

Quantifying the Multiple Benefits of Energy Efficiency and Renewable Energy

A Guide for State and Local Governments



2018 Edition

PART ONE

The Multiple Benefits of Energy Efficiency and Renewable Energy

DOCUMENT MAP

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ABOUT THIS CHAPTER

This chapter provides an overview of the purpose of the overall *Guide.* It defines energy efficiency and renewable energy and describes why quantifying the multiple benefits of energy efficiency and renewable energy may be valuable to a decision maker or analyst. This chapter sets the context for the subsequent chapters that describe the framework, methods, and tools analysts can use to quantify the electricity system, emissions and health, and economic benefits of energy efficiency and renewable energy.

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PREFACE

State and local energy efficiency and renewable energy investments can produce significant benefits, including lower fuel and electricity costs, increased grid reliability, better air quality and public health, and more job opportunities. Analysts can quantify these benefits so that decision makers can comprehensively assess both the costs and the benefits of their energy policy and program choices.

The U.S. Environmental Protection Agency (EPA) State and Local Energy and Environment Program is pleased to release the 2018 edition of *Quantifying the Multiple Benefits of Energy Efficiency and Renewable Energy: A Guide for State and Local Governments.* The *Guide* is intended to help state and local energy, environmental, and economic policy makers and analysts identify and quantify the many benefits of energy efficiency and renewable energy to support the development and implementation of cost-effective energy efficiency and renewable energy initiatives.

This *Guide* starts by describing, in Part One, the multiple benefits of energy efficiency and renewable energy and explaining the value of quantifying these benefits so that they are considered along with costs. In Part Two, the *Guide* shows policy makers and analysts how they can quantify the direct electricity, electricity system, emissions, health, and economic benefits of energy efficiency and renewable energy. It provides detailed information about a range of basic-to-sophisticated methods analysts can use to quantify each of these benefits, with key considerations and helpful tips for choosing and using the methods. Part Two includes case studies and examples of how analysts have quantified the benefits of state or local energy efficiency and renewable energy policies, programs, and investments. The chapters in Part Two also describe tools and resources available for quantifying each type of benefit.

The original 2010 version, *Assessing the Multiple Benefits of Clean Energy: A Resource for States,* was the first to organize and present a comprehensive review of the multiple benefits of clean energy and the methods available to quantify them. It became a cornerstone resource for EPA's State and Local Energy and Environment Program.

This 2018 edition includes:

- The latest information about the methods analysts can use and the available tools that support them
- New graphics that clearly present steps to quantify benefits and make it easier to understand the process
- Recent real-life examples and case studies where benefits have been quantified

Analysts can use the new *Guide* to learn how to quantify the multiple benefits of energy efficiency and renewable energy initiatives.

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

1.1. OVERVIEW: ASSESSING THE MULTIPLE BENEFITS OF ENERGY EFFICIENCY AND RENEWABLE ENERGY

Across the nation, state and local governments are increasingly adopting and updating policies and programs that encourage energy efficiency and renewable energy to achieve their energy, environmental, and economic goals. As of 2018, more than half of the states are actively implementing:

- Policies and programs to save energy in public-sector buildings and fleets and to improve the operational efficiency and economic performance of states' assets
- Mandatory or voluntary energy efficiency resource standards or targets
- Energy efficiency programs for individuals or businesses
- Mandatory or voluntary renewable portfolio standards (RPSs)
- Financial incentives to individuals, businesses, and/or utilities to encourage renewable energy or energy efficiency (DSIRE, 2018; ACEEE, 2017)

These policies have helped states and localities reduce harmful air pollutants, improve public health, lower energy costs and the costs of compliance with national air quality standards, create jobs, and improve the reliability and security of the nation's energy system.

Although the multiple benefits of these policies are clear in hindsight, some state energy efficiency and renewable energy policies faced initial resistance because the benefits were not fully appreciated or factored into the quantitative comparison of costs and benefits that often drives decision-making. This *Guide* provides valuable information to help analysts and policy makers understand: a range of energy and non-energy benefits associated with energy efficiency and renewable energy, the methods they can use to quantify them credibly, and key considerations for their analyses. With this information, state and local agencies can evaluate options in a more accurate manner by assessing the comprehensive benefits of proposed policies and programs—not just the costs.

WHAT ARE ENERGY EFFICIENCY AND RENEWABLE ENERGY?

The methods described in this *Guide* can be used to assess the impacts of a range of policies, including demand- and supply-side strategies, which generally fall within the following categories:

Energy efficiency reduces the amount of energy needed to provide the same or improved level of service to the consumer in an economically efficient way. Common policies include resource and technology standards, codes, and incentives that can advance the deployment of energy efficient technologies, and practices across all sectors of the economy.

Combined heat and power (CHP), also known as cogeneration, improves the conversion efficiency of traditional energy systems by using waste heat from electricity generation to produce thermal energy for heating or cooling in commercial or industrial facilities.

Demand response measures aim to reduce customer energy demand at times of peak electricity demand to help address system reliability issues; reduce the need to dispatch higher-cost, less-efficient generating units to meet electricity demand; and delay the need to construct costly new generating or transmission and distribution capacity. Demand response programs can include dynamic pricing/tariffs, price-responsive demand bidding, contractually obligated and voluntary curtailment, and direct load control/cycling (FERC, 2017).

Renewable energy is energy generated partially or entirely from non-depleting energy sources for direct end use or electricity generation. Renewable energy definitions vary by state, but usually include wind, solar, and geothermal energy. Some states also consider low-impact or small hydro, biomass, biogas, and waste-to-energy to be renewable energy sources.

Clean **distributed generation** (DG) refers to small-scale renewable energy and CHP at the customer or end use site.

For in-depth information on more than a dozen policies and programs that state policy makers are using to meet their energy, environmental, and economic objectives, see EPA's publication, *Energy and Environment Guide to Action: State Policies and Best Practices for Advancing Energy Efficiency, Renewable Energy, and Combined Heat and Power* at https://www.epa.gov/statelocalenergy/energy-and-environment-guide-action.

1.1.1. Assessing Benefits with Costs

With typical policy analysis, the costs of an energy policy are tallied but the benefits may be underestimated or very limited in scope. A full accounting of costs is necessary, but it does not tell the complete story of how a new policy will affect a state, tribe, or community. Underrepresenting benefits—or not including them at all—in a final analysis hinders clear decision-making and can prevent environmental, energy, and/or economic policy makers from capturing all the potential gains associated with pursuing energy efficiency and renewable energy policies.

Consider a state utility commission that is evaluating whether it should approve a proposed energy efficiency program. The commission will typically require the program administrator to assess the cost-effectiveness of the program. Depending on the approach used by the administrator, the analysis may not include a balanced comparison of costs and benefits. For example, it may include all of the costs associated with the expanded program, along with the savings in electricity and resulting cost savings (i.e., benefits) to businesses and households that are likely to accrue from it, but exclude other benefits (such as health benefits) that arise from emissions reductions and economic benefits that derive from higher demand for energy-efficient equipment and services. Although such a limited analysis is somewhat informative, it overstates the net cost of the program. Quantifying these benefits would more accurately depict the broader value of energy efficiency or renewable energy programs.

In another example, suppose a state energy office is considering the expansion of a solar energy program primarily because the state is looking to diversify electricity generation. As part of its cost-benefit analysis, it may quantify only the additional cost to administer the expanded policy or program, the cost of additional investment in the solar panels, and the direct energy benefits (e.g., the renewable electricity generation). Suppose, however, that the governor has set a priority on job creation in the state and the state air agency is concerned about meeting national air quality goals. If the energy office were to expand its analysis to examine the potential impacts of the initiative on employment or emissions, it could demonstrate how the expanded solar program could help the state achieve other goals. Quantifying the program's multiple benefits, including the non-energy benefits, could facilitate integrated planning across government agencies, enabling states to maximize benefits across numerous priorities and implement fewer policies and programs to achieve their goals.

As these examples illustrate, understanding the full range of emissions reductions and resulting environmental, human health, and/or economic benefits from existing and proposed energy efficiency and renewable energy measures can help planners:

- Identify opportunities to improve the environment and public health, the energy system, and the economy.
- Reduce the compliance costs of meeting air quality standards.
- Demonstrate the broad value of energy efficiency and renewable energy initiatives, including the non-energy benefits, to state and local decision makers.
- Meet multiple goals more easily and at a lower cost than if addressed separately.

Figure I-1: When to Assess the Multiple Benefits of Energy Efficiency and Renewable Energy During the Policy Planning and Evaluation Process

Figure I-1 above depicts the policy, planning, and evaluation process and highlights when quantifying the multiple benefits of energy efficiency and renewable energy typically can be most helpful.

1.1.2. Filling Information Gaps

Why, then, isn't the complete range of benefits included as a standard component of benefit-cost analyses? Perhaps the most common reason is that many policy analysts and policy makers are simply unaware of the many benefits or, if they *are* aware, they don't know how to quantify them credibly.

This *Guide* aims to fill these information gaps for state and local decision makers. This segment, Part One, describes the electricity system, emissions, health, and economic benefits that can result from energy efficiency and renewable energy policies and programs. Part Two, "Quantifying the Benefits: Framework, Methods, and Tools," describes how analysts can quantify these benefits using a range of basic-to-sophisticated approaches. Part Two also includes information about specific tools and data that analysts can use to conduct benefit analyses, and provides case studies illustrating how these tools and data have been used.

IMPORTANT NOTES ON THE SCOPE OF THIS *GUIDE*

Because the practice of quantifying the costs of policies is widely understood, the focus of this *Guide* is on describing the practice of quantifying the *benefits* of policies.

This *Guide* focuses on electricity system, emissions, health, and economic benefits from energy efficiency and renewable energy programs. Energy efficiency and renewable energy programs can have other energy-related benefits (e.g., from combined heat and power) and other environmental benefits (e.g., to water quality), but they are not covered in detail here.

The *Guide* also focuses on benefits in the electricity sector as opposed to the energy sector in general, although some of the analytic tools described can be applied more broadly. The *Guide* itself does not consider other sectors such as transportation (where, for example, electric vehicles may be able to provide grid services when not in use). Consideration and inclusion of these other types of benefits and sectors could further enhance the comprehensiveness of an analysis.

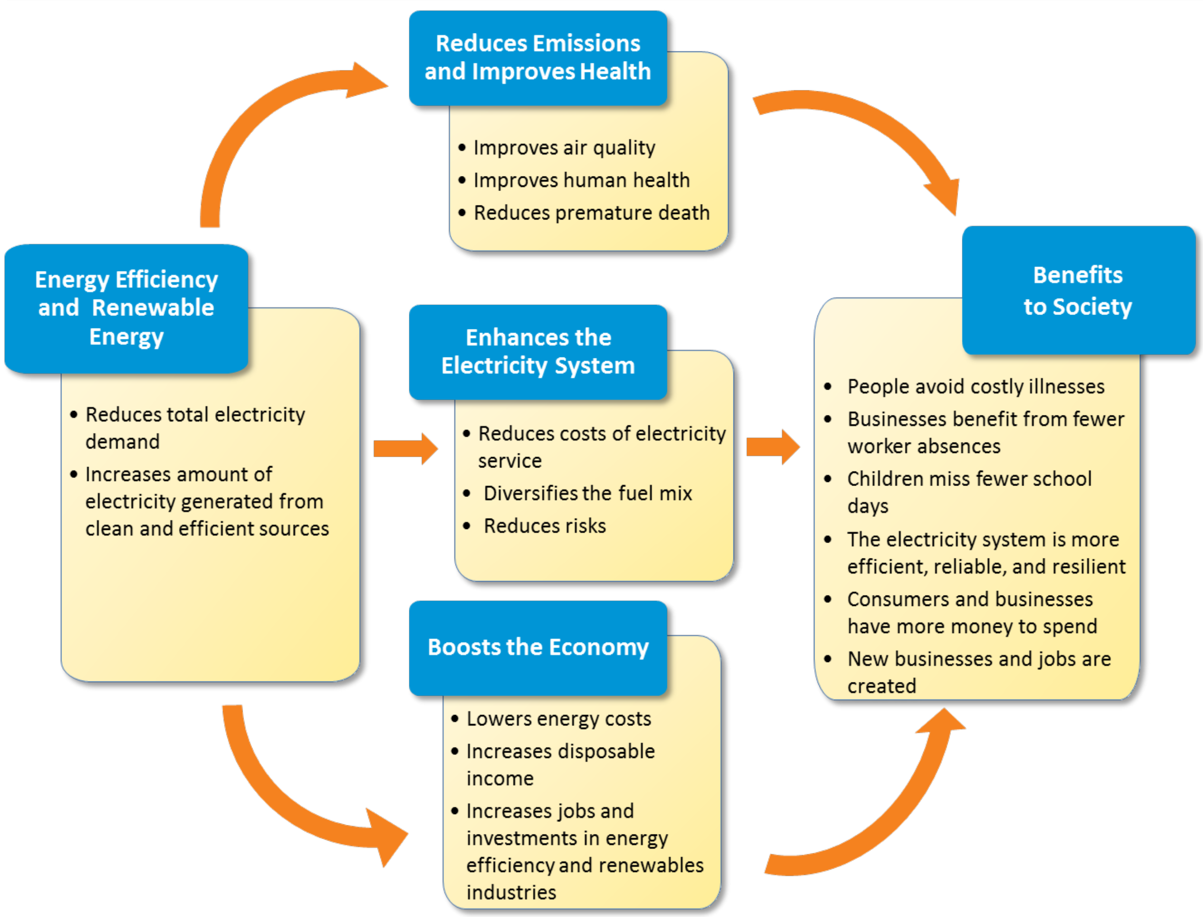
1.2. WHAT ARE THE BENEFITS OF ENERGY EFFICIENCY AND RENEWABLE ENERGY?

Energy efficiency and renewable energy policies can reduce the demand for and supply of energy generated from fossil fuels (e.g., natural gas, oil, and coal-fired power plants). Although this reduction in demand can lead to negative impacts (i.e., losses in revenue to the fossil fuel industry) that should be considered during policy analyses, it can also generate electricity system, emissions, health, and economic benefits for businesses, individuals, and society.

Electricity savings and renewable energy generation provide the basis for estimating the many benefits of energy efficiency and renewable energy to the electricity system, to emissions and public health, and to the economy, as depicted in Figure I-2 and described below.

- *Electricity system benefits*: Energy efficiency and renewable energy initiatives—in combination with demand-response measures—can help protect electricity producers and consumers from the costs of adding new capacity to the system and from energy supply disruptions, volatile energy prices, and other reliability and security risks.
- *Emissions and health benefits*: Fossil fuel-based electricity generation is a source of air pollution that poses risks to human health, including respiratory illness from fine-particle pollution and ground-level ozone (U.S. EPA, 2016a). The burning of fossil fuels for electricity is also the largest source of greenhouse gas (GHG) emissions from human activities in the United States, contributing to global climate change (U.S. EPA, 2017). Improving energy efficiency and increasing the use of renewable energy can reduce fossil fuel-based generation and its associated adverse health and environmental consequences.
- *Economic benefits:* Many of the electricity system, emissions, and health benefits yield overall economic benefits to the state. These benefits include savings in energy and fuel costs for consumers, businesses, and the government; new jobs in, profits for, and tax revenue from companies that support or use energy efficiency and renewable energy, such as construction, manufacturing, and services; and higher productivity from employees and students taking fewer sick days.

Figure I-2: The Multiple Benefits of Energy Efficiency and Renewable Energy

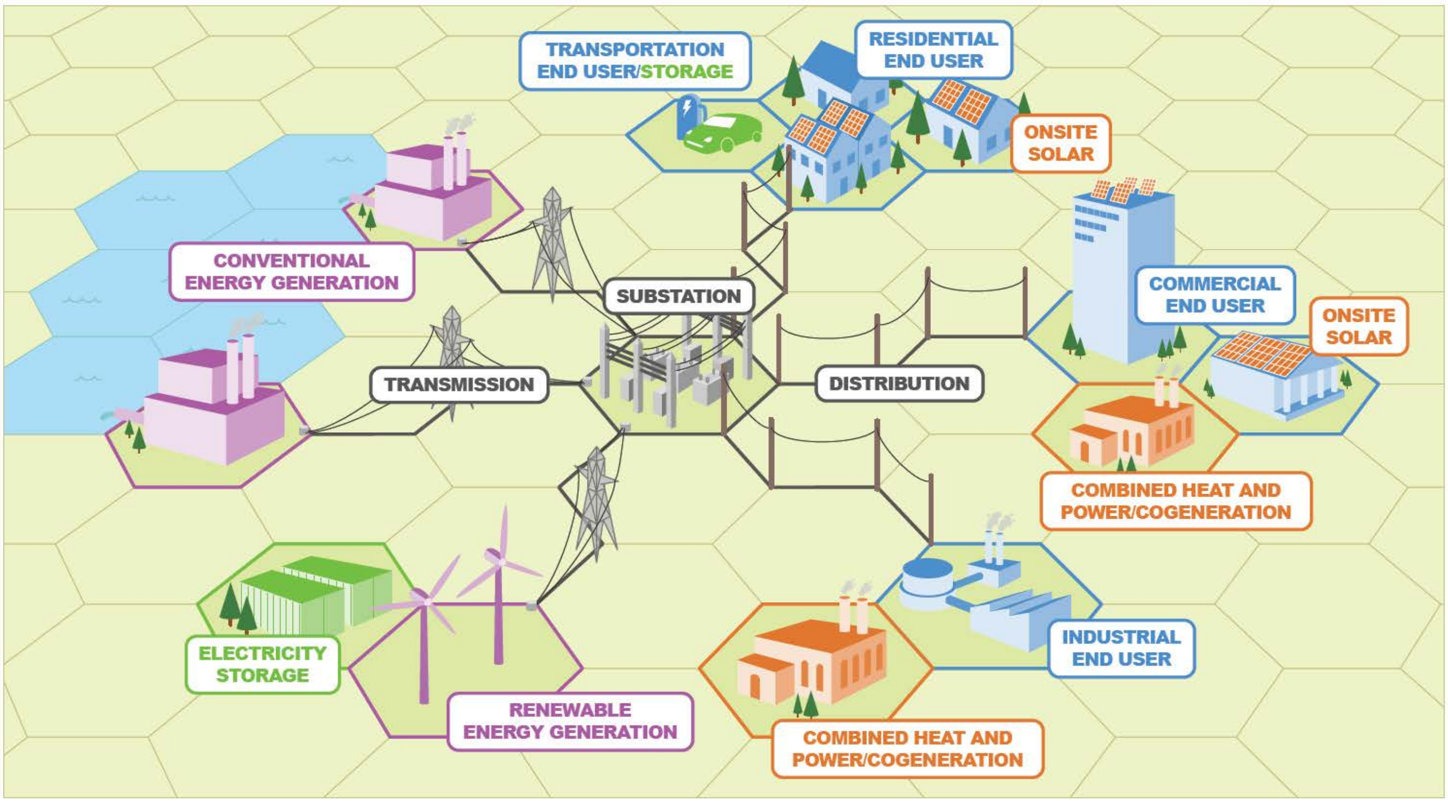


These three types of benefits are described in greater detail on the following pages. As mentioned earlier, descriptions of methods that analysts can use to quantify many of these impacts, as well as available tools, data, and case studies are found in Part Two, “Quantifying the Benefits: Framework, Methods, and Tools,” of this *Guide*.

