capable of handling complex chemical transformations (i.e., photochemical models), as well as short- and long-range transport.
- *Sources affected.* The number and types of sources that result in emissions directly affect the selection of an appropriate air quality model. A model that is appropriate for modeling the impact of a single generating facility with a tall smokestack would be inappropriate for analysis of an initiative that would affect electricity generation throughout the region.
- *Timeframe.* Pollutants have different relevant exposure timeframes for human health impacts. For some pollutants, human health impacts result from long-term exposure; for other pollutants, human health impacts result from short-term (e.g., daily or hourly) exposure. The impact assessment timeframe can be a key factor in determining appropriate methods for modeling air quality impacts of emissions reductions.
- *Data availability and resolution.* Sophisticated air quality models require large amounts of input data describing a variety of characteristics of the energy-environment system, including emissions inventory data, ambient air quality monitoring data, and meteorological data. Availability of required data is a key factor in selecting a method.
- *Geographic scope.* Selecting the most appropriate analytical tool to model air quality impacts depends on the geographic scope of the analysis. Modeling large geographic areas (e.g., a state or a group of states) often requires a different model than modeling smaller areas (e.g., a city).
- *Meteorological and topographical complexities.* When structuring an air quality impact analysis, it is important for analysts to consider regional meteorological and topographical conditions that may affect the transport and chemical reaction of pollutants within a region's atmosphere and which air quality models can account for these factors.

4.2.4. Step 4: Quantify Health and Related Economic Effects

Health research has established relationships between air pollution, air quality, and health effects that range from respiratory symptoms and missing a day of school or work, to severe effects such as hospital admissions, heart attacks, onset of chronic heart and lung diseases, and premature death. Quantifying the avoided health impacts from reducing air pollution emissions and improving air quality using well-established methods has become a helpful way for analysts to describe the benefits of energy efficiency and renewable energy programs.



Presenting the benefits of clean air initiatives in tangible terms such as reduced incidences of adverse health effects can be a valuable way to differentiate between program options and an effective technique for communicating some of the most important advantages of energy efficiency and renewable energy. This section describes basic and sophisticated modeling methods for estimating the human health effects of air quality changes and the monetary value of avoided health effects, a key component of a comprehensive economic benefit-cost analysis.

Methods for Quantifying Health Impacts

The health benefits of air quality improvements and the related economic benefits can be estimated through basic or sophisticated modeling methods. Basic modeling methods use results from existing studies, such as regional impact analyses, to extrapolate a rough estimate of the health impacts of a single new facility or energy efficiency or renewable energy initiative. More sophisticated modeling methods involve more calculations and are typically applied using screening-level analytical models that can run quickly on a desktop computer, or rigorous and complex computer models that often run on powerful computers and may involve a series of separate models. Basic and sophisticated methods are described below.

Basic Method

A common reduced-form (or screening-level) method for characterizing the monetized human health benefits of improved air quality is to use pre-calculated health "benefit-per-ton" or a health "benefit-per-kWh" estimate or factor as measured in dollars per ton of PM reduced or dollars per kWh of fossil-based electricity avoided. Monetized health benefit factors:

- Relate changes in the emissions of a pollutant or changes in fossil fuel-based electricity generation to the number of avoided cases of premature death and illness to estimate the economic value of these avoided cases.
- Involve a type of "benefits transfer" analysis, where the results from comprehensive modeling (e.g., a regional control strategy for all coal-fired power plants within a region) are used to approximate the effects of a similar project that shares many of the same attributes.
- Are generally used to quantify fine particle- or ozone-related short-term health impacts but are also used to quantify the value of long-term climate damages avoided by reducing carbon dioxide (CO₂) (e.g., social cost of carbon); depending on the metric, they are multiplied against the change in:
 - ▶ Emissions (in tons) of each precursor of PM_{2.5} (e.g., directly emitted PM_{2.5}, SO₂, NO_x) or ozone (e.g., NO_x, VOCs) or of each ton of CO₂
 - ▶ Fossil fuel-based electricity generation (in kWh)
- Represent a simplified composite of the air quality modeling, health impacts estimation, and valuation estimation steps used in more complex approaches described under the section, "Sophisticated Methods," below.

AIR POLLUTION-RELATED HEALTH EFFECTS ANALYSTS CAN QUANTIFY, INCLUDE, BUT ARE NOT LIMITED TO:

- Premature death (i.e., mortality)
- Chronic and acute bronchitis
- Non-fatal heart attacks
- Respiratory or cardiovascular hospital admissions
- Upper and lower respiratory symptom episodes
- Asthma-related health effects
- Asthma emergency room visits
- Minor restricted activity days
- Work or school loss days

Basic monetized health benefit factors are only first-order approximations of the results that a rigorous analysis might estimate. They do not provide detail about the specific number and type of health incidences avoided, just the economic value of avoiding them as determined in a separate analysis. However, they can serve as pragmatic benefits analysis tools and can be especially useful in assessing the monetized benefits of projects where it is impractical to conduct a complex analysis of each alternative. Benefit factors can be useful as “rule of thumb” factors during screening analysis, when formal air quality modeling analyses are not feasible due to time and resource constraints. They can also be used as a more formal part of the analysis of proposed projects.

EPA BENEFIT PER-TON FACTORS

EPA developed sector-based benefit per-ton factors for 17 key source categories, including electricity generating units, residential wood burning, and petroleum refineries. Applying these factors simply involves multiplying the emissions reduction by the relevant benefit per-ton metric.

<https://www.epa.gov/benmap/sector-based-pm25-benefit-ton-estimates>

Strengths of using monetized health benefit factors:

- *Simplicity.* Users need only know the anticipated or historical level of emissions reductions.
- *Resource efficiency.* Generating benefits factors requires only a simple spreadsheet.
- *Speed.* Results can be generated very quickly.

Limitations of using monetized health benefit factors estimates:

- *Limited ability to account for spatial heterogeneity.* The benefit per-ton factors are best viewed as the average benefits of emissions reductions within a specific spatial scale—either nationwide or within one of a few specific urban or other geographical areas. In general, the benefit per-ton factors are most appropriate for characterizing the benefits of broad-scale emissions reductions.
- *Limited flexibility.* Users are unable to modify any of the assumptions within the benefit per-ton or benefit-per-kWh metrics, including the types of interventions used (in the case of benefit-per-kWh factors), epidemiological studies used to relate air quality changes and health impacts, year of population exposure, valuation functions, or air quality modeling.

Sophisticated Methods

Instead of or in addition to using benefit factors or metrics as described above, analysts can use a more sophisticated method, such as the *damage function method*, to quantify human health and related economic effects of air quality changes. The damage function method incorporates air pollution monitoring data, air quality modeling data, U.S. Census Bureau data, population projections, and baseline health information to relate a change in ambient concentration of a pollutant to population exposure, and quantifies the incidence of new or avoided adverse health endpoints. Sophisticated methods like this one address the complex relationship between changes in air quality and health with more granularity and specificity in the results than basic methods. They would be most appropriate to use when emissions reductions and air quality changes vary across geographic areas, when multiple pollutants are reduced simultaneously, when a high degree of spatial resolution is needed, when impacts on specific health effects or specific populations are desired, or when the analyst wants flexibility regarding the assumptions about analysis year, health impacts, or economic values.

Conducting a sophisticated analysis using a damage function method involves:

1. Estimating the effects on various health end points associated with changes in ambient air quality (e.g., ozone and/or PM_{2.5}), and
2. Calculating the economic value of the avoided health effects.

These two steps are described in greater detail below.²¹

1. Estimating the effects on various health end points associated with changes in ambient ozone and/or PM_{2.5}.

Analysts estimate health effects as follows:

$$\text{Health Effect} = \text{Air Quality Change} * \text{Health Effect Estimate} * \text{Exposed Population} * \text{Health Baseline Incidence}$$

Where:

- *Air Quality Change* is the difference between the starting air pollution level (i.e., the baseline) and the air pollution level after some change, such as a new regulation (i.e., the control). Methods to quantify air quality changes were described in “Step 3: Estimate Air Quality Changes From Reductions,” and serve as a starting point for quantifying overall health effects.
- *Health Effect Estimate* is an estimate of the percentage change in the risk of an adverse health effect due to a one-unit change in ambient air pollution. Epidemiological studies are a good source for effect estimates. The health effect estimate is typically quantified using a damage or concentration-response (C-R) function which represents the relationship between the concentration of a particular pollutant and the response by the population. For example, the concentration of the pollutant may be fine particulate matter (PM_{2.5}) in µg/m³ per day, and the population response may be the number of premature deaths per 100,000 people per day. C-R functions are estimated in epidemiological studies. A functional form is chosen by the researcher, and the parameters of the function are estimated using data on the pollutant (e.g., daily levels of PM_{2.5}) and the health response (e.g., daily mortality counts).²²
- *Exposed Population* is the number of people affected by the air pollution reduction in a given area. Most health effect factors vary by population age, and so it is important to gather population data that are stratified by these same age ranges. U.S. Census Bureau data are a good source for this information. In addition, private companies may collect this information and offer it for sale.
- *Health Baseline Incidence* (i.e., rate) is an estimate of the average number of people who die (or suffer from some adverse health effect) in a given population over a given period of time. For example, the health incidence rate might be the probability that a person will die in a given year. In some cases, where ailments are prevalent within the population, like for asthma, analysts would also use the prevalence rate that estimates the percentage of the general population with a given ailment. Baseline incidence and prevalence data can be found across a number of sources, including but not limited to the: Centers for Disease Control (CDC) WONDER database (<http://wonder.cdc.gov/>), Healthcare Cost and Utilization Project family of databases, American Lung Association, National Center for Education Statistics, National Health Interview Survey, and epidemiological literature.

2. Calculating the economic value of the avoided health effects

Once analysts calculate the number of health effect cases expected to increase or be avoided, they can calculate the economic value of those changes in health effects as follows:

²¹ Steps for conducting a sophisticated analysis using a damage function method stem from the U.S. EPA’s 2017 Benefits Mapping and Analysis Program Community Edition (BenMAP-CE) User’s Manual, available at: https://www.epa.gov/sites/production/files/2015-04/documents/benmap-ce_user_manual_march_2015.pdf.

²² For more information about the types of functional forms available, see Environmental Benefits Mapping and Analysis Program – Community Edition (BenMAP-CE) User’s Manual Appendix C: Deriving Health Impact Functions at https://www.epa.gov/sites/production/files/2017-04/documents/benmap_ce_um_appendices_april_2017.pdf or the User Manual of the CO-Benefits Risk Assessment (COBRA) Screening Model Appendix C: Health Impact Functions.

*Economic Value = Health Effect * Value of Health Effect*

Where:

- *Health Effect* is the number of cases estimated for a given population and time period, as calculated above.
- *Value of Health Effect* is based on methods from published economics literature.

Studies are available that use a variety of valuation methods, including surveys to elicit peoples' willingness to pay to reduce the risk of a particular health impact and estimates of the typical financial cost of the illness in terms of direct medical costs to a hospital or medical professional and/or the opportunity costs associated with an illness. One value commonly found in economic literature, for example, is the value of a statistical life (VSL), which is based on peoples' willingness to pay for small reductions in mortality risks.²³ Analysts can use single values found in the literature or look across a range of studies to determine an intermediate value. For example, EPA typically cites \$8.7 million as the unit VSL. This estimate is the mean of a distribution fitted to 26 VSL estimates that appear in the economics literature and that have been identified in the Section 812 Reports to Congress as "applicable to policy analysis." This represents an intermediate value from a variety of estimates, and it is a value EPA has frequently used in regulatory impact analyses as well as in the Section 812 Retrospective and Prospective Analyses of the Clean Air Act.²⁴

It is important to note that the economics literature concerning the appropriate method for valuing reductions in premature mortality risk is still developing. The adoption of a value for the projected reduction in the risk of premature mortality is the subject of continuing discussion within the economics and public policy analysis communities. Issues such as the appropriate discount rate and whether there are factors, such as age or the quality of life, that should be taken into consideration when estimating the value of avoided premature mortality are still under discussion.

Strengths of using sophisticated methods:

- *High resolution:* Higher degree of resolution regarding health effects and geography.
- *Robust outputs:* Ability to estimate health and related economic impacts of simultaneous changes in multiple pollutants.
- *Flexibility:* Flexibility to modify underlying assumptions regarding the relationship between and timing of emissions changes, health effects, and related economic values.

Limitations of using sophisticated methods:

- *Data intensiveness:* Sophisticated methods require a high level of health, population, and economic data.
- *Resource intensiveness:* It may be costly or time intensive to compile datasets and appropriately represent the relationships between emissions changes and health.
- *High complexity:* These methods require a high level of expertise related to health impact modeling.

Sophisticated analyses of health and related economic impacts involve numerous data points and calculations and so modeling tools are typically used to quantify health impacts. EPA has developed two tools, the Co-Benefits Risk Assessment (COBRA) Health Impact Mapping and Screening Tool and the Environmental Benefits Mapping and Analysis

²³ For additional information on mortality risk valuation, see <https://www.epa.gov/environmental-economics/mortality-risk-valuation#means>.

²⁴ For more information on how the value is derived, see Appendix I of *BenMAP-CE User's Manual, Appendices*, U.S. EPA, 2017. https://www.epa.gov/sites/production/files/2017-04/documents/benmap_ce_um_appendices_april_2017.pdf.

Program – Community Edition (BenMAP-CE), to make it easier for analysts to quantify health and related economic impacts of changes in air pollution or air quality.

Table 4-7 compares methods and specific tools and resources available for quantifying health impacts to help analysts understand when they might select one method or tool over another. If an analyst is interested in quantifying the changes in health incidences *and* the health-related economic value associated with changes in PM, for example, he or she could select either of the sophisticated EPA tools listed, COBRA or BenMAP-CE. If air pollution changes (e.g., in tons and not concentrations) are an input to the analysis, the analyst would use the COBRA model, since BenMAP-CE requires air *quality* changes as inputs, not just emissions. Alternatively, if the analyst wanted to quantify the changes in health incidences and the health-related economic value associated with changes in ground-level ozone, he or she would select the BenMAP-CE model and would need to conduct air quality modeling before using the tool.

Table 4-7: Examples of Tools and Resources That Quantify Health Impacts

EPA Tool or Factor		Basic Approach		Sophisticated Approach	
		Benefit-per-Ton Factors	Benefit-per-kWh Factors	COBRA ^a	BenMAP-CE
Type of effect estimated	Changes in the number of health incidences			X	X
	Economic value of changes in number of health incidences	X	X	X	X
Emissions analyzed	Changes in PM _{2.5}	X	X	X	X
	Changes in ozone				X
Type of input data required	Changes in air pollution (e.g., tons)	X		X	
	Changes in electricity generation (kWh)		X		
	Changes in air quality (e.g., µg/m ³)				X
Level of expertise required	Novice	X	X	X	
	Experienced	X	X	X	X
User flexibility	Includes/uses default functions and values	X	X	X	X
	Allows users to change assumptions and values			X	X

^a COBRA 3.0, released in September 2017, allows users to change assumptions related to population and baseline incidence.

Analysts can, and often do, combine methods and models. For instance, a Lawrence Berkeley National Laboratory study used a variety of analytic tools—ReEDS, AVERT, and COBRA—that apply methods described in this chapter to quantify monetized health benefits and climate benefits of increased solar energy production in the United States (Wiser, R. et al., 2016). Section 4.3., “[Case Studies](#),” describes two other analyses that also combined methods (and tools) to quantify emissions and health impacts of energy efficiency and renewable energy. For additional information on available tools and resources for quantifying health effects, see Section 4.4., “[Tools and Resources](#).”

4.3. CASE STUDIES

The following two case studies illustrate how some of the methods described earlier have been applied to quantify the emissions and/or health benefits of energy efficiency and renewable energy. Information about a range of tools and resources analysts can use to quantify these benefits, including those used in the case studies, is available in Section 4.4., “Tools and Resources.”

