CHAPTER FOUR

# Assessing the Air Pollution, Greenhouse Gas, Air Quality, and Health Benefits of Clean Energy Initiatives

## Many states and localities are exploring or implementing clean energy policies to achieve greenhouse gas (GHG) and criteria air pollutant[1] emission reductions.

For example, New Mexico's Climate Change Advisory Group Action Plan estimates that clean energy measures could achieve more than one-third of the 35 million metric tons of potential carbon dioxide ($CO_2$) reductions identified in New Mexico in 2020, representing around 15 percent of the projected baseline emissions levels in 2020 (New Mexico Climate Change Advisory Group, 2006). The Metropolitan Washington Council of Governments included renewable energy and energy efficiency measures in its May 2007 State Implementation Plan (SIP) for the 8-Hour Ozone Standard. These measures are expected to avoid almost 150,000 MWh of generation and 0.17 tons of $NO_x$ daily (Metropolitan Washington COG, 2007).

GHG and criteria air pollutant emission reduction estimates are important measures of the potential or realized benefits of clean energy, and are a critical first step for further environmental benefits analysis. Once emitted, some criteria air pollutants are transported in

1 *Criteria air pollutants are particle pollution (often referred to as particulate matter), ground-level ozone, carbon monoxide, sulfur oxides, nitrogen oxides, and lead. The Clean Air Act requires EPA to set National Ambient Air Quality Standards for these air pollutants. EPA calls these pollutants "criteria" air pollutants because it regulates them by developing human health-based and/or environmentally based criteria (i.e., science-based guidelines) for setting permissible levels (U.S. EPA, 2008d).*

DOCUMENT MAP



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the atmosphere potentially for long distances. Some "primary" pollutants are directly harmful to exposed humans and the environment, while other "secondary" pollutants can affect human health after they form as a result of photochemical reactions in the atmosphere. For example, nitrogen oxides ($NO_X$) and volatile organic compounds (VOCs) react under certain meteorological conditions to form ozone ($O_3$), a principal component of photochemical smog. Estimating the impact of changes in criteria air pollutant emissions on ambient air quality and the related environmental and health impacts can enhance a state's understanding of the potential benefits that can result from clean energy measures.[2]

Understanding a range of environmental and human health benefits from existing and proposed clean energy measures can help state planners:

1. Identify opportunities where meeting today's energy challenges can serve as an environmental improvement strategy,

2. Potentially reduce the compliance costs of meeting air quality standards by offering more options to states, and

3. Build support for clean energy initiatives among state and local decision makers.

This chapter is designed to help states understand the methods, models, opportunities, and issues associated with assessing the GHG, air pollution, air quality, and human health benefits of clean energy options. While it focuses primarily on emissions from electricity, the methods and tools presented in this chapter could be applied to emissions from other sources.

- Section 4.1, *How Clean Energy Initiatives Result in Air and Health Benefits*, describes the environmental and health benefits of clean energy and addresses several key issues associated with estimating these benefits.

- Section 4.2, *How States Estimate the GHG, Air, and Health Benefits of Clean Energy*, presents four key steps a state can take to estimate the air and health benefits of clean energy and describes related methods, tools and issues.

  - Section 4.2.1, *Step 1: Develop and Project a Baseline Emissions Profile*, focuses on developing and projecting an emissions inventory to establish a baseline from which progress can be measured.

  - Section 4.2.2, *Step 2: Quantify Air and GHG Emission Reductions from Clean Energy Measures*, provides guidance on quantifying GHG and criteria air pollutant emission reductions that result from clean energy measures.

  - Section 4.2.3, *Step 3: Quantify Air Quality Impacts*, describes how to estimate the changes in air quality that result from air pollution emission reductions.

2 *By influencing climate change, GHGs can indirectly lead to air quality and health effects. Climate change can lead to more frequent extreme heat events and exacerbate air quality problems through increased temperatures. Methane, which is a key GHG, contributes to ground-level ozone formation. Criteria air pollutants, however, are directly linked to changes in air quality and human health effects in scientific literature. For this reason, this chapter addresses the air quality and human health benefits associated with reducing criteria air pollutant, but not GHG, emissions.*

**STATES ARE QUANTIFYING THE ENVIRONMENTAL BENEFITS OF CLEAN ENERGY POLICIES**

Several states have quantified the emission reductions and air and health benefits from their clean energy measures and determined that the measures are helping them reduce their air pollution and GHGs.

A recent evaluation of The *Wisconsin Focus on Energy Program's* energy efficiency and renewable energy projects funded by the Utility Public Benefits fund, for example, shows that during the period from program inception in July 2001 through June 30, 2006, the state has displaced annual emissions from power plants and utility customers of about: [a]

- 5.8 million pounds of $NO_x$,
- 2.6 billion pounds of $CO_2$,
- 11.4 million pounds of $SO_2$, and
- 46 pounds of mercury (Hg)

In 2004, the Texas Commission on Environmental Quality evaluated the *Texas Emissions Reduction Plan* and calculated that it achieves an annual reduction of $NO_x$ emissions of 346 tons through energy efficiency and renewable energy. $NO_x$ reductions over the period 2007–2012 are projected to range from 824 tons per year in 2007 to 1,416 tons per year in 2012.

*Sources: DOA, 2006; Haberl et al., 2007*

[a] *These emission values vary greatly by type of pollutant, due primarily to the content of carbon, sulfur, nitrogen, and mercury in fossil fuels. For example, $CO_2$ emission reductions from clean energy programs are comparatively high because fossil fuels are rich in carbon, and $CO_2$ is a primary product of fossil fuel combustion. On the other hand, the concentration of Hg in fuel (primarily coal) is very small, and so emission reductions of Hg are also small compared with reductions of other pollutants.*

- Section 4.2.4, *Step 4: Quantify Human Health and Related Economic Effects of Air Quality Impacts*, addresses the quantification of public health impacts based on estimates of air pollution or air quality changes.

- Section 4.3, *Case Studies*, presents examples of how two states, Texas and Wisconsin, have estimated the air quality and health benefits resulting from their clean energy programs.

## 4.1 HOW CLEAN ENERGY INITIATIVES RESULT IN AIR AND HEALTH BENEFITS

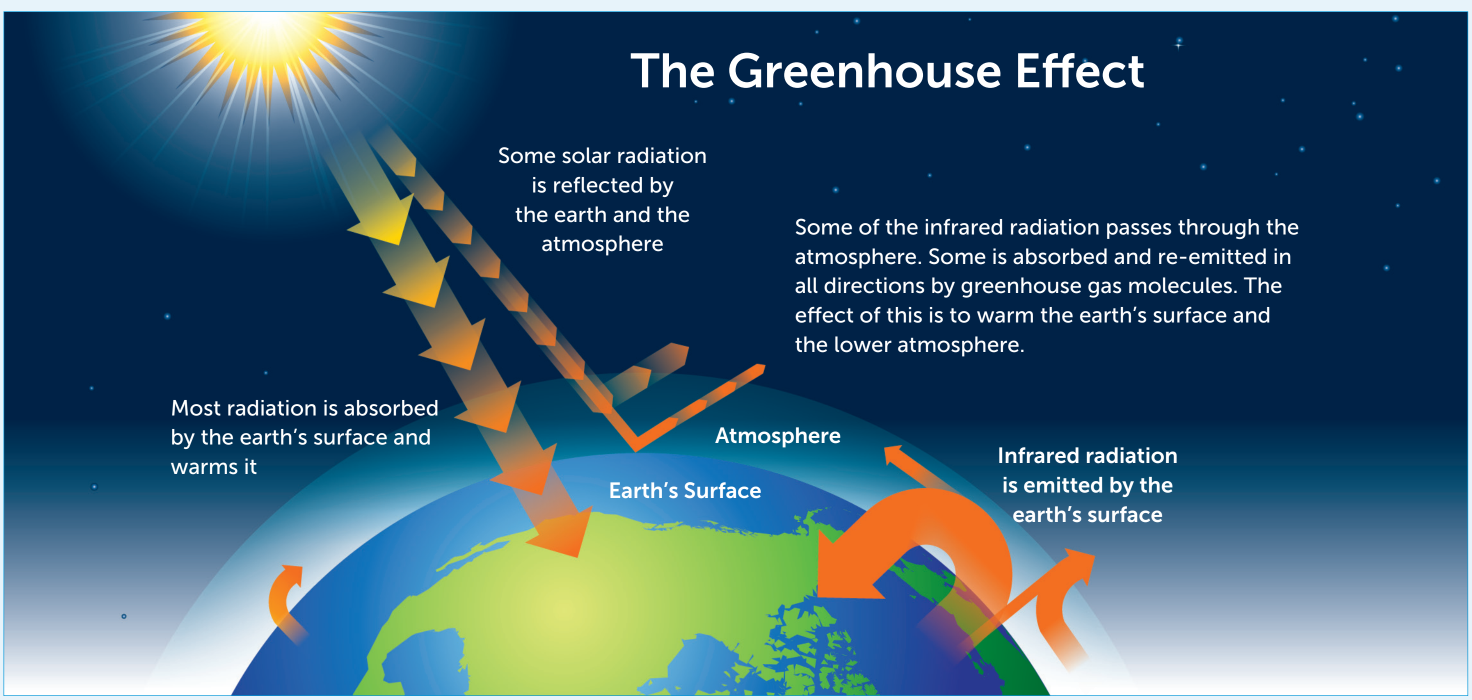
Electricity generation from fossil fuels is a major source of many types of air pollution, including GHGs and criteria air pollutants. These emissions contribute to a variety of environmental issues, including global warming and human health problems, which are described below.

GHG emissions occur naturally and absorb some of the heat that would otherwise escape to space (see Figure 4.1.1, *The Greenhouse Effect*). GHGs keep the planet warmer than it would otherwise be through this natural "greenhouse effect." Human activity-related, or anthropogenic, GHGs, such as those from electricity generation, are increasing the greenhouse effect and are very likely responsible for most of the observed increase in global average temperatures since the mid-20th century.

The process of generating electricity from fossil fuels is the single largest source of anthropogenic carbon dioxide ($CO_2$) emissions in the United States, representing 39 percent of $CO_2$ emissions in 2006 (U.S. EPA, 2008b). GHGs are also emitted during the refinement, processing, and transport of fossil fuels. These gases accumulate and can remain in the atmosphere for decades to centuries, affecting the global climate system for the long term. Measures to reduce GHGs in the near term, therefore, may have a large impact on our ability to meet long-term climate objectives.

Criteria air pollutants affect air quality and human health directly and in the short term. The use of fossil fuels for electric generation causes increased levels of these pollutants in the atmosphere. Some criteria pollutants, including particle pollution (often referred to as particulate matter or PM), carbon monoxide, sulfur dioxide ($SO_2$) and nitrogen oxides ($NO_x$), are directly emitted into the atmosphere as the result of fossil fuel combustion. Ozone ($O_3$) and fine particulate matter

FIGURE 4.1.1 THE GREENHOUSE EFFECT



($PM_{2.5}$) are "secondary" pollutants that form in the air when directly emitted criteria pollutants and other precursor air pollutants, such as volatile organic compounds (VOCs), react or interact. $O_3$ and $PM_{2.5}$ are of particular concern because they are most prevalent and are linked with a variety of respiratory and cardiovascular illnesses and death.[3]

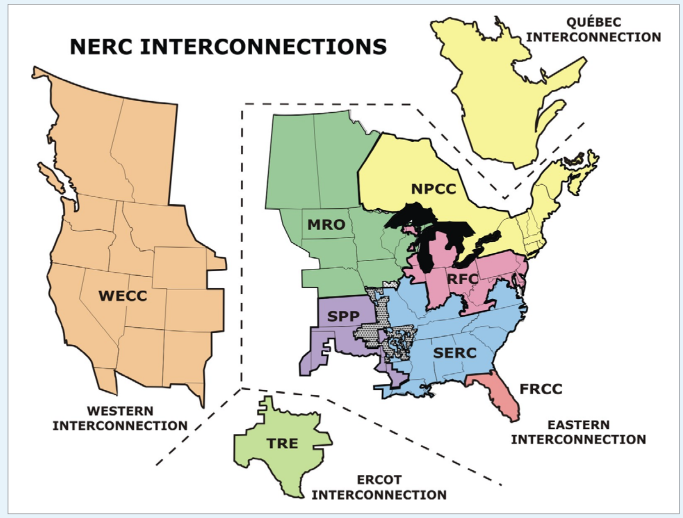
GHGs and criteria air pollutants have different effects on air quality and human health due to their different temporal and spatial characteristics. While GHGs have a global effect and can last more than 100 years, criteria air pollutants have a local to regional effect on air quality and human health, and can dissipate in hours or days. Clean energy measures that reduce criteria air pollutants, therefore, can result in almost immediate local improvements in air quality and human health. In addition, the location and timing of the emissions from criteria air pollutants is very important in determining how significantly they affect human health. Since these pollutants tend to dissipate over time and space, those that occur far away from populations will have less of an impact on human health than those closer to densely populated areas. In contrast, the impact of GHGs on the overall climate system is not affected by the specific location of an emission. One ton of GHG emitted in one location affects the global climate system the same as one ton of the same GHG in a different location.

Clean energy measures reduce the emission of the pollutants described above and related effects on health or the global climate by reducing demand for fossil fuel-based electricity through either:

- Reducing total electric demand through energy efficiency, or
- Directly displacing conventional electricity supplies with clean distributed generation (DG) or renewable energy sources.

The impact of any kind of clean energy resource on air pollutant and GHG emissions and its subsequent effect on human health or global climate change varies depending on the generation sources that are displaced and the resource that is displacing the generation.[4]

## FIGURE 4.1.2 NERC INTERCONNECTIONS




*Source: NERC, 2008.*

To estimate emission reductions associated with clean energy, it is important to determine which resources are expected to be displaced. This was discussed in detail in Chapter 3 and is repeated here in summary form for completeness. Estimating the emissions associated with the displaced generation presents challenges due to (1) the complex way that electricity is generated and transmitted across the United States and (2) uncertainty about the future location of emissions due to market-based environmental programs such as cap and trade. These challenges are discussed below.

- **Electricity Generation, Transmission, and Distribution**. The continental United States and Canada are divided into four interconnected alternating current (AC) grids (the Eastern, Western, Quebec, and Electric Reliability Council of Texas [ERCOT] Interconnections) as depicted in Figure 4.1.2, *NERC Interconnections*. Each of the grids is electrically isolated with only a limited number of direct current (DC) ties connecting them. However, within each of these grids, electricity is imported or exported continuously among the numerous power control areas.

  The demand for electricity varies by season and by time of day. Some power plants—the baseload coal plants and other plants with low variable operating costs such as nuclear and hydroelectric—operate at very high levels. The output of other generators

3 *Tropospheric $O_3$ also acts as a strong GHG. Different components of $PM_{2.5}$ have both cooling (e.g., sulfates) and warming (e.g., black carbon) effects on the climate system.*

4 *DG and combined heat and power (CHP) units often burn fossil fuels as their primary fuel source. In this case, net emissions (i.e., displaced emissions less the emissions of the DG or CHP unit) also depend on the technology and fuel source for the DG or CHP unit.*

**CLEAN ENERGY AND LEAKAGE**

The goal of clean energy policies is typically to reduce emissions within the state or larger region where the policies are implemented. However, due to the interconnected and dynamic nature of the power system, the benefits of clean energy policies may not be completely realized within the region. As utilities and control area operators seek to operate the system to minimize the cost of providing electricity, power transactions occur across the area, both on a long-term contract basis and on a spot basis. As a result, reductions in electricity demand in the region where clean energy policies have been implemented may not always result in corresponding reductions in electricity generation in the same region, depending on the relative cost of this generation and that of neighboring regions.