1.2.1. Electricity System Benefits

Energy efficiency and renewable energy initiatives can be cost competitive with other energy options and can provide benefits to the U.S. electricity system (illustrated in Figure I-3). For example, an analysis of 20 state energy efficiency programs found that these programs cost utilities on average 2.3 cents per kilowatt-hour, about one-half to one-third the cost of new resource options such as building power plants (LBNL, 2015; Lazard, 2017).

Figure I-3: The U.S. Electricity System



For more information on the U.S. electricity system, visit: https://www.epa.gov/energy/about-us-electricity-system-and-its-impact-environment.

Energy efficiency and renewable energy initiatives and investments produce both *primary* and *secondary* electricity system benefits.

- *Primary benefits* are those conventionally recognized for their ability to reduce the overall cost of electric service over time, such as the avoided costs of electricity generation or avoiding the need to build new power plants. These benefits can occur over the long run, the short run, or both. Some of these benefits are significant and most can be quantified.
- *Secondary benefits* indirectly reduce electricity system costs (such as deferred long-term investments), increase reliability, and improve energy security. Secondary benefits tend to be harder to quantify and, therefore, are less frequently assessed than primary benefits. Nevertheless, it is useful to identify these benefits and quantify them, when possible, to reflect both the costs and benefits of energy efficiency and renewable energy most accurately.

These benefits are described in greater detail below.

Primary Electricity System Benefits

Primary electricity system benefits of energy efficiency and renewable energy that can be included in a policy analysis include:

- *Avoided costs of electricity generation or wholesale electricity purchases:* Energy efficiency and renewable energy policies and programs can save money by lowering fuel costs and reducing costs for purchased power or transmission services associated with traditional generation.
- *Deferred or avoided costs of expanding power plant capacity:* Energy efficiency and renewable energy can play a critical role in meeting increased demand for electricity, in delaying or avoiding the need to build or upgrade power plants, or in reducing the size of needed additions.[1] This saves on capital investments and annual fixed costs (e.g., labor, maintenance, taxes, and insurance), which can translate into lower customer bills.
- *Avoided electricity loss in transmission and distribution (T&D):* Delivering electricity results in some losses due to the resistance of wires, transformers, and other equipment. For every unit of energy consumption that an energy efficiency initiative avoids or distributed renewable energy resource generates, it also avoids the associated energy loss during delivery of electricity to consumers through the T&D system and reduces waste in the system. [2]
- *Deferred or avoided costs of expanding T&D capacity:* Energy efficiency and renewable energy resources that are located close to where electricity is consumed can delay, reduce, or avoid the need to build or upgrade T&D systems or reduce the size of needed additions as electricity demand increases.[3] These savings can occur over the long run, the short run, or both.

WHOLESALE ELECTRICITY MARKETS AND FORWARD CAPACITY MARKETS

The **wholesale electricity market** operates through an auction system where electricity generators place bids, typically valued at their marginal operating costs (i.e., the operating cost required to produce each Megawatt-hour of electricity), to provide electricity during a specific time period in the near term. The grid operator then dispatches (i.e., assigns) generators, from lowest to highest cost, to meet electricity demand, and compensates all electricity generators at the price paid for the last and most expensive unit of electricity needed to meet demand.

Forward capacity markets—in which electricity system operators solicit bids to meet estimates of future peak electricity needs (typically a few years ahead)—signal future capacity needs. In these markets, energy efficiency and renewable energy resources can compete equally with conventional capacity providers, and thus may reduce the market signal to invest in conventional capacity.

Secondary Electricity System Benefits

Secondary electricity system benefits include:

- *Avoided ancillary service costs:* Ancillary services are electricity system functions that ensure reliability, rather than provide power.[4] Energy efficiency and renewable energy resources that reduce demand and are located close to where electricity is used—or support smooth operation of the power grid—can reduce some ancillary

[1] *Although electricity demand in the United States as a whole has been flat or decreasing for nearly 20 years, the accelerating use of electric vehicles is likely to increase electricity demand over the next five to 10 years. Furthermore, some states or regions may experience increasing demand from population growth.*

[2] *Renewable central-station generation incurs the same T&D losses as those from fossil fuel-based sources.*

[3] *In the long run, it is mostly energy efficiency and distributed renewable energy generation capacity that defers T&D costs. Grid-scale renewable energy resources' need for T&D infrastructure is similar to traditional generating units.*

[4] *Examples of ancillary services include operating reserves (e.g., responding to sudden gaps in supply and demand of electricity) and voltage support (e.g., maintaining voltage levels).*

service costs, save fuel, and lower emissions by allowing some units to shut down, and may delay or avoid the need for investment in new generation to provide ancillary services.

- *Lower wholesale market clearing prices:* Energy efficiency and renewable energy policies and programs can lower the demand for electricity or increase the supply of electricity (renewable energy generators typically have little to no marginal operating costs), respectively, causing wholesale markets to clear at lower prices. This benefit can be dramatic during peak hours.
- *Better reliability and power quality:* The electric grid is more reliable if it is under less stress during peak hours, especially in regions where transmission is constrained. Integrating energy efficiency and onsite renewables can increase the reliability of the electricity system, because power outages are less likely to occur when the system is not strained; diversify the generation mix, making the system less vulnerable to outages; and potentially enhance power quality, which is important for the operation of some electrical equipment. For example, energy storage can be used to store excess renewable energy for later use; it can be installed close to where energy will be consumed, potentially alleviating congestion on T&D systems during peak periods. Storage technologies with rapid response capabilities can also be used to help manage fluctuations on the electricity grid caused by the intermittency of some renewable energy resources. Due to their flexibility and ability for rapid response, system operators are exploring automated demand response and storage for better integrating distributed renewable energy resource.
- *Avoided risks related to long lead-time investments:* Decisions to construct new electricity generating units are based on long-term projections of energy demand and electricity sale prices and it is expected that power plants will operate for long periods of time, often as long as 40 years, to fully recover construction and operating costs. Although energy efficiency and renewable energy resources certainly have some risk (e.g., underperformance compared with expectations), they can be attractive alternatives due to their modular nature and their relatively quick installation and disconnection time.
- *Reduced risk by deferring investment in traditional, centralized resources until environmental policies take shape*: Utilities prefer certainty around future legislative and regulatory policies before investing in large, traditional electricity resources. Uncertainty creates risks. As noted above, energy efficiency and renewable energy resources are typically developed at a smaller scale than traditional, centralized resources, and provide an incremental approach to deferring decisions on larger, more capital-intensive projects.
- *Improved fuel diversity:* Utilities that rely on a limited number of power sources can be vulnerable to price, availability, and other risks associated with any single fuel source. In contrast, the costs of energy efficiency and most renewable energy resources, such as solar or wind, are relatively unaffected by prices of other fuels and thus provide a hedge against price spikes. The greater the diversity in technology, the less likelihood of supply interruptions and overall reliability problems.
- *Strengthened energy security:* Due to its critical importance in providing power to the U.S. economy, the electricity system is vulnerable to attacks and natural disasters. Using diverse domestic energy efficiency and renewable energy resources bolsters energy security by reducing the vulnerability of the electricity system when attacks or natural disasters occur.

1.2.2. Emissions and Health Benefits

Energy efficiency and renewable energy can reduce air pollution and its negative consequences. For example, one analysis found that compliance with state RPSs in 2013 reduced national emissions from the power sector by 77,4000 metric tons of sulfur dioxide (SO_2), 43,900 metric tons of nitrogen oxides (NO_x), and 4,800 metric tons of fine particulates

($PM_{2.5}$) (NREL, 2016). Electricity generation is a major source of air pollution, including criteria air pollutants and GHGs. GHGs are also emitted during the refinement, processing, and transport of fossil fuels. These pollutants contribute to many environmental problems that can harm human health, including poor air quality and climate change, as described below.

Criteria Air Pollutants

Criteria air pollutants—such as particle pollution (often referred to as particulate matter or PM), ground-level ozone (O_3), carbon monoxide (CO), SO_2, NO_x, and lead (Pb)—lower air quality and can be harmful to human health.[5] Using fossil fuels to generate electricity increases levels of these pollutants in the atmosphere. Once emitted, some criteria air pollutants circulate widely, potentially for long distances.

Some "primary" air pollutants (e.g., PM, CO, SO_2, and NO_x), are directly harmful to people and the environment. Other "secondary" air pollutants form in the air when primary air pollutants and other precursor air pollutants, such as volatile organic compounds (VOCs), react or interact. For example, primary air pollutants such as NO_x and VOCs react under certain weather conditions to form O_3, a secondary air pollutant. O_3 is a principal component of photochemical smog that can cause coughing, throat irritation, difficulty breathing, lung damage, and can aggravate asthma (U.S. EPA, 2016c).[6] $PM_{2.5}$ is also a secondary air pollutant of particular concern because of its prevalence and links with many respiratory and cardiovascular illnesses and death (U.S. EPA, 2016b).[7]

Criteria air pollutants have local and regional effects and can dissipate in hours or days, so reducing them can have immediate positive benefits. Policies and programs that avoid or reduce the use of fossil fuel energy and criteria air pollutants, such as energy efficiency and renewable energy initiatives, can:

- *Improve air quality* by reducing or avoiding harmful criteria air pollutants, which yields direct and immediate health benefits to people, as described below. Air quality improvements can also strengthen ecosystems' health, increase crop and timber yields, and increase visibility.
- *Enhance public health* by reducing incidences of premature death, asthma attacks, and respiratory and heart disease; avoiding related health costs; and reducing the number of missed school and workdays due to illnesses.

Hazardous Air Pollutants

Hazardous air pollutants (HAPs), also known as toxic air pollutants or air toxics, are pollutants that are known or suspected to cause cancer or other serious health effects, such as reproductive effects or birth defects, or adverse environmental effects. HAPs, such as mercury, can be by-products of fossil fuel-based electricity generation. For example, in the United States, power plants that burn coal to create electricity account for about 42 percent of all manmade mercury emissions (U.S. EPA, 2016a). Mercury exposure at high levels can harm the brain, heart, kidneys, lungs, and immune system of people of all ages.

Energy efficiency and renewable energy policies and programs that reduce emissions of mercury and other HAPs can help avoid the negative health impacts of exposure.

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[5] *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.*

[6] *Tropospheric O_3 also acts as a strong GHG.*

[7] *Different components of $PM_{2.5}$ have both cooling (e.g., sulfates) and warming (e.g., black carbon) effects on the climate system.*

Greenhouse Gases

GHGs—such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), and sulfur hexafluoride (SF_6)—trap heat in the atmosphere that would otherwise escape to space, and contribute to climate change. GHGs from natural sources help keep the Earth habitable, as the planet would be much colder without them. However, GHGs from human activities, such as from electricity generation, are building up in the atmosphere and contributing to climate change.[8] In the United States, the combustion of fossil fuels to generate electricity was the largest single source of CO_2 emissions in 2015, accounting for about 35 percent of total U.S. CO_2 emissions and 29 percent of total U.S. GHG emissions (U.S. EPA, 2017).

Increasing GHG emissions changes the climate system in ways that affect our health, environment, and economy. For example, climate change can influence crop yields, lead to more frequent extreme heat waves, and make air quality problems worse. CH_4, a potent GHG, also contributes to the formation of ground-level ozone, which is a harmful air pollutant and component of smog.

GHGs accumulate and can remain in the atmosphere for decades to centuries, affecting the global climate system for the long term. Because of this, measures like energy efficiency and renewable energy that immediately avoid or reduce GHGs can create long-lasting and positive benefits for the atmosphere and human health while also achieving short-term air quality and health benefits.

Regional Haze

When sunlight encounters tiny pollution particles in the air, haze forms and reduces the clarity and color of what humans see. PM pollution is the major cause of reduced visibility (haze) in parts of the United States, including many of our national parks.

Air pollutants that create haze come from a variety of natural sources, such as soot from wildfires, and manmade sources, such as motor vehicles, electric utility and industrial fuel burning, and manufacturing operations. Some of the pollutants that form haze have also been linked to serious health problems and environmental damage, as described earlier. In addition, particles such as nitrates and sulfates contribute to acid rain formation, which makes lakes, rivers, and streams unsuitable for many fish, and erodes buildings, historical monuments, and paint on cars.

Policies and programs that avoid or decrease the PM pollution, like energy efficiency and renewable energy initiatives, can also reduce haze and acid rain, and lessen negative health impacts.

1.2.3. Economic Benefits

Energy efficiency and renewable energy initiatives can provide a number of important economic benefits for people, communities, and entire state economies. For example, a study conducted for Efficiency Vermont, the nation's first energy efficiency utility, found that every $1 million in efficiency program spending in Vermont creates a net gain of 43 job-years. Every $1 of program spending yields a net increase of nearly $5 in cumulative gross state product, an additional $2 in Vermonters' incomes over 20 years, and more than $6 in gross energy savings (Optimal Energy and Synapse Energy, 2011).

Energy efficiency and renewable energy initiatives affect the economy both *directly* and *indirectly*, by affecting individuals, businesses, or institutions directly involved in the investment as well as by having an effect on others who

[8] The International Panel on Climate Change (IPCC) has concluded that human-caused GHG emissions are extremely likely—defined as having a greater than 95 percent probability of being true—to be responsible for more than half of the observed increase in global average temperatures since the mid-20th century (IPCC, 2014).

are less directly involved.[9] This section provides an overview of the direct and indirect economic effects of energy efficiency and renewable energy initiatives that are used to quantify the economic benefits. They are briefly summarized in Table I-1.

Table I-1: Summary of Economic Effects from Energy Efficiency and Renewable Energy Initiatives

<table>
<tr><th rowspan="2">Type of Policy or Program</th><th colspan="3">Economic Effects</th></tr>
<tr><th>Direct</th><th>Indirect</th><th>Both Direct and Indirect</th></tr>
<tr><td>Demand-side</td><td>▪ Household and business costs
▪ Program administrative costs
▪ Energy cost savings to households and businesses
▪ Sector transfers</td><td rowspan="2">▪ Increased disposable income
▪ Increased income, employment, and output in some industries
▪ Reduced cost of doing business
▪ Decreased income, employment, and output in some industries
▪ Expanded in-state market for some products and services, and attraction of new businesses and investment</td><td rowspan="2">▪ Health
▪ Employment
▪ Output
▪ Gross state product
▪ Income</td></tr>
<tr><td>Supply-side</td><td>▪ Construction costs
▪ Operating costs
▪ Program administrative costs
▪ Displacement savings
▪ Waste heat savings</td></tr>
</table>

Direct Economic Effects

Direct effects include changes in sales, income, or jobs associated with the immediate effects of an expenditure or change in demand. The direct effects of policies or programs that affect energy *demand*, such as those that stimulate investments in energy-efficient equipment by the commercial or residential sectors, will differ from the direct effects of initiatives that affect the *supply* of energy, such as RPSs.

Direct Economic Effects of Demand-Side Initiatives

Energy efficiency and renewable energy initiatives that affect the demand (or customer) side of energy services typically change the energy consumption patterns of business and residential consumers by reducing the quantity of energy required for a given level of production or service. Demand-side energy efficiency initiatives lead to direct costs and savings, including:

- *Household and business costs:* Costs for homeowners and businesses to purchase and install more energy-efficient equipment. For policies supported by a surcharge on electric bills, the surcharge is an included cost.
- *Program administrative costs:* Dollars spent operating the efficiency initiative—including labor, materials, and paying incentives to participants.
- *Energy cost savings:* The money saved by businesses, households, and industries resulting from reduced energy costs (including electricity, natural gas, and oil cost savings), reduced repair and maintenance costs, deferred equipment replacement costs, and increased property values. Energy cost savings are typically reported in total dollars saved.