4.3.1. Regional Greenhouse Gas Initiative – Emissions and Health Benefits

Benefits Assessed in Analysis

- NO_x reductions
- SO₂ reductions
- Health benefits from reduced air pollution

Savings Metrics Assessed

- Tons of air pollution reduced
- Present value of health benefits (e.g., reduced asthma and respiratory disease) from air pollution reductions

Energy Efficiency/Renewable Energy Program Description

The Regional Greenhouse Gas Initiative (RGGI) is a regional market-based regulatory program designed to reduce GHG emissions from the electric power section. RGGI started in 2009 and, as of early 2018, nine states in the Northeast and Mid-Atlantic participate: Connecticut, Delaware, Massachusetts, Maryland, Maine, New Hampshire, New York, Rhode Island, and Vermont. RGGI is a cap-and-trade program that auctions GHG allowances to regulated power plants. Since 2009, RGGI has raised more than \$3 billion through these auctions to support the RGGI states’ investments in energy efficiency, renewable energy, and other public benefit programs.

While RGGI is primarily a GHG regulatory program, the change in electricity generation in the region to comply with the regulations, along with the investments in energy efficiency and renewable energy from the allowance auction revenue, have resulted in significant reductions of emissions of criteria pollutants from the electricity sector.

Methods Used

In 2017, Abt Associates released an analysis of the public health benefits resulting from RGGI during the first two compliance periods (covering 2009 to 2014). This analysis relied on existing work by Analysis Group, which modeled the change in electricity dispatch at EGUs between 2009 and 2014, comparing a base scenario that excludes RGGI against a scenario that includes RGGI, using two separate electricity dispatch models: GE MAPS™ and PROMOD®.

Abt estimated the change in NO_x and SO₂ emissions at each power plant based on the modeled change in electricity generation at each plant. The change in generation was multiplied by plant-specific NO_x and SO₂ emissions rates (lbs./MWh), which were derived from data from eGRID, the National Emissions Inventory, and EPA’s Clean Air Markets Division. The emissions were calculated using the following equation:

$$\text{Total Annual Emissions (lbs)} = \text{Annual Electricity Generation (MWh)} \times \text{Emissions Rate (lbs/MWh)}$$

The public health benefits were estimated using both COBRA and BenMAP-CE. COBRA was used to conduct the air quality modeling, and BenMAP-CE was used to estimate the incidence and value of the health impacts. The analysis used BenMAP-CE rather than COBRA for the health effects modeling because the analysis covered a 6-year period, and it was

easier to analyze multiple years in BenMAP-CE than in the version of COBRA available at the time.²⁵ Abt developed revised emissions baselines for COBRA for each of the years from 2009 to 2014 based on data from EIA on the change in use of coal and natural gas in the electricity sector during that period. The baseline was also adjusted to account for other relevant regulations outside of RGGI, such as Maryland’s Healthy Air Act of 2006, which resulted in the installation of SO₂ controls at some power plants starting in 2009.

Results

RGGI resulted in improved air quality throughout the Northeast states and created major benefits to public health and productivity, including avoiding hundreds of premature deaths and tens of thousands of lost work days. In total, the cumulative health benefits from RGGI between 2009 and 2014 are estimated at between \$3.0 and \$8.3 billion, with a central estimate of \$5.7 billion. Table 4-8 provides the summary results of the analysis.

The analysis estimated positive health benefits in each state in the Northeast and Mid-Atlantic, including some states that do not participate in RGGI, such as Pennsylvania and New Jersey. However, the benefits were not evenly distributed throughout the region. The majority of the benefits in the region were due to SO₂ emissions reductions at a small number of coal plants in the Mid-Atlantic. Figure 4-6 shows a map of the distribution of benefits throughout the region.

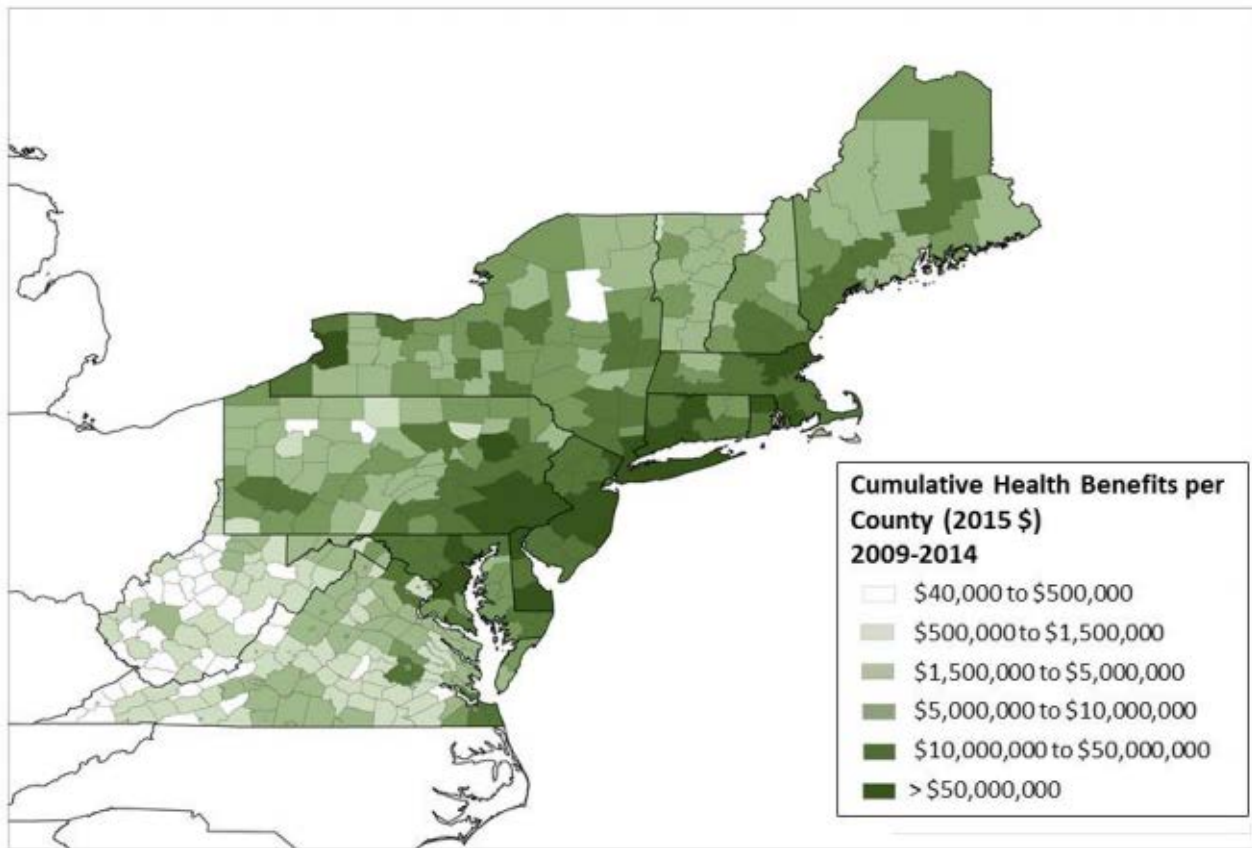
Note that the analysis did not account for ozone or any other co-benefits of RGGI, such as improved ecosystem services. The analysis also did not consider the ongoing health benefits associated with energy efficiency and renewable energy investments that persist beyond 2014. As such, the estimated health benefits presented in this analysis are likely conservative.

Table 4-8: Summary of Cumulative RGGI Health Benefits, 2009–2014

Avoided Health Effects	Avoided Mortality		
	<ul style="list-style-type: none"> ▪ 300–830 premature adult deaths 		
	Avoided Morbidity		
	<ul style="list-style-type: none"> ▪ 35–390 nonfatal heart attacks ▪ 420–510 cases of acute bronchitis ▪ 8,200–9,500 asthma exacerbations ▪ 13,000–16,000 respiratory symptoms 		
Value of Avoided Health Effects	Other Avoided Impacts		
	<ul style="list-style-type: none"> ▪ 180–220 hospital admissions ▪ 200–230 asthma emergency room visits ▪ 39,000–47,000 lost work days ▪ 240,000–280,000 days of minor restricted activity 		
	Low	Central	High
	\$3.0 billion	\$5.7 billion	\$8.3 billion

²⁵ Note that this analysis used COBRA v2.71. The current version of COBRA (v.3.0) includes new features, such as the ability to import user-defined baselines, population projections, and baseline health incidence datasets, which make it easier to analyze multiple years of data.

Figure 4-6: Cumulative Health Benefits of RGGI, 2009–2014



Source: Abt Associates, 2017.

For More Information

Resource Name	Resource Description	URL Address
Regional Greenhouse Gas Initiative – Emissions and Health Benefits Case Study		
<i>Analysis of the Public Health Benefits of the Regional Greenhouse Gas Initiative, 2009–2014</i>	This is the full 2017 report by Abt Associates that describes the analysis of the public health benefits of RGGI in more detail.	http://abtassociates.com/RGGI
<i>The Economic Impacts of the Regional Greenhouse Gas Initiative on Ten Northeast and Mid-Atlantic States: Review of the Use of RGGI Auction Proceeds from the First Three-Year Compliance Period</i>	This 2011 report discusses the modeling performed by the Analysis Group to determine the impacts of RGGI on the electricity sector during the first compliance period (2009–2011).	http://www.analysisgroup.com/uploadedfiles/content/insights/publishing/economic_impact_rggi_report.pdf
<i>The Economic Impacts of the Regional Greenhouse Gas Initiative on Nine Northeast and Mid-Atlantic States: Review of RGGI’s Second Three-Year Compliance Period (2012–2014)</i>	This 2015 report is a follow up on the first report from the Analysis Group. It discusses the impacts of RGGI on the electricity sector during the second compliance period (2012–2014).	http://www.analysisgroup.com/uploadedfiles/content/insights/publishing/analysis_group_rggi_report_july_2015.pdf

4.3.2. Environmental and Health Co-Benefits from U.S. Residential Energy Efficiency Measures

Benefits Assessed in Analysis

- Air pollutant reductions (NO_x, SO₂, CO₂)
- Economic benefits
- Air quality benefits
- Human health benefits

Savings Metrics Assessed

- Value of annual health benefits for 2013 from reduced mortality (\$, number of premature deaths per year)
- Value of CO₂ emissions reductions based on the social cost of carbon (\$)
- Residential electricity savings (in terms of both terawatt-hours [TWh] and as a percent of residential electricity consumption)
- Tons of air pollution reduced

Energy Efficiency/Renewable Energy Program Description

In 2016, researchers from Boston University and the University of North Carolina Chapel Hill published an analysis that estimated the potential health co-benefits from increasing residential insulation (including walls, ceilings, and floors) to building code standards set in the 2012 International Conservation Code (IECC) for all single-family homes across the continental United States in 2013.

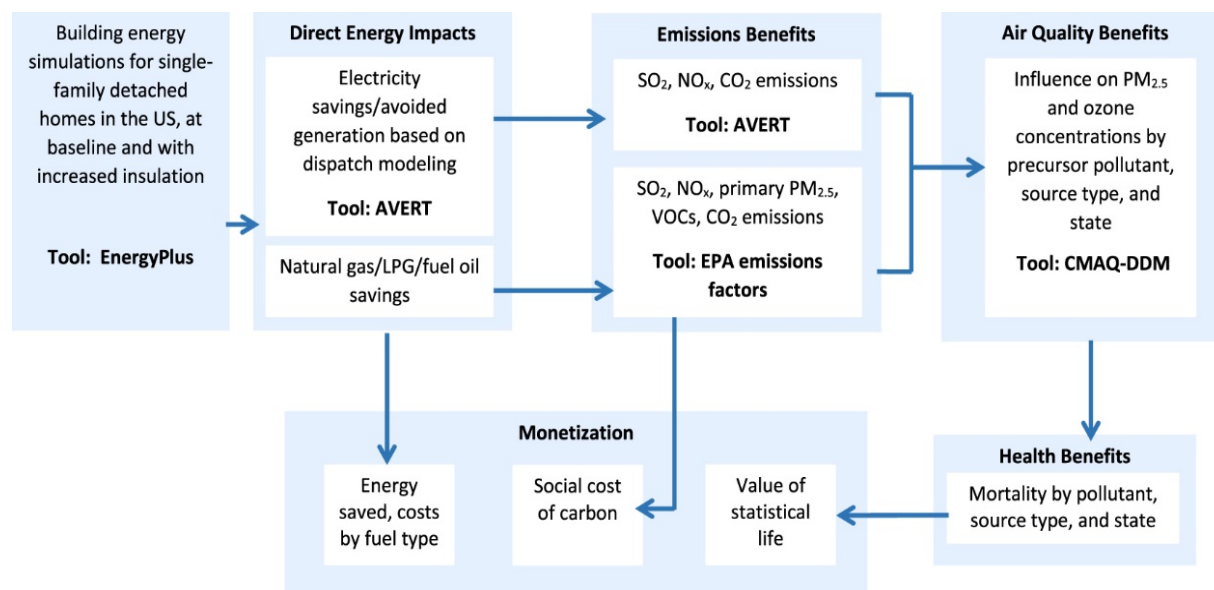
Methods Used

To evaluate the potential health co-benefits from increasing residential energy efficiency, the analysts utilized a multi-component model (see Figure 4-7) to quantify the expected energy impacts; to quantify the resulting emissions reductions, air quality, and health impacts; and to monetize these impacts to determine the economic benefits in dollars.

Energy Impacts

- The researchers estimated energy savings produced by retrofitting single-family homes with insulation to meet the 2012 IECC by using the energy simulation program EnergyPlus. Residential building prototypes used for this study were obtained from the DOE's Building Energy Code Program and modified to be representative of U.S. single-family homes, based on data from the EIA's 2009 Residential Energy Consumption Survey (RECS).
- The EnergyPlus model was run for all single-family homes with both current insulation and improved insulation. The energy savings from increased energy efficiency were calculated by comparing energy consumption between these two scenarios based on state-specific templates assigned by RECS.

Figure 4-7: Multi-Component Model Framework Used for the Co-Benefits Assessment



Source: Levy et al., 2016.

Emissions Impacts

- The analysts used EPA’s AVERT tool to calculate reductions in SO₂, NO_x, and CO₂ by state and season for EGUs.²⁶ See the Dispatch Curve Analysis method described in Section 4.2.2., “Step 2: Quantify Expected Emissions Reductions” for more information on the method that AVERT uses. Electricity savings from the EnergyPlus model were matched to the dispatch regions used by AVERT based on the number of households in each region.

Air Quality Benefits

- Atmospheric concentrations of PM_{2.5} and ozone at the state level were calculated using the Community Multiscale Air Quality (CMAQ) model v.4.7.1 based on AVERT outputs and from residential combustion data. The Weather Research Forecast Model and EPA’s 2005 National Emissions Inventory provided additional inputs for the model.

Estimating Health Benefits

- Estimates of the mortality rate for PM_{2.5} were obtained from two existing cohort studies that measured the link between exposure to this pollutant and health outcomes. An increase in PM_{2.5} of 1 µg m⁻³ for annual ambient concentrations was estimated to result in a 1-percent increase in the mortality rate.
- Estimates of the mortality rate for ozone were obtained from exposure studies in multiple U.S. cities and meta-analyses that derived estimates from similar studies. A 10-parts-per-billion increase in daily 8-hour maximum concentrations was estimated to increase the daily mortality rate by 0.4 percent.

Monetizing Benefits

- The VSL metric described under Sophisticated Methods in Section 4.2.4, “Step 4: Quantify Health and Related Economic Effects,” was used to monetize health benefits. The analysts used a VSL of \$9.7 million in 2013 dollars, with a lower bound of \$2 million and an upper bound of \$20 million. The VSL, discount rates, and the mortality lag structure are modeled on practices used by EPA when conducting regulatory impact analyses.

²⁶ At the time of the analysis, AVERT did not include estimates of direct PM_{2.5}. The analysts, therefore, did not quantify direct PM_{2.5} impacts but used the SO₂ and NO_x outputs to quantify changes in secondary PM_{2.5}. AVERT was updated in 2017 to include direct PM_{2.5} enabling more comprehensive analyses of PM-related benefits.