Reductions in electricity demand levels in the Mid Atlantic region from clean energy policies, for example, might be expected to reduce generation in the Mid Atlantic region. However, if the cost of this now-excess generation in the Mid Atlantic is less than the neighboring regions' marginal sources of generation, it may be economic to use these now-available resources to meet demand in those neighboring regions, thereby displacing more expensive generation. For example, clean energy policies put in place in Pennsylvania may result in reduced emissions in the New England region as lower cost, coal-fired generation is freed up to displace more expensive oil- or gas-fired steam units in New England. The extent of these generation and associated emissions shifts will depend on the cost differential, available transmission capacity, reliability considerations, environmental constraints, and a number of other factors. This shifting of displaced resources from one area to another is often called "leakage" and is an important consideration when assessing the emissions benefits of clean energy programs.

rises and falls throughout the day, responding to changing electricity demand. Other generators are used as "peaking" units and are operated only during the times of highest demand.

A group of system operators across the region decides when and how to dispatch electric generation from each power plant in response to the demand at the time. System operators decide which power plants to dispatch and in what order based on demand at that moment and the cost or bid price. Baseload plants are dispatched first. These plants are typically characterized as having low operating costs, and may be operated at a constant rate. Examples include coal and nuclear plants. Peaking units are dispatched last. These units are typically characterized as having high operating costs, and also have the ability to be dispatched quickly. Examples include natural gas turbines and diesel generators. The fuels, generation efficiencies, control technologies, and emission rates vary greatly from plant to plant by season and time of day. The emissions effects of energy demand reductions, therefore, also vary by load levels, time of day, and season. As discussed later in this section, the interconnected basis of the system, along with least-cost dispatch practices, has implications for the impacts of the effectiveness of clean energy programs in the region in which they are implemented. Specifically, there is potential for generation and emissions leakage from the implementing region to neighboring regions if specific measures are not taken to limit this.

Other conditions besides demand and cost affect dispatch. Transmission constraints, when transmission lines become congested, can make it difficult to dispatch power from far away into areas of high electricity demand. Extreme weather events can decrease the ability to import or export power from neighboring areas. "Forced outages," when certain generators are temporarily not available, can also shift dispatch to other generators. System operators must keep all these issues in mind when dispatching power plants. For more information about how the electric system works, see Section 3.1, *How Clean Energy Can Achieve Electric System Benefits*.

- **Air Emission Cap and Trade Programs**. Air emission cap and trade programs, such as the Acid Rain Program,[5] set annual limits (i.e., caps) on fossil-fuel-fired electric generators' emissions and play an important role in ensuring that air pollutant emissions are reduced.

Under cap and trade programs, each utility or generator typically receives a certain number of allowances, each of which is an authorization to emit one ton of a specific air pollutant (e.g., $SO_2$). A generator must obtain enough allowances to cover its emissions. If a generator has excess allowances, due, for example, to the installation of air pollution control devices, it can bank the allowances for later use or sell the allowances to another company, depending upon the specific program rules. If a generator does not expect to have enough allowances to authorize its emissions, it can buy allowances, install emissions controls, or curtail its activity.

The trading component of the cap and trade program allows for the most cost-effective emission reductions to occur first. If the demand for

5 *The Acid Rain Program regulates $SO_2$ and $NO_X$ emissions in the continental United States to reduce acid deposition caused by these emissions.*

allowances decreases or the supply of excess allowances increases (e.g., because clean energy measures result in reduced fossil-fuel-fired electricity generation) the cost of achieving the cap decreases, but the cap itself does not change. While cap and trade programs ensure a certain reduced level of emissions and can result in a more diversified energy system, trading emission allowances means that it can be difficult to attribute emission reductions to specific clean energy measures, and that in some cases clean energy measures may not result in net emission reductions at all.

Despite these challenges, tools and methods exist for states to address these issues and estimate air emission reductions, air quality changes, and human health effects associated with clean energy policies. These approaches are described below in Section 4.2, *How States Estimate the GHG, Air and Health Benefits of Clean Energy*.

## 4.2 HOW STATES ESTIMATE THE GHG, AIR, AND HEALTH BENEFITS OF CLEAN ENERGY

Analysis to quantify the greenhouse gas, air pollution, air quality, and human health benefits of clean energy initiatives involves four basic steps:

1. Develop and project a baseline emissions inventory,
2. Quantify the air and GHG emission reductions from the clean energy measures,
3. Estimate the changes in air quality resulting from these emission reductions, and
4. Estimate the human health and related economic effects of these air quality changes.

These steps often occur linearly, as shown in Table 4.2.1, *Steps for Estimating GHG, Air, and Health Benefits of Clean Energy Initiatives*. This is because estimating some of the benefits, such as improved air quality and reduced human health effects, requires information generated in previous steps—specifically the timing and type of generation displaced by the clean energy measures.

Some states may not be interested in estimating all of the benefits described in this section, or they may not achieve benefits in each area. For example, as described in Section 4.1, *How Clean Energy Initiatives Result in Air and Health Benefits*, while criteria air pollutants

**GUIDANCE ON CREDITS FOR EMISSION REDUCTIONS FROM CLEAN ENERGY**

EPA has developed a State Implementation Plan (SIP) guidance document that provides a step-by-step procedure for quantifying the benefits. It describes the following two options for state and local governments to address the presence of a cap and trade program when quantifying emission reductions from clean energy:

- Retire commensurate amount of allowances, or
- Demonstrate that an emission or air quality benefit is expected to occur even in the presence of such a cap and trade program.

*Source: U.S. EPA, 2004.*

are linked directly with air quality changes and human health effects, greenhouse gas emissions are indirectly linked to air quality and human health effects.[6] Thus, if a state clean energy policy yields GHG impacts but very low criteria air pollutant impacts, it may not be worthwhile to continue evaluating the air quality and subsequent health impacts because they likely would be negligible.

The remainder of this section describes basic and sophisticated modeling approaches, and related protocols, data needs, tools, and resources that states can use during each step in the process of quantifying the GHG, air, and human health benefits of clean energy initiatives.

### 4.2.1 STEP 1: DEVELOP AND PROJECT A BASELINE EMISSIONS PROFILE

The initial step in measuring clean energy emissions reductions is to prepare a state-level emissions inventory and projection that documents the baseline, or the emissions that occur without any additional clean energy policies. This baseline can include historical, current, and projected emissions data and provides a clear reference case against which to measure the emission impacts of a clean energy initiative.

Emissions inventories and projections are typically created for criteria air pollutants to support air quality attainment planning, or for GHGs to support climate change action plans, but do not necessarily include both GHGs and criteria air pollutants. However, an inventory that includes both types of emissions will

6 *Nevertheless, clean energy measures that reduce GHGs may also reduce criteria air pollutants, thus resulting in direct health benefits.*

## TABLE 4.2.1 STEPS FOR ESTIMATING GHG, AIR, AND HEALTH BENEFITS OF CLEAN ENERGY INITIATIVES

| Step 1. | Step 2. | Step 3. | Step 4. |
|---|---|---|---|
| **Develop and Project a Baseline Emissions Profile (Section 4.2.1)** | **Quantify Air and GHG Emission Reductions from Clean Energy Measures (Section 4.2.2)** | **Quantify Air Quality Impacts (if any) (Section 4.2.3)** | **Quantify Human Health and Related Economic Effects of Air Quality Impacts (Section 4.2.4)** |
| **Criteria Air Pollutants** | | | |
| **a.** Select method.<br>**b.** Compile criteria air pollutants from available sources into inventory.<br>**c.** Develop a forecast using assumptions about future and available tools. | **a.** Develop criteria air pollutant reductions from clean energy using:<br>▪ energy savings estimates,<br>▪ operating characteristics of clean energy resource (load profile),<br>▪ emissions factors, and<br>▪ control technology data.<br>Compare against the baseline. | Use criteria air pollutant data to estimate changes in air quality with an air quality model. | **a.** Use data on air quality changes and epidemiological and population information to estimate health effects.<br>**b.** Apply economic values of avoided health effects to monetize benefits. |
| **Greenhouse Gas Emissions** | | | |
| **a.** Select method.<br>**b.** Compile greenhouse gas emissions from available sources into inventory.<br>**c.** Develop a forecast using assumptions about future and available tools. | **a.** Develop greenhouse gas emission reductions from clean energy using:<br>▪ energy savings estimates and a profile of when these impacts will occur,<br>▪ operating characteristics of clean energy resource,<br>▪ emissions factors, and<br>▪ fuel data.<br>**b.** Compare against the baseline. | n/a | n/a |

facilitate a more comprehensive analysis of the emissions benefits of clean energy and the value of clean energy policies. This is important because many options that reduce GHGs may, in fact, reduce criteria air pollutants and indirectly yield health benefits. On the other hand, 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 will result in both criteria air pollutant benefits and GHG emission reductions. The impact on air pollution is less certain, however, if a state switches from natural gas to biomass-generated energy. It is important to take these considerations into account when evaluating the air and health benefits of clean energy measures. Developing a baseline that includes both GHGs and criteria air pollutants serves as a future point of reference for retrospective program evaluation as well as a basis for making well-informed policy and planning decisions.

Typically, a state's air agency creates the criteria air pollutant inventory every three years as part of its responsibility to meet National Ambient Air Quality Standards established under the Clean Air Act. GHG emissions inventories can be developed by state air or other agencies, but since states are not required by federal law to inventory their GHG emissions, the practice varies from state to state. State energy offices or universities sometimes develop GHG inventories on an annual basis or every few years. If inventories

### SOURCES OF AIR POLLUTION EMISSIONS

Air emission sources are grouped into four categories: point, area, mobile (on-road and non-road), and biogenic 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**: Sources of air pollution from highway vehicles such as cars and light trucks, heavy trucks, buses, engines, and motorcycles.

**Non-Road Mobile Source**: Pollutants emitted by 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**: Emissions produced by living organisms, such as a forest that releases hydrocarbons.

*Sources: Texas Commission on Environmental Quality, 2008; U.S. EPA, 2008.*

### EMISSIONS FACTOR APPROACH

An emissions factor quantifies the amount of a pollutant released to the atmosphere from a "unit" of an activity or source (e.g., lbs $CO_2$ per therm $CH_4$ burned). The emissions estimates are calculated by multiplying the emissions factor (e.g., pounds of $NO_x$ per kWh produced) by the activity level (e.g., kWh produced). Emissions factors can be calculated based on the chemical composition of the fuels burned or determined by emissions monitors.

Emissions factors for $CO_2$, $NO_x$, $SO_2$, and other pollutants are available from:

- **EPA's Emissions Factors and Policy Applications Center**
  *http://www.epa.gov/ttn/chief/efpac/.html*
- **EPA's Emissions & Generation Resource Integrated Database(eGRID)**
  *http://www.epa.gov/egrid*
- **EPA's U.S. Greenhouse Gas Inventory Reports**
  *http://www.epa.gov/climatechange/emissions/usinventoryreport.html*
- **Intergovernmental Panel on Climate Change Emissions Factor Database (EFDB)**
  *http://www.ipcc-nggip.iges.or.jp/EFDB/main.php*

are available, states can use them in their assessment of clean energy policies rather than develop a new baseline emissions inventory. Sources of completed state and local inventories that states and localities can adopt for use in their analyses include:

- *EPA State GHG Inventories*: EPA maintains a Web site on state GHG inventories, which includes a table of state CO2 emissions from fossil fuel consumption by sector. ***http://epa.gov/climatechange/emissions/state_energyco2inv.html***

Links to maps and summaries of existing state-compiled greenhouse gas inventories are also available on this Web site.[7] ***http://epa.gov/climatechange/emissions/state_ghginventories.html***

- *Local Government Inventories*. Many local governments have compiled GHG and/or criteria air pollutant inventories through the auspices of ICLEI's Cities for Climate Protection or the U.S. Conference of Mayor's Climate Protection Agreement. These inventories have typically been developed using the CACPS Tool described below. Many of these local inventories can be found online.
- *National Emissions Inventory (NEI)*. States can use the NEI to help establish an inventory of criteria and hazardous pollutants. EPA prepares a national database of air emissions information 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 (HAPs). The database also includes estimates of annual emissions, by source, of air pollutants in each area of the country. The NEI includes emission estimates for all 50 states, the District of Columbia, Puerto Rico, and the Virgin Islands, and is updated every three years. ***http://www.epa.gov/ttn/chief/eiinformation.html***

If existing baseline inventories are not available, states can develop their own using methods and tools described below.

7 *State CO2 estimates are based on state energy data from the Energy Information Administration (EIA), which maintains a database of state energy-related data including fuel consumption by sector, electricity consumption, and forecasts of the electric generation sector (U.S. DOE, 2008b).*

### Approaches to Developing a Baseline Emissions Inventory

There are two basic approaches for developing state emissions inventories for criteria air pollutants and/or GHGs: top-down and bottom-up approaches. Both inventory approaches require energy use estimates and emissions factors to convert estimates of energy use into estimates of emissions, as described in the text box *Emissions Factor Approach*. Top-down and bottom-up approaches vary in their level of data and aggregation and can serve different purposes. While the inventory development process can be time- and resource-intensive, it does not necessarily entail complex modeling methods.

Table 4.2.2, *Comparison of Top-Down and Bottom-Up Approaches for Developing a Baseline Air and/or GHG Emissions Inventory and Projection*, compares the key aspects of top-down and bottom-up approaches. The following section presents information about each approach for developing an emissions inventory, including their strengths and weaknesses, appropriate applications, relevant data sources and resources, and the tools available to states. Methods and approaches for projecting inventories out into the future are also described. For further information on described tools, see the Information Resource Description table at the end of this chapter.

#### *Top-Down Inventory Development*

A top-down inventory contains aggregated activity data across the state or community, and is used to generate state-wide estimates of emissions of GHGs or criteria air pollutants. For example, a top-down inventory might report emission estimates for categories such as an industry within a state; it would not contain data on emissions from specific facilities or buildings.

**TABLE 4.2.2 COMPARISON OF TOP-DOWN AND BOTTOM-UP APPROACHES FOR DEVELOPING A BASELINE AIR AND/OR GHG EMISSIONS INVENTORY AND PROJECTION**

| Tools | Protocols | Advantages | Disadvantages | When to Use this Method |
|---|---|---|---|---|
| **Top-Down Inventory** | | | | |
| ▪ EPA's State Inventory Tool for GHGs.<br>▪ National Association of Clean Air Agencies (NACAA) and International Council for Local Environmental Initiatives (ICLEI) Clean Air and Climate Protection Software (community- or state-wide inventory). | ▪ Intergovernmental panel on Climate Change.<br>▪ EPA's Emissions Inventory Improvement Program. | ▪ Can capture all emissions in a state.<br>▪ Reliable data are available for most major sources. | ▪ Does not provide in-depth sectoral emission detail.<br>▪ Use of state average factors may lead to some uncertainty or error in estimates.<br>▪ Lacks spatial resolution needed for air quality modeling. | ▪ State-wide estimates of emissions.<br>▪ State-wide GHG inventories.<br>▪ Area source emission estimates for criteria air pollutants. |
| **Bottom-up Inventory** | | | | |
| ▪ NACAA and ICLEI's Clean Air and Climate Protection Software (government operations inventory).<br>▪ Emission Reporting Data (e.g., Acid Rain Program Data, or facility specific emission reports). | ▪ EPA Climate Leaders GHG Inventory Protocol.<br>▪ The World Resources Institute (WRI) and World Business Council on Sustainable Development (WBCSD) GHG Protocol.<br>▪ California Registry Protocols.<br>▪ The Climate Registry. | ▪ Can provide more detailed or nuanced profile of emissions.<br>▪ Allows analysis of indirect emissions sources (purchased electricity, etc). | ▪ Requires highly disaggregated data which may be difficult to obtain.<br>▪ May not capture all emissions in a state. | ▪ Sector-specific GHG inventories.<br>▪ Stationary source emission estimates for criteria air pollutants.<br>▪ When data required for top-down inventory are not available. |

### GHG REGISTRIES

GHG registries are systems for quantifying and reporting GHG emissions and/or activities to reduce emissions that are developed by collaborations of organizations, such as states or firms. By establishing consistent emission reporting protocols, a registry provides a common framework for entities to complete a GHG inventory of their own emissions or emissions reductions and a credible repository for the data over time. Such a collection of entity-level emissions data can help inform a state's understanding of emission sources and activities being taken to reduce emissions. A registry does not serve the same function as an inventory since it does not provide a comprehensive or complete set of data on all emissions sources.