[9] Some analyses describe a third type of impact, induced effects. Induced effects result from the additional purchases of goods and services by consumers and governments that are affected directly or indirectly by the energy efficiency or renewable energy policy (e.g., increased wage income is spent on additional goods). These effects are typically called out by input-output modelers, while other analyses do not highlight them explicitly. In this chapter, induced effects are included under the indirect effects category unless indicated otherwise.

- *Sector transfers:* Both the increased flow of money to companies that design, manufacture, and install energy-efficient equipment and the reduced flow of dollars to other energy companies, including electric utilities, as demand for electricity and less-efficient capital declines.

These direct costs and savings shift economic activity among different players in the economy. For example, households may increase spending on products that improve energy efficiency, such as foam insulation, as a result of a particular energy efficiency program, increasing revenue for the companies that produce and install foam insulation. To pay for the cost of the insulation, they may reduce spending on other goods and activities, lowering revenue for those businesses that would have otherwise received it. The stream of energy cost savings that results from the insulation may increase disposable income that households can spend on other goods and services. The reduced demand for electricity, however, may decrease revenue for utilities unless the state's utility revenue structures allow for program cost recovery or financial incentives for energy efficiency programs.[10] Together, the shifts caused by demand-side initiatives may result in economy-wide macroeconomic impacts, such as effects on income, employment, and overall economic output. An analysis of the magnitude and direction of the impacts can help policy makers design policies that provide the greatest overall benefit to a state or locality.

Direct Economic Effects of Supply-Side Initiatives

Supply-side energy efficiency and renewable energy policies and programs change the fuel and generation mix of energy resources or otherwise alter the operational characteristics of the energy supply system. Supply-side policy measures generally support the development of utility-scale renewable energy and combined heat and power (CHP) applications, and/or clean distributed generation (DG). The direct effects of supply-side initiatives arise from the costs of manufacturing, installing, and operating the renewable energy or CHP equipment supported by the initiative, as well as the energy savings and possible reduction of energy supply costs from fuel substitution among participants in the supply-side program and their customers. The direct costs and savings of renewable energy, CHP, and DG initiatives include:

- *Construction costs:* Money spent to purchase the renewable energy, CHP, and DG equipment; installation costs; costs of grid connection; and onsite infrastructure construction costs (such as buildings or roads)
- *Operating costs:* Money spent to operate and maintain the equipment during its operating lifetime and the cost of production surcharges applied to consumers
- *Program administrative costs:* Money spent operating the initiative—including labor, materials, and paying incentives to participants
- *Displacement savings:* Money saved by utilities from displacing traditional generation, including reducing purchases (either local or imports) of fossil fuels and lowering operation and maintenance costs from existing generation resources
- *Waste heat savings:* Savings accrued by utilities or other commercial/industrial businesses that use waste heat from CHP for both heating and cooling

Together, the shifts caused by supply-side initiatives may affect income, employment, and economic output in the state through the following factors:

- Increased economic activity in the renewable energy industry for both in-state and export markets

[10] At least 27 states have offered utilities the opportunity to benefit financially from operating effective energy efficiency programs. These financial incentives reward utilities based on the level of energy savings produced and/or cost-effectiveness of their energy efficiency programs (ACEEE, 2015). It is important to consider each individual state's utility revenue structure when exploring the effect of energy efficiency and renewable energy programs.

- Reduced spending on fossil fuel imports (or increased inflow of dollars for fossil fuel exports, if a state is a net fossil fuel exporter), allowing those dollars to remain within the state

Indirect Economic Effects

Indirect effects include "upstream" or "downstream" changes in sales, income, or jobs resulting from changing input needs in affected sectors. Indirect effects start to emerge once the direct effects interact with the overall state, local, or regional economy.

Upstream effects occur among businesses supplying goods and services to industries directly involved in the energy efficiency or renewable energy initiative. For example, the construction of roads and foundations for a wind farm requires purchases of asphalt and cement from other economic sectors, which in turn must make purchases to support operations. Downstream effects occur as the regional economy responds to lower energy costs, a more dependable energy supply, and a better economic environment that fosters expansion and attracts new business growth opportunities. Downstream indirect effects may include:

- Increased disposable income available for non-energy purchases[11]
- Increased income, employment, and output by stimulating production and sales of renewable energy and energy-efficient equipment by existing businesses within the state
- Reduced cost of doing business and improved overall competitiveness for non-energy companies
- Decreased income, employment, and output for fossil fuel producers and their suppliers within the state
- Expanded in-state market for renewable energy and/or energy efficiency products and services, and attraction of new businesses and investment[12]

Both Direct and Indirect Economic Effects

Some effects may be both direct and indirect, and apply to both demand and supply policies and programs. Examples of these types of benefits include:

- *Health*: Energy efficiency and renewable energy policies that reduce criteria air pollutants may improve air quality and avoid illnesses and deaths, as described above. Fewer illnesses mean fewer sick days taken by employees, better productivity, and fewer hospitalizations associated with respiratory illnesses and cardiac arrest. Fewer worker deaths can result in continued economic benefits to the state.
- *Employment*: Energy efficiency and renewable energy initiatives create jobs. These jobs can be temporary, short-term jobs as well as long-term jobs—created directly from the energy efficiency and renewable energy activities (e.g., in a company that expands due to increased demand for their products) and indirectly via economic multiplier effects (e.g., from restaurants and retail stores who get more customers because of new jobs).
- *Output*: Energy efficiency and renewable energy programs that stimulate new investments and spending within a state can increase output, which is defined as the total value of all goods and services produced in an economy, including all intermediate goods[13] purchased and all value added. Higher sales for energy-efficient or

[11] An increase in disposable income may be reduced by any program costs imposed. Generally, however, the net effect to consumers of energy efficiency programs is positive (Browne, Bicknell, and Nystrom, 2015; IEA, 2014).

[12] See also MTC (2005) and Heavner and Del Chiaro (2003) for additional information on evaluating energy efficiency and renewable energy market potential and fostering so-called "clean energy clusters."

[13] Intermediate goods are products that are used as inputs in the production of other products, such as steel used to manufacture cars or bricks used to build houses.

renewable energy goods in the local economy, increased government spending, bigger investment levels, and higher exports of energy efficiency or renewable energy products by state industries will enhance output.

- *Gross state product*: Expansion of energy efficiency and renewable energy-related investments and businesses can increase the total market value of the goods and services produced by labor and property in a state (i.e., gross state product). The gross state product is analogous to the national concept of gross domestic product and represents the state's economic output minus any intermediate inputs acquired from beyond the state.
- *Income*: A net increase in income associated with energy efficiency and renewable energy initiatives can occur due to increased employment or wages. Income effects from energy efficiency and renewable energy investments include changes in personal income or disposable income. Personal income is the sum of all income received. Disposable income is the income that is available for consumers to spend or save; that is, personal income minus taxes and social security contributions plus dividends, rents, and transfer payments.

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PART TWO
CHAPTER 1

Quantifying the Benefits: An Overview of the Analytic Framework

DOCUMENT MAP

CHAPTER 1 CONTENTS

ABOUT THIS CHAPTER

This chapter presents a four-step framework for quantifying the multiple benefits of energy efficiency and renewable energy, and provides an overview of the general process for assessing benefits, which is described in more detail in subsequent chapters.

1.1. OVERVIEW: A FRAMEWORK FOR QUANTIFYING THE MULTIPLE BENEFITS OF ENERGY EFFICIENCY AND RENEWABLE ENERGY

Analysts can use the framework, methods, and tools described here to quantify the electricity system, emissions, health, and economic benefits of energy efficiency and renewable energy. Part Two of this *Guide* presents key considerations for analysts and the steps they can follow to quantify and incorporate benefits into policy analyses and decision-making. These steps include:

1. Determine the scope of and strategy for the analysis.
2. Determine the expected or actual direct electricity impacts of the initiative(s).
3. Quantify the electricity system, emissions, health, and/or economic benefits of interest.
4. Use information to support a balanced comparison of costs and benefits during decision-making processes.

Figure 1-1 illustrates how these steps relate to the overall policy planning and evaluation process depicted in Figure 1-1 of Part One.

This overview chapter introduces each step of the overall framework, as shown in Figure 1-2. The rest of Part Two describes methods, tools, and resources analysts can use to implement Steps 2 and 3, and includes examples and case studies.

IMPORTANT NOTES ON THE SCOPE OF THIS *GUIDE*

Because the practice of quantifying the costs of policies is widely understood, the focus of this *Guide* is on describing the practice of quantifying the *benefits* of policies.

This *Guide* focuses on methods and tools to quantify the electricity system, emissions, health, and economic benefits from energy efficiency and renewable energy programs. Energy efficiency and renewable energy programs can have other energy-related benefits (e.g., from combined heat and power) and other environmental benefits (e.g., to water quality), but they are not covered in detail here.

The *Guide* also focuses on benefits in the electricity sector as opposed to the energy sector in general. It does not consider other sectors such as transportation (where, for example, electric vehicles may be able to provide grid services when not in use). Consideration and inclusion of these other types of benefits and sectors could further enhance the comprehensiveness of an analysis.

1.1.1. Step 1: Determine the Scope of and Strategy for the Analysis

Step 1 identifies the goals and boundaries of the analysis, narrowing the areas of focus for subsequent steps.

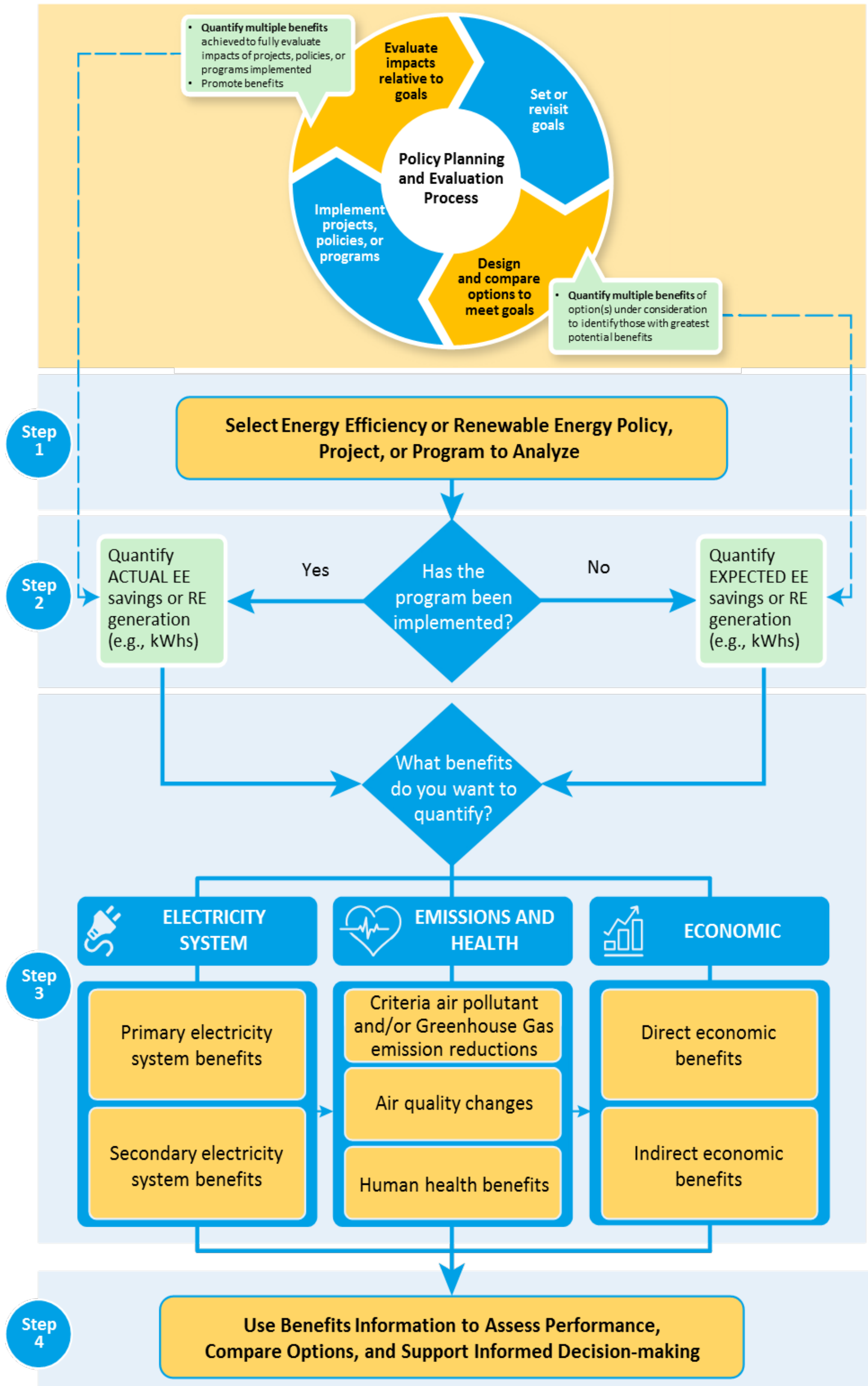
Identifying the Purpose, Priorities, and Constraints

When getting started, an analyst must decide which policies or programs to evaluate, which benefits to assess, the nature of the analysis and its level of rigor, and the constraints on the scope of the analysis imposed by available resources. Considering the questions below will help analysts design the analysis, determine its boundaries, and select the appropriate methods and/or tools.

- *Why is the analysis being conducted?* The answer to this question will determine the scope and goals of the analysis. For example, will the results of the analysis be used primarily for informational purposes (e.g., to assess how a proposed initiative could contribute to a jurisdiction's priorities), to support environmental or economic development planning and implementation decisions, or to inform regulatory reporting?
- *Which energy efficiency and renewable energy goals, policies, activities, and/or programs will be evaluated?*[1] Analysts can focus on the benefits of a single energy efficiency or renewable energy activity (e.g., retrofitting a single state or local government building) or an entire program (e.g., the state or locality's portfolio of energy efficiency activities, renewable portfolio standard [RPS], or green purchasing program). The activities chosen can be identified based on the jurisdiction's overall energy policy and planning goals, regulatory or legislative requirements, or findings from studies that indicate which activities are most likely to result in energy savings and other benefits.

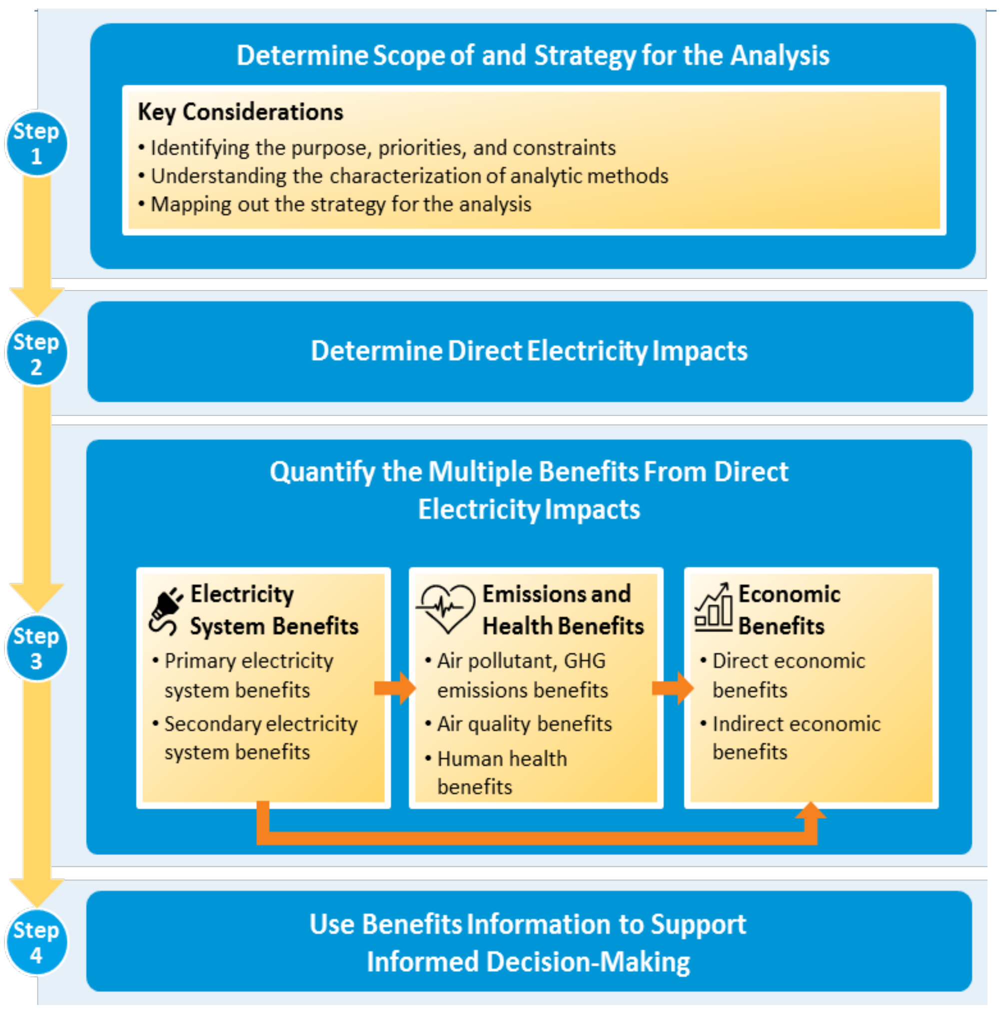
[1] *For information about best practices in designing and implementing energy efficiency and renewable energy policies, see U.S. EPA's* Energy and Environment Guide to Action: State Policies and Best Practices for Advancing Energy Efficiency, Renewable Energy, and Combined Heat and Power, 2015 Edition *at https://www.epa.gov/statelocalenergy/energy-and-environment-guide-action.*

Figure 1-1: How the Policy Planning and Evaluation Process Relates to the Process for Quantifying Multiple Benefits



- *Which benefits will be analyzed?* Analysts may concentrate on estimating some or all of the benefits, depending on the purpose and scope of the initiative. This decision will depend on the audience and its interests, available financial and staff resources, and the type and scope of the energy efficiency or renewable energy initiative(s) being assessed. For example, in a state where the governor has prioritized increasing renewables for the purposes of economic development and greenhouse gas (GHG) emissions reductions, an analyst with limited staff and resources would want to quantify, at a minimum, the macroeconomic (e.g., employment, gross state product, tax revenue) and emissions impacts for options under consideration. When developing a statewide energy or environmental plan, or assessing a new energy efficiency or renewable energy initiative that has broad goals and will be of interest to a large range of stakeholders, however, it may be more appropriate to assess a wider range of benefits.
- *What level of rigor is required?* Most benefits can be assessed using a range of basic to sophisticated methods. The rigor with which decision makers analyze benefits depends on factors such as the types of benefits being analyzed, the proposal's status in the development and design process, whether the proposal will be used to meet regulatory requirements, and the level of investment being considered.
- *What financial and staff resources, or external expertise, are available?* Financial, time, and staff resource constraints may limit the range of methods analysts can choose from, and will influence their approach for estimating benefits.
- *What kinds of data are available?* Sophisticated analytic methods can require an extensive amount of data (e.g., hourly electricity generation or emissions data), depending on the type and complexity of the analysis. Basic methods typically require less data and can often be used when data availability is a challenge.
- *Is the analysis retrospective or prospective?* Estimating actual benefits from an existing program retrospectively will involve different steps than estimating future benefits. Estimates of future benefits require more assumptions and involve more uncertainty

Figure 1-2: A Framework for Quantifying the Multiple Benefits of Energy Efficiency and Renewable Energy



than retrospective analyses. Note that this *Guide* focuses on forward-looking analyses, even though many of the same methods and tools can be used for retrospective analyses.