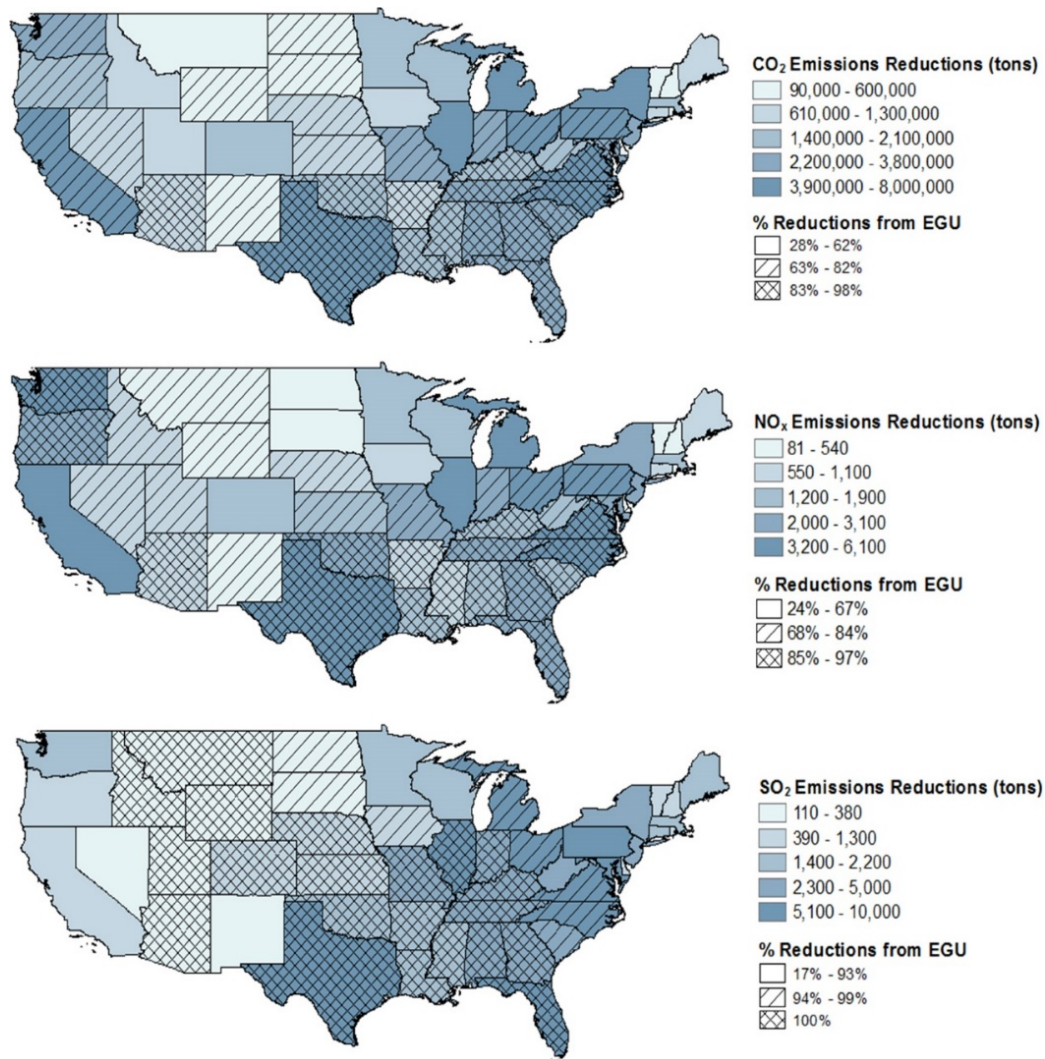
- The economic benefits of reduced CO₂ emissions are calculated using the social cost of carbon developed by the federal government’s Interagency Working Group on the Social Cost of Carbon in 2013. A discount rate of 3 percent was used for the primary estimate, with other discount rates used for sensitivity testing.

Results

The analysts found that the improvement in residential energy efficiency measures would result in 320 fewer premature deaths per year due to the reduction in criteria pollutants nationally, representing \$2.9 billion in health co-benefits. They estimated that the CO₂-related benefits would be \$3.8 billion and that the scenario could result in \$11 billion in economic benefits from reduced energy consumption. Based on their analysis, the researchers found that an increase of residential energy efficiency equivalent to the scenario modeled would result in national climate and health co-benefits of \$49 per ton of EGU CO₂ emissions reduced, with a range across states from \$12 to \$390 per ton of EGU CO₂ reduced.

For a state-by-state breakdown of the results, Figure 4-8 shows emissions reductions by state for CO₂, NO_x, and SO₂, indicating the percent of reductions attributable to changes in generation from EGUs, while Figure 4-9 shows the change in premature deaths per year, with pie charts for each state indicating the contribution of specific emissions reductions to these changes.

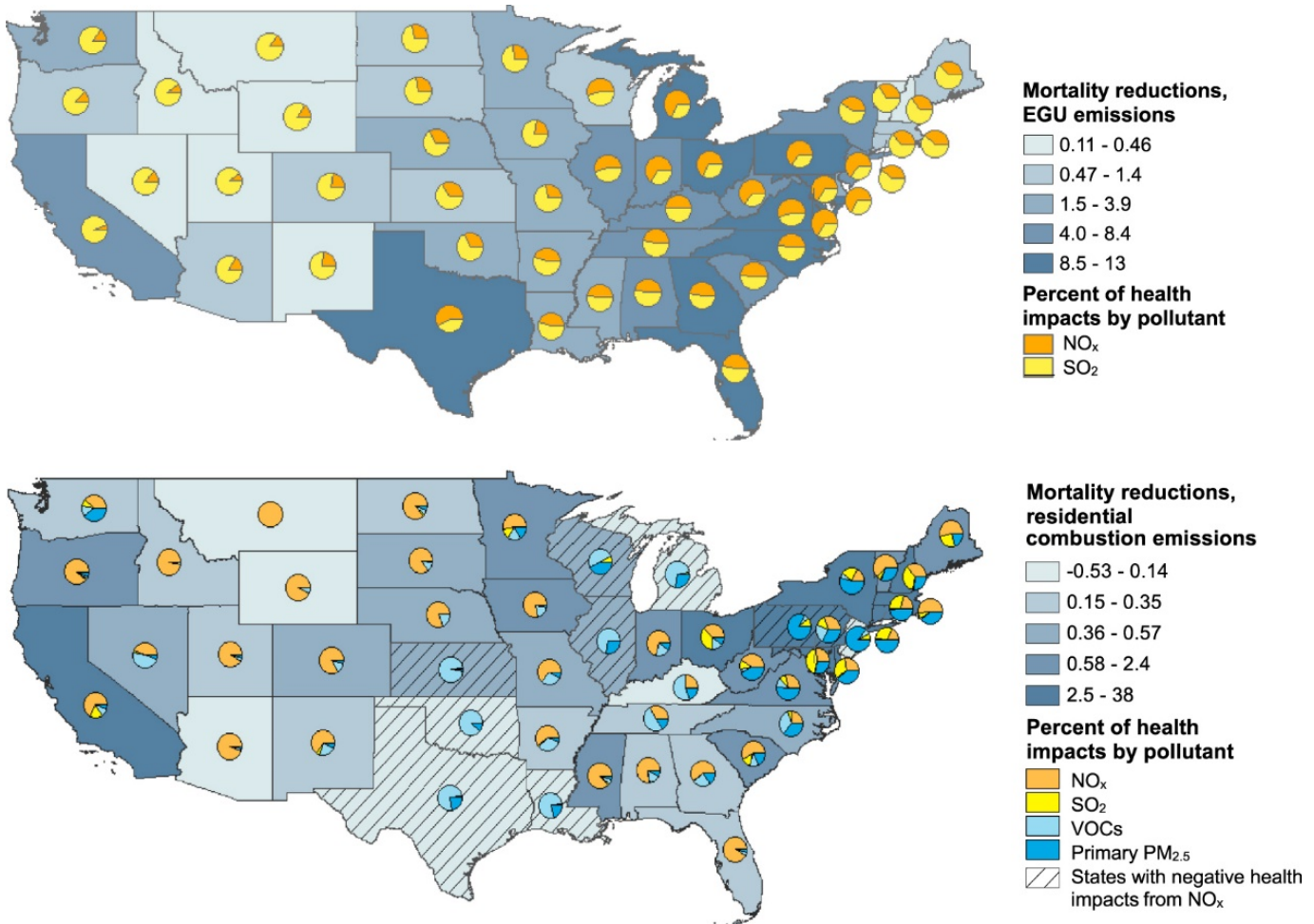
Figure 4-8: Annual Emissions Reductions by State



Source: Levy et al., 2016.

Note: Emissions reductions represent the total reductions from both EGUs and residential combustion sources.

Figure 4-9: Annual Mortality Reductions by State



Source: Levy et al., 2016.

Note: Mortality reductions are shown as the change in the number of premature deaths per year.

For More Information

Resource Name	Resource Description	URL Address
Environmental and Health Co-Benefits from U.S. Residential Energy Efficiency Measures Case Study		
“Carbon Reductions and Health Co-Benefits From U.S. Residential Energy Efficiency Measures”	This 2016 paper (Levy et al.) documents this analysis and was published in <i>Environmental Research Letters</i> .	http://iopscience.iop.org/article/10.1088/1748-9326/11/3/034017/meta

4.3.3. Minnesota Power’s Boswell Unit Retrofit – Emissions and Health Benefits

Benefits Assessed in Analysis

- SO₂ reductions
- PM reductions
- Mercury reductions (only a qualitative estimate of potential benefits)

Savings Metrics Assessed

- Tons of air pollution reduced
- Present value of health benefits (e.g., reduced asthma and respiratory disease) from air pollution reductions

Energy Efficiency/Renewable Energy Program Description

In 2012, Minnesota Power submitted an emissions reduction proposal, the *Boswell Unit 4 Environmental Improvement Plan*, under the state’s Mercury Emissions Reduction Act of 2006. The Boswell generating station was built in the 1980s and is the largest power plant in Minnesota, with a capacity of 585 MW. The emissions reduction plan proposed replacing air pollution control equipment for Unit 4 at the Boswell plant with a \$240 million scrubbing system that would reduce sulfur dioxide (SO₂), particulate matter (PM), and mercury emissions.

Methods Used

In 2013, the Minnesota Pollution Control Agency (MPCA) used air quality and air dispersion modeling to translate projected annual emissions reductions based on the Boswell Unit 4 plan into changes in air quality. The baseline emissions were taken from MPCA’s Annual Emissions Inventory for Unit 4 for 2011. The emissions reduction projections were based on the proposal Minnesota Power submitted to MPCA in 2012 for the retrofit project. MPCA used the Comprehensive Air Quality Model with Extensions (CAMx), version 5.41, to translate the reductions in SO₂ and PM emissions from the Unit 4 retrofit to changes in ambient concentrations of fine particulate matter (PM_{2.5}).

The MPCA used EPA’s Environmental Benefits Mapping and Analysis Program (BenMAP) to assess the health and economic benefits of pollution reduction.

Results

Since 2015, the Boswell Unit 4 retrofit reduced SO₂ by nearly 40 percent, PM by 80 percent, and mercury emissions by nearly 90 percent (Table 4-9).

The health benefits of the emissions reductions include an estimated two to four avoided mortalities per year (Table 4-10). The total annual value of the health benefits from Boswell’s PM_{2.5} emissions reductions are between \$14 and \$31 million (Table 4-11).

Although the health benefits from mercury reductions are not easily quantified, the MPCA found that “the weight of evidence supports a general finding that reducing mercury emissions will lead to economic benefits in terms of health improvements.” For example, the MPCA report provides estimates from the literature on the annual human health benefits from avoiding declining IQ in children, ranging from \$1,300 to \$7,000 per pound of mercury reduced. Using these values, MPCA estimated \$270,000 to \$1.4 million of annual benefits of avoiding mercury emissions in the state of Minnesota.

Table 4-9: Annual Emissions for Minnesota Power Boswell Energy Center Unit 4

	SO ₂ (tons/year)	PM (tons/year)	Mercury (lbs./year)
Baseline, prior to plan implementation	1,061	1,275	228
After implementation of plan	647	259	26
Emissions decrease	414	1,016	202
Percentage change	-39%	-80%	-89%

Note: Based on 2011 emissions levels.

Table 4-10: Estimate of the Annual Reduction in PM_{2.5}-Related Health Outcomes from Boswell Energy Center Unit 4 Multi-Pollutant Reduction Plan

Health Effect	Annual Reduction in Deaths and Illness		
	Minnesota	Modeled Portions of Adjacent States*	Total**
Mortality (low estimate)	1	1	2
Mortality (high estimate)	2	1	4
Nonfatal heart attack	1	1	2
Hospital admissions, cardiovascular	0	0	0
Hospital admissions, respiratory	0	0	0
Emergency room visits, respiratory	0	0	1
Acute bronchitis	2	1	2
Lower respiratory systems	19	12	32
Upper respiratory symptoms	28	18	45
Asthma exacerbation	28	18	47
Work loss days	125	78	203
Acute respiratory symptoms	740	468	1,208

* The region covered in this assessment includes portions of the neighboring states.

** Due to rounding, totals may not agree with the sum of subtotals.

Table 4-11: Estimated Value of Benefits from Reductions in SO₂ and PM_{2.5} at Boswell Energy Center Unit 4

Health Effect	Estimated Value of Benefits (\$ Thousands)		
	Minnesota	All Other States	Total*
Mortality (low estimate)	\$7,928	\$5,866	\$13,771
Mortality (high estimate)	\$17,914	\$13,252	\$31,166
Nonfatal heart attack	\$93	\$73	\$167
Acute respiratory symptoms	\$47	\$30	\$76
All other health effects**	\$36	\$24	\$60
Sum, with the low mortality estimate	\$8,104	\$5,992	\$14,096
Sum, with the high mortality estimate	\$18,090	\$13,378	\$31,469
Sum, benefits not related to mortality	\$176	\$126	\$302

* Due to rounding, totals may not agree with the sum of subtotals.

** Health effects with estimate values below \$100,000 are hospital admissions for cardiovascular and respiratory problems, emergency room visits for asthma, acute bronchitis, respiratory symptoms (both upper and lower), days of work lost, and exacerbation of asthma.

For More Information

Resource Name	Resource Description	URL Address
MN Power Boswell Unit Retrofit– Emissions and Health Benefits Case Study		
<i>Review of Minnesota Power’s Boswell Unit 4 Environmental Improvement Plan</i>	This is the full 2013 report published by the Minnesota Pollution Control Agency describing the analysis of the public health benefits of the Boswell Unit 4 retrofit in more detail.	https://minnesotapuc.legistar.com/View.ashx?M=F&ID=2649199&GUID=5F09E82D-9086-4C19-B106-F77CFE7624F2

4.3.4. New York State Offshore Wind Master Plan – Emissions and Health Benefits

Benefits Assessed in Analysis

- SO₂ reductions
- NO_x reductions
- PM reductions

Savings Metrics Assessed

- Tons of air pollution reduced
- Health benefits from air pollution reductions

Energy Efficiency/Renewable Energy Program Description

In 2017, the New York State Energy Research and Development Authority (NYSERDA) conducted a screening-level analysis of the air quality benefits of using wind power, as documented in its *Offshore Wind Master Plan*, to meet New York’s Clean Energy Standard, which requires that 50 percent of New York’s electricity come from renewable sources by 2030. The analysis examined the potential benefits if the state were to meet its Clean Energy Standard in part by using 2,400 MW of offshore wind energy to supply electricity to New York City and Long Island in 2030. The screening-level analysis compared the air quality benefits of offshore wind to another scenario in which the Clean Energy Standard was met using other renewable energy technologies. Therefore, both scenarios included the same total amount of renewable energy generation; however, the offshore wind scenario delivered zero-emission electricity directly to New York City and Long Island, reducing the need for generation from high-emission facilities in these densely populated areas.

Methods Used

NYSERDA used PROMOD to model the impact of offshore wind energy development on the electricity market and the resulting emissions at power plants in New York and 14 other states throughout the Northeast and Mid-Atlantic regions, including Connecticut, Delaware, Illinois, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, Ohio, Pennsylvania, Rhode Island, Virginia, Vermont, and West Virginia.

The results of the PROMOD modeling were reductions in SO₂, NO_x, and PM_{2.5} in the offshore wind scenario compared to the non-offshore wind scenario. These emissions reductions were entered into COBRA to estimate the health impacts in 2030.

Results

The analysis estimated that the offshore wind scenario would result in a reduction of 780 tons of SO₂, 1,800 tons of NO_x, and 180 tons of PM_{2.5}, beyond the scenario in which the Clean Energy Standard is met with other renewable technologies. The health impacts analysis estimated that these emissions reductions would result in 18 fewer premature deaths annually. The total health benefits of the offshore wind scenario were valued between \$73 million and \$165 million across all 15 states.