Examples of registry efforts are:

- ***The Climate Registry*** is a collaboration among states, provinces, and tribes to develop a common greenhouse gas emissions registry system across multiple governments. Corporations with operations in multiple states will be able to report emissions using a consistent reporting protocol and management system. *http://www.theclimateregistry.org/*.
- ***The California Climate Action Registry (CCAR)*** was established by California statute as a registry for GHG inventories for corporate reporting within the state. CCAR has developed a general protocol and additional industry-specific protocols that give guidance on how to inventory GHG emissions for participation in the Registry. *http://www.climateregistry.org/*
- ***The Voluntary Reporting of GHG Program*** is a mechanism by which corporations, government agencies, individuals, and organizations can report their GHG emissions, emission reductions, and sequestration activities to the federal Energy Information Agency. It was established under Section 1605(b) of the Energy Policy Act of 1992. *http://www.eia.doe.gov/oiaf/1605/index.html*
- ***EPA's Mandatory GHG Reporting Rule***, as requested by Congress under the FY2008 Consolidated Appropriations Act, became effective December 29, 2009. It requires sources above certain threshold levels monitor and report GHG emissions and applies to fossil fuel suppliers and industrial gas suppliers, direct GHG emitters and manufacturers of heavy-duty and off-road vehicles and engines.. *http://www.epa.gov/climatechange/emissions/ghgrulemaking.html*

Because the spatial characteristics of criteria air pollutants are important, an ideal inventory would include very detailed, source-specific data that can be used in air quality modeling. However, some sources, such as area sources (e.g., residential 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 approach.[8] See the text box *Sources of Air Pollution Emissions* above for a summary of the different sources.

While there may be circumstances where a state desires significant detail about the sources of its GHG emissions, GHG inventories do not require the same level of detailed spatial resolution since, as described above, a ton of GHGs in one part of the state affects global climate change in the same way as a ton of the same GHG in another part of the state. For GHG emission inventories, the top-down approach is most appropriate when developing state-wide estimates of emissions and developing emission reduction targets.

## Protocols

It is important to develop an inventory that adheres to a comprehensive and detailed set of methodologies for estimating emissions. For GHG emissions, these methodologies are usually derived from standards established by the Intergovernmental Panel on Climate Change (IPCC, 2008). Specific methods, tools, and protocols for developing top-down baseline GHG emissions inventories, forecasting future emissions, and tracking changes are available at both the state and local levels. For criteria air pollutants, these methodologies are usually derived from standards established by EPA's Emissions Inventory Improvement Program (EIIP), which offers guidance for developing inventories of criteria and hazardous air pollutants and greenhouse gas emissions (EPA, 2007). The protocols vary depending on the type of inventory data a state collects.

## Data Needs

To complete a top-down state-wide energy-related emissions inventory, a state needs a variety of data, such as state-wide electricity generation; energy consumption by sector; and coal, oil, and natural gas production and distribution.[9] Many of these data are available from national sources, such as the Energy Information Agency (EIA) State Energy Data System (U.S. DOE, 2008a). Data on economic activity and human population levels may be needed to supplement data sources. These data are also available from national sources such as the Bureau of Economic Analysis'

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

9 *To expand the inventory beyond energy, 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.*

Regional Accounts and the Census Bureau Population Estimates. Some tools, such as the State Inventory Tool, described below, provide default values states can use. Additional sources are described later in this section.

## Tools

Tools to help state and local governments develop GHG and criteria air pollutant emission inventories include:

- *EPA's State Inventory Tool.* States can use EPA's State Inventory Tool to develop top-down GHG inventories. This interactive spreadsheet software tool is based on IPCC guidelines. States can enter their own data or use pre-loaded state-specific emissions factors and activity levels from federally managed databases, such as EPA's eGRID (***http://www.epa.gov/egrid***) and DOE's EIA. The State Inventory Tool can calculate GHG emissions from energy consumption as well as from industrial processes, agriculture, forestry, and waste management. This tool is generally used to develop state-wide inventories that can be tracked over time, to determine sectors a state might target for reductions and to measure long-term progress against state-wide or community-wide goals over time. The State Inventory Tool is designed to generate inventories for each year in a time series (currently 1990–2006). ***http://www.epa.gov/climatechange/emissions/state_guidance.html***

- *Clean Air and Climate Protection Software Tool.* Local governments can use the *Clean Air and Climate Protection Software (CACPS)* tool to develop a top-down inventory of both criteria air pollutants and GHGs associated with electricity, fuel use, and waste disposal. CACPS is a Windows-based software tool and database developed by the National Association of Clean Air Agencies (NACAA)[10] and the International Council for Local Environmental Initiatives (ICLEI), with EPA funding. The 2005 version of the tool is provided free to state and local governments. More recent versions can be purchased from ICLEI.

  While available to state as well as local governments, the CACPS tool is most appropriate for developing locality-wide or government operations GHG inventories based on IPCC guidelines with the inclusion of criteria air pollutants. The CACPS tool:

  - is based on end-use energy consumption and excludes agriculture, forestry, industrial, and energy production;
  - requires users to complete each inventory year separately; and
  - allows for analysis of indirect emissions (e.g., electricity imported from another state, waste sent to out-of state landfills).

  It is important to note, however, that CACPS does not include location-specific criteria air pollutant inventories and so it is difficult to interpret air quality impacts. ***http://www.cacpsoftware.org/***

### *Bottom-up Inventory Development*

While top-down inventories are developed using high-level, aggregated energy and economic information, bottom-up inventories are built from source, equipment population, and activity data. Bottom-up inventory development involves collecting information on source number and type from individual entities (e.g., businesses, local governments) within the state. This approach can supplement state-wide GHG and other air pollutant emission inventories by providing additional, more detailed information. Data collected in this manner may provide a more accurate estimate of emissions within particular sectors (e.g., state-owned government buildings). A more detailed and time consuming method than the top-down approach, bottom-up inventory development provides comprehensive estimates of precursor emissions and details regarding spatial and temporal attributes that are required for air quality modeling applications.

For criteria air pollutant inventories, bottom-up inventories are most appropriate for developing more accurate estimates for on-road, non-road, and stationary source emissions that can easily be attributed to individual sectors or sources (e.g., major industrial and commercial emission sources, such as electricity generators, manufacturing processes and chemical processes). For GHG emission inventories, the bottom-up approach is most appropriate when developing sector-specific inventories, when the data required for a top-down inventory are not available, or to provide a better match when evaluating multi-pollutant controls.

## Protocols

As with the top-down inventory, it is important to develop a bottom-up inventory that adheres to a

*10 Formerly the State and Territorial Air Pollution Program Administrators and Association of Local Air Pollution Control Officials (STAPPA/ALAPCO).*

comprehensive and detailed set of methodologies for estimating emissions. For GHG emissions, there are several protocols that states can use, including:

- *EPA Climate Leaders GHG Inventory Protocol*. The Climate Leaders Protocol includes overall guidance to corporations in the Climate Leaders Partnership on issues such as defining inventory boundaries, identifying GHG emission sources, defining and adjusting a base year, reporting requirements, and goal-setting. ***http://www.epa.gov/climateleaders***

- *The GHG Protocol*. The GHG Protocol is a joint effort of the World Resources Institute (WRI) and the World Business Council on Sustainable Development (WBCSD). The protocol was designed for corporate inventories, but can be adapted for use by state governments quantifying emissions from their own operations. The protocol provides step-by-step guidance on calculating 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/***

- *Local Government Operations Protocol for the Quantification and Reporting of Greenhouse Gas Emissions Inventories, released in September 2008*. The Local Government Operations Protocol was created to help local governments develop consistent and credible emission inventories based on internationally accepted methods. 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://www.icleiusa.org***

  For criteria air pollutants, methodologies are usually derived from standards established by EPA's EIIP program, which offers guidance for developing inventories of criteria and hazardous air pollutants. ***http://www.epa.gov/ttn/chief/eiip/techreport/***

## Data Needs

Bottom-up inventories are data-intensive. Often data are not as readily available from national databases as for top-down inventories and thus may require a significant level of effort and time to collect. To conduct a bottom-up GHG inventory of the utility sector, for example, a state would collect data on the fossil fuel consumption of every electricity production site in the state and convert it to GHG quantities based on the carbon content of the specific fuels that were used. Alternatively, for sources for which data exist, a state can gather and analyze continuous emissions monitoring (CEM) data for electric utilities.

If a state is interested in developing an inventory of its operations-related emissions, it would collect and compile data on its 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.

Bottom-up criteria air pollutant inventories typically use data gathered through surveys and reports from emission sources, source permits, stack test data, and CEM data. As described above, while obtaining data can be difficult, the bottom-up approach can yield a more detailed or nuanced profile of emissions for a particular sector than a top-down approach. More information about existing data sources is provided below.

## Tools

States can use a variety of tools to help develop bottom-up GHG and criteria air pollutant inventories.

**For GHG inventories:**

- *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. A new feature of Portfolio Manager lets users see how their buildings' $CO_2$ emissions compare with other buildings in the same region and across the country, and measure their progress in reducing emissions. The tool can be used to identify buildings with the most potential for energy efficiency improvements. ***http://www.energystar.gov/index.cfm?c= evaluate_performance.bus_portfoliomanager_carbon***

**For criteria air pollutant inventories:**

- Point Sources: Most criteria pollutant inventories for point sources are developed from permits and other facility data rather than from a series of tools. One tool that may complement this approach is the *Landfill Gas Emissions Model* (LandGEM), a free, automated estimation tool with a Microsoft Excel interface that can be used to estimate emission rates for total landfill gas, methane, $CO_2$, nonmethane organic compounds, and individual air pollutants from municipal solid waste landfills. ***http://www.epa.gov/ttn/catc/dir1/landgem-v302-guide.pdf***

- Mobile Sources: Inventories for on-road and non-road mobile sources can be aided by tools such as:
  - *MOBILE6*, a computer program that estimates emission rates for mobile pollutants such as hydrocarbon (HC), carbon monoxide (CO), oxides of nitrogen ($NO_X$), exhaust particulate matter (which consists of several components), tire wear particulate matter, brake wear particulate matter, sulfur dioxide ($SO_2$), ammonia ($NH_3$), six hazardous air pollutants (HAPs), and carbon dioxide ($CO_2$). MOBILE6 focuses on gasoline-fueled and diesel highway motor vehicles, and for certain specialized vehicles such as natural-gas-fueled or electric vehicles that may replace them. MOBILE6 uses county or link-level VMT, speed, registration, and roadway classification data to estimate emissions from motor vehicles. ***http://www.epa.gov/OMS/m6.htm***
  - *NON ROAD 2005* calculates past, present, and future emission inventories (i.e., tons of pollutant) for all nonroad vehicle and equipment categories (e.g., recreational vehicles, agricultural equipment, industrial equipment) except commercial marine, locomotives, and aircraft. The fuel types included in the model are gasoline, diesel, compressed natural gas, and liquefied petroleum. The model estimates exhaust and evaporative HC, CO, $NO_x$, particulate matter, $SO_2$, and $CO_2$ emissions. The user can select a specific geographic area (i.e., national, state, or county) and time period (i.e., annual, monthly, seasonal, or daily) for analysis. The NONROAD tool includes estimates of equipment population and activity and appropriate emissions factors to estimate emissions from these types of sources. ***http://www.epa.gov/oms/nonrdmdl.htm***
  - *Motor Vehicle Emission Simulator (MOVES)* is a replacement for MOBILE6 and NONROAD that EPA is currently developing. This new emission modeling system will estimate emissions for on-road and nonroad mobile sources, cover a broad range of pollutants, and allow multiple scale analysis—from fine-scale analysis to national inventory estimation. When fully implemented, MOVES will serve as the replacement for MOBILE6 and NONROAD for all official analyses associated with regulatory development, compliance with statutory requirements, and national/regional inventory projections. ***http://www.epa.gov/otaq/models/moves/index.htm***

### Data Sources and Additional Resources for Top-Down and Bottom-Up Inventories

Many sources of data exist that states can use as they compile 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. These resources are listed in Table 4.2.3 and described below.

- *Emissions & Generation Resource Integrated Database (eGRID)*. This free, publicly available software from EPA has data on annual $SO_2$, $NO_x$, $CO_2$, and Hg emissions for most power plants in the United States. eGRID also provides annual average non-baseload emission rates, which may better characterize the emissions of load-following resources.[11] By accessing eGRID, states can find detailed emissions profiles for every power plant and electric generating company in the United States. ***http://www.epa.gov/egrid***
- *Emissions Collection and Monitoring Plan System (ECMPS)*. EPA collects data in five-minute intervals from Continuous Emissions Monitors (CEMS) at all large power plants in the country. The ECMPS is a new system of reporting emissions data, monitoring plans, and certification data, and replaces the *Emission Tracking System (ETS)* that previously served as a repository of $SO_2$, $NO_x$, and $CO_2$ emissions data from the utility industry. ***http://www.epa.gov/airmarkets/business/***
- *WRI Climate Analysis Indicators Tool*: The Climate Analysis Indicators Tool (CAIT–U.S.) provides a free, comprehensive, and comparable database of GHGs and other climate-relevant indicators for U.S. states. ***http://cait.wri.org/***

*11 "Load-following" refers to the order in which different types of generating equipment are used to meet changing electricity demand.*

## TABLE 4.2.3 SOURCES OF AIR POLLUTANTS AND GHG EMISSIONS DATA, INVENTORIES

| Data Source | Type of Air Pollutant or GHG Emissions | | | | | Approach | |
|---|---|---|---|---|---|---|---|
| | $SO_2$ | $NO_x$ | $CO_2$ | Other GHGs | Hg | Top-Down | Bottom-Up |
| National Emissions Inventory (NEI) | x | x | | | x | x | x |
| eGRID | x | x | x | x | x | x | x |
| Emissions Collection and Monitoring Plan System (ECMPS) | x | x | x | | | | x |
| World Resources Institute Climate Analysis Indicators Tool | | | x | x | | x | |
| EPA State GHG Inventories | | | x | x | | x | |
| Local GHG Inventories | | | x | x | | x | |

- *State Agencies and Universities*: Many state agencies and universities collect emissions and/or energy data within their state, which can be compiled into an inventory.

### Forecasting Future Emissions

To conduct a prospective analysis of potential emission reductions from a future policy, it is necessary to develop forecasts of both the new policy case and the "business as usual" (BAU) case that does not include the new policy.[12] Emission projections provide a basis for:

- Developing control strategies for State Implementation Plans (SIPs) or mitigation measures for Climate Change Action Plans;
- Conducting air quality attainment analyses; and
- Tracking progress toward meeting air quality standards or GHG reduction goals.

When developing emission projections, an attempt is made to account for as many of the important variables that affect future year emissions as possible. States can project future emissions based on historic trends and expectations about numerous factors, including projections of population growth and migration, economic growth and transformation, fuel availability and prices, technological progress, changing land-use patterns, and climate change.[13] The degree to which any of these specific drivers is important is a function of the projection horizon. For example, climate change impacts may be negligible for a five- to ten-year projection.