Understanding the Characterization of Analytic Methods Described in this *Guide*

The *Guide* distinguishes between "basic" methods that may require few resources and that a government agency's own staff may be able to easily implement and "intermediate" to more "sophisticated" modeling methods that may require significant financial and time commitments. This distinction is imprecise, as the sophistication of methods and models can be judged along a broad continuum, but it helps convey differences in complexity. For purposes of this *Guide*:

- *Basic methods* (e.g., spreadsheet analyses, trend extrapolations) are based on relatively simple formulations, such as the use of activity data (e.g., changes in generation levels) and factors (e.g., emission factors). In these methods, there is no attempt to represent the underlying system. Instead, they rely on factors or trends to capture what would be expected to result. These factors and other inputs require relatively little time or expense to develop, and are most appropriate for short-term analyses. Although simpler methods can provide a reasonable level of precision, users should decide whether the method and results are suitable for their intended purpose.
- *Intermediate methods* require some technical expertise but allow analysts flexibility to make adjustments and reflect different energy efficiency and renewable energy assumptions and savings. These methods typically have transparent assumptions, normally do not require software licensing fees, and are computationally simpler than sophisticated methods. Intermediate methods may be more credible than basic methods and tend to be most appropriate for short-term analyses.
- *Sophisticated methods* are characterized by extensive underlying data and relatively complex formulations that represent the fundamental engineering and economic decision-making (e.g., power sector system dispatch or capacity expansion modeling), or complex physical processes (such as in air dispersion modeling). Sophisticated models provide greater detail than the basic methods, and can capture the complex interactions within the electricity market and with other markets or systems. They are computationally intensive and may require considerable time and resources to operate. These methods are generally appropriate for short- or long-term analyses, or analyses where unique supply-and-demand forecasts are needed to incorporate the specific changes being considered.

UNDERSTANDING THE STRENGTHS AND LIMITATIONS OF MODELS AND ANALYTIC METHODS

Regardless of which analytic method or model is chosen, it is important to understand its strengths and limitations. Specifically, it is important to recognize:

- Models can provide a consistent framework for exploring how a system is likely to respond to different stimuli and for conveying the degree of uncertainty surrounding best estimates.
- Models are mathematical representations of physical or economic processes in the real world, and are only as good as our understanding of these processes. The results will be influenced by the model's design, flexibility, and complexity. For example, an optimization model is designed to show what *should be done* under assumed conditions, by identifying the most effective or least expensive approach. A simulation model, on the other hand, describes only what *might happen* under a range of scenarios. Simulation models offer insights into how a complex system responds to changing conditions under specific assumptions.
- Data inputs and assumptions have a significant effect on model outcomes, some more than others. Many of these inputs are uncertain. For example, drivers such as fuel prices, weather, unit availability, load levels and patterns, technology performance, future market structure, and regulatory requirements are all subject to uncertainty.

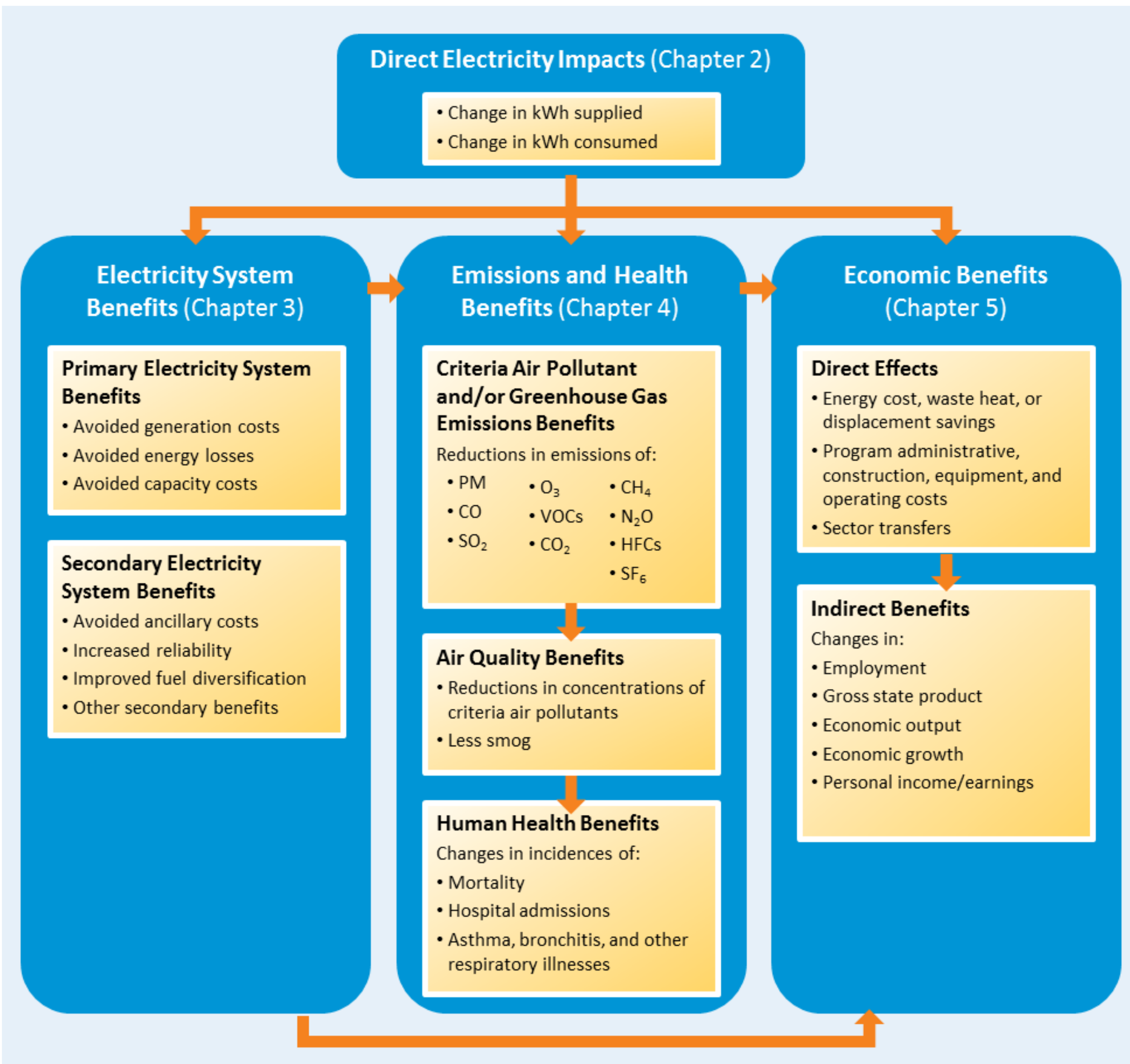
When selecting a method, it is helpful to understand the strengths and limitations of any approach. For more information, see the text box, "Understanding the Strengths and Limitations of Models and Analytic Methods." Many of these strengths and limitations are described in greater detail in the individual chapters that follow.

Mapping Out the Strategy for the Analysis

Once analysts have identified the purpose of the analysis, what benefits to quantify, and the level of rigor required, it is helpful to understand the interactions among and relationships between the various impacts and benefits. This will help them determine the order of analyses, the specific benefits they will need to quantify along the way, and the types of methods they will need to explore and use.

Figure 1-3 below, portrays the relationship between the direct electricity impacts quantified in "Step 2: Determine Direct Electricity Impacts," and the electricity system, emissions, health, and economic benefits quantified in "Step 3: Quantify the Multiple Benefits from Direct Electricity Impacts." It also identifies the chapter where the methods and tools to quantify direct electricity impacts and specific benefits can be found in the *Guide*. It can help analysts map out the necessary parts of the analysis upfront and steer them to the appropriate chapters for information about methods, data needs, available tools and data resources, and case studies.

Figure 1-3: Mapping Out the Relationships Between Direct Electricity Impacts and the Benefits of Energy Efficiency and Renewable Energy Initiatives



For example, consider analysts from a state or local agency with a small budget who are asked to do an informal analysis of the health benefits of a suite of energy efficiency programs. To measure health benefits, the analysts must first quantify the expected direct electricity impacts, in kilowatt-hours (kWh), using methods described in Chapter 2, "Estimating the Direct Electricity Impacts of Energy Efficiency and Renewable Energy." They will use the electricity impacts to estimate the quantity and type of emissions changes expected from the programs. Then the analysts can assess the related air quality changes anticipated at a local level. These air quality changes can then be used to estimate negative health effects that will be avoided due to the reduction in electricity demand. The analysts can calculate the monetary value associated with the negative health effects avoided to determine a comprehensive picture of the benefits. Methods for quantifying the emissions, air quality, and health impacts are described in Chapter 4, "Quantifying the Emissions and Health Benefits of Energy Efficiency and Renewable Energy." The analysts can use any of the relevant methods (e.g., basic to sophisticated) described in the *Guide* to quantify the electricity system, emissions, air quality, health, and economic impacts, but because the analysis is informal and the budget is low, the analysts may determine that the basic and intermediate approaches are the quickest and most economical to use for their purposes and start with them when they are exploring their options.

Now suppose an analyst needs to conduct a detailed, multi-sectoral, multi-year analysis of the direct and indirect macroeconomic (e.g., employment) impacts from a suite of energy efficiency programs for regulatory purposes and has a large budget for the analysis. The analyst would still start with the kWh saved, but would follow a different approach to the analysis, looking to Chapter 5, "Estimating the Economic Benefits of Energy Efficiency and Renewable Energy," to identify the most appropriate method(s) and tools to trace the expected flow of financial investments (rather than emissions) throughout the economy. Because a regulatory analysis demands a higher level of rigor, the analyst must explore more sophisticated, often costly, methods in addition to the basic and intermediate approaches.

KEY POINTS TO CONSIDER WHEN PLANNING AN ANALYSIS

- All methods involve predictions, inherent uncertainties, and many assumptions.
- The approach selected should match the question being asked. For example, simple tools should not be used to answer sophisticated, complex questions.
- The models, assumptions, and inputs used in the analysis should be transparent and well documented.
- Expert input and assumptions as well as expert peer review of the final results can enhance the credibility and usefulness of the analysis.

1.1.2. Step 2: Determine Direct Electricity Impacts

Step 2 involves estimating the potential electricity savings or renewable energy generation impacts of a program or policy. These electricity impacts (e.g., kWh avoided or generated) are critical because they serve as a key input for subsequent analyses of electricity system, air, health, and economic impacts. To determine the direct electricity impacts of policies and programs, an analyst typically develops or adopts business-as-usual projections of the electricity generation and consumption expected without them. The analyst then develops estimates of the electricity savings and renewable energy generation impacts expected from the energy efficiency and renewable energy programs (e.g., based on funding levels and assumptions about participation in the programs) to compare against their projections. Chapter 2, "Estimating the Direct Electricity Impacts of Energy Efficiency and Renewable Energy," describes in detail a range of methods, data, and tools available to estimate the electricity impacts that can then be used as a foundation for quantifying benefits.

1.1.3. Step 3: Quantify the Multiple Benefits From Direct Electricity Impacts

The impacts of an initiative do not end with their direct electricity impacts. The analyst can use the electricity impact estimates to assess the benefits of the programs to the overall electricity system and economy, as well as the environmental quality and public health benefits. For example, imagine an energy efficiency initiative where the electricity savings deliver a significant reduction in electricity demand. In this case, the energy efficiency programs could reduce electricity demand enough to delay or eliminate the need to construct a costly new power plant. This would be a benefit to the electricity system. Reducing generation of fossil fuel-based electricity will reduce emissions of criteria air pollutants and GHGs. Reducing criteria air pollution improves air quality in the near term and can lead to public health benefits. These benefits can be estimated and assigned an economic value. Consumers would enjoy reduced energy costs, which could lead to an increase in spending on other consumer goods and services. The economic benefits of the public health improvements (e.g., improved productivity from fewer sick days), energy cost and system savings, and investments in energy efficient equipment as well as non-energy products and services would likely stimulate the economy and create jobs.

In Step 3, the analyst quantifies the electricity system benefits, emissions and health benefits, and economic benefits, based on the estimates of direct electricity savings or renewable energy generation developed in Step 2. Chapters 3, 4, and 5 describe methods, data, and tools that can be used to perform these analyses. For any estimate of policy impacts, it is important to document clearly all the details of the analysis, including the scope of the analysis, the analytic approach used along with any limitations of the approach, and all of the underlying assumptions used in the analysis and their sources. Transparency about the approach and assumptions, as described in the box, "Being a Critical Reviewer of Analyses," will help to ensure that reviewers and decision makers can properly evaluate, interpret, and use the results.

BEING A CRITICAL CONSUMER OF ANALYSES

For anyone reviewing an analysis of policy impacts, it is helpful to identify any influences that might have affected the results. To help the reviewer do this, an analyst should clearly document the following elements:

- **Sponsor of the analysis**. In order to flag any potential biases, it is helpful to understand who sponsored or paid for an analysis.
- **Scope of the analysis**, including costs and benefits considered. While this *Guide* helps analysts quantify the potential benefits of policies to compare against the costs, some analyses consider only the costs or include estimates for only a very limited set of benefits. When reviewing results of an analysis that did not include benefits, it is helpful to recognize that the impacts presented are not comprehensive.
- **Analytic approach used and any limitations**. Taking time to understand the approach used in the analysis can help a decision maker or other reviewer judge whether the approach was appropriate for the purpose. If the purpose of the analysis is regulatory, for example, the level of rigor will likely be a more important consideration than in analyses used for simple screening purposes. A decision maker may have more confidence in a sophisticated analysis using known tools, or one that has gone through an independent technical peer review process, than a quick, back-of-the-envelope analysis. That said, a rough analysis may be more valuable in certain contexts where efficiency and speed are critical, such as a simple screening exercise.
- **Underlying assumptions**. Similarly, reviewing and understanding the assumptions made during the analysis, and the rationales behind those assumptions, can help a decision maker or other reviewer determine whether they are reasonable and objective. Typical questions include: Did the analysis use local data (e.g., economic, energy, fuel, technology) or rely on national data that may lack locally relevant detail? Does the analysis assume changes in prices and/or technology over time, and if so, how are they expected to change? Did the analysis include a sensitivity analysis for unknown variables that could vary significantly? Did the team conducting the analysis cite credible sources to clearly justify its assumptions and/or consult with experts or stakeholders to otherwise review the analysis?

1.1.4. Step 4: Use Benefits Information to Support Informed Decision-Making

This final step in the framework serves to ensure that information on the multiple benefits of energy efficiency and renewable energy is considered during the decision-making process. Incorporating this information into decisions can be facilitated by ensuring that a range of benefits are considered as criteria for selecting policy or program options, and by understanding the ways in which information on the benefits of energy efficiency and renewable energy can be used to support different types of planning.