For More Information

Resource Name	Resource Description	URL Address
New York State Offshore Wind Master Plan – Emissions and Health Benefits Case Study		
<i>New York State Offshore Wind Master Plan</i>	This is the full 2017 report describing the master plan for the development of offshore wind for New York, including a discussion of the screening-level analysis of the air quality and health benefits.	https://www.nyscrda.ny.gov/All-Programs/Programs/Offshore-Wind/New-York-Offshore-Wind-Master-Plan

4.4. TOOLS AND RESOURCES

A number of data sources, protocols, general resources, and tools are available for analysts to implement the methods described in this chapter. This section lists these resources and where you can obtain them, organized by specific analytic step.

Please note: While this Guide presents the most widely used methods and tools available to states for assessing the multiple benefits of policies, it is not exhaustive. The inclusion of a proprietary tool in this document does not imply endorsement by EPA.

4.4.1. Tools and Resources for Step 1: Develop and Project a Baseline Emissions Profile

A range of data sources, emission factors, protocols, projections, and/or tools are available to analysts to develop and project their own top-down or bottom-up baseline emissions profile.

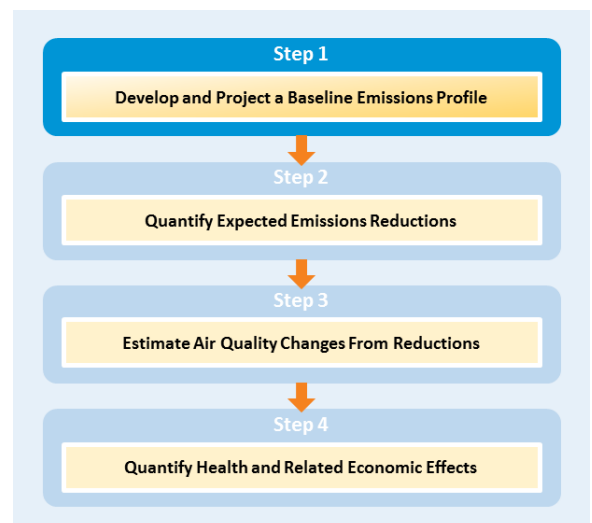
Data Sources for Top-Down or Bottom-Up Inventory Development

Analysts can use a variety of data sources to develop top-down or bottom-up inventories. Some of these data sources focus specifically on criteria air pollutants, some focus on GHGs, and some include both. Other sources provide already-compiled emissions estimates.

Potential Sources of Emissions Data

GHG Emissions (Only) Data Sources

- **EPA’s State Energy CO₂ Emissions.** EPA maintains this website that provides state CO₂ emissions inventories from fossil fuel combustion by end-use sector (commercial, industrial, residential, transportation, and electric



power). Pollutant types: CO₂. Scope coverage: Scope 1.²⁷ <https://www.epa.gov/statelocalenergy/state-co2-emissions-fossil-fuel-combustion>

- **EPA's U.S. Greenhouse Gas Reporting Program (GHGRP).** The GHGRP collects annual reporting of U.S. GHG emissions and other relevant information from large fuel suppliers and facilities that emit 25,000 metric tons or more per year. These data span a variety of sectors; facilities from 41 source categories are required to report. EPA publishes these data annually for download and through their interactive Facility Level Information on Greenhouse Gases Tool (FLIGHT). Pollutant types: CO₂, other GHGs. Scope coverage: Scope 1. <https://www.epa.gov/ghgreporting>
- **World Resources Institute Climate Analysis Indicators Tool 2.0.** The Climate Analysis Indicators Tool (CAIT 2.0) is a free, comprehensive, and comparable database of GHGs and other climate-relevant indicators for U.S. states. Pollutant types: CO₂, other GHGs. Scope coverage: Scope 1. <http://cait.wri.org/>

Criteria Air Pollutant (Only) Data Sources

- **EPA's National Emissions Inventory (NEI).** Analysts can use the NEI to help establish an inventory of criteria air pollutants and hazardous air pollutants. The NEI is a national database of air emissions information prepared by EPA with input from numerous state and local air agencies, tribes, and industry. The database contains information on stationary and mobile sources that emit criteria air pollutants and their precursors, as well as hazardous air pollutants. The database also includes estimates of annual emissions, by source, of air pollutants in each area of the country. The NEI includes emissions estimates for all 50 states, the District of Columbia, Puerto Rico, and the Virgin Islands, and is updated every 3 years. Pollutant types: SO₂, NO_x, Hg. Scope coverage: Scope 1. <https://www.epa.gov/air-emissions-inventories/national-emissions-inventory>

Data Sources with Both Criteria Air Pollutant and GHG Emissions

- **EPA's Air Markets Program Data (AMPD).** EPA collects data in 5-minute intervals from continuous emissions monitor systems (CEMSs) at all large power plants in the country. The AMPD is a new system of reporting emissions data, monitoring plans, and certification data, and replaces the Emissions Tracking System that previously served as a repository of SO₂, NO_x, and CO₂ emissions data from the utility industry. Pollutant types: SO₂, NO_x, CO₂. Scope coverage: Scope 1. <http://ampd.epa.gov/ampd/>
- **EPA's Emissions & Generation Resource Integrated Database (eGRID).** This free, publicly available software from EPA has data on annual SO₂, NO_x, CO₂, and Hg emissions for most power plants in the United States. eGRID also provides annual average non-baseload emissions rates, which may better characterize the emissions of marginal resources. By accessing eGRID, analysts can find detailed emissions profiles for every power plant and electric generating company in the United States. Pollutant types: SO₂, NO_x, CO₂, other GHGs, Hg. Scope coverage: Scopes 1 and 2. <https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid>

Potential sources of **economic and population** data:

- **Bureau of Economic Analysis' Regional Accounts.** This resource contains data on gross domestic product by state and metropolitan area, and can be used to supplement data for a top-down inventory. <https://www.bea.gov/regional/>

²⁷ Data sources are labeled as having scope 1 coverage if they provide data on direct emissions from power plants that are within a local government area or state. Data sources are labeled as having scope 2 coverage if they provide data on electricity consumption, or emission factors for electricity consumption within a local government area or state

- **Census Bureau Population Estimates.** This resource contains data on annual population estimates, and can be used to supplement data for a top-down inventory.
<https://factfinder.census.gov/faces/nav/jsf/pages/index.xhtml>
- **EPA’s Integrated Climate and Land Use Scenarios (ICLUS) Population Projections.** ICLUS describes and disseminates scenarios of land use and population growth, which can be used in assessments of future global change impacts. <https://www.epa.gov/iclus>

Potential sources of **state and local energy** data:

- **EIA’s State Energy Data System (SEDS).** This database has state energy-related data including electricity consumption and fuel consumption by sector. It includes annual data back to 1960. Pollutant types: CO₂. Scope coverage: Scopes 1 and 2. <http://www.eia.gov/state/seds/>
- **DOE’s State and Local Energy Data (SLED).** DOE’s SLED tool provides energy market data specific to individual cities and states. The tool provides an overview of the GHG emissions in each city, as well as national and state energy sources for electricity production. Pollutant types: CO₂. Scope coverage: Scope 2.
<http://apps1.eere.energy.gov/sled/#/>
- **State or Local Governments.** In order to estimate emissions that arise from state or local government operations, an analyst would need to collect and compile data on energy and electricity use, process emissions, waste generated, and other emissions-generating activities. These data are often obtained from utility bills, fleet records, and similar records.

Other potential data sources:

- **Universities.** Many universities collect emissions and/or energy data for their state, which can be compiled into an inventory.

Table 4-12: Sources of Air Pollutant and GHG Emissions Data, Inventories

Data Source	Type of Air Pollutant or GHG Emissions						Method		Scope	
	SO ₂	NO _x	PM _{2.5}	CO ₂	Other GHGs ^a	Hg	Top-Down	Bottom-Up	Scope 1	Scope 2
National Emissions Inventory (NEI)	x	x	x			x	x	x	x	
eGRID	x	x		x	x		x	x	x	x
Air Markets Program Data (AMPD)	x	x		x				x	x	
World Resources Institute Climate Analysis Indicators Tool (CAIT 2.0)				x	x		x		x	
EPA State CO ₂ Emissions				x			x		x	
Local GHG Inventories				x	x		x		x	x
U.S. Greenhouse Gas Reporting Program (FLIGHT)				x	x			x	x	
DOE State and Local Energy Data (SLED)				x			x			x
EIA State Energy Data System (SEDS)				x			x		x	x
Universities	x	x	x	x	x	x	x	x	x	x

^a Other GHGs may include CH₄, N₂O, HFCs, PFCs, SF₆, and NF₃.

Emission Factors for CO₂, NO_x, SO₂, and Other Pollutants

There are several available factors analysts can use to apply when using the emission factor approach to develop a top-down or bottom-up inventory. When assessing power sector emissions for inventories, analysts should use a “system average” emission factor since it represents the average emissions intensity of the region throughout the year. Regional emission factors are recommended because they best represent the dynamic nature of the electricity grid.

Resources that provide **emission factors for CO₂, NO_x, SO₂, and other pollutants**:

- **EPA’s Clearinghouse for Inventories and Emissions Factors (CHIEF).** This site contains air emissions inventories, emission factors, modeling inputs, electronic reporting, and information on emissions monitoring techniques that are applicable to both statewide and community-wide emissions inventories. <https://www.epa.gov/chief>
- **EPA’s Emissions & Generation Resource Integrated Database (eGRID).** eGRID is a comprehensive source of data on the environmental characteristics of almost all electric power generated in the United States. These environmental characteristics include emissions for NO_x, SO₂, CO₂, CH₄, and N₂O emissions rates. This database also includes data on net generation, resource mix, and many other attributes. The data are aggregated by state, North American Electric Reliability Corporation (NERC) region, eGRID sub-region, balancing authority area, and U.S. total. <https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid>
- **EPA’s Power Profiler.** The Power Profiler is a web-based tool that allows users to enter in their zip code and utility, and it provides CO₂, NO_x, and SO₂ emission factors for the user’s region based on eGRID data. http://oaspub.epa.gov/powpro/ept_pack.charts

Resources that provide **emission factors for GHGs only**:

- **EPA’s Center for Corporate Climate Leadership GHG Emission Factors Hub.** EPA’s GHG Emission Factors Hub provides organizations with a regularly updated and easy-to-use set of default emission factors for organizational GHG reporting collated from both EPA’s Greenhouse Gas Reporting Program and the Center’s technical guidance. <https://www.epa.gov/climateleadership/center-corporate-climate-leadership-ghg-emission-factors-hub>
- **EPA’s U.S. Greenhouse Gas Inventory Report.** This annual report provides a comprehensive accounting of total GHG emissions for all man-made sources in the United States. The gases covered by the inventory include carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, sulfur hexafluoride, and nitrogen trifluoride. The Inventory also calculates carbon dioxide emissions that are removed from the atmosphere by “sinks,” e.g., through the uptake of carbon and storage in forests, vegetation, and soils. <https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks>
- **Intergovernmental Panel on Climate Change (IPCC) Emission Factor Database (EFDB).** The EFDB is a library where users can find emission factors and other parameters with background documentation or technical references that can be used for estimating GHG emissions and removals. <http://www.ipcc-nggip.iges.or.jp/EFDB/main.php>

Inventory Development Protocols and Tools

Analysts can use a range of available protocols and tools to develop a top-down inventory as described below.

Protocols and Resources for Inventory Development

Developing an inventory that adheres to a comprehensive and detailed set of methodologies for estimating emissions is important because this helps ensure the inventory is created in a transparent manner using a consistent framework. Specific methods and protocols for developing top-down or bottom-up baseline emissions inventories are available at

both the state and local levels. Guidance from the protocols vary depending on the type of inventory data a state collects.

For GHG (Only) Inventories

- **GHG Protocol Accounting and Reporting Standard for Cities.** The GHG Protocol is a joint effort of the World Resources Institute and the World Business Council on Sustainable Development. The GHG Protocol has developed many protocols for accounting for GHG emissions. The one that is most relevant to state and local governments is the Global Protocol for Community-Scale Greenhouse Gas Emissions Inventories. This protocol provides step-by-step instructions for setting boundaries and accounting for emissions from various emissions sources within the state or community. <http://www.ghgprotocol.org/greenhouse-gas-protocol-accounting-reporting-standard-cities>
- **GHG Protocol Corporate Accounting and Reporting Standard.** For measuring GHG emissions for state and local government operations, analysts can use the Corporate Accounting and Reporting Standard. This protocol was designed for corporate inventories, but can be adapted for use by state and local governments that want to quantify emissions from their own operations. The protocol provides step-by-step guidance on measuring, managing, and reporting GHG emissions from specific sources (e.g., stationary and mobile combustion, process emissions) and industry sectors (e.g., cement, pulp and paper, aluminum, iron and steel, and office-based organizations). <http://www.ghgprotocol.org/corporate-standard>
- **EPA’s Center for Corporate Climate Leadership GHG Inventory Guidance.** The Center for Corporate Climate Leadership provides overall guidance to corporations on topics such as defining inventory boundaries, identifying GHG emissions sources, providing current emission factors, defining and adjusting a base year, reporting requirements, and goal setting. <http://www.epa.gov/climateleadership/inventory/index.html>
- **EPA’s U.S. GHGRP Reporting Protocols.** The GHGRP program provides methodologies to estimate emissions from individual sources. These methodologies can help states estimate direct GHG emissions (both fuel combustion and process emissions) from direct-emitting facilities, suppliers, and carbon dioxide injection facilities. GHGRP also provides measures to verify emissions, as well as methods to directly monitor emissions, such as a CEMS. Factsheets: <https://www.epa.gov/ghgreporting/ghgrp-methodology-and-verification>. Methods: http://www.ecfr.gov/cgi-bin/text-idx?tpl=/ecfrbrowse/Title40/40cfr98_main_02.tpl
- **ICLEI U.S. Community Protocol.** ICLEI’s U.S. Community Protocol is a technical document containing methodologies and best practices designed to provide guidance on top-down GHG emissions inventory development. <http://icleiusa.org/publications/us-community-protocol/>
- **IPCC Methodology Reports.** The IPCC provides guidelines to inform GHG inventory preparation across all sectors. http://www.ipcc.ch/publications_and_data/publications_and_data_reports.shtml#4
- **Local Government Operations Protocol for the Quantification and Reporting of GHG Emissions Inventories.** The Local Government Operations Protocol was created in 2010 to help local governments develop consistent and credible emissions inventories based on internationally accepted methods. It allows users to select the level of disaggregation so that it can be used for top-down or bottom-up inventories. Developed in partnership by the California Air Resources Board, California Climate Action Registry, ICLEI – Local Governments for Sustainability, and The Climate Registry, it involved a multi-stakeholder technical collaboration that included national, state, and local emissions experts. <http://icleiusa.org/ghg-protocols/>
- **The Climate Registry Protocols (TCR).** TCR provides a set of protocols that detail best practices in GHG accounting, as well as voluntary reporting program requirements. Each protocol in TCR was developed by

reaching a consensus among industry, environmental, and government stakeholders.