Several guidance documents and tools are available to help states understand methodologies and data sources for factors relevant to projections, including:

- EPA *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 onroad and nonroad mobile sectors. It describes data sources and tools states might use for their projections. ***http://www.epa.gov/ttn/chief/eiip/techreport/volume10/x01.pdf***
- *EPA State GHG Projection Tool*. States can use this EPA spreadsheet tool to create forecasts of BAU GHG emissions through 2020. Future emissions are projected using a combination of linear extrapolation of the results from the State Inventory Tool, described above, combined with economic, energy, population, and technology forecasts. The tool can be customized, allowing states to enter their own assumptions about future growth and consumption patterns. ***http://www.epa.gov/climatechange/wycd/stateandlocalgov/analyticaltools.html***

*12 When conducting a prospective analysis of clean energy policies that have already been implemented, a forecast of emissions is not necessary although it could facilitate projecting the future benefits of existing programs. For a retrospective analysis, the impacts of the existing clean energy program could be backed out of the forecast and reintroduced to estimate the impacts.*

*13 Some of these factors are closely related, and will rely on specific components of these trends that may include electricity imports and exports, power plant construction or retirement, domestic vs. imported agricultural production, waste production, number of road vehicles, tons of freight transported, vehicle miles traveled, and environmental regulations.*

## TABLE 4.2.4 COMPARISON OF BASIC AND SOPHISTICATED APPROACHES FOR QUANTIFYING AIR POLLUTANT AND GHG EMISSION EFFECTS OF CLEAN ENERGY INITIATIVES

| Tools | Advantages | Disadvantages | When to Use this Method |
|---|---|---|---|
| **Basic Approaches** | | | |
| ▪ eCalc<br>▪ OTC Workbook[a]<br>▪ CACPS | ▪ Transparent.<br>▪ Modest level of time, technical expertise, and labor required.<br>▪ Inexpensive. | ▪ May be imprecise.<br>▪ May be inflexible.<br>▪ May have embedded assumptions that have large impacts on outputs. | ▪ Preliminary studies for short-term resource planning.<br>▪ Designing new programs and evaluating existing ones.<br>▪ Regulatory compliance and energy plans. |
| **Sophisticated Approaches** | | | |
| ▪ ENERGY 2020<br>▪ NEMS<br>▪ IPM<br>▪ MARKAL<br>▪ PROSYM<br>▪ GE MAPS<br>▪ PROMOD | ▪ More rigorous than basic modeling methods.<br>▪ May be perceived as more credible than basic modeling methods.<br>▪ Allows for sensitivity analysis.<br>▪ May explicitly account for and quantify leakage. | ▪ Less transparent than spreadsheet methods.<br>▪ Labor- and time- intensive.<br>▪ Often high software licensing costs.<br>▪ Requires assumptions that have large impact on outputs.<br>▪ May require significant technical experience. | ▪ State Implementation Plans.<br>▪ Late-stage resource planning.<br>▪ Rate cases.<br>▪ Project financing.<br>▪ Regulatory compliance and energy plans. |

[a] *The OTC workbook is a spreadsheet tool that was developed from specific results of the PROSYM model.*

- *The Clean Air and Climate Protection Software Tool.* As described above, states or localities can use this tool to project an emissions baseline of GHGs and criteria air pollutants into the future, and measure the effects of different policies upon the forecast. *http://www.icleiusa.org/cacp*

States can also project future emissions based on their energy baseline projections. More information about forecasting energy baselines is available in Chapter 2, *Assessing the Potential Energy Impacts of Clean Energy Initiatives*.

### 4.2.2 STEP 2: QUANTIFY AIR AND GHG EMISSION REDUCTIONS FROM CLEAN ENERGY MEASURES

Once states have developed their baseline emission estimate or business as usual forecast, they can estimate the emissions that are avoided when implementing clean energy measures. Although an emission reduction estimation can be performed independently from a baseline emissions forecast, aligning many of the assumptions in the baseline case and the clean energy measures case is a desirable exercise. Table 4.2.4 shows that states can use either basic or sophisticated approaches to quantify air emission reductions from clean energy measures.

Basic approaches typically include spreadsheet-based analyses that use emissions factor relationships or other assumptions to estimate reductions. Sophisticated approaches are usually more complex and involve dynamic electricity or energy system representations that predict energy generation responses to policies and calculate the effects on emissions. (For more specific information on these energy-related models, see Chapters 2 and 3.)

#### Key Considerations for Selecting an Approach for Quantifying Emission Reductions from Clean Energy

As summarized in Table 4.2.4, there are advantages and disadvantages to each approach for quantifying emission reductions. States can use this information as guidance in determining the most appropriate approach for their particular goals. It is important for states to:

- Consider the cost of each potential approach and/or tool and the resources required;
- Determine whether the tools or methods can be used to estimate the pollutants and emissions of interest;[14] and
- Decide between a complex, detailed approach and a simple, transparent screening-level approach based on their pros and cons and relative importance of each.

Basic and sophisticated approaches, including associated uncertainties and limitations, are described in greater detail below.

## Basic Approaches to Quantifying Emission Reductions

Basic, screening-level, approaches involve: 1) establishing the operating characteristics of the clean energy resource, also known as its load profile; 2) identifying the marginal generation unit and developing avoided emissions factors; and 3) calculating the total emissions reductions by multiplying the avoided emissions factor by the avoided electricity generation (i.e., as calculated in Chapter 2, *Assessing the Potential Energy Impacts of Clean Energy Initiatives*). These procedures are illustrated in the flowchart in Figure 4.2.1 and described in greater detail below.

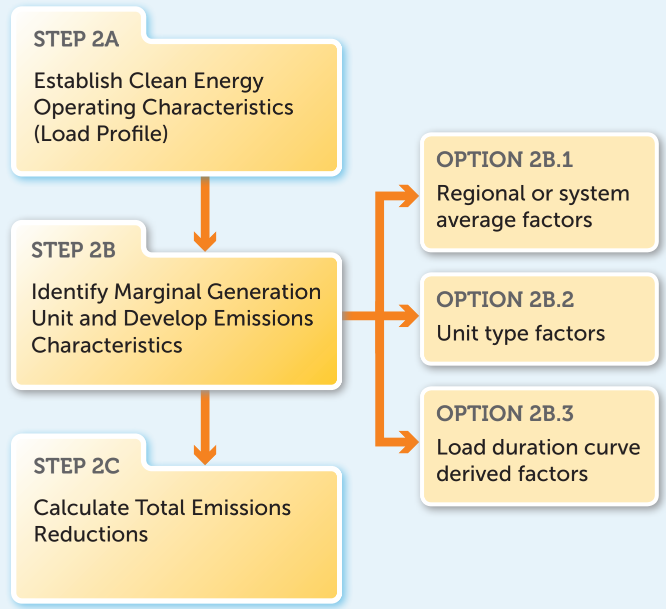
### *Step 2a: Establish Clean Energy Operating Characteristics (Load Profile)*

As previously discussed in Chapter 2, *Assessing the Potential Energy Impacts of Clean Energy Initiatives*, the first step when applying a basic modeling approach is to determine the specific ways that the clean energy initiative will affect either demand for electricity or available supply. This involves considering the following issues related to the operating characteristics, or load profile, of the clean energy measures:

- How much energy will the clean energy measure generate or save? (See Chapter 2 for more information)
- When and where will the electricity generation offset occur (e.g., season of year, time of day)? In the case of energy efficiency measure, load impact profiles describe the hourly changes in end use demand resulting from the program or measure. In the case of energy resources, the generation profiles (for wind or PV, for example) are required. (See Chapter 3)
- What, if any, are the emissions characteristics of the clean energy resource (e.g., emissions characteristics of using renewable fuels such as digester gas)?

*14 The Model Energy Efficiency Program Impact Evaluation Guide, which was developed as part of the National Action Plan for Energy Efficiency (NAPEE), provides further guidance on how to quantify emissions reductions (NAPEE, 2007).*

**FIGURE 4.2.1 BASIC APPROACHES FOR QUANTIFYING AIR AND GREENHOUSE GAS REDUCTIONS FROM CLEAN ENERGY**




### *Step 2b: Identify the Marginal Generation Unit and Develop Emissions Characteristics*

Next, identify the marginal generation source and its associated emissions characteristics. The marginal generating source, as described earlier, is the last generating unit to be dispatched in any hour, based on least-cost dispatch (thus it is the most expensive on a variable cost basis). The emissions characteristics of this unit can be expressed as an emissions factor for each pollutant, and are expressed in pounds per MWh. These factors represent the reduction in emissions per pound of energy generation avoided due to energy efficiency or due to clean energy resources supplied to the system.

There are several different approaches that can be used to characterize the marginal generation source and its associated emissions factor. As described in Chapter 3, these include (1) system average, (2) factors based on unit type or other characteristic that correlates

## TABLE 4.2.5 COMPARISON OF METHODS TO IDENTIFY MARGINAL UNIT AND ASSOCIATED EMISSIONS FACTOR

| Method | Advantages | Disadvantages | When to Use this Method |
|---|---|---|---|
| Regional or system average based on historical year | ▪ Computationally simple.<br>▪ Less labor and data required than for unit type or dispatch curve analysis. | ▪ Insensitive to dispatch process.<br>▪ Neglects power transfers between areas.<br>▪ History may not be good indicator of future. | ▪ Rough estimates of clean energy benefits for displacing emissions. |
| Based on unit type (capacity factor rule) | ▪ Simpler and less labor required than dispatch curve analysis.<br>▪ Considers generation resource characteristics. | ▪ Somewhat insensitive to dispatch process.<br>▪ Inaccurate for baseload clean energy resources. | ▪ Preliminary planning and evaluation of clean energy resources, especially those that operate during peak times. |
| Derived from dispatch curve analyses | ▪ More sensitive to dispatch process than regional or system average and unit type methods. | ▪ Higher data requirements than regional or system average and unit type methods. | ▪ Planning and regulatory studies. |

with likelihood of displacement (e.g., capacity factor), and (3) factors derived from dispatch curve analyses. Information about the advantages, disadvantages, and when to use each method is summarized in Table 4.2.5, *Comparison of Methods to Identify Marginal Unit and Associated Emissions Factor*. Each method is described in more detail below.

- *Regional or system average emissions factors*. This approach typically involves taking an average of the annual emissions of all electricity generating units in a region or system over the total energy output of those units. Data on emission rates averaged by utility, state, and region are available from EPA's eGRID database. For example, using eGRID, states can locate emissions factors by eGRID subregion, state, or by specific boiler, generator, or plant.

  While easy to apply, this method ignores the fact that some units (such as baseload electricity generating units) are extremely unlikely to be displaced by clean energy resources (see text box *What Energy Source is Displaced?*). Baseload units and other units with low variable operating costs (e.g., hydro and renewables) can be excluded from the regional or system average to partially address this shortcoming. Some approaches, therefore, take a fossil-only average.

### WHAT ENERGY SOURCE IS DISPLACED?

It is important to note that only a small number of generating plants are affected by a clean energy measure. Power systems are generally dispatched based on economics, with the lowest-cost resource dispatched first and the highest-cost resource dispatched last. The lowest-cost units (known as baseload units) operate at all times and are often fueled by coal. Higher-cost units such as gas- and oil-fired units are brought online during peak use times. These are the units that will be displaced by a clean energy measure. This helps identify where the GHG and air pollutant benefits are likely to occur (See Section 3.1, *How Clean Energy Can Achieve Electric System Benefits*, and Section 3.2, *How States Can Estimate the Electric System Benefits of Clean Energy*, for a more detailed explanation of how generation resources are dispatched).

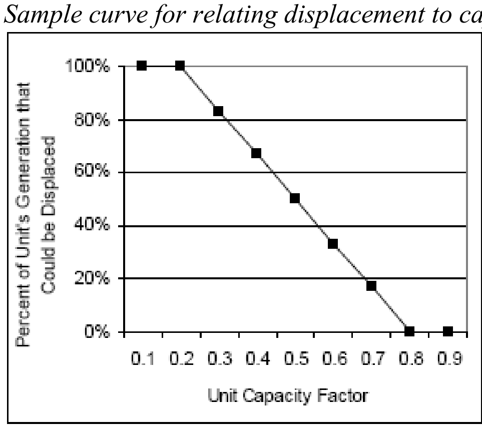
Other methods for identifying the marginal unit and its emissions factors attempt to recognize that what is on the margin is a function of the time that clean energy load impacts (or energy generation) occurs. The most complete of these time-dependent methods would analyze the impact of changes in load for the 8,760 hours in a year using dispatch models. Basic methods try to approximate this using proxies, including unit type and capacity factor, as described further below.

## FIGURE 4.2.2 CAPACITY FACTORS AND UNIT DISPLACEMENT FOR BASELOAD AND LOAD-FOLLOWING PLANTS

In general, baseload plants operate all of the time throughout the year because their operating costs are low and because they are typically 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.

The capacity factor of a plant can be used as a proxy for how likely the plant is to be displaced by a clean energy measure. The following graph shows an example of a displacement curve, or a rule for relating the likelihood that a unit's output would be displaced to its capacity factor. Baseload plants on the right side of the curve, such as nuclear units, are assumed to be very unlikely to be displaced; peak load plants on the left, such as combustion turbines, are much more likely to be displaced.

*Sample curve for relating displacement to capacity factor*




*Source: Keith and Biewald, 2005.*

- *Displaced unit and emissions factors identification based on type of unit.* As described above, system or regional average emissions factors do not take into account the fact that some electricity generating units are more likely to be displaced by clean energy resources than others. (See Section 3.1, *How Clean Energy Can Achieve Electric System Benefits* and Section 3.2, *How States Can Estimate the Electric System Benefits of Clean Energy*, for a more detailed explanation of how generation resources are dispatched.) The unit type approach for estimating emissions factors takes into account that some classes of units are more likely to be displaced than others by the operation of clean energy measures.

For example, assume coal, nuclear, and hydro plants provide baseload power for an electricity grid. Higher-cost units will operate in a cyclic manner, increasing their output during peak daytime hours. A more efficient new gas-fired unit may be counted on to increase output during the day and decrease output at night, while older, less efficient and more expensive gas and oil units or combustion turbines are only dispatched during the peak output periods. This method can be made more representative by disaggregating the unit types as much as possible (e.g., by unit type, heat rate, and controls).

Estimating emissions factors based on unit type involves the following steps.

1. *Estimate the percentage of total hours each type of unit (e.g., coal-fired steam, oil-fired steam, gas combined-cycle, gas turbine, etc.) is likely to be on the margin* (the highest-cost unit dispatched at any point in time is said to be "on the margin" and is known as the "marginal unit") and thus to have its output displaced given the load profile of the new clean energy resource. This is discussed further in Chapter 3.

2. *Determine the average emission rate for each unit type* (in pounds of emissions per MWh output). This can be determined based on public data sources such as EPA's eGRID database or standard unit type emissions factors from EPA AP-42, an available resource for estimated emissions 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.

Using average emissions to approximate displaced emissions involves significant simplifications of electric system operations. For example, the emission rates for each existing generating unit may vary considerably. Similarly, plants of a certain type may have different operating costs and load-following ca-

*15 Note that AP-42 does not provide GHG emissions factors; for GHGs, use fuel-specific emissions 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 emission rates. EPA AP-42 is available at* ***http://www.epa.gov/ttn/chief/ap42/index.html*** pabilities.[16] For example, baseload units operate virtually all the time, load-following units are routinely turned off at night and used most days to meet the higher daytime electricity demand, and peaking units only operate during the highest demand periods (such as hot summer afternoons). Due to the operating characteristics of many types of clean energy projects, the electricity produced or saved is likely to displace electricity from load-following and peaking units in the short term, rather than from baseload units.[17] Generalizations must also be made about the type of generating unit that is on the margin, which may vary considerably across different control areas and time periods.

A limitation of this approach is that it misses important system-level dynamics. For example, reducing emissions of a regulated pollutant may result in shifts in other dispatch decisions in the short and long term. This is particularly true if those emission reductions have a market value (as in cap and trade system). For example, if an energy efficiency option allows for reduced output from a high-emitting oil/gas steam unit during the shoulder period (i.e., that period when demand falls below peak levels but above minimum, base load levels), it may allow increased operation of a coal plant (one not running at full utilization already) at an increased capacity factor. This may reduce system costs all while maintaining emissions at capped levels. In other words, the clean energy option has allowed the operator to reduce emissions compliance costs through dispatch changes. Over the longer term these impacts may include changes in retrofit or build decisions.