Including a Variety of Benefits as Criteria for Policy Selection

Energy efficiency and renewable energy policies and programs are typically selected based on their potential to meet a specific goal (usually energy-related) set by a state or local government. When deciding which options to choose, however, it is helpful to expand the criteria to include other priorities—such as goals for air quality and economic growth—to which energy efficiency and renewable energy initiatives can contribute.

Developing these criteria involves balancing priorities and requirements specific to the state or locality's needs and circumstances. Typical assessment criteria include energy savings, economic costs and benefits, and feasibility-related criteria (such as political feasibility and the timeframe for implementation). By using methods described in this *Guide*, state and local decision makers can expand this set of criteria to include a broader range of quantified expected benefits from proposed energy efficiency and renewable energy programs, such as emissions and health-related criteria (e.g., changes in air pollutant emissions, health impacts), economic development-related criteria (e.g., jobs created or lost), and electricity system-related impacts (e.g., avoided costs of new generation or transmission and distribution [T&D] losses). Including these benefits increases the comprehensiveness and balance of the analysis and makes it easier to illuminate clearly the strategic trade-offs among options and across a range of priorities.

How States and Localities Have Used Energy Efficiency and Renewable Energy to Support Other Goals

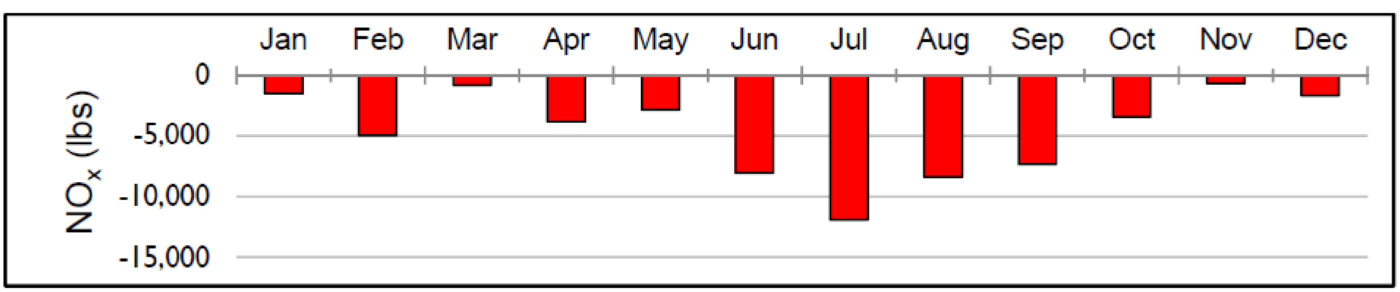
Many state and local governments have integrated their energy efficiency and renewable energy programs with other environmental, energy, and economic programs. This allows them to take full advantage of the multiple benefits generated by energy efficiency and renewable energy programs, strengthening the impact of other programs and meeting broader goals. Examples of this kind of integration are presented below.

Using Energy Efficiency and Renewable Energy to Achieve Environmental Goals

Many regions, states, and localities are incorporating energy efficiency and renewable energy into strategies to meet their air quality and/or climate change objectives (U.S. EPA, 2012; U.S. EPA, 2016). Quantifying the multiple benefits of energy efficiency and renewable energy programs can provide key data for use in developing state implementation plans (SIPs), GHG emissions reduction plans, and air pollution and/or GHG emissions cap-and-trade programs that include clean energy programs. (See Chapter 4, "Quantifying the Emissions and Health Benefits of Energy Efficiency and Renewable Energy," for more information.)

State and local governments are using innovative voluntary control measures, including energy efficiency and renewable energy, to help achieve or maintain attainment with national air quality standards. Clark County, Nevada, for example, estimated the emissions impacts of its renewable energy measures to identify whether and how they support attainment with the national ozone standard. The county found that renewables displaced 411,600 Megawatt-hours in 2015, leading to a reduction of 55,100 pounds (27.5 tons per year) of NO_x, an important ozone precursor, helping the county stay in attainment with the standard (Clark County, 2016). Figure 1-4 shows the monthly estimates of NO_x impacts from the county's renewables in 2015.

Figure 1-4: Monthly NO_x Reductions in 2015 from Renewables in Clark County, Nevada



State and local governments are also using energy efficiency and renewable energy to advance reductions under their SO_2 and NO_x cap-and-trade programs. For example, set-asides or carve-outs reserve a portion of the total capped allowances to be distributed to clean energy initiatives. In addition, state and local governments are using energy efficiency and renewable energy measures in their climate change action plans to reduce CO_2 emissions from the electric power sector (U.S. EPA, 2016). Quantifying the potential emissions benefits from implementing or expanding the use of energy efficiency and renewable energy helps demonstrate the value of these choices from an environmental perspective.

Using Energy Efficiency and Renewable Energy to Achieve Energy Planning Goals

Regional, state, and local energy plans often include energy efficiency and renewable energy activities and goals, such as RPSs or energy efficiency resources standards. By quantifying the electricity system benefits of proposed initiatives, state and local governments can identify the most effective approaches and develop realistic goals to include in their state or local energy plans.

In 2014, for example, the New York State Energy Research and Development Authority (NYSERDA) commissioned a study to assess the potential for increased adoption of energy efficiency and renewable energy technologies to help the state meet objectives outlined in the New York State Energy Plan (NYSERDA, 2014). The study found that the economic and achievable potential for energy efficiency translates into a 45 percent and 18 percent reduction, respectively, from energy sales forecasted for 2030. See Table 1-1, below.

Table 1-1. Potential Savings from Energy Efficiency Relative to New York State Energy Sales Forecast, 2030

	Energy Savings		
Scenario	Electric (GWh)	Natural Gas (TBtu)	Petroleum Fuels (TBtu)
Economic Potential	**91,856**	**321.1**	**120.0**
% of Forecast	***45%***	***32%***	***53%***
Residential	28,553	148.7	72.3
Commercial	58,550	136.8	45.1
Industrial	4,753	35.7	2.6
Achievable Potential	**36,328**	**107.9**	**43.0**
% of Forecast	***18%***	***11%***	***20%***
Residential	9,415	49.4	26.4
Commercial	25,407	47.0	15.4
Industrial	1,506	11.5	1.3
Savings from EEPS	**17,013**	**14.1**	**n/a**
% of Forecast	***8%***	***1%***	

Note: GWh is Gigawatt-hours and TBtu is trillion British thermal units. EEPS is the current New York State Energy Efficiency Portfolio Standard.
Source: NYSERDA, 2014.

The study also found that renewable resources have the technical potential to provide more than half of the state's energy for buildings and electric generation alone in 2030. These results fed into the final 2015 *New York State Energy Plan*, which requires 50 percent of all electricity to be generated with renewable energy sources and a 23 percent reduction in energy consumption from buildings, all while achieving a 40 percent reduction in GHG emissions from 1990 levels (New York State, 2015).

States can also require utilities to develop plans that are consistent with state energy goals. Utilities can be required to file either integrated resource plans (IRPs) or portfolio management strategies with the state public utility commission, depending upon whether the state has a vertically integrated or restructured electricity system.[2] These IRPs and

[2] In some states, utilities are vertically integrated, meaning that one company is responsible for electricity generation, transmission, and distribution over a given service territory. State public utility regulators have authority over these utilities. In other states, where the electric power industry has been restructured, ownership of electric generation assets has been decoupled from T&D assets, and retail customers have their choice of electricity suppliers. In states where restructuring is active, state public utility regulators do not have authority to regulate the companies responsible for electricity generation, but they can regulate the electricity distribution utilities.

portfolio management strategies often use some type of multiple benefits analysis in the program evaluation criteria (NESP, 2017).

Using Energy Efficiency and Renewable Energy to Achieve Economic Development Goals

Most states and localities are looking to stimulate economic growth, attract new businesses, and create new jobs. Analysts can quantify the potential economic benefits expected from energy efficiency and renewable energy programs to assess their economic value. For example, in 2015, Wisconsin commissioned a study to estimate actual economic impacts of the state's Focus on Energy program—a statewide energy efficiency and renewable energy initiative that provides information, technical support, and financial incentives to Wisconsin residents and businesses—over the 2011–2014 timeframe and project the cumulative impacts from 2015 to 2038. The study's estimated economic impacts include:

- A net increase of more than 19,000 job-years from 2011 to 2038 (6,235 from 2011 to 2014 and 13,056 from 2015 to 2038)
- More than $1.4 billion in disposable income for residents ($382 million from 2011 to 2014 and $1.053 billion from 2015 to 2038)
- $2.85 billion in increased value added to gross state product ($638 million from 2011 to 2014 and $2.216 billion from 2015 to 2038)
- More than $5.5 billion in sales for Wisconsin businesses ($1.424 billion from 2011 to 2014 and $4.078 billion from 2015 to 2038) (Cadmus, 2015)

Quantifying these benefits helps to demonstrate the economic value the incentives and support offerings provided by Focus on Energy can generate for the state. It allows decision makers to compare across options so that they can select, design, or adapt policies and programs that best align with their economic development priorities.

Using Energy Efficiency and Renewable Energy to Achieve Multiple Goals Simultaneously

Rather than quantifying the environmental, energy, or economic benefits of energy efficiency and renewable energy in isolation, a more comprehensive and increasingly popular approach is for state and local government analysts to quantify the multiple environmental, energy, *and* economic benefits of their initiatives. This type of inclusive analysis enables states or local agencies to more fully understand the potential value of their energy efficiency and renewable energy policy choices across a wide range of impacts. The state of Maryland, for example, quantified the multiple energy, economic, and emissions benefits over the lifetime of the investments generated by EmPOWER Maryland, a program created by the legislature to meet the state's goal of reducing Maryland's per-capita electricity consumption and peak demand by 15 percent from to a 2007 baseline, by the end of 2015. The Maryland Energy Administration (MEA) and Maryland Public Service Commission (Maryland PSC) analyzed the impact as part of their annual reporting requirements and found that between 2007 and 2015, the program achieved cumulative savings of 5,394 Gigawatt-hours (99 percent of the target) and peak demand reductions of 2.1 Gigawatts (100 percent of the target).

MEA estimated that the total benefits of the EmPOWER Maryland program's energy efficiency upgrades and related investments, over their useful lifetimes, amount to:

- 38.9 billion kWh in lifetime energy savings
- $4.39 billion in lifetime energy bill savings
- 26 million metric tons of avoided carbon dioxide emissions (Maryland PSC, 2016)

The program also helped reduce energy burdens for nearly 21,000 low-income households in the state, decreasing their annual energy bills by $340 on average, or approximately 20 percent (U.S. EPA, 2017).

Based on these results, the Maryland PSC established an order in 2015 to continue EmPOWER Maryland past the end of the year, setting post-2015 annual incremental electric energy efficiency goals of 2 percent of a utility's weather-normalized gross retail sales, with a ramp-up rate of 0.2 percent per year. These goals are scheduled to take effect starting in 2018 (Maryland PSC, 2017).

1.2. PART TWO ROADMAP

The remaining chapters in this *Guide* are organized by type of benefit. Each chapter describes in detail the range of methods, data, and tools available to quantify the benefits and includes case studies showing how other analysts have applied the methods and/or tools.

- **Chapter 2, "Estimating the Direct Electricity Impacts of Energy Efficiency and Renewable Energy,"** discusses methods that can be used to estimate the future electricity savings of energy efficiency programs and future electricity production by renewable energy options. The chapter lays out the steps involved in developing these estimates, including:
  - Developing a business-as-usual energy forecast
  - Estimating potential direct electricity impacts
  - Creating an alternative policy forecast
- **Chapter 3, "Assessing the Electricity System Benefits of Energy Efficiency and Renewable Energy,"** describes the range of methods, data, available tools, and case studies for estimating primary and secondary electricity system benefits.
  - *Primary electricity system benefits* are quantified frequently using readily available methods and include:
    - Avoided cost of electricity generation or wholesale electricity purchases
    - Avoided cost of new generation
    - Avoided T&D losses
    - Deferred or avoided T&D capacity costs
  - *Secondary electricity system benefits* are often more difficult to quantify and include:
    - Avoided ancillary service costs
    - Reductions in wholesale market prices
    - Increased reliability and improved power quality
    - Avoided risks associated with long lead-time investments, such as the risk of overbuilding the electricity system
    - Reduced risks from deferring investments in power plants until future environmental policies take shape
    - Improved fuel diversity and energy security
- **Chapter 4, "Quantifying the Emissions and Health Benefits of Energy Efficiency and Renewable Energy,"** describes the range of methods, data, available tools, and case studies to help analysts:
  - Develop a baseline emissions inventory
  - Quantify emissions reductions from energy efficiency and/or renewable energy

- Estimate air quality changes that occur from the emissions changes
- Estimate the human health impacts, including avoided incidences of heart attacks, respiratory illnesses, asthma attacks, premature death, and lost work or school days
- Monetize the economic value of the health impacts

- **Chapter 5, "Estimating the Economic Benefits of Energy Efficiency and Renewable Energy,"** describes the methods, available tools, and case studies analysts can use to estimate the economic benefits, including:
  - Employment
  - Economic output (i.e., total value of all goods and services produced in an economy)
  - Gross state product (i.e., combined value added from all of a state's industries)
  - Economic growth
  - Personal income/earnings

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PART TWO
CHAPTER 2

Estimating the Direct Electricity Impacts of Energy Efficiency and Renewable Energy

DOCUMENT MAP

PART ONE
The Multiple Benefits of Energy Efficiency and Renewable Energy

PART TWO
Quantifying the Benefits: Framework, Methods, and Tools

CHAPTER 1
Quantifying the Benefits: An Overview of the Analytic Framework

CHAPTER 2
Estimating the Direct Electricity Impacts of Energy Efficiency and Renewable Energy

CHAPTER 3
Assessing the Electricity System Benefits of Energy Efficiency and Renewable Energy

CHAPTER 4
Quantifying the Emissions and Health Benefits of Energy Efficiency and Renewable Energy

CHAPTER 5
Estimating the Economic Benefits of Energy Efficiency and Renewable Energy

CHAPTER 2 CONTENTS

ABOUT THIS CHAPTER

This chapter provides policy makers and analysts with information about methods they can use to estimate the future electricity savings of energy efficiency programs and future electricity generation from renewable energy options. These direct electricity impacts serve as a basis for analyzing the benefits described in later chapters of this *Guide*, and help demonstrate the value of a policy, project, or program.

2.1. OVERVIEW

Policies and programs to improve energy efficiency and increase the use of renewable energy can have direct, measurable impacts on electricity demand and production. Estimating these impacts can help state officials:

- Demonstrate the electricity-related impacts of energy efficiency, renewable energy, and combined heat and power (CHP) programs
- Evaluate the potential impacts of new goals, targets, or legislative actions
- Evaluate the potential effectiveness (including cost-effectiveness) of technology- or sector-specific energy efficiency and renewable energy programs in saving electricity or increasing renewable energy generation
- Compare energy efficiency and renewable energy options under consideration

Estimates of potential electricity savings or renewable energy generation provide the foundation for all of the analyses described in subsequent chapters of this *Guide*. They form the basis for a comprehensive analysis of a program's multiple benefits—including benefits to the electricity system, economy, environment, and public health—and can help demonstrate the potential value of a program.

This chapter is designed to help analysts and decision makers in states and localities understand the methods, tools, opportunities, and considerations for assessing the direct electricity impacts of energy efficiency and renewable energy policies, programs, and measures. The range of methods and tools in this chapter is not exhaustive, and inclusion of a specific tool does not imply U.S. Environmental Protection Agency (EPA) endorsement. Although not the explicit focus of this chapter, energy efficiency and renewable energy initiatives can also affect the use of onsite fuels, such as natural gas. Many of the methods and tools to estimate direct electricity impacts can be used more broadly to determine other energy impacts, if desired.

Direct electricity impacts can be estimated prospectively, for planning purposes, or retrospectively, such as to evaluate the performance of initiatives after implementation. These two approaches may complement each other: for example, data from retrospective analyses can be used to inform prospective estimates of the impacts of new or expanded initiatives. This *Guide* is intended to inform analyses for planning purposes so it focuses mainly on techniques for estimating *prospective* electricity savings or renewable energy generation; i.e., impacts expected to occur in the future as a result of a state's proposed energy efficiency and renewable energy initiatives.[1] Section 2.4., "Tools and Resources," includes resources analysts can use to learn more about retrospective methods.