<https://www.theclimateregistry.org/tools-resources/reporting-protocols/general-reporting-protocol>

Data Sources

- **DOE's State Energy Data (SEDS).** EIA's state energy statistics are housed in the SEDS, which contains historical information on energy production, consumption, prices, and expenditures by state to aid in analysis and forecasting. <https://www.eia.gov/state/seds/>
- **DOE's State and Local Energy Database – City Energy Profiles.** City energy profiles are intended to help cities perform planning exercises and implement clean energy projects. The profiles contain information on city energy use and activity data. Each city energy profile includes a range of summary information on GHG emissions; electricity generation; natural gas and other fuel source costs; renewable energy resource potential; transportation, buildings, and industry data; and applicable policies and incentives. <https://apps1.eere.energy.gov/sled/#/>
- **EPA's Facility Level Information on Greenhouse Gases Tool (FLIGHT).** FLIGHT gives access to GHG data reported to EPA by large emitters, facilities and inject CO₂ underground, and suppliers of products that result in GHG emissions when used in the United States. FLIGHT allows users to view data in several formats including maps, tables, charts, and graphs for individual facilities or groups of facilities. The database is searchable and allows comparison of emissions trends over time and download data. <https://ghgdata.epa.gov/ghgp/main.do>
- **EPA's State CO₂ Data.** EPA provides state CO₂ emissions inventories from fossil fuel combustion, by end-use sector (commercial, industrial, residential, transportation, and electric power), in metric tons of CO₂ from 1990 through 2015. <https://www.epa.gov/statelocalenergy/state-co2-emissions-fossil-fuel-combustion>

For Criteria Air Pollutant Inventories

- **EPA's Air Emissions Inventory Guidance Documents.** This website lists the latest available guidance on developing emissions inventories to meet SIP requirements. <https://www.epa.gov/air-emissions-inventories/air-emissions-inventory-guidance-documents>
- **EPA's Emissions Inventory Guidance for Implementation of Ozone and Particulate Matter National Ambient Air Quality Standards (NAAQSs) and Regional Haze Regulations.** This document provides guidance on how to develop emissions inventories to meet SIP requirements for complying with the 8-hour ozone NAAQSs, the 24-hour and annual PM_{2.5} NAAQSs, and the regional haze regulations. https://www.epa.gov/sites/production/files/2017-07/documents/ei_guidance_may_2017_final_rev.pdf

Local-Scale Emissions Inventory Development

- **EPA's Assessment of Local-Scale Emissions Inventory Development by State and Local Agencies.** This report presents results from a state and local air agency focus group on emissions inventories completed in 2010. The report includes focus group recommendations on actions that can be taken by state and local air agencies in developing local-scale emissions inventories, including how to identify key sources in a planning area and methods for inventory improvement. <https://www.epa.gov/air-emissions-inventories/local-scale-emission-inventory-development>

Tools for Inventory Development

Tools for developing top-down or bottom-up baseline GHG emissions inventories, forecasting future emissions, and tracking changes are available at both the state and local levels.

Tools for Developing Top-Down GHG Inventories

- **ClearPath™ Tool.** Local governments can use ICLEI’s ClearPath™ tool to develop a top-down inventory of GHGs associated with electricity, fuel use, and waste disposal based on ICLEI’s U.S. Community Protocol; track emissions progress over time; project scenarios; analyze benefits of reduction measures; and visualize alternative planning scenarios. <http://icleiusa.org/clearpath/>
- **EPA’s Local Inventory Tool.** This suite of interactive spreadsheet tools was developed to support help municipal governments across the United States to evaluate the GHG emissions associated with their municipal operations and community-wide emissions. <https://www.epa.gov/statelocalenergy/local-greenhouse-gas-inventory-tool>
- **EPA’s State Inventory Tool.** State analysts can use EPA’s State Inventory Tool to develop top-down GHG inventories. This interactive spreadsheet software tool is based on IPCC guidelines and contains default emission factors and activity data for most sectors for a 1990–2015 timeseries. The tool can be used to calculate both generation-based and consumption-based energy inventories. <https://www.epa.gov/statelocalenergy/state-inventory-and-projection-tool>
- **EPA’s Tribal Inventory Tool.** This suite of interactive spreadsheet tools was developed to support help tribal governments across the United States to evaluate the GHG emissions associated with their municipal operations and community-wide emissions. <https://www.epa.gov/statelocalenergy/tribal-greenhouse-gas-inventory-tool>

Tools for Developing Bottom-Up GHG Inventories

For Buildings

- **EPA’s ENERGY STAR® Portfolio Manager®.** Portfolio Manager is a free, interactive ENERGY STAR energy management tool that enables users to track and assess energy and water consumption for a single building or across a portfolio of buildings. The tool can be used to identify buildings with the most potential for energy efficiency improvements. A new feature of Portfolio Manager allows users to see how their buildings’ CO₂ emissions compare with other buildings across the country, and to measure their progress in reducing emissions. The tool also has the functionality to compare the GHG performance of a user’s facility against the performance of a building with energy efficiency equal to the nation median using data from DOE’s national Commercial Building Energy Consumption Survey. Table 4-13 shows an example of this comparison for a hypothetical school. <https://www.energystar.gov/buildings/facility-owners-and-managers/existing-buildings/use-portfolio-manager>

Table 4-13: Sample Comparison of a User’s Facility Against the National Median Building

Property Name	Year Ending	ENERGY STAR Score (1–100)	Total GHG Emissions (Metric Tons CO ₂ e)	National Median Total GHG Emissions (Metric Tons CO ₂ e)
Sample School	8/31/2017	60	112.2	123.6

Tools for Developing Bottom-Up Criteria Air Pollutant Inventories

For a Range of Sources

- **EPA’s Air Emissions Inventory Tools.** EPA provides a range of tools that are used for reporting NEI datasets to EPA’s Emissions Inventory System or for otherwise developing the NEI. <https://www.epa.gov/air-emissions-inventories/air-emissions-inventory-tools>

Tools for Developing Bottom-Up Criteria Air Pollutant and/or Greenhouse Gas Inventories

For Point Sources

Most criteria air pollutant inventories for point sources are developed from permits and other facility data rather than from a series of tools, however there are tools that can complement this method, including:

- **EPA's Landfill Gas Emissions Model (LandGEM).** LandGEM is a free, automated estimation tool with a Microsoft Excel interface that can be used to estimate emissions rates for total landfill gas, methane, CO₂, non-methane organic compounds, and individual air pollutants from municipal solid waste landfills. <http://www.epa.gov/ttn/catc/dir1/landgem-v302-guide.pdf>

For Mobile Sources

Inventories for on-road and non-road mobile sources can be aided by tools such as:

- **EPA's Motor Vehicle Emission Simulator (MOVES).** MOVES was developed by EPA as a replacement for the MOBILE6 and NONROAD models. This emissions modeling system estimates emissions for on-road and non-road mobile sources, covers a broad range of pollutants, and allows multiple scale analysis—from fine-scale analysis to national inventory estimation. MOVES is used for all official analyses associated with regulatory development, compliance with statutory requirements, and national/regional inventory projections. It is the EPA-approved model for state and local governments to develop SIPs and transportation conformity analyses outside of California. <http://www.epa.gov/otaq/models/moves/>

Projecting Future Emissions: Protocols, Resources, and Tools

Several protocols, resources, and tools are available to help analysts project future emissions.

Protocols and Resources for Emissions Projections

- **EPA's Clean Power Plan Technical Support Document (TSD): Incorporating RE and Demand-Side EE into State Plan Demonstrations.** This TSD explains how analysts can project carbon dioxide emissions from electricity generation. The TSD's methodology instructs states on how to create a baseline electricity demand forecast, adjust it for any potential energy efficiency and renewable energy actions states are expected to take, and translate the adjusted baseline forecast into projected carbon dioxide emissions. While developed specifically for the Clean Power Plan, it provides helpful information about the key forecasting assumptions and methods in general. <https://www.epa.gov/sites/production/files/2015-11/documents/tsd-cpp-incorporating-re-ee.pdf>
- **EPA's Emissions Inventory Guidance for Implementation of Ozone and Particulate Matter National Ambient Air Quality Standards (NAAQS) and Regional Haze Regulations.** This document provides guidance on how to develop emissions inventories to meet SIP requirements for complying with the 8-hour ozone NAAQS, the revised PM NAAQS, and the regional haze regulations. Section 5.3.1 of the document provides guidance on incorporating emissions projections from EGUs into state plans. <https://www.epa.gov/air-emissions-inventories/air-emissions-inventory-guidance-implementation-ozone-and-particulate>
- **EPA's EIIP Technical Report Series, Volume X: Emissions Projections.** This document provides information and procedures to state and local agencies for projecting future air pollution emissions for the point, area, and on-road and non-road mobile sectors. While the data sources and tools states provided are dated, the methodologies may inform state and local agency methods. <https://www.epa.gov/sites/production/files/2015-08/documents/x01.pdf>
- **EPA's Power Sector Modeling Website.** This website describes the assumptions EPA uses for modeling the power sector. EPA uses the Integrated Planning Model (IPM)[®] to analyze the projected impact of environmental policies on the power sector in the 48 contiguous states and the District of Columbia. IPM is used to evaluate the

cost and emissions impacts of policies that limit SO₂, NO_x, CO₂, hydrogen chloride (HCl), and mercury (Hg).
<http://www.epa.gov/airmarkets/power-sector-modeling>

- **EPA’s Roadmap for Incorporating Energy Efficiency and Renewable Energy Policies and Programs in State and Tribal Implementation Plans.** This resource published in 2012 provides guidance on how emissions impacts of energy efficiency and renewable energy programs can be factored into a SIP to demonstrate attainment of the NAAQSs; Appendix I includes a roadmap for emissions quantification methods. <https://www.epa.gov/energy-efficiency-and-renewable-energy-sips-and-tips/basic-information-incorporating-energy>

Tools for Emissions Projections

- **ClearPath™ Tool.** Analysts can use ClearPath™ to develop a top-down inventory of GHGs associated with electricity, fuel use, and waste disposal based on ICLEI’s U.S. Community Protocol; track emissions progress over time; project scenarios; analyze benefits of reduction measures; and visualize alternative planning scenarios. <http://www.icleiusa.org/tools/clearpath>
- **EPA’s State GHG Projection Tool.** This EPA spreadsheet tool can be used to create projections of BAU GHG emissions through 2030. Future emissions are projected using linear extrapolation of the results from the State Inventory Tool, combined with economic, energy, population, and technology projections. The tool can be customized, allowing states to enter their own assumptions about future growth and consumption patterns. <https://www.epa.gov/statelocalenergy/state-inventory-and-projection-tool>

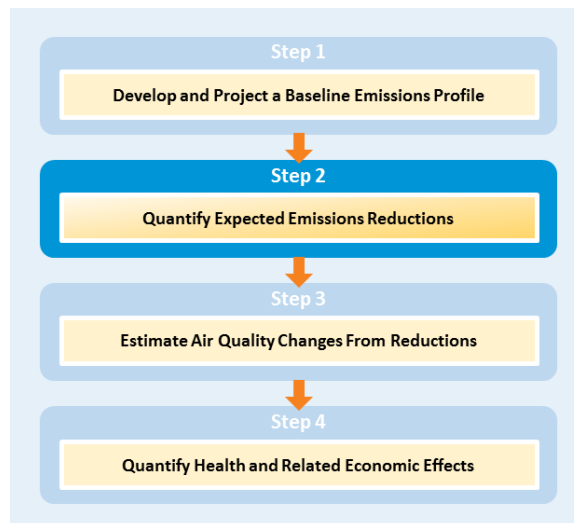
4.4.2. Tools and Resources for Step 2: Quantify Expected Emissions Reductions

Analysts can use a range of available data sources, emission factors, and/or tools to quantify emissions reductions expected from energy efficiency and renewable energy measures.

Establishing Operating Characteristics/Data on Load Profiles

Analysts can use a variety of available data sources to establish the operating characteristics of energy efficiency on an hourly to annual basis, the first step when quantifying criteria air pollutant and/or GHG emissions changes using a basic-to-intermediate method.

- **EPA’s Air Markets Program Data (AMPD).** EPA collects data in five-minute intervals from CEMSs at all large power plants in the country. The AMPD is a new system of reporting emissions data, monitoring plans, and certification data, and replaces the Emissions Tracking System that previously served as a repository of SO₂, NO_x, and CO₂ emissions data from the utility industry. <http://ampd.epa.gov/ampd/>
- **EIA’s Electricity Data.** This database contains statistics on electric power plants, capacity, generation, fuel consumption, sales, prices, and customers and can be used to assess generator-specific operating costs, historical utilization, and emissions rates. <http://www.eia.gov/electricity/data.cfm>
- **New York Independent System Operator (NYISO) Data.** NYISO, a regional grid operator, on hourly regional load data and transfer data between ISOs. http://www.nyiso.com/public/markets_operations/market_data/load_data/index.jsp



Emission Factors for CO₂, NO_x, SO₂, and Other Pollutants

This section provides information on where to find emission factors for the electric power sector, as well as other air pollution source categories. As noted under the description of basic approaches for quantifying the emissions reductions expected from energy efficiency and/or renewable energy, analysts can use preexisting emission factors to convert the electricity impacts into emissions reductions. When assessing power sector emissions for inventories, analysts should consider using a “system average” emission factor since it represents the average emissions intensity of the region throughout the year. However, when assessing the emissions impact from an energy efficiency or renewable energy project, analysts should use a marginal emission factor or more sophisticated modeling method that represents the emissions characteristics of the generation being displaced by the project.

Factors Specific to the Electric Generation Source Category (Only)

- **EPA’s AVERT Emission Factors.** EPA has developed customized marginal emission factors for 10 regions across the U.S. These emission factors are provided for four categories: wind, utility solar photovoltaic, a portfolio of energy efficiency measures, and baseload energy efficiency measures. AVERT emission factors come from a tool that is used for Clean Air Act compliance, so getting magnitude of emissions reductions from a similar source is a good screening for regulatory purposes. <https://www.epa.gov/statelocalenergy/avoided-emission-factors-generated-avert>
- **EPA’s Emissions & Generation Resource Integrated Database (eGRID).** eGRID is a comprehensive source of data on the environmental characteristics of almost all electric power generated in the United States. These environmental characteristics include air emissions for nitrogen oxides, sulfur dioxide, carbon dioxide, methane, and nitrous oxide emissions rates; net generation; resource mix, and many other attributes. <https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid>

Table 4-14: When to Use eGRID vs. New AVERT Preexisting Electricity-Related Emission Factors

If You:	Use:
<ul style="list-style-type: none">▪ Have been using eGRID already in your calculations and want to continue to use the same data source for consistency purposes▪ Are interested in using a CO₂e value or want a factor for methane or nitrous oxide▪ Are looking at a small level of disaggregation (20+ regions)	eGRID emission factors
<ul style="list-style-type: none">▪ Are interested in using a CO₂ value from a previous recent year▪ Want an emission factor for PM_{2.5} emissions to estimate health impacts in COBRA▪ Are looking for an emission factor that reflects a specific renewable energy resource, such as wind or solar▪ Are interested in representing a portfolio of energy efficiency programs or a program that saves the same amount of energy throughout the year (e.g., street lighting or refrigerator change out)	AVERT emission factors

Factors Across Multiple Air Pollution Sources Categories

- **EPA’s AP-42 Compilation of Air Pollutant Emission Factors.** AP-42 has been published since 1972 as the primary compilation of EPA's emission factor information. It contains emission factors and process information for more than 200 air pollution source categories. <https://www.epa.gov/air-emissions-factors-and-quantification/ap-42-compilation-air-emission-factors>

Tools for Quantifying Emissions Reductions

There are a range of tools, from basic to sophisticated, that analysts can use to quantify the emissions impacts of energy efficiency and renewable energy. The tools chosen should match the purpose and method as described in Section 4.2.2.,

“Step 2: Quantify Expected Emissions Reductions,” of this chapter. The tools below apply the basic, intermediate, and sophisticated methods described earlier and are categorized accordingly.

Basic Tools

Basic tools typically use preexisting emission factors, such as those derived from eGRID, AVERT, historical proxy unit(s), or historical dispatch behavior for a group of units within a specific region, to estimate reductions. These tools have transparent assumptions, are normally free, require less knowledge of specific energy efficiency and renewable energy data, and user technical expertise than intermediate and sophisticated tools.