As an alternative to estimating the fraction of the time each unit type is on the margin, some analyses estimate the likelihood that a unit type could be displaced using a displacement curve based on capacity factors, shown in Figure 4.2.2, *Capacity Factors and Unit Displacement for Baseload and Load-Following Plants*. The capacity factor is the ratio of how much electricity a plant produces to how much it could produce, running at full capacity, over a given time period. Historical data on, or estimates of, capacity factors for individual plants are available from EPA's eGRID database.

Displacement rules do not capture some aspects of electric 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, affecting the change in net emissions from the clean energy project. According to a displacement rule, this plant would be more likely to be displaced even though it would rarely if ever be on the margin. Nevertheless, adding this level of detail when estimating emissions factors will generally produce a more credible and accurate estimate of displaced emissions than relying simply on an unweighted system average emissions rate.

- *Emissions Factors Derived from Dispatch Curve Analyses* Load curve analysis is a method for determining tons of emissions avoided by a clean 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). Table 4.2.6, *Hypothetical Load for One-Week Period on Margin and Emission Rate* and Figure 4.2.3, *A hypothetical dispatch curve representing 168 hours by generation unit, ranked by load level*, provide a combined example of a dispatch curve that represents 168 hours (a one-week period) during which a hypothetical clean energy resource would be operating.

Table 4.2.6 illustrates this process for a one-week period. There are ten generating units in this hypothetical power system, labeled 1 through 10. Column [3] shows the number of hours that each unit is on the margin, and column [4] shows the unit's $SO_2$ emission rate. The weighted average $SO_2$ emission rate for these units is 5.59 lb/MWh.

In many cases, dispatch curves are available from the local power authorities and load balancing authorities (e.g., a regional Independent System Operator (ISO)). If this information is not available, states can attempt to construct their own analysis.

Constructing a dispatch curve requires data on:

16 *"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.*

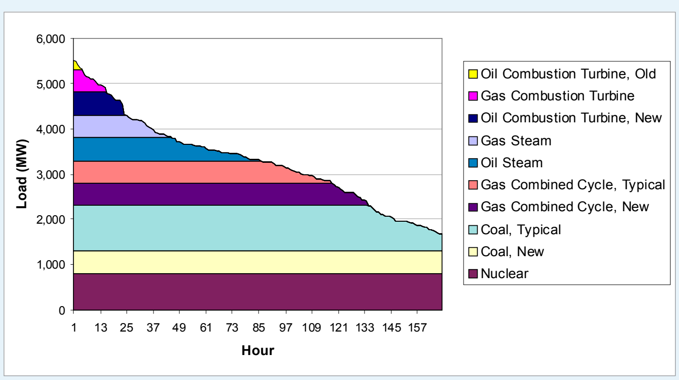
17 *In the longer term, the electricity saved from EE or produced from CE projects not specific to time of day (e.g., CHP, geothermal, not solar) can displace electricity from baseload resources.*

### TABLE 4.2.6 HYPOTHETICAL LOAD FOR ONE-WEEK PERIOD: HOURS ON MARGIN AND EMISSION RATE

| [1] | [2] | [3] | [4] |
|---|---|---|---|
| Unit | Unit name | Hours on margin | SO2 emission rate (lb/MWh) |
| 1 | Oil Combustion Turbine, Old | 5 | 1.00 |
| 2 | Gas Combustion Turbine | 10 | 0.00 |
| 3 | Oil Combustion Turbine, New | 9 | 1.00 |
| 4 | Gas Steam | 21 | 0.10 |
| 5 | Oil Steam | 40 | 12.00 |
| 6 | Gas Combined Cycle, Typical | 32 | 0.01 |
| 7 | Gas Combined Cycle, New | 17 | 0.01 |
| 8 | Coal, Typical | 34 | 13.00 |
| 9 | Coal, New | 0 | 1.00 |
| 10 | Nuclear | 0 | 0.00 |

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

### FIGURE 4.2.3 A HYPOTHETICAL LOAD DURATION/DISPATCH CURVE REPRESENTING 168 HOURS (SHOWN IN HALF-DAY INCREMENTS) BY GENERATION UNIT, RANKED BY LOAD LEVEL




*Source: Developed by Synapse Energy, unpublished, 2007.*

1. Historical utilization of all generating units in the region of interest;

2. Operating characteristics, including costs and emissions rates of the specific generating units, for each season;

3. Energy transfers between the control areas of the region and outside the region of interest in order to address leakage issues (see text box *Clean Energy and Leakage* earlier in this chapter); and

4. Hourly regional electricity demand (or loads).

Data on operating cost, historical utilization, and generator-specific emission rates can typically be obtained from the EIA (*http://www.eia.doe.gov/cneaf/electricity/page/data.html*), or the local load balancing authority. When generator cost data are not available, capacity factors (from the eGRID database, for example) for traditional generating units can be used to approximate the relative cost of the unit (those with the highest capacity factors are assumed to have the lowest cost). As an exception, variable power resources such as wind and hydropower are assumed to have lower costs than fossil fuel or nuclear units.

If unit-level cost data are available, calculating the weighted average of each unit's emission rate, as shown in Table 4.2.6, is preferable to aggregating plants, especially when there is considerable variation in the emission rates within each unit type.

Operational data (or simplifying assumptions) regarding energy transfers between the control areas of the region and hourly regional loads can be obtained from the ISO or other load balancing authority within the state's region.

Load duration curve analysis 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 method can become labor-intensive relative to other basic modeling methods for estimating displaced emissions if data for constructing the dispatch curve are not readily available. Another disadvantage is that it is based on the assumption that only one unit will be on the margin at any given time; this is not generally true in most regions.

- *Summary of Emissions Factor Methods*. In general, for each of the three methods—regional or system emissions factors, factors based on unit type, and factors derived from load duration/dispatch curve analyses—the more detailed the analysis, the more accurate the results, but the more involved it is to make the calculations. The accuracy of the analysis can be improved by calculating separate emissions factors for a number of different time periods during which load and unit operations are known to vary (e.g., peak and off-peak times in the winter and summer months). Ideally, several years of historical emissions and generation data would be used in calculating the average emission rate. For the latter two methods (i.e., emissions factors based on unit types and derived from load duration/dispatch curve analyses), the number of hours that the unit type is on the margin would also be incorporated into the calculation.

### *Step 2c: Calculate Total Emissions Reductions*

Total emission reductions are calculated by applying the emissions factor developed during Step2b *Identify the Marginal Generation Unit and Develop Emissions Characteristics* to the clean energy resource's level of activity, determined during Step 2a *Establish Clean Energy Operating Characteristics*.

In the final analysis of net emission impacts, it is also important to consider any GHG or criteria air pollution emissions that a clean energy initiative might produce during the production or generation of renewable fuels (e.g., landfill gas, biomass generation). For example, biomass generation releases about the same amount of $CO_2$ as burning fossil fuels. However, because biomass is a fuel derived from organic matter, including, but not limited to, wood and paper products, agricultural waste, or methane (e.g., from landfills), these materials are part of the natural carbon cycle and therefore do not contribute to global warming. Thus, all biomass $CO_2$ emissions (including those from renewable methane) are assigned a value of zero because these organic materials would otherwise release $CO_2$ (or other greenhouse gases) through decomposition.

## Tools

Several tools that take a basic modeling approach to estimating emissions reductions are available to states:

**USING LOAD DISPATCH CURVE EMISSIONS FACTORS TO ANALYZE THE EMISSIONS IMPACT OF WISCONSIN'S ENERGY EFFICIENCY PROGRAMS**

In 2004, the Wisconsin Department of Administration (DOA) released an analysis of the air emission impacts of its Focus on Energy efficiency program. The DOA's evaluation team used a load dispatch curve analysis to estimate which generating plants were "on the margin" during different time periods. Using EPA's CEM data on historical plant operations and emissions reported to EPA, emissions factors were developed for the marginal generating units for different time periods (e.g., peak and off-peak hours during winter and summer) for NOx, SO2, and CO2). These factors were then used to analyze the effects of different energy efficiency programs.

The study found that the marginal units' emission rates tend to be higher during off-peak hours (particularly in winter) than on-peak hours. The study suggests that energy efficiency programs that cut energy consumption in Wisconsin when system demands (and power supply costs) are low may produce the greatest reductions in emissions. For more information on Wisconsin's Focus on Energy program, see Section 4.3.2, Wisconsin - Focus on Energy Program.

*Source: Erickson et al., 2004.*

- *The Clean Air and Climate Protection Software* (CACPS) tool can be used to estimate emissions reductions in addition to the functions already mentioned above. ICLEI updated and re-released this software in April 2009. Web site: ***http://www.icleiusa.org/cacp***

- *The OTC Workbook*: The OTC Workbook is a free tool developed for the Ozone Transport Commission to help local governments prioritize clean energy actions. The Workbook uses a detailed Microsoft Excel spreadsheet format based on electric power plant dispatch and on the energy savings of various measures to determine the air quality benefits of various actions taken in the OTC Region. This tool is simple, quick, and appropriate for scenario analysis. It can calculate predicted emission reductions from energy efficiency, renewables, energy portfolio standards (EPSs), and multi-pollutant proposals. The tool contains two kinds of default emission rate: system average (for assessing EPSs) and marginal (for assessing displacement policies). Users can also input their own data. ***http://www.otcair.org***

- *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

#### ELECTRIC ENERGY EFFICIENCY AND RENEWABLE ENERGY IN NEW ENGLAND: THE OTC WORKBOOK

An analysis conducted by the Regulatory Assistance Project (RAP) explains how energy efficiency and renewable energy have led to many positive effects on the general economy, the environment, and energy security in New England while also quantifying these effects in several new ways. The report assesses the air quality effects of efficiency and renewable investments using the OTC Workbook tool. The analysis finds that there is clear progress in reducing $CO_2$ emissions from the deployment of energy efficiency and renewable energy. The projections by the OTC Workbook indicate that due to current energy efficiency programs, 22.5 million tons of $CO_2$ emissions are avoided from 2000–2010.

*Source: The Regulatory Assistance Project. http://www.raponline.org/Pubs/RSWS-EEandREinNE.pdf*

#### A RESOURCE FOR CALCULATED AVOIDED EMISSIONS: THE MODEL ENERGY EFFICIENCY PROGRAM IMPACT EVALUATION GUIDE

*The Model Energy Efficiency Program Impact Evaluation Guide* provides guidance on model approaches for calculating energy, demand, and emissions savings resulting from energy efficiency programs. The Guide is provided to assist in the implementation of the National Action Plan for Energy Efficiency's five key policy recommendations and its Vision of achieving all cost-effective energy efficiency by 2025. Chapter 6 of the report presents several methods for calculating both direct onsite avoided emissions and reductions from grid-connected electric generating units. The chapter also discusses considerations for selecting a calculation approach (NAPEE, 2007).

customer choice, which allows many electricity customers to choose the source of their power. ***http://www.epa.gov/cleanenergy/powerprofiler.htm***

- *eCalc*: eCalc is an online tool that identifies emission reductions from energy efficiency and renewable energy measures in the Electric Reliability Council of Texas (ERCOT) region. The eCalc tool incorporates both energy modeling (assessing the energy saved by a given measure) and emissions modeling (determining the emissions avoided by those energy savings). The energy modeling capability is extremely robust and detailed, accounting for a wide array of load types with weather normalization. It also includes energy production profiles for wind and solar power. Several states have approached the Energy Systems Laboratory (ESL) at Texas A&M University about developing other versions of eCalc. While the underlying code can be transferred, states will need to customize data such as weather, geography, building standards, emissions regulations, grid characteristics, and other factors. ***http://ecalc.tamu.edu/***

Note that many of these spreadsheet-based and other tools rely on models to estimate the underlying emission rates. For example, the OTC Workbook relied on runs of the PROSYM model to establish the emission rates, and eCalc integrates several legacy models depending on the user's desired analysis type. These tools thus have the same underlying concerns as those raised earlier, such as being dependent on key driving assumptions; to the extent that these tools and their inputs are not regularly updated, these key assumptions may no longer be applicable and relevant.

### *Limitations of Basic Approaches*

Basic approaches for quantifying displaced emissions are analytically simple and the data are readily available. However, they involve a less rigorous approach than sophisticated modeling approaches; policy-making and regulatory decisions typically require more rigorous analysis. Basic approaches:

- *Are best suited for estimating potential emission reduction benefits for a relatively short time frame* (e.g., one to three years). Longer-term analyses would require emissions factors that account for impacts on the addition and retirement of energy sources over time and changes in market conditions including environmental requirements.
- *Do not typically account for imported power*, which may be from generating units with very different emissions characteristics than the units within the region or system. These methods also do not account for future changes in electricity import/export patterns, which may change the marginal energy sources during operation of the clean energy measure.
- *Do not account for the myriad factors that influence generating unit dispatch on a local scale*. For example, the emissions impacts of a clean energy resource within a load pocket (an area that is served by local generators when the existing electric system is not able to provide service, typically due to transmission constraints) would affect unit dispatch very differently than measures in an unconstrained region. Higher-cost units must be dispatched in a load pocket because energy cannot be imported from lower-cost units outside of the area.

For these reasons, use of basic approaches is often limited to providing preliminary estimates of emission reductions and reporting approximate program impacts data for annual project reports and program evaluations that do not involve regulatory compliance. Nevertheless, when using basic approaches it is important to remember that the more detailed the representation of the study area, the more precise and reliable the emissions estimates.

### Sophisticated Approaches to Quantifying Emissions Benefits

Sophisticated modeling approaches, such as electric dispatch and capacity planning models, can be used to compare baseline energy and emissions forecasts with scenarios based on implementation of clean energy measures. Using sophisticated models to estimate emissions that are displaced as a result of clean energy measures generally results in more accurate estimation of emission impacts than using the basic approaches, but can be more resource-intensive.

Many of the models used to characterize or project changes in electricity supply and demand also provide estimates of the air pollution and GHG impacts associated with clean energy policies. Thus, by comparing clean energy policy scenarios with the BAU case, they facilitate quantification of emissions benefits. Two key types of models used to estimate emissions are electric dispatch models and capacity expansion (also referred to as system planning or planning) models. An electric dispatch model typically answers the question: how will this clean energy measure affect the operations of existing power plants? In other words, the model quantifies the emission reductions that occur in the short term. A capacity expansion model answers the question: how will this clean energy measure affect the composition of the fleet of plants in the future? A capacity model typically takes a long-term view and can estimate emission reductions from changes to the electricity grid, 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 aggregate time scale than dedicated hourly dispatch models. Models that address dispatch and capacity expansion handle both the short and long term. These models are summarized in Table 4.2.7, *Comparison of Sophisticated Modeling Approaches for Quantifying Air and GHG Emission Effects of Clean Energy Initiatives*, and are described in more detail in Chapters 2 and 3).

## 4.2.3 STEP 3: QUANTIFY AIR QUALITY IMPACTS

When criteria air pollutants are reduced through clean energy measures, as determined under Step 2, the ambient concentrations of both primary and secondary criteria air pollutants are also likely to be reduced. Estimating air quality improvements associated with emission changes is another step in a thorough analysis of the benefits of clean energy initiatives.[18]

Modeling ambient air quality impacts can be a complex task, however, requiring sophisticated air quality models and extensive data inputs (e.g., meteorology). Many state and local government air program offices already use rigorous air quality modeling approaches for their State Implementation Plans, as required by the Clean Air Act. These approaches, summarized below, can also be used in evaluating clean energy benefits.