2.2. APPROACH

Direct electricity impacts for prospective analyses of future policies can be estimated using three steps as depicted in Figure 2-1 and described below:

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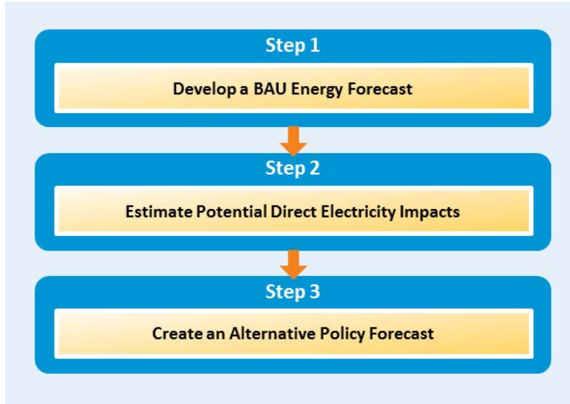
[1] *For information on retrospective methods for estimating energy savings from energy efficiency, see the* National Action Plan for Energy Efficiency, Model Energy Efficiency Program Impact Evaluation Guide*, December 2012 (http://energy.gov/sites/prod/files/2013/11/f5/emv_ee_program_impact_guide.pdf), EPA's* Lead by Example Guide*, June 2009 (https://archive.epa.gov/epa/statelocalclimate/state-lead-example-guide.html), and EPA's* Draft Evaluation, Measurement, and Verification (EM&V) Guidance for Demand-Side Energy Efficiency*, August 2015 (https://blog.epa.gov/blog/wp-content/uploads/2016/12/EMV-Guidance-12192016.pdf).*

1. **Develop a business-as-usual (BAU) forecast** of energy supply and demand. This involves taking a look at the historical demand-and-supply portfolio within a state (i.e., developing the historical baseline), identifying any energy-related policies or modifications to existing ones that have been approved but not yet implemented, and then projecting demand and supply forward based on assumptions about the future. The projection is a BAU energy forecast that illustrates what energy demand, consumption, and supply will most likely be in the absence of additional energy efficiency and renewable energy policies (beyond those already considered in planning for future energy efficiency opportunities, energy supply requirements, and infrastructure needs).[2]

Figure 2-1: Steps to Estimate Future Electricity Impacts of Energy Efficiency and Renewable Energy



2. **Estimate the potential direct electricity impacts** from an energy-related target, from a proposed energy efficiency or renewable energy initiative, or from a portfolio of planned initiatives. These impacts include the expected electricity savings or renewable energy generation levels that are determined by estimating the impact on energy consumption levels and patterns of a specific policy approach, or the energy output from renewable resources.

3. **Create an alternative policy forecast** that adjusts the BAU energy forecast developed under Step 1 to reflect the electricity savings or renewable energy generation estimates developed in Step 2 in a new policy forecast. In the case of energy efficiency, the electricity savings estimates developed in Step 2 are subtracted from the BAU energy forecast developed under Step 1 to create a new policy forecast. For renewable energy supply alternatives, generation estimates from Step 2 are added to the BAU energy forecast. Both types of impacts are used to assess the overall effects of energy efficiency and/or renewable energy on the electric power system (in terms of what is displaced that otherwise would have been operated).

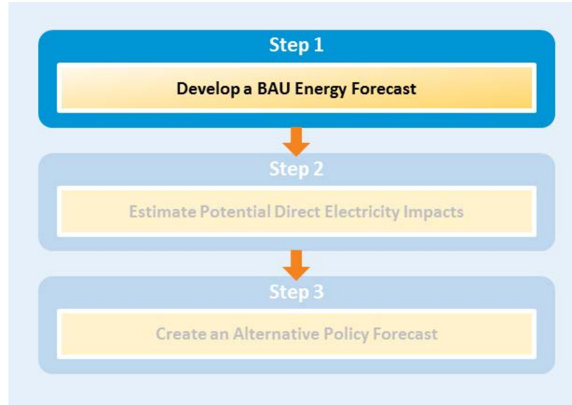
For each of the three steps, the remainder of this chapter describes a range of basic-to-sophisticated modeling methods, along with related protocols, tools, resources, and data analysts can use to quantify the direct electricity impacts of energy efficiency and renewable energy initiatives. Because many details and assumptions are involved in estimating energy efficiency or renewable energy generation and in creating an alternative policy forecast, an analyst needs to choose an approach that is appropriate to the scope of the analysis. As described below, the level of available resources (including budget, personnel, and data) often guides which approach and/or model, if appropriate, to select when developing an estimate of direct electricity impacts. For a quick comparison of policy alternatives, a top-down approach that looks at high-level impacts across the economy may be acceptable, whereas a bottom-up approach that provides greater sector-by-sector detail may be more appropriate for program planning and budget setting.

[2] *Analysts interested solely in electricity-related policies may limit the focus of their baseline forecast to electricity, but a more comprehensive energy baseline forecast can facilitate greater understanding of trade-offs and implications between sectors for cross-cutting policies, such as electrification.*

2.2.1. Step 1: Develop a BAU Energy Forecast

A BAU energy forecast illustrates what energy use will look like in the future, in the absence of additional policies beyond those already in place and planned. It typically includes current and confirmed future programs, such as regulations, standards, and existing energy efficiency programs. The forecast is a reference case against which to measure the electricity impacts of future policy initiatives or unexpected system shocks (e.g., severe weather-related disruptions in energy supply).

The six activities involved in developing a BAU energy forecast are shown in Figure 2-2 and described below.



Step 1a: Define Objectives and Parameters

As part of the process to develop the BAU forecast, analysts:

- Decide if the forecast will be short- or long-term.
- Choose whether the forecast will be built up from estimates of changes at the end-use level (such as changes in the amount of energy used by buildings and equipment) or instead use a top-down model to estimate total sectoral or economy-wide demand.
- Determine the level of detail and rigor necessary (e.g., forecasts for regulatory purposes may have stricter requirements compared with a basic screening effort to evaluate options and impacts).
- Consider the availability of financial, labor, and time resources to complete the forecast.
- Verify the amount of energy data available to inform the forecast.

Collectively, these considerations help analysts choose whether to pursue basic or more sophisticated forecasting approaches.

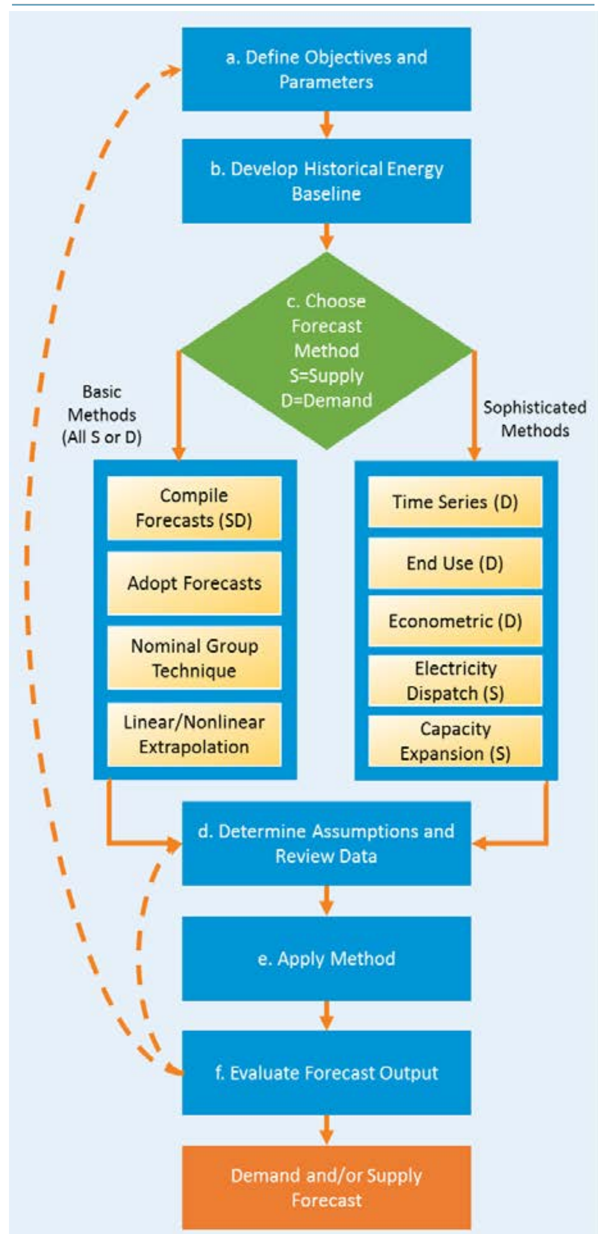
Step 1b: Develop a Historical Energy Baseline

Establishing a historical energy baseline helps analysts understand energy use by sector, as well as their energy resource mix. A baseline can also be used as a yardstick against which to measure the projected energy impacts (such as reductions in demand) of proposed targets, policies, and initiatives.

A comprehensive energy baseline includes the following historical energy data:

- Consumption (demand) by sector or fuel
- Generation (supply) by fuel and/or technology

Figure 2-2: Sample Framework for Developing a BAU Energy Forecast



Consumption (Demand) Data by Sector or Fuel

- Consumption data are typically broken down by type of fuel and/or by the sectors that consume those fuels (i.e., commercial, residential, industrial, transportation, and utility). Each sector can be further disaggregated to show individual sources of energy consumption within that sector. For example, the industrial sector may be disaggregated to mining, construction, and manufacturing, and manufacturing can be further broken down to types of products such as textiles, paper, cement, and electronics.
- The type of consumption data needed for the historical baseline in a BAU forecast is dictated by whether the BAU forecast takes a top-down or bottom-up approach, as explained below.

Top-Down Baselines

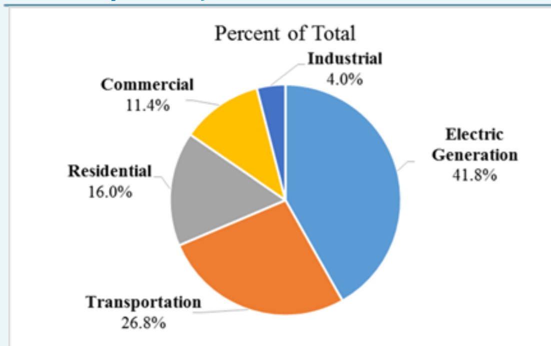
A top-down baseline, using data aggregated by fuel (e.g., natural gas, petroleum, coal, nuclear, and renewables) and sector (e.g. electricity generation, transportation, commercial, residential, and industrial), shows how a state's total energy consumption is spread across sectors. It can reveal trends and opportunities in sectors and help analysts identify which sectors seem most appropriate for further investigation and potential program intervention. A top-down approach would be appropriate if an analyst plans to evaluate or quantify the requirements of a broad, statewide energy efficiency or renewable energy goal.

For example, in 2015, New York released a State Energy Plan, which included a goal to use renewable energy to generate 50 percent of the state's electricity, increase building energy efficiency by 23 percent from 2012 levels, and reduce greenhouse gas emissions by 40 percent below 1990 levels by 2030.

Figure 2-3 illustrates an energy consumption baseline by sector that the New York State Energy Research and Development Authority (NYSERDA) developed. This top-down baseline helped analysts understand how the state's total energy consumption is spread across sectors (e.g. electric generation, transportation, residential, commercial, and industrial) and identify which sectors seem most appropriate for focusing their efforts (NYSERDA, 2013).

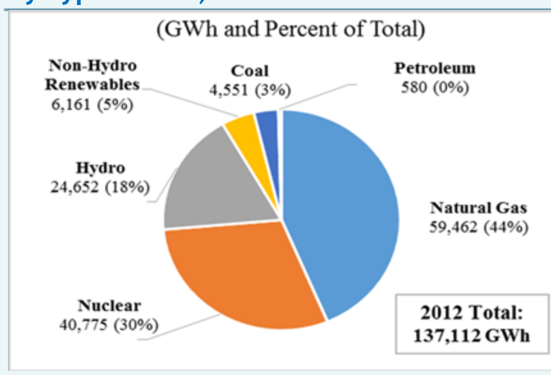
Figure 2-4 illustrates New York's supply-side baseline, which shows electricity generation by type of fuel for 2012, and Figure 2-5 shows how electricity consumption is spread across sectors. These baselines allowed the planning board to evaluate the impact of potential programs relative to baseline generation and consumption.

Figure 2-5: New York Primary Energy Consumption by Economic Sector, 2011



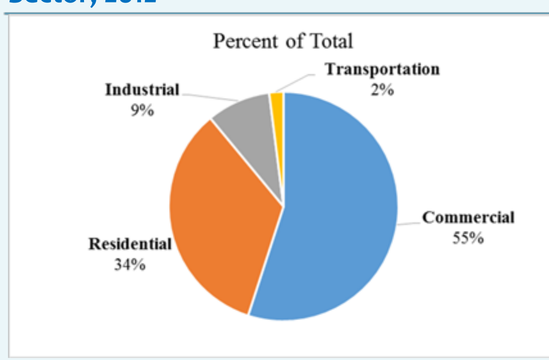
Source: NYSERDA, 2013, p. 4.

Figure 2-5: New York Electricity Generation by Type of Fuel, 2012



Source: EIA State Electricity Profiles, New York.

Figure 2-5: New York Electricity End-Use by Sector, 2012



Source: New York State Energy Planning Board, 2015, page 26.

Bottom-Up Baselines

An alternative or complement to the top-down approach is to develop a bottom-up baseline. A bottom-up baseline is very data-intensive but provides more information about activities within a particular sector than can be obtained from a top-down baseline.

The bottom-up approach is most appropriate if an analyst is exploring a sector- or technology-specific energy efficiency and renewable energy policy. For example, if a state or locality wants to explore which types of buildings are likely to have the greatest potential to help it meet an efficiency improvement goal for buildings, the analyst could develop a bottom-up baseline that depicts the amount of energy per square foot consumed by different types of buildings (e.g., hospitals, schools, low-income housing, and maintenance facilities). If it finds that particular types of buildings tend to consume more energy than others, it might focus on the most cost-effective and efficient opportunities for improvements within those building types.

Both past and future demand for energy reflect the economic and weather conditions of the state or the locality as well as the types and efficiencies of end-use appliances and equipment. Thus, bottom-up BAU forecasts often use a state's official economic projections as a starting point and typically assume normal weather conditions, as described later in this chapter.

Generation (Supply) Data by Fuel and/or Technology

Generation data typically include in-state electricity generation and, to be consistent with in-state consumption, may reflect electricity imports and exports. Electricity generation data also account for transmission and distribution (T&D) losses. As with consumption data, electricity generation data can be categorized by fuel type and sector.[3] Depending on a state's definition of "renewable," renewable fuels can include wood, landfill gas, pyrolysis liquid/gas, geothermal, hydro, solar photovoltaics (PV)/thermal, wind, and municipal solid waste.

There are many sources of consumption and/or generation-related baseline data, as shown in Section 2.4., "Tools and Resources," of this chapter. These sources provide different types of data, including historical and projected supply and demand for electricity, natural gas, and other fuels (discussed in the next section). Note that consumption and generation data (including projections) may not include the impacts of new policies that have been approved but not yet implemented; the impacts of those policies should be estimated and included in the BAU energy forecast.

Step 1c: Choose Forecast Method

Analysts can use a range of basic-to-sophisticated modeling methods to develop their BAU energy forecast and project energy supply and demand. These approaches are based on expectations of future population changes, energy data, and economics. They also depend on assumptions about the performance of current energy efficiency and renewable energy policies that are already included in the historical baseline. This section provides information about basic and sophisticated methods, data needs, and the respective strengths and limitations of each of the methods.

Basic vs. Sophisticated Methods

Basic methods may call for an analyst to either:

- Adopt assumptions made by utilities, independent system operators (ISOs), and regulatory agencies about the projected population, energy situation, and the economy; or
- Compile and develop its own assumptions.

[3] *Local energy baselines can focus on end-use sectors (i.e., residential, commercial, industrial, and transportation) and allocate the fuel used to generate electricity across the sectors that consumed the electricity.*

Basic methods are generally appropriate when conducting screening analyses or developing high-level forecasts when the amount of time or funding is limited or when the forecasted time period is short.

Sophisticated methods can be used for short- or long-term analyses. They provide greater detail than the basic methods, and can capture complex interactions within the electricity and/or energy system. Some analysts might want to consider a more sophisticated modeling method for their demand-and-supply forecasts when they want to:

- Better understand the effects of demand growth on their planned energy supply portfolio in the future, or
- Analyze the impact of significant changes in economic patterns (e.g., a dramatic decrease in housing starts) or energy costs on energy demand and supply.

The tools used in these more advanced methods vary in their complexity and cost. The most sophisticated methods are often data-, time-, and labor-intensive. They can lack transparency, involve software model licensing and data fees, and/or require a significant commitment of staff resources to develop expertise in a model. Unless the tool is used for broader or multiple analyses (e.g., statewide energy planning), it may be impractical for the state or local government to build the capacity to run these models in-house. However, most models are supported by one or more consultants who have access to data and who may be retained for specialized studies.

Basic Forecast Methods: Demand and Supply

Analysts can use a range of basic methods to forecast their BAU energy demand and supply without using rigorous, complicated analyses and software models. These methods generally produce aggregate information about a state's energy future, perhaps with a larger margin of error than more sophisticated approaches.

Basic approaches for forecasting energy demand and supply include a compilation of individual forecast by others, adoption of a preexisting forecast used by others, nominal group techniques, and linear/non-linear extrapolation, as described below.

- *Compilation of individual forecasts by others.* Energy plans from utilities, ISOs, and regulatory agencies often include a demand forecast that reflects electricity savings from energy efficiency programs. Similarly, a corresponding supply plan is likely to include data on existing and projected renewable energy sources, including CHP plants, if significant. Analysts can also aggregate individual load forecasts, generation expansion plans, and evaluations of energy efficiency and renewable energy programs from state agencies, utilities, ISOs, local educational institutions, and special interest groups, such as interveners in rate cases. Compiling forecasts created by different entities can be challenging, because they can vary significantly from each other in terms of underlying assumptions, proprietary concerns, data transparency (e.g., unit generation, costs), and time frame.
- *Adoption of a preexisting forecast used by others.* In some states, an energy office, utility commission, revenue department, or academic organization may have prepared a suitable energy forecast. The U.S. Energy Information Administration's (EIA's) Annual Energy Outlook includes regional demand forecasts. Also, utilities and ISOs may have their own specific forecasts. A regulatory filing requirement (e.g., an integrated resource plan) typically involves development of a comprehensive long-term plan that includes impacts from energy efficiency, reliable demand response, if any, and existing renewable energy plans.[4] However, there may be proprietary constraints to obtaining this information and these forecasts may reflect economic conditions that differ from those in the state where the policies are under consideration.