- **ClearPath™.** Analysts can use ClearPath™ to develop a top-down inventory of GHGs associated with electricity, fuel use, and waste disposal based on ICLEI’s U.S. Community Protocol; track emissions progress over time; project scenarios; analyze benefits of reduction measures; and visualize alternative planning scenarios.
<http://icleiusa.org/clearpath/>
- **Climate Action for URban Sustainability (CURB) Scenario Planning Tool.** This is an interactive scenario planning tool designed specifically to help cities identify and prioritize low-carbon infrastructure and other GHG reduction actions; understand the impact on emissions and financial performance of potential actions; and develop, compare, and explore multiple scenarios. It draws on built-in city, national and region-specific data.
<http://www.c40.org/programmes/climate-action-for-urban-sustainability-curb>
- **DOE’s Grid Project Impact Quantification (Grid Project IQ) Screening Tool.** The Grid Project IQ screening tool provides insight into smart grid related technology deployments. It helps users quickly explore the outcomes of adding a new project to an existing power system from a web browser. With Grid Project IQ, users can quantify changes in total energy, peak power, greenhouse gas and criteria air pollutant emissions, ramping rates, and generation fossil fuel costs. (Note: This tool uses EPA’s AVERT model to estimate emission impacts.)
<https://www.energy.gov/oe/activities/technology-development/grid-modernization-and-smart-grid/grid-project-impact>
- **EPA’s Power Profiler.** The Power Profiler is a web-based tool that allows users to evaluate the air pollution and GHG impact of their electricity choices. The tool is particularly useful with the advent of electric customer choice, which allows many electricity customers to choose the source of their power.
http://oaspub.epa.gov/powpro/ept_pack.charts
- **Metropolitan Washington Council of Governments’ (MWCog’) Avoided Emissions Calculator.** With support from the DOE, this D.C.-based entity has developed the MWCog Avoided Emissions Calculator, a tool to help state and local governments quantify climate and air quality benefits from energy efficiency and renewable energy programs. This spreadsheet-based emissions calculator gives users the ability to calculate the NO_x, ozone, SO₂, and CO₂ emissions benefits of selected energy efficiency and renewable energy measures. This tool has been customized using emissions rates for the Washington metropolitan region, and therefore is especially applicable for government entities in the area. <https://www.mwcog.org/documents/2010/03/31/inclusion-of-energy-efficiency-and-renewable-energy-in-state-implementation-plans-for-air-quality-and-climate-change-air-quality-efficiency-energy-renewable-energy/>
- **State and Utility Pollution Reduction Calculator Version 2 (SUPR2).** The SUPR2 tool provides high-level estimates of the costs and benefits of various policies and technologies that could help an individual state meet its air quality goals. SUPR2’s policy and technology options include energy efficiency, renewable energy, nuclear power, emissions control options, and natural gas. <http://aceee.org/research-report/e1601>

Intermediate Tools

Below are several tools available to states that use intermediate modeling methods to estimate emissions reductions. There can be concerns with these tools, similar to the concerns for sophisticated tools described above in Table 4-6 of Section 4.2.2., “Step 2: Quantify Expected Emissions Reductions.” For example, if the tools and their inputs are not regularly updated, the key underlying assumptions and data may no longer be applicable and relevant.

- **Eastern Regional Technical Advisory Committee’s (ERTAC’s) EGU Forecasting Tool.** ERTAC created the EGU Forecasting tool to project hourly air emissions inventories into the future, on both an annual and episodic peak basis. The tool uses data from EPA’s Clean Air Markets Division, as well as fuel-specific growth rates and other information to calculate the projections. <http://www.marama.org/2013-ertac-egu-forecasting-tool-documentation>
- **EPA’s AVoided Emissions and geneRation Tool (AVERT).** AVERT is used to estimate displaced generation from energy efficiency and renewable energy programs. Displaced generation is then used to estimate avoided emissions based on the historical hourly dispatch method described above, including differentiation of savings by the time of year and time of day. AVERT covers avoided emissions from SO₂, NO_x, PM_{2.5} and CO₂ and splits the contiguous U.S. into ten regions. AVERT can be used to estimate emissions reductions in the current year or near future, but it is based on historical behavior and does not incorporate future variables on fuel or electricity market prices. <https://www.epa.gov/statelocalenergy/avoided-emissions-and-generation-tool-avert>
- **Long-Range Energy Alternatives Planning System (LEAP).** LEAP is an integrated, scenario-based modeling tool developed by the Stockholm Environment Institute. LEAP can be used to track energy consumption, production, and resource extraction in all sectors of the economy at the city, state, national or regional scale. Beginning in 2018, LEAP includes the Integrated Benefits Calculator, which can be used to estimate health (mortality), agriculture (crop loss) and climate (temperature change) impacts of scenarios. It can be used to account for both energy sector and non-energy sector greenhouse gas (GHG) emission sources and sinks, and to analyze emissions of local and regional air pollutants, and short-lived climate pollutants. www.energycommunity.org
- **Time-Matched Marginal Emissions Model.** Resource Systems Group’s Time-Matched Marginal Emissions Model calculates avoided emissions from regional energy efficiency and renewable energy measures on an hourly basis. The model calculates marginal grid emissions rates from fossil fueled units for every hour of the year, and matches them to the corresponding energy efficiency or renewable energy measure in that same hour to calculate avoided emissions. https://www.epa.gov/sites/production/files/2016-03/documents/using_a_time-matched_hourly_marginal_emissions_tool_in_metropolitan_washington.pdf

Sophisticated Tools

Unlike basic-to-intermediate tools, more sophisticated tools, such as economic dispatch and capacity planning models, can provide detailed forecasts of regional supply and demand, and be used to compare baseline energy and emissions forecasts with scenarios based on implementation of energy efficiency and renewable energy measures. Using these types of models generally results in more rigorous estimates of emissions impacts than using basic-to-intermediate methods. However, these tools can also be more resource-intensive.

Economic Dispatch Models

Economic dispatch models determine the optimal output of the EGUs over a given timeframe (1 week, 1 month, 1 year, etc.) for a given time resolution (sub-hourly to hourly). These models generally include a high level of detail on the unit commitment and economic dispatch of EGUs, as well as on their physical operating limitations.

- **GE Multi-Area Production Simulation (MAPS™).** A chronological model that contains detailed representation of generation and transmission systems, MAPS can be used to study the impact on total system emissions that

result from the addition of new generation. MAPS software integrates highly detailed representations of a system's load, generation, and transmission into a single simulation. This enables calculation of hourly production costs in light of the constraints imposed by the transmission system on the economic dispatch of generation. <http://www.geenergyconsulting.com/practice-area/software-products/maps>

- **Integrated Planning Model (IPM)[®]**. This model simultaneously models electric power, fuel, and environmental markets associated with electric production. It is a capacity expansion and system dispatch model. Dispatch is based on seasonal, segmented load duration curves, as defined by the user. IPM also has the capability to model environmental market mechanisms such as emissions caps, trading, and banking. System dispatch and boiler and fuel-specific emission factors determine projected emissions. IPM estimates emissions for NO_x, SO₂, CO₂, and Hg. IPM can be used to model the impacts of energy efficiency and renewable energy resources on the electric sector in the short and long term. <http://www.icf.com/resources/solutions-and-apps/ipm>
- **PLEXOS[®]**. A simulation tool that uses Linear Programming/Mixed Integer Programming optimization technology to analyze the power market, PLEXOS contains production cost and emissions modeling, transmission modeling, pricing modeling, and competitiveness modeling. PLEXOS allows the user to select emissions of interest (e.g., CO₂, NO_x, SO₂, etc.). The tool can be used to evaluate a single plant or the entire power system. <http://www.energyexemplar.com>
- **PROMOD IV[®]**. A detailed generator and portfolio modeling system, with nodal locational marginal pricing forecasting and transmission analysis, PROMOD IV can incorporate extensive details in generating unit operating characteristics and constraints, transmission constraints, generation analysis, unit commitment/operation conditions, and market system operations. <http://new.abb.com/enterprise-software/energy-portfolio-management/market-analysis/promod>
- **PROSYM (Zonal Analysis)[™]**. A chronological electric power production costing simulation computer software package, PROSYM is designed for performing planning and operational studies. As a result of its chronological nature, PROSYM accommodates detailed hour-by-hour investigation of the operations of electric utilities. Inputs into the model are fuel costs, variable operation and maintenance costs, and startup costs. Output is available by regions, by plants, and by plant types. The model includes a pollution emissions subroutine that estimates emissions with each scenario. <http://new.abb.com/enterprise-software/energy-portfolio-management/market-analysis/zonal-analysis>

Capacity Expansion Models

Capacity expansion models determine the optimal generation capacity and/or transmission network expansion to meet an expected future demand level and comply with a set of national, regional, or state specifications.

- **AURORA**. The AURORA model, developed by EPIS LLC, provides electric market price forecasting, estimates of resource and contract valuation and net power costs, long-term capacity expansion modeling, and risk analysis of the energy market. <http://epis.com/aurora/>
- **DOE's National Energy Modeling System (NEMS)**. NEMS is a system-wide energy model (including demand-side sectors) that represents the behavior of energy markets and their interactions with the U.S. economy. The model achieves a supply/demand balance in the end-use demand regions, defined as the nine U.S. Census Bureau divisions, by solving for the prices of each energy product that will balance the quantities producers are willing to supply with the quantities consumers wish to consume. The system reflects market economics, industry structure, and existing energy policies and regulations that influence market behavior. NEMS tracks emissions levels for CO₂, SO₂, and NO_x. https://www.eia.gov/outlooks/aeo/info_nems_archive.php

- **Electric Generation Expansion Analysis System (EGEAS).** This tool was developed by the Electric Power Research Institute, is a set of computer modules that are used to determine an optimum expansion plan or simulate production costs for a pre-specified plan. Optimum expansion plans are based on annual costs, operating expenses, and carrying charges on investment. <http://eea.epri.com/models.html#tab=3>
- **e7 Capacity Expansion.** e7 Capacity Expansion is an energy portfolio management solution from the consulting firm ABB that covers resource planning, capacity expansion, and emissions compliance. It enables resource planners and portfolio managers to assess and develop strategies to address current and evolving RPSs and emissions regulations. <http://new.abb.com/enterprise-software/energy-portfolio-management/commercial-energy-operations/capacity-expansion>
- **e7 Portfolio Optimization.** Portfolio Optimization models unit operating constraints and market conditions to facilitate the analysis and simulation of scenarios. The model optimizes a combined portfolio of supply resources and energy efficiency or distributed generation assets modeled as virtual power plants. <http://new.abb.com/enterprise-software/energy-portfolio-management/commercial-energy-operations/portfolio-optimization>
- **ENERGY 2020.** Energy 2020 is a simulation model available from Systematic Solutions that includes all fuel, demand, and supply sectors and simulates energy consumers and suppliers. This model can be used to capture the economic, energy, and environmental impacts of national, regional, or state policies. Energy 2020 models the impacts of an energy efficiency or renewable energy measure on the entire energy system. User inputs include new technologies and economic activities such as tax breaks, rebates, and subsidies. Energy 2020 uses emissions rates for CO₂ and other GHGs, as well as NO_x, SO₂, and PM_{2.5} for nine plant types included in the model. It is available at the national, regional, and state levels. <http://www.energy2020.com/>
- **Integrated Planning Model (IPM)[®].** This model simultaneously models electric power, fuel, and environmental markets associated with electric production. It is a capacity expansion and system dispatch model. IPM also has the capability to model environmental market mechanisms such as emissions caps, trading, and banking. System dispatch and boiler and fuel-specific emission factors determine projected emissions. IPM estimates emissions for NO_x, SO₂, HCl, CO₂, and Hg. IPM can be used to model the impacts of energy efficiency and renewable energy resources on the electric sector in the short and long term. <http://www.icf.com/resources/solutions-and-apps/ipm>
- **MARKAL/TIMES.** MARKAL and TIMES determine the least-cost pattern of technology investment and utilization required to meet specified end-use energy demands (e.g., lumens for lighting, watts for heating, and vehicle miles traveled for transportation), while tracking the resulting criteria air pollutant and GHG emissions. By adding constraints or changing various assumptions, these models can be applied to examine how those changes affect the optimal evolution of the energy system. The MARKAL model estimates emissions for CO₂, SO₂, and NO_x. <http://iea-etsap.org/index.php/etsap-tools/model-generators/times>
- **NREL's Regional Energy Deployment System model (ReEDS).** This is a long-term capacity expansion model that determines the potential expansion of electricity generation, storage, and transmission systems throughout the contiguous United States over the next several decades. ReEDS is designed to determine the cost-optimal mix of generating technologies, including both conventional and renewable energy, under power demand requirements, grid reliability, technology, and policy constraints. Model outputs are generating capacity, generation, storage capacity expansion, transmission capacity expansion, electric sector costs, electricity prices, fuel prices, and carbon dioxide emissions. ReEDS tracks emissions of CO₂, SO₂, NO_x, and Hg. <http://www.nrel.gov/analysis/reeds/>

- **NREL’s Resource Planning Model (RPM).** RPM is a capacity expansion model designed to examine how increased renewable deployment might impact regional planning decisions for clean energy or carbon mitigation analysis. RPM includes an optimization model that finds the least-cost investment and dispatch solution over a 20-year planning horizon for different combinations of conventional, renewable, storage, and transmission technologies. The model is currently only available for regions within the Western Interconnection, while a version for regions in the Eastern Interconnection is under development. RPM tracks power sector emissions for CO₂, SO₂, NO_x, and Hg. <https://www.nrel.gov/analysis/models-rpm.html>

General Resources for Quantifying Emissions Reductions

- **CarbonCount™ Quantitative Scoring System for Green Bonds.** In March 2015, Alliance to Save Energy released a paper to introduce CarbonCount™, a metric that evaluates bond investments in U.S.-based energy-efficiency and renewable-energy projects based on the expected reduction in carbon dioxide (CO₂) emissions resulting from each \$1,000 of investment. https://www.ase.org/sites/ase.org/files/carboncounttm_paper_.pdf
- **EPA’s Incorporating Renewable Energy and Demand-Side Energy Efficiency into State Plan Demonstrations.** This 2015 document describes acceptable methods for including the projected impacts of energy efficiency and renewable energy policies in a forecast when demonstrating planned compliance with national air quality regulatory requirements. <https://www.epa.gov/sites/production/files/2015-11/documents/tsd-cpp-incorporating-re-ee.pdf>
- **EPA’s Roadmap for Incorporating Energy Efficiency and Renewable Energy Policies and Programs in State and Tribal Implementation Plans.** This resource published in 2012 provides guidance on how emissions impacts can be factored into a SIP to demonstrate attainment of the NAAQSs; Appendix I includes a roadmap for emissions quantification methods. <https://www.epa.gov/energy-efficiency-and-renewable-energy-sips-and-tips>
- **Metropolitan Washington Council of Governments Inclusion of Energy Efficiency and Renewable Energy in State Implementation Plans for Air Quality and Climate Change.** This report contains specific recommendations on approaches for inclusion of energy efficiency and renewable energy programs in regional air quality and climate and energy sustainability plans. The website includes a link to a basic emissions calculator. <https://www.mwcog.org/documents/2010/03/31/inclusion-of-energy-efficiency-and-renewable-energy-in-state-implementation-plans-for-air-quality-and-climate-change-air-quality-efficiency-energy-renewable-energy/>
- **NREL’s Evolution of Wholesale Electricity Market Design with Increasing Levels of Renewable Generation.** This resource describes the impact of renewables on the wholesale market. <https://www.nrel.gov/grid/power-market-design.html>
- **SEE Action Energy Efficiency Program Impact Evaluation Guide.** This resource provides guidance on methods for calculating energy, demand, and emissions savings resulting from energy efficiency programs. The guide is provided to assist public and private energy efficiency portfolio administrators, program implementers, and evaluators on evaluating energy efficiency actions and programs. Chapter 6 of the report presents several methods for calculating both direct onsite avoided emissions and reductions from grid-connected EGUs. The chapter also discusses considerations for selecting a calculation method. <https://www4.eere.energy.gov/seeaction/publication/energy-efficiency-program-impact-evaluation-guide>
- **Synapse’s A Guide to Clean Power Plan Modeling Tools.** This report dissects and discusses a spectrum of compliance modeling tools in the context of modeling Clean Power Plan-related decisions. <http://www.synapse-energy.com/sites/default/files/Guide-to-Clean-Power-Plan-Modeling-Tools.pdf>

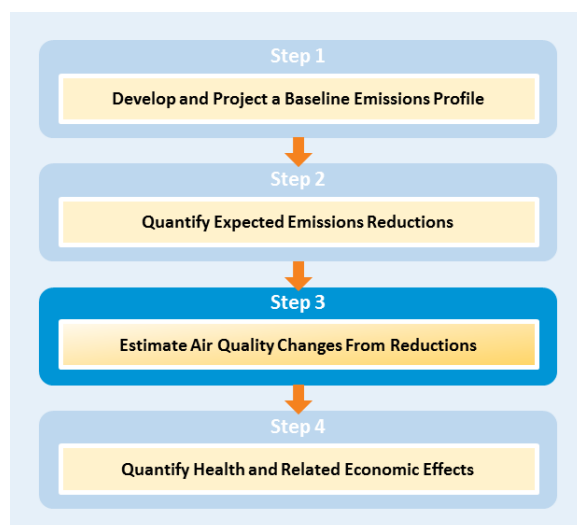
4.4.3. Tools and Resources for Step 3: Estimate Air Quality Changes From Reductions

Analysts can use a range of available resources and tools to quantify air quality impacts based on air pollution impacts determined in “Step 2: Quantify Expected Emissions Reductions.”