### Approaches to Quantifying Air Quality Changes

Sophisticated computer models are often necessary to prepare detailed estimates of the impact of emission changes on ambient air pollution concentrations. There are three broad types of relevant air quality models: dispersion models, photochemical models, and receptor models. All of these models require location-specific information on emissions and source characteristics, 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 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 emission 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 currently recommends using either

*18 "Concentrations" versus "emissions:" Ambient—or surrounding—air concentration levels are the key measure of air quality and are based on the monitored amount (e.g., in units of micrograms per cubic meter [µg/m3] or parts per million [ppm]) of a pollutant in the air. Emission levels are based on estimates and monitored measurements of the amount (e.g., in units of tons) of a pollutant released to the air 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 over time and distance. The health-based standards (National Ambient Air Quality Standards) for criteria pollutants are based on concentration levels. The pollutant concentration to which a person is exposed is just one of the factors that determines if health effects occur—and their severity if they do occur (U.S. EPA, 2009).*

## TABLE 4.2.7 COMPARISON OF SOPHISTICATED MODELING APPROACHES FOR QUANTIFYING AIR AND GHG EMISSION EFFECTS OF CLEAN ENERGY INITIATIVES

| Examples of models | Advantages | Disadvantages | When to Use this Method |
|---|---|---|---|
| **Electric Dispatch** | | | |
| ▪ PROSYM<br>▪ GE MAPS<br>▪ PROMOD | ▪ Provides very detailed estimations about specific plant and plant-type effects within the electric sector.<br>▪ Provides highly detailed, geographically specific, hourly data. | ▪ Often lacks transparency.<br>▪ May require technical experience to apply.<br>▪ Labor- and time- intensive.<br>▪ Often high labor and software licensing costs.<br>▪ Requires establishment of specific operational profile of the clean energy resource. | Often used for evaluating<br>▪ Specific projects in small geographic areas,<br>▪ Short-term planning (0-5 years), and Regulatory proceedings. |
| **Capacity Expansion or Planning** | | | |
| ▪ NEMS<br>▪ IPM<br>▪ ENERGY 2020<br>▪ LEAP | ▪ Model selects optimal changes to the resource mix based on energy system infrastructure over the long term (10–30 years).<br>▪ May capture the complex interactions and feedbacks that occur within the entire energy system.<br>▪ Provides estimates of emission reductions from changes to generation mix.<br>▪ May provide plant specific detail and perform dispatch simultaneously (IPM). | ▪ Requires assumptions that have large impact on outputs (e.g., future fuel costs).<br>▪ May require significant technical experience to apply.<br>▪ Often lacks transparency of spreadsheet due to complexity.<br>▪ Labor- and time- intensive.<br>▪ Often high labor and software licensing costs. | Long-term studies (5–25 years) over large geographical areas such as:<br>▪ State Implementation Plans,<br>▪ Late-stage resource planning,<br>▪ Statewide energy plans, and<br>▪ GHG mitigation Plans. |

the AERMOD Modeling System or CALPUFF in SIP revisions analysis for existing sources and for New Source Review. Numerous other dispersion models are available as alternatives or for use in a screening analysis. ***http://www.epa.gov/scram001/dispersionindex.htm***

- *Photochemical Models*. The second type of air quality models are photochemical models. Photochemical models include many of the complex physical and chemical processes that occur in the atmosphere as gaseous emissions of different chemicals react and form $PM_{2.5}$ and ozone. These models perform complex computer simulations, and can be applied at a variety of scales from the local to the global level. Photochemical models include EPA's Community Modeling and Analysis System (CMAQ) and the Comprehensive Air Quality Model (CAMx). A range of photochemical-type air quality tools are also available for use in assessing control strategies. One example is the Modeled Attainment Test Software (MATS), a PC-based software tool for SIP attainment demonstrations recently developed by EPA. While MATS is not an air quality model per se, it combines CMAQ or CAMx results with monitor data to calculate design values. ***http://www.epa.gov/scram001/photochemicalindex.htm***

- *Receptor Models*. Receptor models can identify and quantify 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.

## TABLE 4.2.8 AIR QUALITY MODELS CURRENTLY RECOMMENDED BY EPA AND AVAILABLE AT EPA'S SCRAM

| Model Acronym | Model Name | Description |
|---|---|---|
| **Dispersion Models** | | |
| CALPUFF | EPA-approved version of the California Puff Model | Single source model with air chemistry for secondary formation. Can analyze secondary formation of ozone and PM2.5. |
| AERMOD | American Meteorological Society/EPA Regulatory Model | Recommended single source model for direct dispersion modeling (no air chemistry). Replaced Industrial Source Complex (ISC) family of models. Capable of multiple and area source analysis. |
| **Photochemical Models for both Ozone and PM2.5 ("One Atmosphere" models)** | | |
| CAMx | Comprehensive Air Quality Model with eXtensions | For ozone, particulate matter, inorganic and organic PM2.5/PM10, mercury and other toxics. |
| CMAQ | Community Multi-Scale Air Quality model | For ozone, fine particles, toxics, acid deposition, and visibility degradation. |
| **Receptor Models** | | |
| CMB | 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 CMB. Many of the source profiles, however, are outdated. |
| UNMIX | N/A | The EPA UNMIX model "unmixes" the concentrations of chemical species measured in the ambient air to identify the contributing sources. |
| PMF | Positive Matrix Factorization | 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. |

*Source: U.S. EPA, 2008c.*

Instead, receptor models use the chemical and physical characteristics of gases and particles measured at the source and receptor to identify the presence of, and to quantify source contributions to, receptor concentrations. These models are therefore a natural complement to other air quality models and are used as part of SIPs for identifying sources contributing to air quality problems. *http://www.epa.gov/scram001/receptorindex.htm*

Additional models are available and may be suitable for clean energy benefits analysis. EPA's Support Center for Regulatory Modeling (SCRAM) provides information about the latest versions of models, as well as the status of current recommendations of models for regulatory purposes. Examples of all three of these types of models are available at SCRAM and are summarized in Table 4.2.8, *Air Quality Models Currently Recommended by EPA and Available at EPA's SCRAM*. *http://www.epa.gov/scram001/aqmindex.htm*

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. Such local or regional models are suitable for conducting clean energy benefits analysis, and the expertise and data needed by these models are often available within a state. An example of such a tool is the Assessment of Environmental Benefits (AEB) modeling system, described in the text box, which is currently configured for use by the southeastern states.

Recently, approaches have been developed that use the output of photochemical and dispersion models to create screening tools that can be used to quickly evaluate expected responses to emissions changes. These screening tools use information from a series of model simulations in which precursor emissions are reduced by specified amounts (e.g., 10 percent $NO_X$, 20 percent $NO_X$, 10 percent VOC, 20 percent VOC, etc.) and the responses by various pollutants (e.g., ozone) are assessed for each simulation to create a pollutant "response surface" for a given area. Once the series of simulations has been completed for a particular region, the users can use the tool to more readily identify the emission 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 then re-run the full model for the identified scenarios to more accurately evaluate the spatial and temporal aspects of the expected response. Although these screening tools provide a quick way of evaluating the expected response for a variety of scenarios, time and resources are required to develop the initial response surface for each pollutant and each given area of interest.

Examples of air quality screening tools include:

- *EPA Response Surface Modeling (RSM)*: RSM is based on a new approach known as air quality metamodeling, which aggregates numerous 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 Community Multi-Scale Air Quality (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. RSM has been successfully tested and evaluated for $PM_{2.5}$ and ozone, respectively (U.S. EPA, 2006a).

- *EPA's Source-Receptor (S-R) matrix*: The S-R matrix is a reduced-form model based on a regional dispersion model, the Climatological Regional Dispersion Model (CRDM), which provides the relationship between emissions of $PM_{2.5}$ or particle precursors and county-level $PM_{2.5}$ concentrations. The S-R matrix is used to evaluate $PM_{2.5}$ in the Co-Benefits Risk Assessment (COBRA) screening model described later in this chapter (U.S. EPA, 2006b).

**ASSESSMENT OF ENVIRONMENTAL BENEFITS MODELING SYSTEM**

The Assessment of Environmental Benefits (AEB) modeling system is a web-based tool designed for southeast states to use in estimating the ozone and PM impacts of their energy efficiency and renewable energy projects. This coupled energy-air quality modeling system was developed for use in the SIP development process.

AEB takes user-provided inputs of electricity impacts (efficiency gains or net generation) of location-specific energy efficiency and renewable energy projects and estimates the reduced emissions and air quality improvements that will occur by the avoided conventional electricity generation.

*Source: Imhoff, 2006*

## Key Considerations When Selecting a Method to Assess Air Quality Impacts

Air quality impact analyses enable clean 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.

- *The Pollutants for Analysis*. Deciding what pollutants to model is a critical decision when selecting a model. Directly emitted primary pollutants—such as CO, $SO_2$, direct PM, and many air toxics—require models capable of modeling dispersion and transport (i.e., dispersion models). Secondarily formed pollutants such as $O_3$ and most $PM_{2.5}$ are formed by chemical reactions occurring in the atmosphere with other pollutants. Secondary pollutants are considerably more difficult to model, requiring a model capable of handling the 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 are further distinguished by the exposure timeframe that is most relevant to human health impacts—e.g., long-term average exposure vs. short-term daily or hourly exposure. The impact assessment timeframe can be a key factor in determining appropriate approaches for modeling air quality impacts of clean energy initiative-based emission reductions.

- *Data Availability and Resolution*. Air quality models require large amounts of input data describing a variety of characteristics of the energy-environment system, including emission inventory data, ambient air quality monitoring data, and meteorological data.
- *Geographic Scope*. Selecting the most appropriate analytical tool to model air quality impacts also depends upon the geographical scope of the analysis. Modeling large geographical areas (e.g., a state or a group of states) often requires a different model than when modeling smaller areas (e.g., a city)
- *Meteorological and Topographical Complexities*. When structuring an air quality impact analysis, it is also important to consider regional meteorological and topographical conditions that may affect the transport and chemical reaction of pollutants within a region's atmosphere. Thus, it is important to determine whether air quality models can account for these factors.

### 4.2.4 STEP 4: QUANTIFY HUMAN HEALTH AND RELATED ECONOMIC EFFECTS OF AIR QUALITY IMPACTS

A central question for many clean energy stakeholders regards the negative human health effects that can be avoided through clean energy-related emission reductions. Estimates of the numbers of avoidable health impacts—from reduced school absences and lost work days to avoided premature deaths—have become standard and powerful techniques to describe the benefits of air-related programs. Quantifying the avoidable health effects associated with clean energy initiatives is an analytical step that typically builds on the estimates of emission reductions and air quality changes. Health research has established strong relationships between air pollution and health effects ranging from fairly mild effects such as respiratory symptoms and missing a day of school or work, to more severe effects such as hospital admissions, heart attacks, onset of chronic heart and lung diseases, and premature death.

Presenting the benefits of clean air initiatives in such tangible terms as reduced cases of health effects can be a valuable analytical tool to help differentiate between alternative program options, as well as a very effective technique for communicating some of the most important advantages of clean energy. This section describes basic and sophisticated modeling approaches to estimate 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 Human Health Impacts

Estimating the health benefits of air quality improvements can be achieved through basic or sophisticated modeling methods. Basic modeling approaches 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 clean energy initiative. Sophisticated modeling approaches include screening-level analytical models that can run quickly on a desktop computer, and rigorous and complex computer models that often run on powerful computers and involve a linked series of separate models. Basic and sophisticated approaches are described below.

##### *Basic Modeling Approach*

A common basic modeling approach for quantifying the human health effects of a clean energy initiative involves determining the "health benefit value per ton of emission" (also referred to as the benefit per ton, or BPT) to estimate average monetized benefits of an incremental change in pollutant or pollutant precursor. This is a form of "benefits transfer" analysis, where the results from an extensive analysis (e.g., a regional control strategy for all coal-fired power plants within a region) are used to approximate the effects of a smaller project in the same region (e.g., a local clean power initiative). In effect, these metrics represent a composite of the air quality modeling, health impacts estimation, and valuation estimation steps used in more complex models, such as the BenMAP model described below.

EPA has recently developed $PM_{2.5}$ BPT estimates categorized by key $PM_{2.5}$ precursors, source category, and location of the county (Fann, 2008). Applying these estimates simply involves multiplying the emission reduction by the relevant BPT metric.

BPT measures are only first-order approximations of the results that a rigorous analysis might estimate. However, they can serve as pragmatic benefits analysis tools and can be especially useful in assessing the benefits of small projects where it is impractical to conduct a complex analysis of each alternative.

The role of BPT benefit estimates varies: some states develop these estimates as a useful "rule of thumb" used during screening analysis when formal air quality modeling analyses are impractical due to time and resource constraints, while other states use the estimates as a more formal part of the analysis of proposed projects.

The advantages of BPT estimates include:

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

Disadvantages of the BPT estimates include:

- *Limited ability to account for spatial heterogeneity*. The BPT estimates are best viewed as the average benefits of emission reductions within a specific spatial scale—either nationwide or within one of a few specific urban areas. In general, the BPT estimates are most appropriate for characterizing the benefits of broad-scale emission reductions.
- *Inflexible*. Users are unable to modify any of the assumptions within the BPT metrics, including the selection of C-R functions, year of population exposure, valuation functions, or air quality modeling.
- *Based on multiple assumptions*. A series of modeling assumptions are embedded within the BPT metrics. Consequently, the greater the divergence between these embedded assumptions and the policy context to which the user applies the BPT metrics, the greater the uncertainty.

A challenge with using BPT measures arises if a clean air project reduces emissions of multiple pollutants simultaneously (e.g., $SO_2$ and $NO_x$). In order to reach a more accurate benefit-per-ton estimate, is important to apportion the benefits among each of the multiple types of emission reductions.

### *Sophisticated Modeling Approaches*

Two sophisticated modeling approaches, which vary in terms of complexity, are used to quantify the human health impacts of air quality changes: integrated modeling and linked modeling.

## Integrated Modeling

Screening-level integrated models include emissions, air quality, health effects, and economic valuation within a single software application that runs quickly on a desktop computer.

An integrated model typically allows the user to enter potential emissions from one or more emission categories, and then apply a series of methods to estimate air quality changes, population exposure, avoided health effects, and the economic values of the quantified benefits. These models are not as rigorous as the linked approach, but can quickly enable a less experienced analyst to prepare a screening-level analysis of many different clean energy alternatives. EPA's COBRA model is an example of an integrated screening-level model.

### *Integrated Modeling with COBRA*

EPA's Co-Benefits Risk Assessment (COBRA) model is a computer-based screening model that employs user-specified emission reduction estimates to estimate air quality changes and health effects. It is a stand-alone Windows application that enables users to:

- Approximate the impact of emission changes on ambient air pollution,
- Translate these ambient air pollution changes into related health effect impacts,
- Monetize the value of those health effect impacts, and
- Present the results in various maps and tables.

Using COBRA enables policy analysts to quickly and easily obtain a 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 allow users to quickly and easily analyze the health effects of changes in emissions of PM.

The COBRA screening tool is based on the following methodology.

### EXAMPLES OF AIR QUALITY HEALTH MODELS

COBRA (a screening-level integrated model)

- Suited to less-experienced modelers.
- Requires air pollution emissions data, which the model converts to air quality changes, as an input.
- Includes health effects of PM.
- Uses EPA-provided default concentration-response (C-R) functions and economic values.

BenMAP (a linked model)

- Suited to experienced modelers, although a new one-step approach improves accessibility and training is available.
- Requires air quality data, which must be estimated exogenously, as an input.
- Includes health effects of PM and ozone.
- Uses EPA-provided C-R functions and economic values, and also allows user-specified functions.