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[4] *For information about how utilities integrate energy efficiency into resource planning, see* Guide to Resource Planning with Energy Efficiency: A Resource of the National Action Plan for Energy Efficiency*, November 2007. See* https://www.epa.gov/sites/production/files/2015-08/documents/resource_planning.pdf*, or Lawrence Berkeley National Laboratory's 2016 report,* The Future of Electricity Resource Planning*, at* https://emp.lbl.gov/publications/future-electricity-resource-planning.

- *Nominal group techniques (NGTs).* NGTs are structured group discussions (in-person or through multi-stage questionnaires)[5] among a small group of experts or stakeholders to form consensus opinions, including expectations and assumptions for the future. They can be used to develop forecasts or to develop inputs to the preceding methods or more complex models. The type most commonly used in forecasting is the Delphi method.[6] Working with multiple experts in group discussions provides value, but the resulting forecasts depend strongly on which experts or other stakeholders are chosen.
- *Linear/non-linear extrapolation.* This method involves spreadsheet analysis where historical demand growth rates and electricity production trends (or trends from an alternative forecast) are used to extrapolate base-year data into the future. The accuracy of this approach depends on the accuracy of the "borrowed" growth rates, and the knowledge and experience of the analyst when applying historical trends. A strength of this approach is that it is easy to set data up in a spreadsheet and extrapolate it for preliminary forecasting. A limitation is that this method may result in an inaccurate forecast if it excludes important variables beyond demand growth factors and electricity—such as weather; season; plant retirements or construction, operation, or capital costs; emissions; or macroeconomic growth.

Table 2-1 summarizes the strengths and limitations of each basic method and describes when each can be used.

Table 2-1: Comparison of Basic Methods for Forecasting Energy Demand and Supply

Methods	Strengths	Limitations	When It Can Be Used
Compilation of individual forecasts by others	Easy to gather	Driven by different and in some cases outdated assumptions; proprietary concerns; possible short time horizons; may or may not provide information on construction requirements, fuel use, emissions, and costs; gaps in coverage	For high-level, low-cost, preliminary and quick analysis
Adoption of a complete forecast used by others	Easiest method	May not cover the desired timeframe; assumptions may not comport with desired state/regional outlook; may lack comparable geographic scope; may be proprietary	For high-level, low-cost, preliminary and quick analysis
Nominal group techniques (NGT)	Consensus building	Time consuming and may be relatively expensive	When input and buy-in from multiple experts are desired
Linear and/or non-linear extrapolation of baseline	Quick (easy to implement); more robust data analysis	May not capture impact of significant changes (e.g., plant retirements); possible errors in formulas, inaccurate representation of demand and supply	For high-level analysis with simple escalation factors based on history or from other sources; when generation dispatch by type of plant is known

Sophisticated Forecast Methods

Analysts may want to consider a sophisticated forecasting method when they require a more comprehensive understanding of their energy profile or when they have experienced or anticipate significant changes in their energy or economic patterns.

Sophisticated methods involve the use of data- and resource-intensive computer-based models to generate detailed forecasts that may reflect:

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[5] *In multi-stage questionnaires, a first questionnaire typically presents a series of statements that participants rate on a scale. Responses to it are used to create the second questionnaire, which includes the individual respondent's rating for each statement together with the median rating from all participants for comparison.*

[6] *In Vermont, a similar approach was used through a public workshop process in which electric industry stakeholders provided their input on the state's energy plan.*

- Historical trends
- Economic and/or engineering relationships
- Future expectations about prices
- Technologies and technology development
- Operating constraints
- Regulatory expectations (e.g., environmental regulations)

Whereas basic forecast methods are applied similarly to demand-and-supply forecasts, sophisticated approaches generate separate demand-and-supply forecasts that can be integrated once developed. As such, sophisticated models that apply the sophisticated methods for developing demand-and-supply forecasts are described separately below.

Demand Forecast

Once the historical baseline is developed, analysts can develop an energy demand forecast using time-series, end-use, or econometric models. These models can be used for short- and long-term load forecasting, comprehensive load analysis, modeling, and "day-after" settlement. Each model and its strengths and limitations are described below.

Time-Series Models

Time-series models apply a trend line to historical data and assume the future will roughly follow that line. These analyses are based on the assumption that the data (and the variable being forecast) have a structure or pattern, such as a trend and/or seasonal variation. Future events are forecast based on known past events and patterns. Inputs require an analysis of historical patterns in demand for electricity. Performing a time-series analysis can involve simply looking at aggregate demand and developing a forecast based on the pattern of that demand, or analysts may decide to perform a more detailed breakdown of the demand into customer type (e.g., residential, commercial, industrial) and application of each cyclical pattern over time to develop the total demand forecast.

Strengths of time-series models:

- *Simplicity.* These analyses are relatively straightforward to conduct.
- *Data availability.* Historical data are widely available by year, fuel, end-use, or sector (residential, commercial, and industrial).

Limitations of time-series models:

- *Data limitations.* Historical data may reflect technological changes and other unique phenomena that are unlikely to occur again, thus complicating or invalidating the forecast.
- *Structural limitations.* It is hard to reflect future structural changes even if they are anticipated.
- *Static relationships.* Time-series models cannot reflect dynamic supply-demand-price feedbacks.

End-Use Models

End-use models develop load profiles (charts illustrating variations in demand over a specific time) of each customer type—such as residential, commercial, and industrial—by analyzing the historical energy consumption of appliances and equipment, including the impact of any existing demand-side management (DSM) programs. They may also use specific surveys from customers about future growth and contraction. This approach can also include an economic forecast that provides gross state product (GSP) and consumer electricity prices.

Strengths of end-use models:

- *Reasonableness.* Use of load profiles for each customer class being served provides a reasonable estimate of demand.
- *Specificity.* Users can elect to use project-specific models to help assess building demand estimates.

Limitations of end-use models:

- *Time- and resource-intensive.* Collecting the data can require considerable time and expense.

Econometric Models

Econometric models quantify relationships over time between energy demand and variables that affect it, such as economic activity, energy prices, and weather. For example, the model output may show that as income increases, energy demand increases. These relationships can be applied in detailed demand and energy consumption forecasting. Econometric methods are sometimes used in combination with end-use methods. Examples of and more information about econometric models are provided in Chapter 5 of this *Guide*.

Strengths of econometric models:

- *Robustness.* They create a robust demand forecast if driven with a robust economic forecast.

Limitations of econometric models:

- *Time- and resource-intensive.* Significant time and cost may be required to prepare the inputs and review the results.

Supply Forecast

Utilities, ISOs, and other sophisticated energy market participants use economic dispatch or capacity expansion models for hourly, daily, monthly, and long-term forecasting of electricity supply. These models require large volumes of data on electric generating plants, transmission capabilities, and a demand forecast. As with any analysis, the better the quality of that data, the better the results. Although the costs to acquire the software and data may be prohibitive for some users, these models generally provide more comprehensive estimates on energy and capacity output than basic modeling approaches. The complexity of these models often results in agencies and stakeholders working with utilities to coordinate the application of the models in policy analyses and in regulatory proceedings.

Economic Dispatch Models

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

Key uses: An economic dispatch model typically answers the question: How will this energy efficiency or renewable energy measure affect the operations of *existing* power plants? Economic dispatch models provide forecasts of wholesale electric prices for each hour (i.e., system marginal costs) and the hourly operations of each unit that occur in the short term (0–5 years).

Capacity Expansion or Planning Models

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

Key uses: A capacity expansion model answers the question: How will this energy efficiency or renewable energy measure affect the composition of the fleet of plants in the future? A capacity expansion model typically takes a long-term view (5–40 years) and can estimate electricity sector impacts including the addition and retirement of power plants, rather than changes in how a set of individual power plants is dispatched. Some capacity expansion models include economic dispatch modeling capability, although typically on a more aggregated time scale than dedicated hourly dispatch models. Capacity expansion models that also include dispatch modeling capabilities can be used to address both the short and long-term implications of energy efficiency and renewable energy initiatives.

Table 2-2 compares the types of models covering both economic dispatch and capacity expansion (or planning) and lists examples of specific modeling tools. Information about the tools listed is available in Section 2.4., "Tools and Resources." These methods are described in more detail in Chapter 3, "Assessing the Electricity System Benefits of Energy Efficiency and Renewable Energy."

Table 2-2: Comparison of Sophisticated Modeling Methods for Forecasting Electricity Supply

Strengths	Limitations	When to Use This Method	Examples of Models[a]
Economic Dispatch			
▪ Provides very detailed estimations about specific plant and plant-type effects within the electric sector ▪ Provides highly detailed, geographically specific, hourly data ▪ Ideal for estimating wholesale electric prices and hours of operation and production	▪ Often lacks transparency ▪ Requires technical experience to apply ▪ May be labor-, data-, and time-intensive ▪ Often involves high labor and software licensing costs ▪ Requires establishment of a specific operational profile for the energy efficiency or renewable energy resource ▪ Cannot estimate avoided capacity costs from energy efficiency and renewable energy investments	Often used for evaluating: ▪ Specific projects in small geographic areas ▪ Short-term planning (0–5 years) and regulatory proceedings	▪ GE MAPS™ ▪ IPM® ▪ PLEXOS® ▪ PROMOD IV® ▪ PROSYM™
Capacity Expansion or Planning			
▪ Selects optimal changes to the resource mix based on energy system infrastructure over the long term (5–30 years) ▪ May capture the complex interactions and feedbacks that occur within the entire energy system ▪ Provides estimates of emissions reductions from changes to the electricity production and/ or capacity mix ▪ May provide plant-specific detail and perform dispatch simultaneously (IPM) ▪ Designed specifically for resource planning ▪ Can estimate avoided capacity costs	▪ Often lacks transparency due to complexity ▪ Requires significant technical experience to apply ▪ May be labor- and time-intensive ▪ Often involves high labor and software licensing costs ▪ Requires assumptions that have a large impact on outputs (e.g., future fuel costs)	Used for long-term studies (5–40 years) over large geographical areas such as: ▪ SIPs ▪ Late-stage resource planning ▪ Statewide energy plans ▪ Greenhouse gas mitigation plans	▪ AURORA ▪ DOE's NEMS ▪ EGEAS ▪ e7 Capacity Expansion ▪ e7 Portfolio Optimization ▪ ENERGY 2020 ▪ EPA's GLIMPSE ▪ IPM® ▪ LEAP ▪ NREL's ReEDS ▪ NREL's RPM

[a] *For more information about individual tools, see Section 2.4., "Tools and Resources."*

Step 1d: Determine Assumptions and Review Data

After choosing the forecasting approach or model type, the next step is to determine or review assumptions about population, energy, and economic variables, such as energy prices, existing energy efficiency programs, productivity, GSP, and the labor force upon which projections of energy demand and supply depend. If the BAU forecast is adopted from another information source, such as EIA's Annual Energy Outlook, regional transmission organization (RTO), or regional council, it is useful to review the growth rates, policy assumptions, and economic conditions to ensure they represent a state's best available assumptions and are aligned with the goals of the forecast.

It is also useful to review possible data sources and collect the data required for the analysis. The following types of data are used in estimating energy consumption and supply baselines and forecasts:

- *Population data* are used to estimate the amount and types of demand expected in the future and to examine trends.
- *Economic variables* are projected as they relate to energy so that the analyst can better understand the historical relationships between energy and the economy, and anticipate how these relationships may exist in the future.
- *Electricity and fuel prices* are projected using assumptions as to how they may change in the future based on supply and demand expected.
- *Impacts of existing and on-the-books energy efficiency programs* avoid the double-counting of impacts, as described in the box "Projecting Future Emissions from the Power Sector."

For a list of available data sources for this information, see Section 2.4., "Tools and Resources."

Almost all providers of economic dispatch and capacity expansion models also offer a data set that can be used to apply these models to a regional electricity system. Data from any source must be examined to ensure that they are consistent with the assumptions of the entities that will use the model results, and to check for outliers, errors, and inconsistencies in the data. Typically, the data available for a historical baseline and BAU forecast lag several years. For this reason, the current and most recent years may be part of the forecast and not the history. It is important, therefore, to ensure that the data derived for recent years reflect the current energy supply and demand as much as possible.

At this point in the process, it may be necessary to review the data to detect and remove corrupt or inaccurate records and/or fill in any data gaps. If data points are missing for particular years, it may be necessary to interpolate the existing data or use judgment to fill in gaps. This will minimize the likelihood of generating results based on calculations that are skewed due to missing or out-of-range data, producing an inaccurate forecast. Some private data providers also offer data cleaning services. Practical application of any of these data bases, however, requires due diligence in looking for data outliers, missing values, and screening for errors in data. It is rare for users to obtain a fully clean data set, consistent with their individual assumptions, from any one source.

Step 1e: Apply Forecast Method

The next step is to apply the selected method or model to forecast the historical baseline energy data, based on the assumptions about future population, economic, and energy expectations. Clearly documenting the assumptions used in the forecast is a key aspect of this step. When documenting an energy forecast, consider both the historical baseline (using consumption or generation data) and the expected impacts of any energy policies that have been approved but not yet implemented (and thus not reflected in the baseline). A historical baseline alone may not accurately represent BAU; the impacts of policies that are already "on the books" but not yet in force also need to be considered in the BAU forecast. Clearly documenting the expected impacts of energy efficiency policies already incorporated in the historical baseline and BAU assumptions helps avoid double-counting when examining future program potential or impacts and builds credibility. When using a model, it is worth taking time to verify whether the assumptions are documented in a transparent way, and to ensure that the analyst has a solid understanding of the basic operations of the model (i.e., the algorithms used to produce the model outputs).

PROJECTING FUTURE EMISSIONS FROM THE POWER SECTOR

Projecting future emissions from the power sector normally requires information from an electricity demand forecast as a basis for predicting how future generation requirements will grow over time. Many demand forecasts are available, including EIA's Annual Energy Outlook. For any forecast, it is important to understand the underlying assumptions, including which energy efficiency and renewable energy programs are already incorporated in the forecast.

EPA has developed a methodology that states can use to estimate the energy impacts of key energy efficiency and renewable energy on-the-books policies that are not explicitly reflected in the EIA's Annual Energy Outlook electricity projections, and include them in their baseline projections. These policies include Energy Efficiency Resource Standards, dedicated sources of energy efficiency program funding that are adopted in state law and/or codified in rule or order, such as programs funded by RGGI, public benefits funds and forward capacity market revenues. EPA solicited peer and public review of its methodology, and comments received have been addressed and incorporated into a paper (*Including Energy Efficiency and Renewable Energy Policies in Electricity Demand Projections*) that describes the methodology, available at https://www.epa.gov/sites/production/files/2015-08/documents/including_ee_and_re_policies_in_ed_projections_03302015_final_508.pdf.

EPA originally developed this methodology to illustrate how energy efficiency and renewable energy policies could be accounted for in the context of National Ambient Air Quality Standards (NAAQS) State Implementation Plans (SIPs), but the basic methodology can be used by states to develop baseline projections that include a more complete set of policies than those considered in EIA's Annual Energy Outlook projections.

Step 1f: Evaluate Forecast Output

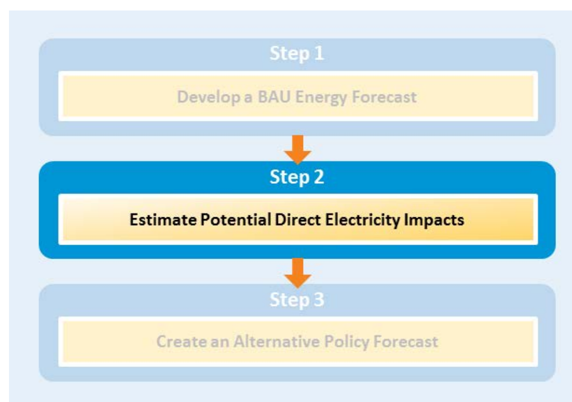
The last step of developing a BAU energy forecast is to review the output to ensure that it is realistic and meets the original objectives. If the analyst determines that any of the forecast does not seem realistic, he or she may need to revisit assumptions and then reapply the approach or model to achieve an acceptable forecast.

Technologies change over time and can alter energy savings estimates. This can alter the BAU forecast and the potential for energy savings. BAU forecasts and energy savings projections should be reevaluated periodically (every 1 to 2 years). This is particularly important under conditions of rapid change.

2.2.2. Step 2: Estimate Potential Direct Electricity Impacts

Once the BAU energy forecast is complete, the next step is to estimate the potential direct electricity impacts of the proposed energy efficiency and renewable energy programs or policies that are under consideration. Direct electricity impacts include:

- Electricity savings from new energy efficiency initiatives
- Electricity production from new renewables
- Electricity savings, if any, from other new electricity supply options such as CHP and distributed generation



Analysts can estimate the direct electricity impacts from broad goals and targets, often using top-down approaches that look at high-level impacts across the economy, or from specific policies or programs, typically using bottom-up approaches that provide greater sector-by-sector detail. Approaches to estimating both types of direct electricity impacts are described below.