General Resources for Quantifying Air Quality Impacts

EPA has developed some general resources to help analysts quantify air quality impacts, including:

- **EPA’s Indoor Air Quality Benefits of Energy Efficiency and Renewable Energy.** This website displays information on improving air quality, such as source control, ventilation improvements, and air cleaners.
<https://www.epa.gov/indoor-air-quality-iaq/improving-indoor-air-quality>
- **EPA’s Support Center for Regulatory Modeling (SCRAM).** SCRAM provides information about the latest versions of models, as well as the status of current model recommendations of models for regulatory purposes.
<https://www.epa.gov/scram>



Tools for Quantifying Air Quality Impacts

There are a range of tools available for analysts to use to estimate changes in air quality from changes in emissions levels. Most are sophisticated models that produce a detailed, rigorous analysis and require a high level of sophistication, however, some screening-level (i.e., reduced-form) approaches are available as described below. In addition, some states have developed air quality models tailored to their specific region. These models are typically used for air quality policy development purposes, or for air quality forecasting as part of an air quality index alert system. Local or regional models are suitable for conducting energy efficiency and renewable energy benefits analysis, and the expertise and data needed by these models are often available within a state.

Screening and Reduced-Form Tools and Resources

- **EPA’s Response Surface Modeling (RSM).** RSM is based on a method known as air quality metamodeling, which aggregates pre-specified individual air quality modeling simulations into a multi-dimensional air quality “response surface.” RSM is a metamodel of an air quality model developed using the CMAQ Modeling system. It is a reduced-form prediction model using statistical correlation structures to approximate model functions through the design of complex multi-dimension experiments.
https://www3.epa.gov/scram001/reports/pmnaaqts_tsd_rsm_all_021606.pdf
- **EPA’s Source-Receptor (S-R) Matrix.** The S-R Matrix is a reduced-form model based on the Climatological Regional Dispersion Model, which provides the relationship between emissions of PM_{2.5}, NO_x, SO₂, ammonia (NH₃), or VOCs and county-level PM_{2.5} ambient concentrations. The S-R Matrix is used to evaluate PM_{2.5} in the COBRA screening model. To obtain the COBRA model, visit <https://www.epa.gov/statelocalenergy/co-benefits-risk-assessment-cobra-screening-model>. To learn more about the S-R Matrix, see Appendix A of the COBRA User Manual: <https://www.epa.gov/sites/production/files/2015-08/documents/cobra-manual.pdf>

Sophisticated Modeling Tools

When quantifying the air quality impacts of emissions changes, more sophisticated tools are available that provide a finer level of resolution than what is possible with the screening tools. These types of tools include photochemical

models, dispersion models and receptor models as described below. EPA recommends the models depicted in Table 4-15 for air quality modeling to assess control strategies and source impacts.

Table 4-15: Air Quality Models Currently Recommended by EPA and Available at EPA's SCRAM

Model Acronym	Model Name
Dispersion Models	
AERMOD	American Meteorological Society/EPA Regulatory Model
N/A	CALPUFF
Photochemical Models for Both Ozone and PM_{2.5} (“One Atmosphere” Models)	
CAMx	Comprehensive Air Quality Model with eXtensions
CMAQ	Community Multiscale Air Quality model
SMAT-CE	Software for the Modeled Attainment Test – Community Edition
REMSAD	Regional Modeling System for Aerosols and Deposition
UAM-V	Urban Airshed Model Variable Grid
Receptor Models	
CMB	Chemical Mass Balance
N/A	EPA Unmix 6.0
PMF	Positive Matrix Factorization

For more information, see: <https://www.epa.gov/scram>.

Photochemical Modeling

Photochemical air quality models have become widely recognized and routinely utilized tools for regulatory analysis and attainment demonstrations by assessing the effectiveness of control strategies. These photochemical models are large-scale air quality models that simulate the changes of pollutant concentrations in the atmosphere using a set of mathematical equations characterizing the chemical and physical processes in the atmosphere. These models are applied at multiple spatial scales from local, regional, national, and global.

General Resources About Photochemical Models

- **EPA’s Support Center for Regulatory Atmospheric Modeling (SCRAM).** Photochemical models are large-scale air quality models that simulate the changes of pollutant concentrations in the atmosphere using a set of mathematical equations characterizing the chemical and physical processes in the atmosphere. These models are applied at multiple spatial scales from local, regional, national, and global. EPA’s SCRAM webpage describes the types of photochemical models commonly used in air quality assessments and provides links to several photochemical air quality models. <http://www3.epa.gov/scram001/photochemicalindex.htm>

Photochemical Models

- **CAMx.** CAMx is a regional photochemical dispersion model that allows for integrated "one atmosphere" assessments of tropospheric air pollution (ozone, PM, air toxics) over spatial scales ranging from neighborhoods to continents. <http://www.camx.com/>
- **CMAQ.** CMAQ models multiple air pollutants including ozone, PM, and a variety of air toxics to help air quality managers determine the best air quality management scenarios for their communities, regions, and states. The tool can provide detailed information about air pollutant concentrations in any given area for any specified emissions or climate scenario. <https://www.cmascenter.org/cmaq/> OR <https://www.epa.gov/cmaq>

- **REMSAD.** REMSAD was designed to calculate the concentrations of both inert and chemically reactive pollutants by simulating the physical and chemical processes in the atmosphere that affect pollutant concentrations over regional scales. It includes those processes relevant to regional haze, PM, and other airborne pollutants, including soluble acidic components and Hg. <http://remsad.icfconsulting.com/>
- **UAM-V.** The UAM-V Photochemical Modeling System was a pioneering effort in photochemical air quality modeling in the early 1970s and has been used widely for air quality studies focusing on ozone. It is a three-dimensional photochemical grid model designed to calculate the concentrations of both inert and chemically reactive pollutants by simulating the physical and chemical processes in the atmosphere that affect pollutant concentrations. This model is typically applied to model air quality "episodes"—periods during which adverse meteorological conditions result in elevated ozone pollutant concentrations. <http://uamv.icfconsulting.com/>

Dispersion Modeling

Dispersion models rely on emissions data, source and site characteristics (e.g., stack height, topography), and meteorological inputs to predict the dispersion of air emissions and the impact on concentrations at selected downwind sites. Dispersion models do not include analysis of the chemical transformations that occur in the atmosphere, and thus cannot assess the impacts of emissions changes on secondarily formed PM_{2.5} and ozone. These models can be used for directly emitted particles (such as from diesel engines) and air toxics.

General Resources About Dispersion Models

- **EPA's Preferred/Recommended Dispersion Models.** EPA requires the use of dispersion models for State Implementation Planning revisions for existing sources and for New Source Review and Prevention of Significant Deterioration programs. EPA's recommended models include AERMOD, CALPUFF, and others. <https://www.epa.gov/scram/air-quality-dispersion-modeling-preferred-and-recommended-models>

Dispersion Models

- **AERMOD.** AERMOD is a steady-state plume model that incorporates air dispersion based on planetary boundary layer turbulence structure and scaling concepts, including treatment of both surface and elevated sources, and both simple and complex terrain. EPA currently recommends using the AERMOD Modeling System both for SIP revisions analysis for existing sources and for new source review. <https://www.epa.gov/scram/air-quality-dispersion-modeling-preferred-and-recommended-models#aermod>
- **CALPUFF.** CALPUFF is a multi-layer, multi-species non-steady-state puff dispersion model that simulates the effects of time- and space-varying meteorological conditions on pollution transport, transformation, and removal. CALPUFF can be applied on scales of tens to hundreds of kilometers. It includes algorithms for sub-grid scale effects (such as terrain impingement), as well as, longer range effects (such as pollutant removal due to wet scavenging and dry deposition, chemical transformation, and visibility effects of PM concentrations). <https://www.epa.gov/scram/air-quality-dispersion-modeling-preferred-and-recommended-models#calpuff>

Receptor Modeling

Receptor models are mathematical or statistical procedures for identifying and quantifying the sources of air pollutants at a receptor location. Unlike photochemical and dispersion air quality models, receptor models do not use pollutant emissions, meteorological data and chemical transformation mechanisms to estimate the contribution of sources to receptor concentrations. Instead, receptor models use the chemical and physical characteristics of gases and particles measured at source and receptor to both identify the presence of and to quantify source contributions to receptor concentrations.

General Resources About Receptor Modeling

- **EPA’s Receptor Models.** EPA has developed the Chemical Mass Balance and Unmix 6.0 models as well as the Positive Matrix Factorization (PMF) method for use in air quality management. These models are a natural complement to other air quality models and are used as part of SIPs for identifying sources contributing to air quality problems. <https://www3.epa.gov/ttn/scram/receptorindex.htm>

Receptor Models

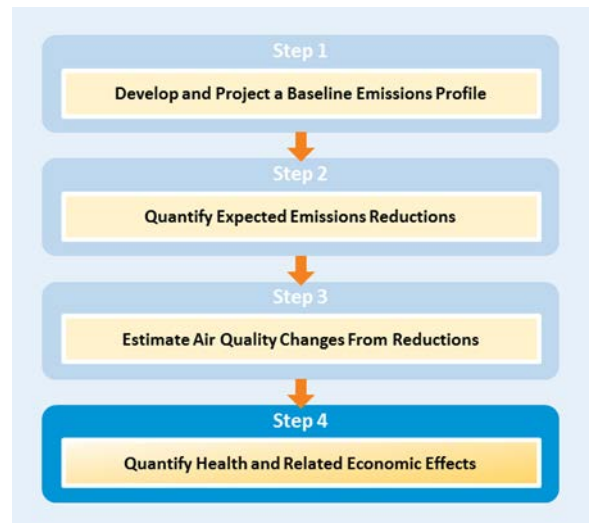
- **EPA’s Chemical Mass Balance.** The EPA-CMB Version 8.2 uses source profiles and speciated ambient data to quantify source contributions. Contributions are quantified from chemically distinct source types rather than from individual emitters. Sources with similar chemical and physical properties cannot be distinguished from each other by Chemical Mass Balance. Many of the source profiles, however, are outdated. https://www3.epa.gov/ttn/scram/receptor_cmb.htm
- **EPA’s Unmix 6.0 Model.** The EPA Unmix 6.0 model “unmixes” the concentrations of chemical species measured in the ambient air to identify the contributing sources. <https://www.epa.gov/air-research/unmix-60-model-environmental-data-analyses>
- **Positive Matrix Factorization (PMF).** PMF is a form of factor analysis where the underlying co-variability of many variables (e.g., sample to sample variation in PM species) is described by a smaller set of factors (e.g., PM sources) to which the original variables are related. The structure of PMF permits maximum use of available data and better treatment of missing and below-detection-limit values. <https://www.epa.gov/air-research/positive-matrix-factorization-model-environmental-data-analyses>

4.4.4. Tools and Resources for Step 4: Quantify Health and Related Economic Effects

Analysts can use a range of available tools to quantify human health and related economic effects of air quality impacts from energy efficiency and renewable energy.

Health Benefit Factors

- **EPA’s Benefit-per-kWh (BPK) Factors.** EPA is developing a set of factors to estimate the monetized public health benefits per kWh of energy efficiency or renewable energy projects, policies, or programs. EPA expects to release BPK factors for different regions of the country and different project types (wind, solar, and energy efficiency) in August 2018. Analysts will be able to multiply the BPKs by the estimated amount of kWh of electricity produced or reduced by the project or program to estimate the value of health benefits in dollars. <https://www.epa.gov/energy/quantifying-health-and-economic-benefits-energy-efficiency-and-renewable-energy-policies>
- **EPA’s Response Surface Model (RSM)-based Benefit-per-Ton Estimates.** EPA used a reduced-form modeling approach to develop tables reporting the PM-related benefits of reducing directly emitted PM_{2.5} and PM_{2.5} precursors from certain classes of sources to an estimate of the monetized PM_{2.5}-related health benefits. Applying these estimates simply involves multiplying the emissions reduction by the relevant benefit per-ton metric. <https://www.epa.gov/benmap/response-surface-model-rsm-based-benefit-ton-estimates>



- **EPA’s Sector-based PM_{2.5} Benefit-per-Ton Estimates.** EPA developed benefit per-ton estimates for 17 key source categories, including electricity generating units, residential wood burning, and petroleum refineries. Applying these factors simply involves multiplying the emissions reduction (in tons) by the relevant benefit per-ton metric. <https://www.epa.gov/benmap/sector-based-pm25-benefit-ton-estimates>

Tools for Quantifying Health Impacts and Related Economic Values

EPA has developed two tools that apply the damage function method to quantify health and related economic impacts, the **COBRA Health Impact Screening and Mapping Model** and EPA’s **Benefits Mapping and Analysis Program (BenMAP-CE)**.

COBRA

EPA’s COBRA Health Impact Screening and Mapping Model employs user-specified emissions reductions to estimate air quality changes and health effects and monetize them. COBRA is a stand-alone application that is appropriate for less experienced and sophisticated modelers, and enables users to:

- Approximate the impact of emissions changes on ambient PM_{2.5} concentrations.
- Translate these ambient air pollution changes into related health effect impacts as shown in the box, “COBRA Health Outputs.”
- Monetize the value of those health effect impacts.
- Present the results in various maps and tables as shown in Figure 4-10.

Using COBRA enables policy analysts to obtain a relatively straightforward first-order approximation of the benefits of different policy scenarios and to compare outcomes in terms of air quality (i.e., changes in PM concentrations and pollutants associated with the secondary formation of PM, at the county, state, regional, or national level) or health effects. COBRA is designed to give users a straightforward way to analyze the health effects of changes in emissions of PM.

COBRA HEALTH OUTPUTS

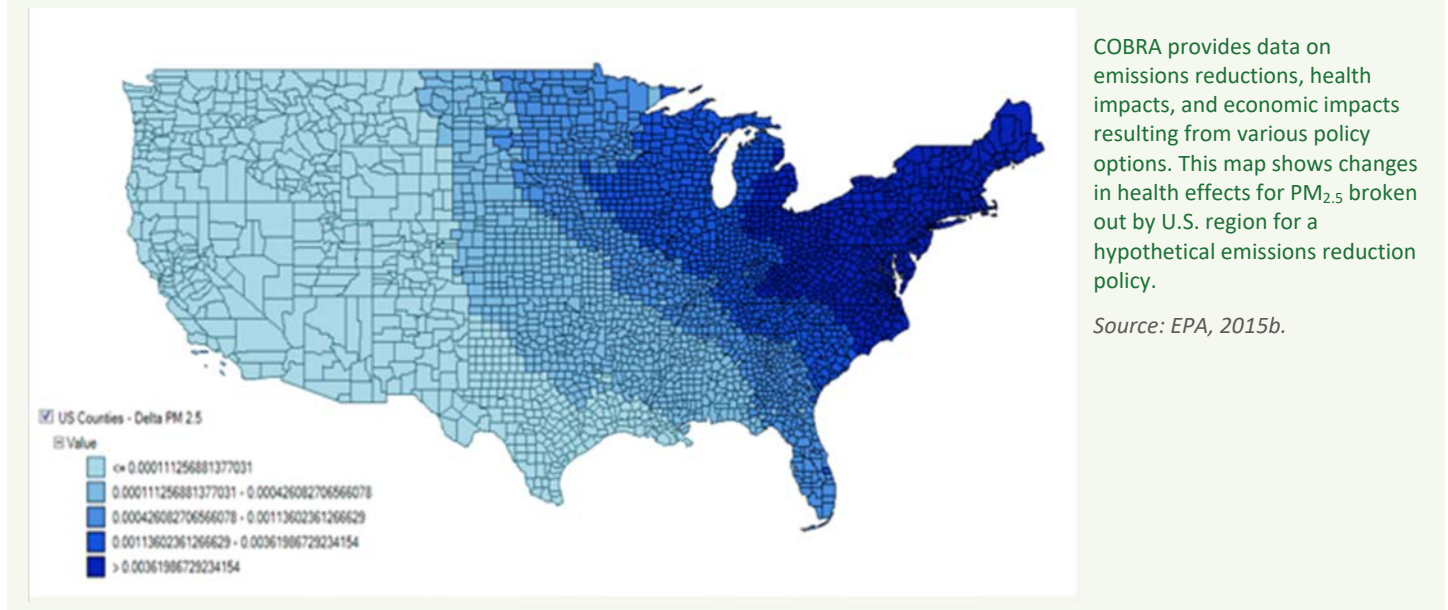
- Mortality
- Chronic and acute bronchitis
- Non-fatal heart attacks
- Respiratory or cardiovascular hospital admissions
- Upper and lower respiratory symptom episodes
- Asthma emergency room visits
- Asthma attacks: Shortness of breath, wheezing, and coughing
- Minor restricted activity days
- Work loss days

How Does COBRA Work?