### HEALTH ENDPOINTS INCLUDED IN COBRA

- Mortality.
- Chronic and acute bronchitis.
- Non-fatal heart attacks.
- Respiratory or cardiovascular hospital admissions.
- Upper and lower respiratory symptom episodes.
- Asthma effects, exacerbations, and emergency room visits.
- Shortness of breath, wheeze, and cough (in asthmatics).
- Minor restricted activity days.
- Work loss days

- The model contains detailed emission estimates for the years 2010 and 2015, developed by EPA. Before running a scenario, users must select one of these years as the baseline for their scenario.
- Users can then create their own scenarios by making changes to the emission estimates specified by the chosen baseline. Changes in $PM_{2.5}$, $SO_2$, $NO_x$, $NH_3$, and VOC emissions can be specified at the county, state, or national level.
- COBRA incorporates user-defined emission changes into a reduced form air quality model, the Source Receptor (S-R) Matrix, to estimate the effects of emission changes on PM concentrations.
- COBRA uses concentration-response (C-R) functions to link the estimated changes in PM concentrations to a number of health endpoints, including premature mortality, chronic bronchitis, and asthma. The C-R functions are based on recent epidemiological studies and are consistent with BenMAP and recent EPA regulatory impact analyses.
- COBRA monetizes the health effects using economic value equations based on those approved in recent EPA rulemakings.

COBRA's use of default C-R function and economic values for health effects 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. However, this strength in ease of use is also a key limitation because COBRA cannot incorporate more sophisticated air quality and health effect modeling techniques. *http://epa.gov/statelocalclimate/resources/cobra.html*

## Linked Modeling

Linked models are rigorous methods that combine emission estimation, air quality estimates, population data, baseline health data, and health concentration-response functions in a geographic-based analysis. This approach uses a series of separate models in sequence: a typical sequence of linked models begins with an electricity generation model, followed by an emissions model, an air quality model, a health effects model, and finally an economic valuation model. The results of each major modeling step is used as an input into the next, resulting in a rigorous overall analysis relying on a series of state-of-the-art modeling components.

While such approaches can be data- and resource-intensive, standard methods and models are available. Linked health effects modeling translates estimated changes in air quality into avoidable cases of a wide range of health effects. EPA's methods and models for conducting health analysis have been reviewed by EPA's Science Advisory Board and the National Academy of Science, and are widely used by EPA, as well as state and local governments, as a routine part of developing air quality programs. An example of a linked model for health effects and valuation is EPA's BenMAP.

**HOW ARE STATES USING COBRA?**

Connecticut worked with EPA and NESCAUM to quantify the economic, air quality, and health benefits of policy options while developing the state's 2005 Climate Change Action Plan. The COBRA model showed that while "the state's (existing) energy efficiency program…was known to achieve a $3 to $1 direct return on investment based on electricity savings… an additional $4 to $1 payback in terms of reduced health costs and public health benefits was identified as a result of reductions in criteria air pollutants."

*Source: Connecticut GSC on Climate Change, 2005.*

### *Linked Modeling with BenMAP*

EPA's Benefits Mapping and Analysis Program (BenMAP) is a Windows-based program that enables users to:

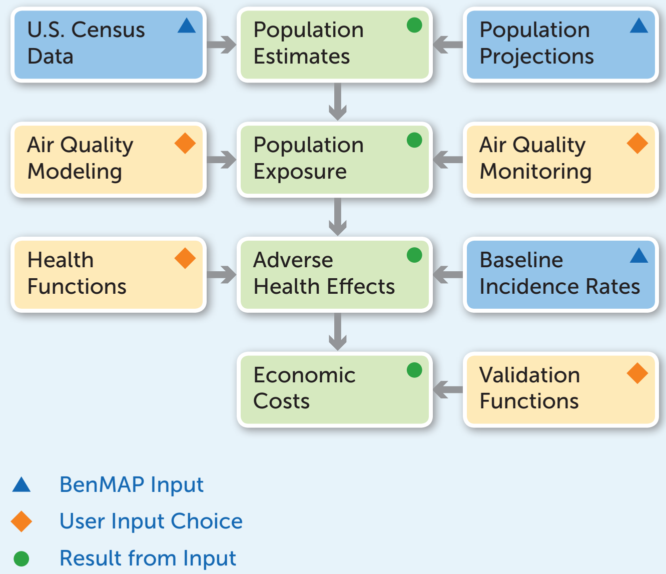
- Estimate the health effects for numerous health endpoints associated with changes in ambient $O_3$ and PM concentrations.
- Monetize the value of health effects.
- Visually inspect results with maps of air pollution, population, incidence rates, incidence rate changes, economic valuations, and other types of data at the county, state, or national level using geographic information systems (GIS).

BenMAP systematically analyzes the health and economic benefits of air pollution control policy scenarios. It is designed to provide flexible and timely analysis, ensure that users can understand the assumptions underlying the analysis, and adequately characterize uncertainty and variability. As a first step, BenMAP estimates impacts to populations from the year 1990 to 2030 according to race, gender, age, and ethnicity. These data are then used to estimate health impacts according to sub-population.

The BenMAP modeling approach is illustrated in Figure 4.2.4 and described below.

- BenMAP applies the damage function approach, a technique used to estimate the health impacts resulting from changes in air pollution. The damage function incorporates air pollution monitoring data, air quality modeling data, Census 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.
- Users typically run BenMAP to estimate the health impacts of a policy scenario, specifying both baseline and post-policy air quality levels. BenMAP then estimates the changes in population exposure.
- Air quality information for the baseline and scenario runs need to be generated exogenously, either from monitor-based air quality data, model-based air quality data, or both.[19] BenMAP includes monitoring data for $O_3$, PM, $NO_2$, and $SO_2$ for a number of years.
- BenMAP then calculates the changes in health effect incidence associated with the change in population exposure by using concentration-response functions (C-R) derived from the epidemiological literature and pooling methods specified by the user.[20] BenMAP uses the estimate of statistical error associated with each C-R function to generate distributions of

**FIGURE 4.2.4 BENMAP HEALTH IMPACTS MODELING PROCEDURE**




19 *BenMAP accepts air quality output from a variety of models, including Regulatory Model System for Aerosols and Deposition (REMSAD), the Comprehensive Air Quality Model with Extensions (CAMx), the Urban Airshed Monitoring-Variable grid model (UAM-V), the Community Multi-Scale Air Quality Model (CMAQ) and EPA's Response Surface Model (RSM). BenMAP can also accept other model results by changing the default input structure.*

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

incidence estimates, as well as a central point estimate. These distributions are helpful for characterizing the uncertainty associated with this component of the health impact assessment.

- BenMAP also calculates the economic value of the avoided or incurred health effects based on valuation approaches from the published economics literature. The estimated economic value of an avoided health outcome is multiplied by total change in events to determine the health benefits of air quality improvements. As with the C-R functions described above, the valuation functions include estimates of statistical error that BenMAP uses to generate distributions of results (EPA, 2003).

One of BenMAP's strengths is that it includes large databases of 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 robust estimates of health impacts with a high degree of spatial resolution (Davidson et al., 2003). ***http://www.epa.gov/air/benmap/***

## Key Considerations When Selecting Methods to Estimate Health Effects and Associated Economic Impacts of Clean Energy

The following issues can be considered when selecting a basic or sophisticated modeling approach:

- *Pollutants to be analyzed*. While health modeling for $O_3$ and PM is the most common approach, analyses are also conducted for $SO_2$ emissions, CO, Hg, and other air toxics emitted by conventional electricity generation.

- *Selection of health effects*. Even though a long list of health effects analysis is possible, in some circumstances a significantly smaller set may be sufficient. EPA has quantified PM-related health effects including premature mortality in adults and infants, chronic bronchitis, non-fatal heart attacks, hospital admissions for respiratory and cardiovascular diseases, emergency room treatment for asthma, asthma attacks, and various "symptom-days" (including work loss days). Quantified ozone-related health effects include respiratory hospital admissions and emergency room visits, and "symptom-days" (including school absences). Recent health research indicates that $O_3$ is also associated with premature mortality, which has been included as a new health effect in recent EPA analyses.

### HOW BENMAP HAS BEEN USED IN CLEAN ENERGY ANALYSIS

For testimony to the Minnesota Public Utilities Commission about building a new clean energy electricity generating facility, Excelsior Energy compared the air quality and health effects of two proposed 600 MW integrated gasification and combined cycle (IGCC) units with two comparable supercritical pulverized coal (SCPC) units. The analysis used REMSAD to model Hg and PM air quality changes, and BenMAP to estimate and value the PM-related health effects. For the IGCC option, for example, the study found that installing IGCC technology would reduce annual emissions by 2,600 tons of SO2, 600 tons of NOx, and 12 pounds of Hg. The largest impacts on PM2.5 concentrations occurred within 80 km of the proposed facility, although small PM impacts also occurred hundreds of miles downwind, affecting millions of additional people. The analysis also found that in 2012, the IGCC units would avoid 12 premature deaths nationally, 20 heart attacks (infarctions), eight new cases of chronic bronchitis, and 200,000 work loss days, and quantified estimates of other health effects ranging from hospital admissions to asthma attacks. The annual value of the one year of reduced health effects was estimated to be $99 million nationally, with $24 million occurring within Minnesota.

*Sources: Excelsior Energy, 2005.*

- *Selection of C-R functions for health analysis*. The specific mathematical functions that estimate the changes in health effects from changes in ambient air quality are typically derived from epidemiological research. For most of the health effects selected for an analysis, a variety of alternative C-R functions are available from different sources. It is important to carefully select functions that appropriately reflect the central estimates and the range of diverse results from different published health studies, while striving to avoid double counting and minimizing the omission of important health effects.

- *Time span*. Estimating the health effects for different pollutants requires different time spans. Ozone health effects typically require hourly air quality estimates, but analysis is sometimes limited to the ozone season, or even modeling a one or two week episode during the peak ozone period. Estimating the health effects of PM, on the other hand, typically requires daily air quality estimates throughout the entire year, or estimates of the impact on the annual mean PM level.

- *Geographic scope*. Every health effects estimation procedure operates at some level of geographic resolution. Some health effects models use the county level for the analysis, while others match the level of the air quality model and use a rectangular grid system. (Hubbell, 2008)

- *Selection of methods for estimating the economic value of avoided health effects.* Estimating the economic value of the avoided cases of each health effect allows stakeholders to more directly compare the economic benefits of a clean energy project with the project's costs. Economic values for each health effect are derived from economic literature, and must be carefully matched to the types of avoided health effects estimated in an analysis.

## 4.3 CASE STUDIES

### 4.3.1 TEXAS EMISSIONS REDUCTION PLAN (TERP)

#### Benefits Assessed in Analysis

- $NO_x$ reductions

#### Clean Energy Program Description

In 2001, the 77th Texas Legislature established the Texas Emissions Reduction Plan (TERP) with the enactment of Senate Bill 5, which required the Texas Commission on Environmental Quality (TCEQ) to promote EE/RE to meet ambient air quality standards and to develop a methodology for computing emission reductions for State Implementation Plans (Haberl et al., 2004). To improve Texas air quality, TERP adopted the goal of implementing cost-effective EE/RE measures to reduce electric consumption by 5 percent per year for five years, beginning in 2002, using a variety of mandatory programs and voluntary financial incentive programs in non-attainment and affected counties.

These programs included:

- Texas Building Energy Performance Standards for residential and commercial building construction.
- An emissions reduction incentive grants program, which provides grants to offset costs associated with reducing $NO_x$ emissions.
- A new technology research and development program, which provides incentives to support R&D that will reduce pollution in Texas.
- A small business program, which helps small businesses and others participate in the TCEQ's incentive program.

#### Methods Used

To meet annual reporting requirements, the TCEQ worked with the State Energy Conservation Office (SECO), the Public Utility Commission (PUC), the Energy Systems Laboratory (ESL) and the Electric Reliability Council of Texas (ERCOT) to develop methodologies for quantifying the $NO_x$ emission reductions associated with energy savings from TERP clean energy projects. A key step in that process was to develop uniform accounting procedures to be applied to the energy savings across the different programs. For example, during 2001 and 2002, $NO_x$ emission reduction values could not be integrated across programs because they were reported to the TCEQ by several agencies in disparate units (i.e., lbs-$NO_x$/year vs. tons-$NO_x$/OSD), time frames (i.e., annual, average daily), and variations in conversion factors (i.e., lbs-$NO_x$/MMBtu, g-$NO_x$/kiloJoule, tons-$NO_x$/MWh).

Each reporting agency used a unique methodology to estimate energy savings from its programs, all of which were subsequently converted to $NO_x$ emission reductions using eGRID average emissions factors as described below.

- For SECO, Energy Service Companies (ESCOs) reported stipulated energy savings for about 100 projects to SECO. These annual estimates of energy savings were then converted into average daily savings for use in the $NO_x$ emissions calculations for the Ozone-Season-Day (OSD) using eGRID.
- For the PUC's utility-based programs, calculated annual savings for more than 100,000 projects are reported to the PUC using a standard template. These savings are then converted to average daily OSD savings for use in the $NO_x$ emissions calculations for the OSD using eGRID.
- For code-compliant construction programs, the ESL developed simulation models for residential buildings using the DOE-2.1e simulation program. ESL's models were then linked to eGRID to automatically convert energy savings into $NO_x$ emission reductions.
- For green power programs, 15-minute metered data, obtained from ERCOT, and average daily values for the Ozone Season Period were used to represent the OSD electricity and $NO_x$ reductions using eGRID.

## Results

- The 2007 annual report on energy savings and emission reductions for energy-code- compliant new residential single, multi-family, and commercial construction reported the following findings (Haberl et al., 2007):
  - The annual energy savings in 2006 amounted to 498,582 megawatt hours (MWh) of electricity and 576,680 million BTUs of natural gas, which led to 361 tons of $NO_x$ reductions in 2006.
  - On a peak summer day—when ozone formation is at its worst—the $NO_x$ reductions in 2006 were calculated to be 2.23 tons per day.
  - Cumulative $NO_x$ reductions, projected to 2013, from energy efficiency savings from code-compliant new residential and commercial construction were determined to be 2,121 tons/year and 10.75 tons/peak-day.

## For More Information

- *Energy Efficiency/Renewable Energy Impact in the Texas Emissions Reduction Plan (TERP): Volume 1 – Summary Report*. Prepared for the Texas Commission on Environmental Quality (TCEQ). August 2007, revised December 2007. *http://esl.eslwin.tamu.edu/docs/documents/ESL-TR-07-12-01.pdf*
- Texas Commission on Environmental Quality (TCEQ). *http://www.tceq.state.tx.us/*
- Texas A&M University, Energy Systems Laboratory, Senate Bill 5. *http://esl.eslwin.tamu.edu/senate-bill-5.html*

## 4.3.2 WISCONSIN – FOCUS ON ENERGY PROGRAM

### Benefits Assessed

- Energy savings
- Renewable energy generation
- Reductions of $NO_X$
- Reductions of $CO_2$
- Reductions of $SO_X$
- Reductions of mercury
- Energy bill savings

### Clean Energy Program Description

Funded by the Utility Public Benefits fund created by the Wisconsin State Legislature in 1999, the Wisconsin Focus on Energy Program aims to reduce energy use and advance clean energy supplies throughout Wisconsin by:

- Promoting energy efficient practices and equipment in new and existing buildings across the residential, industrial, commercial, agricultural, and government sectors;
- Promoting the installation of renewable energy;
- Educating the public about renewable energy; and
- Providing grants for research on the environmental impacts of electric generation.

Focus on Energy programs include the Wisconsin ENERGY STAR Products (ESP) program, Wisconsin ENERGY STAR Homes (WESH), Home Performance with ENERGY STAR (HPWES), as well as other sector- and renewable-energy-focused programs (DOA, 2005).

### Methods Used

To analyze how efficiency programs affect air emissions, the Wisconsin DOA enlisted an independent program evaluation contractor to comprehensively analyze the emission impacts of the state's efficiency programs by quantifying emission reductions for different seasons and hours of the day.