- Users select the time period for the analysis. The model contains detailed emissions estimates for 2017 and 2025, developed by EPA.
- Users can create their own scenarios by making changes to the emissions estimates specified by the chosen baseline. Changes in PM_{2.5}, SO₂, NO_x, NH₃, and VOC emissions can be specified at the county, state, or national level.
- COBRA incorporates the user-defined emissions changes into a reduced-form air quality model, the S-R Matrix, to estimate the effects of emissions changes on PM_{2.5} concentrations. The user-defined NO_x and SO₂ emissions changes may be generated using tools such as EPA’s AVERT.

- COBRA uses C-R functions to estimate public health effects and monetizes the health effects using economic value equations based on those approved in recent EPA rulemakings.

Figure 4-10: Sample COBRA Results



Strengths and Limitations of COBRA

A *strength* of COBRA for the inexperienced analysts is its use of a reduced form air quality model for air quality impacts and default C-R function and economic values for health effects. This removes the burden of selecting these functions and values for users with limited air quality and health modeling experience. The default values in the model are updated to be consistent with current EPA benefits methods. For the more sophisticated user, a *strength* of COBRA is that an analyst can modify the underlying assumptions, values, and baseline, if desired. A *limitation* of the tool is that it only focuses on health benefits from PM and does not include benefits from reductions in ground-level ozone. Another limitation is that it is static and produces results for only a single year at a time.

<https://www.epa.gov/statelocalenergy/co-benefits-risk-assessment-cobra-health-impacts-screening-and-mapping-tool>

BenMAP-CE

EPA's Benefits Mapping and Analysis Program (BenMAP-CE) employs user-specified air quality changes to calculate health effects and monetize them. It is a Windows-based program, appropriate for more experienced modelers, that enables users to:

- Estimate the effects on numerous health endpoints associated with changes in ambient ozone and PM concentrations.
- Monetize the value of health effects.
- Visually inspect results with maps of air pollution, population, incidence rates, incidence rate changes, economic valuations, and other types of data at the county, state, or national level using geographic information systems (GIS).

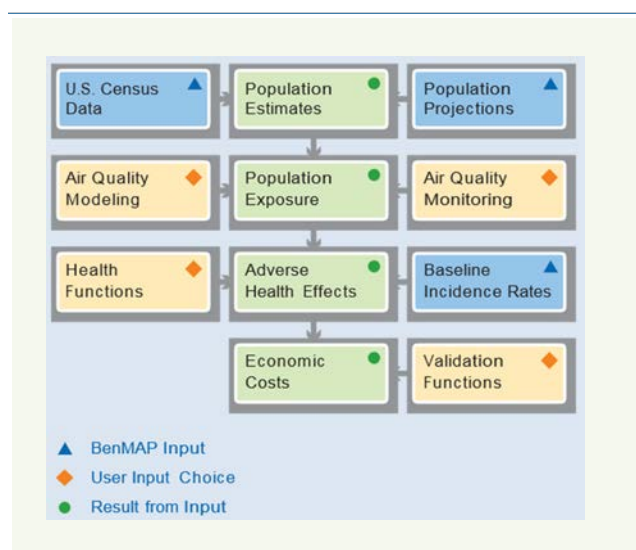
The BenMAP-CE tool is an open-source tool used by civil servants, risk assessors, and public health experts throughout the world. The BenMAP-CE tool is designed to be both flexible and transparent. Users can perform an analysis using built-in U.S. and China data, or incorporate their own air quality, health, and economic data. Novice users can apply a

simple tool that draws upon data from the Global Burden of Disease study (Brauer et al., 2015) to estimate the benefits of reducing fine particle levels in any country of the world. Users typically run BenMAP-CE to estimate the health impacts of a policy scenario, specifying both baseline and post-policy air quality levels. BenMAP-CE then estimates the changes in population exposure.

How Does BenMAP-CE Work?

- Air quality information for the baseline and scenario runs need to be generated externally, either from monitor-based air quality data, model-based air quality data, or both.²⁸ BenMAP-CE includes monitoring data for ozone, PM, NO₂, and SO₂ for a number of years.
- BenMAP-CE then calculates the changes in health effect incidence associated with the change in population exposure by using C-R functions derived from the epidemiological literature and pooling methods specified by the user.²⁹ BenMAP-CE uses the estimate of statistical error associated with each C-R function to generate distributions of incidence estimates, as well as a central point estimate. These distributions are helpful for characterizing the uncertainty associated with each component of the health impact assessment.
- BenMAP-CE also calculates the economic value of the avoided or incurred health effects based on valuation methods from published economics literature. The estimated economic value of an avoided health outcome is multiplied by total change in events to determine the monetized health benefits of air quality improvements. As with the C-R functions described above, the valuation functions include estimates of statistical error that BenMAP-CE uses to generate distributions of results (U.S. EPA, 2015a).
- The BenMAP-CE modeling method is illustrated in Figure 4-11.

Figure 4-11: BENMAP-CE Health Impacts Modeling Procedure



Strengths and Limitations of BenMAP-CE

One of BenMAP-CE's strengths is that it includes numerous C-R functions and economic valuations from which the user can select when performing an analysis. Users can also add new functions. In addition, by using air quality modeling data or actual monitoring data, it provides detailed estimates of health impacts with a high degree of spatial resolution (Wesson et al., 2010). Limitations of BenMAP-CE include its high level of complexity and its requirement that the analyst conduct and then import air quality modeling results as a first step. <http://www.epa.gov/benmap>

²⁸ BenMAP-CE accepts air quality output from a variety of models, including EPA's Community Multi-Scale Air Quality Model (CMAQ), the Comprehensive Air Quality Model with Extensions (CAMx), and EPA's Response Surface Model (RSM). BenMAP-CE can also accept other model results by changing the default input structure.

²⁹ Pooling is a method of combining multiple health effects estimates to generate a more robust single estimate of health impacts.

HOW BENMAP-CE HAS BEEN USED IN ENERGY EFFICIENCY AND RENEWABLE ENERGY ANALYSIS

In 2013, the Minnesota Pollution Control Agency (MPCA) used BenMAP-CE to estimate the benefits of an emissions reduction proposal for Minnesota Power's coal-fired power plant Boswell Unit 4. Their plan was designed to achieve mercury (Hg) reductions by the Mercury Emissions Reduction Act, but also led to lower emissions of SO₂ and PM.

MPCA analyzed the expected impact of pollution control technologies, such as scrubbers and filters, on Unit 4. They estimated that, by the 2016 compliance deadline and compared to 2011 levels, the plan would reduce SO₂ by 39 percent, PM by 80 percent, and Hg by 89 percent.

MPCA then quantified the impact of these emissions reductions on pollution concentrations using photochemical air quality modeling. Air quality changes were entered into BenMAP-CE to estimate monetized health benefits of SO₂ and PM, which were valued between \$14 and \$31 million.

Source: Minnesota Pollution Control Agency, 2013.

4.4.5. Examples of Emission, Air Quality, and Health Benefit Analyses Conducted with EPA's AVERT and/or COBRA

In addition to the case studies earlier, examples of state energy efficiency and renewable energy analyses conducted using EPA's AVERT and/or COBRA models are provided below, organized by tool.

Analyses That Used EPA's AVERT to Quantify Emissions Impacts of Energy Efficiency and Renewable Energy

- **“Assessing Emission Benefits of Renewable Energy and Energy Efficiency Programs.”** This 2015 paper was presented at U.S. EPA's International Emissions Inventory Conference. It presents an approach embodied in EPA's AVoided Emissions and geneRation Tool (AVERT), to assist state and local air quality managers and stakeholders in estimating avoided CO₂, NO_x, and SO₂ emissions from EGUs due to the implementation of energy efficiency and renewable energy policies and resources.
<https://www3.epa.gov/ttn/chief/conference/ei21/session9/deyoung.pdf>
- **“Carbon Reductions and Health Co-benefits from U.S. Residential Energy Efficiency Measures.”** This 2016 paper, published in *Environmental Research Letters*, examined the climate, economic, and health benefits of increased residential insulation regarding fossil fuel powered electricity generating units. The analysis used the AVERT model to estimate emissions reductions resulting from reduced electricity demand.
<http://iopscience.iop.org/article/10.1088/1748-9326/11/3/034017/meta>
- **Clark County, NV's Paths Forward Submissions under U.S. EPA's Ozone Advance Program.** The Clark County Department of Air Quality (DAQ) enrolled in the U.S. Environmental Protection Agency (EPA) Ozone Advance program, June 2013. As a part of their annual “path forward” submissions, Clark County (DAQ) uses EPA's AVoided Emissions and geneRation Tool (AVERT) to calculate emissions reductions attributable to renewable energy and energy efficiency programs implemented in Nevada. <https://www.epa.gov/advance/program-participants-nevada>
- **“The Clean Air Benefits of Wind Energy.”** As detailed in this 2014 white paper, wind energy is widely available across the country and is already playing a significant role in reducing carbon emissions in nearly every state, as well as emissions of other air pollutants. This paper provides state-by-state numbers, calculated using EPA's AVoided Emissions and generation Tool (AVERT), for the emissions reductions attributable to the currently installed wind turbine fleet in the United States. http://awea.files.cms-plus.com/FileDownloads/pdfs/AWEA_Clean_Air_Benefits_WhitePaper_Final.pdf

- **Maine Distributed Solar Valuation Study.** This 2015 study presented a methodology developed under a Commission-run stakeholder review process, a valuation on of distributed solar for three utility territories, and a summary of implementation options for increasing deployment of distributed solar generation in the State. <http://www.maine.gov/tools/whatsnew/attach.php?id=639056&an=1>

Analyses That Used EPA’s COBRA to Quantify Air Quality and Health Impacts of Energy Efficiency and Renewable Energy

- **“Staff White Paper on Benefit-Cost Analysis in the Reforming Energy Vision Proceeding.”** In 2015, the New York Department of Public Service proposed a general framework for evaluating the benefits and costs of alternative utility investments. The paper lists proposed components of a benefit-cost analysis framework and a methodology for valuing benefits and costs, including using COBRA to estimate the health impacts of SO₂ and NO_x emissions. [https://www3.dps.ny.gov/W/PSCWeb.nsf/96f0fec0b45a3c6485257688006a701a/c12c0a18f55877e785257e6f005d533e/\\$FILE/Staff_BCA_Whitepaper_Final.pdf](https://www3.dps.ny.gov/W/PSCWeb.nsf/96f0fec0b45a3c6485257688006a701a/c12c0a18f55877e785257e6f005d533e/$FILE/Staff_BCA_Whitepaper_Final.pdf)
- **“Controlling Episodic Air Pollution with a Seasonal Gas Tax: The Case of Cache Valley, Utah.”** This 2015 paper published in *Environmental & Resource Economics* used longitudinal data to establish a relationship between particulate matter (PM_{2.5}) concentrations and vehicle trips. The authors also analyzed the benefits and costs of a seasonal gas tax and found that the social net benefit of the gas tax depended on the type of benefit analysis used. <https://link.springer.com/article/10.1007/s10640-015-9968-z>
- **“Public Health Impact and Economic Costs of Volkswagen’s Lack of Compliance with the United States’ Emission Standards.”** This 2016 paper, published in the *International Journal of Environmental Resources and Public Health*, used COBRA to quantify the health impacts of extra NO_x emissions from Volkswagen’s non-compliant vehicles in the United States. <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5036724/>
- **Standardized Regulatory Impact Assessment: Computers, Computer Monitors, and Signage Displays.** This 2016 report analyzed the economic impacts of California Energy Commission’s proposed efficiency standards for computers, computer monitors, and signage displays. The analysis used COBRA to monetize the health benefits from potential emissions reductions from the proposed standard. http://www.dof.ca.gov/Forecasting/Economics/Major_Regulations/Major_Regulations_Table/documents/SRIA_APPEFF_2016_All.pdf
- **“The Climate and Air Quality Benefits of Wind and Solar Power in the United States.”** This 2017 article, published in *Nature Energy*, examined the cumulative air quality and climate benefits of solar and wind electricity generation from 2007 to 2015. The analysis considered avoided emissions, avoided damages, comparisons with incentives and market prices, and the impact of cap-and-trade programs. The analysis used COBRA, AP2, and EASIUR to estimate the health benefits of solar and wind generation throughout the United States. <https://www.nature.com/articles/nenergy2017134>
- **Benefit-Cost Evaluation of U.S. DOE Investment in HVAC, Water Heating, and Appliance Technologies.** This 2017 report, commissioned by U.S. DOE, included a rigorous benefit-cost impact evaluation of the one of DOE’s long-standing R&D portfolios within the Building Technology Office’s Emerging Technologies Program: R&D investments in heating, ventilation, and air conditioning (HVAC), water heating, and appliance technologies. It used EPA’s COBRA model to quantify the health benefits associated with the program investments. https://www.energy.gov/sites/prod/files/2017/09/f36/DOE-EERE-BTO-HVAC_Water%20Heating_Appliances%202017%20Impact%20Evaluation%20Final.pdf

- **Virginia Department of Planning and Budget Economic Impact Analysis for 9 VAC 5-140 Regulation for Emissions Trading.** In 2017, the Virginia Department of Environmental Quality used COBRA to estimate the air quality related health co-benefits from SO₂ and NO_x reductions likely to occur under Virginia’s proposed CO₂ Budget Trading Program.
http://townhall.virginia.gov/L/GetFile.cfm?File=C:%5CTownHall%5Cdocroot%5C1%5C4818%5C8130%5CEIA_DEQ_8130_v2.pdf

Analyses That Used EPA’s AVERT and COBRA Models to Quantify Emissions, Air Quality, and Health Impacts of Energy Efficiency and Renewable Energy

- **The Health and Environmental Benefits of Wind and Solar Energy in the United States, 2007–2015.** In 2017, the Lawrence Berkeley National Laboratory published a study that evaluated how a subset of wind and solar energy’s health and environmental benefits evolved over time. The study considers benefits in absolute terms and on a dollar-benefit-per-kWh basis. The study used EPA’s AVERT model to generate estimates of avoided emissions of CO₂, SO₂, NO_x, and PM_{2.5}, and it used COBRA (along with other health benefits models, including EASIUR and AP2) to estimate health impacts from emissions reductions.
<https://emp.lbl.gov/publications/health-and-environmental-benefits>
- **A Retrospective Analysis of the Benefits and Impacts of U.S. Renewable Portfolio Standards.** This 2016 report, produced by Lawrence Berkeley National Laboratory and the National Renewable Energy Laboratory, analyzes historical benefits and impacts of all state RPS policies, in aggregate. It uses EPA’s AVERT models to quantify retrospectively the greenhouse gas and air pollution impacts of state RPS. The analysis uses three different approaches to quantify the health impacts of changes in air pollution, including EPA’s COBRA model.
<http://www.nrel.gov/docs/fy16osti/65005.pdf>
- **Saving Energy, Saving Lives: The Health Impacts of Avoiding Power Plant Pollution with Energy Efficiency.** This 2018 ACEEE report used AVERT and COBRA to quantify the state and local emissions and health impacts, respectively, of achieving a 15-percent reduction in annual electric consumption evenly across the country in a single year. They used the outputs to rank states and the 50 largest U.S. cities based on where the scenario’s energy savings could have the greatest positive impact on the health of people living there.
<http://aceee.org/sites/default/files/publications/researchreports/h1801.pdf>

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