The general approach DOE used to estimate emissions from clean energy programs was to:

- *Develop seasonal and off-peak emissions factors* expressed in pounds of pollutant per MWh or GWh for nitrogen oxides ($NO_x$), sulfur dioxides ($SO_x$), carbon dioxide ($CO_2$), and mercury (Hg) for the regional electricity supply system serving Wisconsin. The DOA used EPA continuous emission monitoring data on historical plant operations and emissions to estimate which generating plants were "on the margin" during different time periods.[21]
- *Multiply the emissions factors by the energy savings from Focus on Energy programs efforts to produce an estimate of the total avoided emissions.*

[21] *EPA Office of Air and Radiation. "Acid Rain/OTC Program Hourly Emissions Data."* *http://www.epa.gov/airmarkets/emissions/raw/index.html*

To determine when the energy savings occurred so that it could apply the corresponding emissions factor (e.g., seasonal, hourly), DOA divided the annual energy savings for each measure into four bins: winter peak, winter off-peak, summer peak, and summer off-peak. DOA made these determinations based on internal evaluations of the operating characteristics of its programs, along with work done by the New Jersey Clean Energy Collaborative and reported in *Protocols to Measure Resource Savings*. ***http://www.njcleanenergy.com/files/file/Protocols_REVISED_VERSION_1.pdf***

- These calculations assume that the energy savings result in reduced generation at the power plants that are operating on the margin during a particular time of day or season. As described earlier in this chapter, the marginal generator is the last generator called upon to meet current demand for electricity, and it can vary over time (within a day and across seasons) as demand changes. Using emissions factors to estimate avoided emissions also assumes that reduced demand is perfectly correlated with reduced emissions.[22]

## Results

The emission benefits for Focus on Energy's business and residential programs by peak/season and program from July 1, 2001 through September 30, 2003 are summarized in Table 4.3.1.

Based on a more recent study update published in 2006, DOA estimates that from July 1, 2001 through June 30, 2006, its programs saved nearly 1 billion kWhs and nearly 50 million therms in annual energy consumption. This is equivalent to annual energy savings of almost $80 million for electricity (kWh) and nearly $50 million in gas savings (therms), and a lifetime dollar value of energy costs saved totaling more than $660 million for electricity saved and more than $430 million for gas saved. These programs have displaced annual emissions from power plants and utility customers by:

- 5.8 million pounds of $NO_X$,
- 2.6 billion pounds of $CO_2$,
- 11.4 million pounds of $SO_X$, and
- 46 pounds of mercury.

With stable funding over the next ten years, the state projects that the Focus on Energy program will add nearly $1 billion in value to Wisconsin's gross state product (DOA, 2006).

Performing this comprehensive emissions factor derivation improved the accuracy of avoided emission estimates from Focus on Energy efficiency programs and allowed the program to take into account differences

22 *This may not always be true. For example, even if demand is reduced in Wisconsin, Wisconsin generators may continue operating as they did before and sell more power out of state.*

### TABLE 4.3.1 EMISSION REDUCTIONS FROM FOCUS ON ENERGY BUSINESS AND RESIDENTIAL PROGRAMS BY PEAK AND SEASON PERIODS (JULY 1, 2001 – SEPTEMBER 30, 2003)

| | Business Programs | | | | Residential Programs | | | |
|---|---|---|---|---|---|---|---|---|
| Period | SOX | NOX | CO2* | Hg | SOX | NOX | CO2* | Hg |
| | Pounds | | | | | | | |
| Summer Off-peak | 444,544 | 216,265 | 89,429,423 | 2.1 | 300,946 | 146,406 | 60,541,736 | 1.4 |
| Summer Peak | 473,349 | 222,184 | 86,362,026 | 1.7 | 311,951 | 146,426 | 56,915,134 | 1.1 |
| Winter Off-peak | 715,544 | 286,218 | 112,858,634 | 2.6 | 597,750 | 239,100 | 94,279,589 | 2.2 |
| Winter Peak | 863,768 | 366,635 | 125,961,032 | 2.7 | 681,608 | 289,316 | 99,397,104 | 2.1 |
| On-site Natural Gas | 757 | 126,146 | 151,313,733 | - | - | - | - | - |
| Total | 2,497,206 | 1,091,302 | 414,611,115 | 9.1 | 1,892,255 | 821,248 | 311,133,562 | 6.8 |

*Source:Erickson et al., 2004.*

across energy efficiency measures in terms of the distribution of energy savings over sectors and periods of time, and develop an optimal portfolio of energy efficiency programs with respect to emission reductions. Using this type of approach, program designers can use the seasonal and peak emissions factors combined with information on load patterns for various types of equipment and businesses to target program efforts towards those areas that would produce the most emissions reductions for a given level of effort (Erickson et al., 2004).

## For More Information

- *Estimating Seasonal and Peak Environmental Emission Factors – Final Report.* Prepared by PA Government Services for the Wisconsin DOA. May 2004. ***http://www.doa.state.wi.us/docs_view2.asp?docid=2404***
- *Focus on Energy Public Benefits Evaluation – Semi-annual Summary Report.* Prepared by PA Government Services for the Wisconsin DOA. September 14, 2005. ***http://www.doa.state.wi.us/docs_view2.asp?docid=5237***
- *Focus on Energy Public Benefits Evaluation – Semi-annual Summary Report.* Prepared by PA Government Services for the Wisconsin DOA. September 27, 2006. ***http://www.focusonenergy.com/files/Document_Management_System/Evaluation/semiannualyearendfy06_evaluationreport.pdf***
- *Focus on Energy Program* ***http://www.focusonenergy.com/***

| Information Resource Description | URL Address |
|---|---|
| **Quantifying Air Emissions Reductions** | |
| **Developing a Baseline Emissions Profile** | |
| DOE's State Energy Consumption, Price, and Expenditure Estimates (SEDS) database. | *http://www.eia.doe.gov/emeu/states/_seds.html* |
| The ICLEI Cities for Climate Protection program Web site has greenhouse gas emissions inventories and plans developed by many major cities in the United States. | *http://www.icleiusa.org/action-center/learn-from-others/action-plans-inventories* |
| State Energy Offices often have energy use data and projections. For example, the New York State Energy Research and Development Authority (NYSERDA) published such data in "Patterns and Trends: New York State Energy Profiles (1993-2007)" (2009). | *http://www.nyserda.org/energy_information/patterns%20&%20trends%201993-2007.pdf* |
| **Basic Modeling Methods** | |
| **Defining operating characteristics/data on load profiles** | |
| The California Database for Energy Efficient Resources (DEER), sponsored by the California Energy Commission and California Public Utilities Commission (CPUC), provides estimates of energy and peak demand savings values, costs, and effective useful life of efficiency measures. | *http://www.energy.ca.gov/deer/* |
| NREL's HOMER simplifies the task of evaluating the economic and technical feasibility of design options for remote, stand-alone, and distributed generation applications (both off-grid and on-grid). | *http://www.nrel.gov/homer/* |
| National Assessment of Emissions Reduction of Photovoltaic (PV) Power Systems (Analysis Group for Regional Electricity Alternatives, Laboratory for Energy and the Environment, and the Massachusetts Institute of Technology, 2004). | *http://www.masstech.org/IS/public_policy/dg/resources/2004_PV-Avoided-Emissons_Main-Rept_MIT-Conners-et-al-1.pdf* |
| Some states or regions have technology production profiles in efficiency and renewable energy potential studies, e.g., *Energy Efficiency and Renewable Energy Resource Development Potential in New York State: Volume Four* contains energy production by costing period for some renewable resources (New York State Energy Research and Development Authority, 2003). | *http://www.nyserda.org/Energy_Information/energy_state_plan.asp* |

| Information Resource Description | URL Address |
|---|---|
| The appendices to the Connecticut Energy Conservation Management Board's *Maximum Achievable Potential Study* (2004) have detailed data about efficiency measures, including kW in summer and winter (available upon request). | *http://www.ctsavesenergy.org/ecmb/documents.php?section=30* |
| NREL's PV Watts calculates location-specific monthly energy production (kWh) from photovoltaic systems. | *http://www.nrel.gov/rredc/pvwatts/* |
| **Data on emissions rates and capacity factors** | |
| EPA's eGRID database provides information on emissions by individual power plants, generating companies, states, and regions of the power grid. | *http://www.epa.gov/egrid* |
| The NEPOOL Marginal Emission Rate Analysis report provides marginal emission rates during four time periods (ozone/one-ozone and peak/off-peak) for $NO_x$, $SO_x$, $CO_2$ for the NEPOOL region. | *http://www.iso-ne.com/genrtion_resrcs/reports/emission/index.html* |
| The Emission Reduction Workbook (OTC Workbook) (Keith, G., D. White, and B. Biewald, 2002) was developed for the Ozone Transport Commission in 2002. | *http://www.synapse-energy.com/Downloads/SynapseReport.2002-12.OTC.OTC-Emission-Reduction-Workbook-v-2.1.02-34-Workbook.xls* |
| EPA's Acid Rain data (recently moved to the Clean Air Markets website) provides hourly data on $SO_2$, $NO_x$, and $CO_2$ emissions for Acid Rain and $NO_x$ SIP Call/OTC units since 1997 (since 1995 for coal-fired units). | *http://camddataandmaps.epa.gov/gdm/index.cfm?fuseaction=prepackaged.select* |
| *Electric Energy Efficiency and Renewable Energy in New England: An Assessment of Existing Policies and Prospects for the Future* (the Regulatory Assistance Project and Synapse Energy Economics, 2005) describes an analysis that used the OTC workbook to estimate emissions reductions from efficiency and renewables in New England. | *http://www.synapse-energy.com/Downloads/SynapseReport.2005-05.RAP-EPA.Efficiency-and-Renewable-Energy-in-New-England.04-23.pdf* |
| *Emerging Tools for Assessing Air Pollutant Emission Reductions from Energy Efficiency and Clean Energy: Phase II Final Report.* Global Environment & Technology Foundation, January 31 2005. | *http://www.4cleanair.org/EmissionsModelingPhaseIIFinal.pdf* |
| *Model Energy Efficiency Program Impact Evaluation Guide* provides guidance on model approaches for calculating energy, demand, and emissions savings resulting from energy efficiency programs. The Guide is provided to assist in the implementation of the National Action Plan for Energy Efficiency's five key policy recommendations and its Vision of achieving all cost-effective energy efficiency by 2025. | *http://www.epa.gov/cleanrgy/documents/evaluation_guide.pdf* |
| *Using Electric System Operating Margins and Build Margins: Quantification of Carbon Emission Reductions Attributable to Grid Connected CDM Projects* (Biewald, B. 2005), prepared for the United Nations Framework Convention on Climate Change (UNFCC), analyzed the impact of reductions in electricity demand and renewable generation on $CO_2$ emissions. | *http://www.synapse-energy.com/Downloads/SynapseReport.2005-09.UNFCCC.Using-Electric-System-Operating-Margins-and-Build-Margins-.05-031.pdf* |
| *Methods for Estimating Emissions Avoided by Renewable Energy and Energy Efficiency* (Keith, G. and B. Biewald, 2005), prepared for U.S. Environmental Protection Agency, evaluates several methods of estimating displaced emissions without using a dispatch model. | *http://www.synapse-energy.com/Downloads/SynapseReport.2005-07.PQA-EPA.Displaced-Emissions-Renewables-and-Efficiency-EPA.04-55.pdf* |
| *Modeling Demand Response and Air Emissions in New England* (Keith, G., B. Biewald, D. White, and M. Drunsic, 2003), prepared for the U.S. Environmental Protection Agency, presents an analysis of the impact of reductions in electricity demand and renewable generation on air emissions. | *http://www.synapse-energy.com/Downloads/SynapseReport.2003-09.US-EPA.NE-DR-and-AE-Modeling.03-01.pdf* |

| Information Resource Description | URL Address |
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| **Sophisticated Modeling Methods** | |
| **Electric Dispatch Models** | |
| Electric dispatch models that can be used to assess displaced emissions include:<br>▪ GE-MAPS (Multi-Area Production Simulation)<br>▪ Market Analytics (PROSYM)<br>▪ PROMOD IV | GE-MAPS<br>*http://www.gepower.com/prod_serv/products/utility_software/en/ge_maps/index.htm*<br>Market Analytics<br>*http://www.ventyx.com/analytics/market-analytics.asp*<br>PROMOD IV<br>*http://www.ventyx.com/analytics/promod.asp* |
| **Capacity Expansion Models** | |
| *Energy Portfolio Management: Tools and Practices for State Public Utility Commissions* (Steinhurst, W., D. White, A. Roschelle, A. Napoleon, R. Hornby, and B. Biewald, 2006) describes a sample of capacity expansion models. | *http://www.synapse-energy.com/Downloads/SynapseReport.2006-07.NARUC.Portfolio-Management-Tools-and-Practices-for-Regulators.05-042.pdf* |
| The Hudson River Foundation financed the *Clean Electricity Strategy for the Hudson River Valley* (Synapse Energy Economics and Pace Law School Energy Project, 2003). This report explores the air-emissions reductions that would likely result from the implementation of a proposed clean energy plan, consisting of new energy efficiency programs, renewable generation, combined heat and power, and retrofit projects. | *http://www.synapse-energy.com/Downloads/SynapseReport.2003-10.Pace.Hudson-River-Clean-Energy-Strategy.02-23.pdf* |
| Capacity expansion models that can be used to assess displaced emissions include:<br>▪ Integrated Planning Model (IPM) (ICF International)<br>▪ National Energy Modeling System (NEMS) (U.S. DOE)<br>▪ ENERGY 2020 | Integrated Planning Model (IPM)<br>*http://www.icfi.com/Markets/Energy/energy-modeling.asp#2*<br>NEMS<br>*http://www.eia.doe.gov/oiaf/aeo/overview/index.html*<br>ENERGY 2020<br>*http://www.energy2020.com/* |
| **Quantifying Air Quality and/or Health Impacts** | |
| SCRAM | *http://www.epa.gov/ttn/scram/* |
| REMSAD | *http://remsad.saintl.com* |
| CAMx | *http://www.camx.com* |
| UAM-V | *http://uamv.saintl.com* |
| CMAQ | *http://www.epa.gov/AMD/CMAQ/CMAQscienceDoc.html* |
| CALPUFF and AERMOD | *http://www.epa.gov/scram001/dispersion_prefrec.htm* |
| COBRA | *http://epa.gov/statelocalclimate/resources/cobra.html* |
| BenMAP | *http://www.epa.gov/air/benmap/* |
| ASAP | *http://www.epa.gov/ttn/ecas/asap.html* |

| Information Resource Description | URL Address |
|---|---|
| **Texas Case Study** | |
| Energy Efficiency/Renewable Energy Impact in the Texas Emissions Reduction Plan (TERP): Volume 1 – Summary Report. Prepared for the Texas Commission on Environmental Quality (TCEQ). August 2007, revised December 2007. | *http://esl.eslwin.tamu.edu/docs/documents/ESL-TR-07-12-01.pdf* |
| Texas Commission on Environmental Quality (TCEQ). | *http://www.tceq.state.tx.us/* |
| Texas A&M University, Energy Systems Laboratory, Senate Bill 5. | *http://esl.eslwin.tamu.edu/senate-bill-5.html* |
| **Wisconsin Case Study** | |
| Estimating Seasonal and Peak Environmental Emission Factors – Final Report. Prepared by PA Government Services for the Wisconsin DOA. May 2004. | *http://www.doa.state.wi.us/docs_view2.asp?docid=2404* |
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| Department of Administration, State of Wisconsin. 2006. Focus on Energy Public Benefits Evaluation – Semiannual Summary Report. Prepared by PA Government Services for the Wisconsin DOA. September. | *http://www.focusonenergy.com/files/Document_Management_System/Evaluation/semiannualyearendfy06_evaluationreport.pdf* |
| Focus on Energy Program | *http://www.focusonenergy.com/* |
| New Jersey Clean Energy Program. 2007. Protocols to Measure Resource Savings, December. | *http://www.njcleanenergy.com/files/file/Protocols_Final_12-20-07_%5B1%5D.pdf* |
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