Step 2a: Estimate Potential Direct Electricity Impacts of Broad Goals and Targets

If a state or locality has or is considering a broad energy efficiency and/or renewable energy goal, it is helpful to estimate the potential impacts of the goal before evaluating specific energy efficiency and/or renewable energy programs and implementation options. For example, an analyst may need to quantify—in terms of kilowatt-hours (kWh) or Megawatt-hours (MWh)—the requirements of an energy efficiency goal or target. If the policy or goal is to have zero growth in electricity demand over the next 10–20 years, it would be necessary to estimate how much energy efficiency would be required to meet that goal. Alternatively, the analyst may need to quantify the impacts of a renewable portfolio standard. These estimates will indicate how much electricity must be saved each year, or how much renewable energy must be provided, respectively, to meet the goals.

ENERGY EFFICIENCY POTENTIAL STUDIES

Energy efficiency potential studies are quantitative analyses of the technical, economic, or achievable/program potential of energy efficiency policies and programs. Many states have used energy efficiency potential studies to make the initial case (or support continued/increased funding) for energy efficiency programs and measures. States have also used potential studies to identify alternatives to new generation, or to identify the specific market sectors, geographic areas, end uses, measures, and programs that have the greatest potential for cost-effective energy savings, or as basis for setting goals/targets such as EERS.

U.S. DOE has developed a catalog of state energy efficiency potential studies, available at http://energy.gov/eere/slsc/energy-efficiency-potential-studies-catalog.

An estimate of direct electricity impacts shows only what the goal or target could achieve. It is not focused on estimating what is cost-effective, what the market might adopt, or when the specific technologies might be adopted. The electricity estimates of any goals, therefore, should be checked against existing energy efficiency or renewable energy potential studies (see box "Energy Efficiency Potential Studies") to make sure they are plausible.

Methods for Estimating Potential Direct Electricity Impacts of Broad Goals and Targets

Methods for these estimates can include both basic and sophisticated approaches, but these high-level estimates will most likely require only the most basic approaches because the focus is simply on quantifying the meaning of the goal (e.g., a 2 percent reduction in demand per year implies a savings of x MWh). Basic approaches typically start with a BAU energy forecast as developed under Step 1. This can be a key input in the effort to determine electricity savings or energy efficiency and renewable energy supply required. The exact methodology chosen, however, will depend on how the goal or target is specified and a host of other factors, such as whether the electricity savings from efficiency are measured from the BAU forecast or from prior years' sales. Also, the extent to which existing programs do or do not count toward the target may affect the calculations. It is helpful for the analyst to think through the details of the goal, policy, or legislation, and how they might affect the methodology and calculations.

THREE EXAMPLES OF STATE ENERGY TARGETS OR GOALS

- Have a rate of zero load growth by 2020.
- Reduce electricity demand by 2 percent per year by 2025, and 2 percent every year thereafter, with reductions to be based on prior three years' actual sales.
- Require utilities to meet 20 percent of generation (or sales) through renewable energy sources by some date in the future (sometimes with interim targets). In some instances, the eligible resource types (including existing), the required mix of renewables types, and geographic source of the renewables may be specified.

Suppose an analyst is determining the anticipated electricity savings or generation needed to achieve an energy efficiency or renewable energy initiative in a target year, such as a renewable energy target to build 100 Megawatts (MW) of wind power capacity by 2020. If appropriate financial incentives are in place to encourage construction of the wind facility, the electricity available in the year after 100 MW of wind facilities are placed in service can be estimated at a very basic level as: 100 MW * 0.28 capacity factor[7] * 8,760 hours/year = 245,280 MWh/year.

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[7] *Capacity factor is defined as the ratio of the electrical energy produced by a generating unit for the period of time compared to the electrical energy that could have been produced at continuous full power operation during the same period. Typical monthly capacity factors for wind range from 20 percent to 40 percent; see http://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_6_07_b.*

An important activity in this example would be to ensure that the capacity factor chosen is applicable to the wind resource being considered. The output of a wind turbine depends on the turbine's size and the wind's speed through the rotor, but also on the site's average wind speed and how often it blows. Data to assess appropriate capacity factors can be identified based on geographic data on wind class (speed). Various guidance resources are available to aid in determining capacity factors and are listed in Section 2.4., "Tools and Resources."

Alternatively, suppose a state agency is considering an Energy Efficiency Resource Standard (EERS) that calls for a 22 percent reduction in electricity sales between 2020 and 2030, based on the achievable potential identified by an energy efficiency potential study. An analyst might estimate the annual impacts of the policy as outlined below (with calculations illustrated in Table 2-3).

First, the analyst needs to develop a pathway, with annual percentage savings targets, that would assure the 22 percent total reduction is reached by the target year. Table 2-3 shows one possible pathway with column 3 showing incremental annual increases in percentage savings from the previous years' sales until the 22 percent target is reached. Next, the analyst applies each year's percentage savings target in column 3 to the previous year's sales in column 2, to calculate energy efficiency savings required. Column 4 shows the cumulative electricity savings required to meet each year's percentage savings target and column 5 shows the cumulative level of electricity savings in kWhs for each year.

Table 2-3: Example of Estimation of Required Energy Efficiency Savings Based on Long-Term Savings Goal or Performance Standard (KWh)

1	2	3	4	5
	Retail Electricity Sales (kWh)	**Annual Electricity Savings as a Percentage of Retail Sales in Prior Year**	**Cumulative Electricity Savings (%)**	**Required Cumulative Electricity Savings (kWh)**
2020	100,000,000			0
2021	100,750,000	1.25%	1.25%	1,250,000
2022	101,017,500	1.75%	3.00%	3,022,500
2023	101,069,925	2.00%	5.00%	5,050,875
2024	100,915,646	2.25%	7.25%	7,327,570
2025	100,821,094	2.25%	9.50%	9,586,986
2026	100,517,711	2.50%	12.00%	12,098,531
2027	100,293,499	2.50%	14.50%	14,575,068
2028	100,116,043	2.50%	17.00%	17,049,895
2029	99,986,628	2.50%	19.50%	19,522,628
2030	99,902,384	2.50%	22.00%	21,997,058

Although the actual path that is followed or the estimates of achieved savings (quantified using evaluation, measurement, and verification [EM&V]) may differ from those shown in this simple exercise, this type of calculation gives an indication of the implications for program requirements and the resulting impact on growth.

If the state has an emissions-related goal, this type of quick, top-down analysis can then be linked to emissions data to determine what portion of the state's emissions targets could be met with a specific percentage EERS. Similar linkages could be made to economic or other goals as well.

Considerations

Factors analysts can consider when estimating the impacts of targets and goals for electricity demand and resources include:

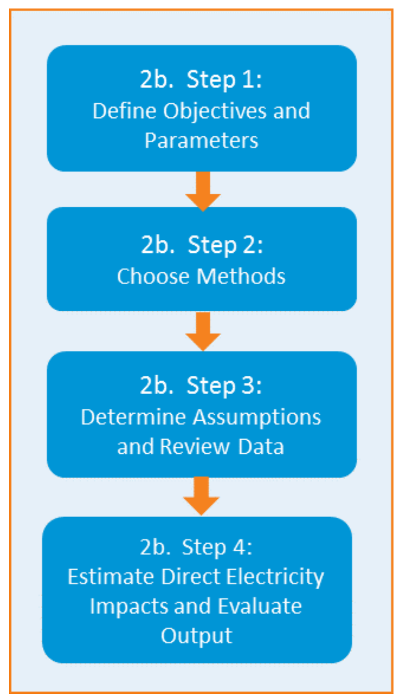
- The historical baseline level of electricity demand and supply (described earlier in this chapter)
- Expected growth over time under BAU (described earlier), including any ongoing energy efficiency or renewable energy efforts that may or may not contribute to the new goal, but will influence baseline conditions
- The likely persistence of energy efficiency savings over time (or changes in the supply of renewable energy)
- Other considerations that may affect the level of savings or supply required, such as rebound effects[8] in energy efficiency programs
- The remaining electricity demands (or supply) after the impacts occur

Quantifying the impacts of broad goals and targets typically requires straightforward mathematical calculations, as shown above, and do not usually involve sophisticated approaches. However, advanced modeling and economic analysis may be required if, for example, a goal or target is tied in some way to an economic indicator or requirement (e.g., if a goal or target has some circuit-breaker or threshold provision, for example, requiring that only energy efficiency costing less than a certain amount be required), or has some dynamic aspects to it (e.g., changing targets in response to achievements).

Step 2b: Estimate Potential Direct Electricity Impacts of Specific Policies, Programs, or Measures

Step 2a demonstrated how estimates of potential direct electricity impacts can be developed to evaluate a *goal or target*. Step 2b discusses ways to estimate the expected results of a specific *policy or program* that is under consideration and has been sufficiently defined to allow meaningful analysis (see Figure 2-6).

Figure 2-6: Steps to Estimate Direct Electricity Impacts of Specific Policies, Programs, or Measures



For example, under Step 2b, an analyst might be looking to estimate:

- The impact of appliance standards in a way that considers the existing stock, current efficiency levels, and consumer decision-making
- The expected response to a utility energy efficiency program, with or without specific information on program focus (what sectors and end uses) and design challenges (e.g., rebate levels)
- The impact of a renewables incentive program

[8] *Energy efficiency reduces the cost of operating energy-consuming technologies. In response, people tend to increase their use of those technologies, partially offsetting the gains from energy efficiency. This phenomenon is known as the rebound effect.*

See the box "Policies and Programs for Which Energy Impacts Might Be Estimated" for more examples.

Estimating the potential direct electricity impacts of specific policies, programs, or measures under Step 2b involves the following sub-steps:

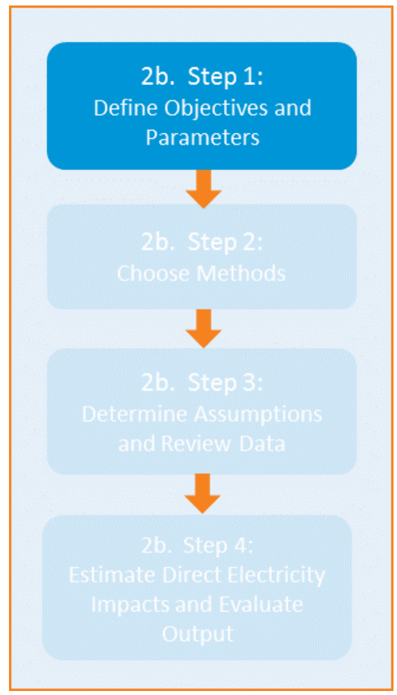
1. Define objectives and parameters.
2. Choose method to estimate potential direct electricity impacts.
3. Determine assumptions and review available data.
4. Estimate direct electricity impacts and evaluate output.

Each of these activities is described in detail below.

POLICIES AND PROGRAMS FOR WHICH ENERGY IMPACTS MIGHT BE ESTIMATED

- Energy efficiency resource standards
- Renewable portfolio standards
- Appliance standards
- Building codes
- Public benefits funds (to fund state or utility-run efficiency or renewables)
- Energy efficiency and renewable energy tax or other financial incentives
- Rebate programs
- Lead by example programs

2b. Step 1: Define Objectives and Parameters



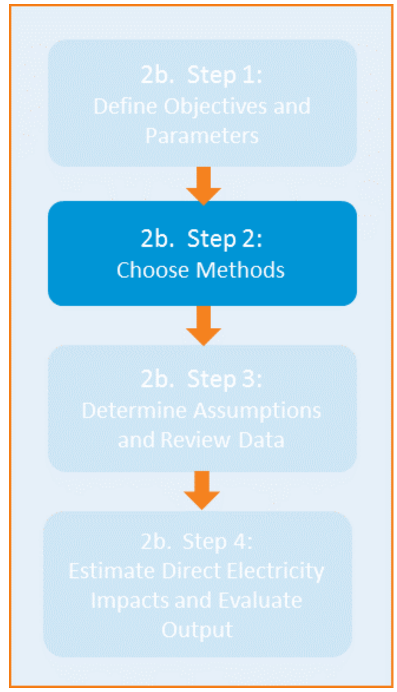
The process of estimating potential direct electricity impacts begins by defining the objectives and parameters of the energy impacts that the analyst plans to estimate. If the objective is to quantify the required electricity savings and/or renewable energy generation from a planned energy efficiency and/or renewable energy initiative or goal for the state legislature, for example, the parameters of the analysis may already be dictated. For example, the legislature has likely specified a due date, a time period to be analyzed, and a desired level of rigor, and may even have required the government to spend a certain amount of money on the analysis. Other analyses, such as those conducted to screen a range of energy efficiency and/or renewable energy options based on a range of benefits, may be less defined.

Analysts should consider the following parameters before choosing an analysis method, model, or dataset(s) to use:

- *Time period for the direct electricity impacts*: Is it a short-term or longer-term projection?
- *Timeliness of the estimates*: Is this due next week or in a year?
- *Level of rigor necessary* to analyze policy impacts: Is this for a screening study or a regulatory analysis that is likely to be heavily scrutinized?
- *Availability of financial, staff, and outside resources* to complete the analysis in the required time period: Is there a budget available for the analysis? Does the agency have internal modeling capabilities?
- *Amount of data available*, or that can readily be acquired, to develop the savings estimate: Are there existing energy efficiency and renewable energy potential studies or similar projects elsewhere that can be adapted to the analysis?

These factors will help analysts choose between simple and more rigorous approaches based upon specific needs and circumstances.

2b. Step 2: Choose Method to Estimate Potential Direct Electricity Impacts



Assessing the potential impacts of energy efficiency or renewable energy programs requires "bottom-up" techniques that build up estimates of impacts based on the considerations described above, along with the fundamentals of the technology, the economics, and market behavior. Bottom-up approaches involve estimating potential energy savings at a very detailed level and rolling up these estimates to the initiative or policy level.

Bottom-up analyses can involve basic calculations, detailed surveys, and/or sophisticated spreadsheet analyses or tools. At a minimum, the analysis will require some level of detail about:

- Individual measure savings or renewable energy generation that can be rolled up into an aggregate estimate or statewide strategy
- Saturation of energy efficiency or renewable energy equipment in the market so that the analyst can determine how much opportunity for new investment is feasible when compared against energy efficiency potential studies (see the box, "Using Energy Efficiency Potential Studies," for more information about these studies)

Depending upon the level of detail desired, estimating the potential impacts can require large amounts of data and, for the more detailed analyses, may be costly. For this reason, analysts often use a combination of methods that involve adapting existing surveys and studies by utilities, trade groups, other states, or the federal government where appropriate and conducting new analyses to fill information gaps or to determine the localized or detailed effects of the proposed policy or program. These two approaches are described below.

Adapt Existing Studies

To reduce time and expense, analysts can explore existing bottom-up studies of similar programs in their state or other states, and adapt the results to their conditions. At the aggregate level this basic method may involve scaling results to the state's BAU energy forecast, perhaps accounting for sectoral share differences if data are available at the sectoral level. For estimates of individual measure or site-level impacts associated with energy efficiency and renewable energy measures, analysts can look to available retrospective studies that can be extrapolated into prospective savings based on an understanding of the state's sectoral and end-use mix. Many resources are available that can provide historical results and/or projected energy efficiency and renewable energy savings, including those listed in Section 2.4., "Tools and Resources."

Analysts can also capture useful data from available potential studies that support the energy efficiency and renewable energy policy decision. For example, a potential study conducted for another state may contain valuable information on the electricity savings associated with different energy efficiency and renewable energy programs, and deemed savings databases from other states will include energy savings for specific energy efficiency measures.[9] Public service commissions' websites usually post utility DSM filings and integrated resource plans, which contain details on energy efficiency and renewable energy plans with estimated electricity impacts.

When using data from other states or regions, it is best to choose areas that have similar climate and customer characteristics. Even so, the assumptions about operating characteristics of different energy efficiency and renewable energy technologies typically need to be adjusted for the specifics of the geographic location that is the focus of the

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[9] *Deemed savings are validated estimates of energy savings associated with specific energy efficiency measures that may be used in place of project-specific measurement and verification.*

study. For example, for energy efficiency measures, adjustments for differences in weather are typically made, along with adjustments for state-specific population characteristics.

Estimates adapted from existing studies can be summed across the populations in each sector, remembering to subtract the market penetration levels for the energy efficiency and renewable energy measures that are already installed (based on the saturation data, described in greater detail in the box below, "Saturation of Energy Efficiency or Renewable Equipment and Practices"). When adapting existing studies to evaluate renewable energy options, decision makers should correct for the relative resource base available given that states have different levels of renewable energy resources (e.g., wind, solar) available.

TOOLS FOR DIRECT SAVINGS OR GENERATION ESTIMATES

Many modeling and analytics tools are available to help analysts estimate the potential direct electricity impacts of energy efficiency and renewable energy measures. An overview of these tools is presented in Section 2.4., "Tools and Resources."

SATURATION OF ENERGY EFFICIENCY OR RENEWABLE ENERGY EQUIPMENT AND PRACTICES

It is valuable to understand how much equipment is already in the market so that analysts can determine a feasible level of investment that a new energy efficiency and renewable energy program or policy could induce. Similarly, information on the prevalence of energy-efficient practices in operations and maintenance (O&M) can inform estimates. The equipment and practices saturation data are typically determined using one or more methods, including:

- *End-use customer saturation surveys.* These surveys provide a relatively cost-effective method of estimating saturation levels for both standard and efficient equipment as well as energy-efficient practices. These on-site, telephone or Internet surveys are conducted to gather information regarding the end-use equipment currently installed at a statistical sample of homes and businesses.
- *Site visits.* Facility managers can provide high-quality estimates of equipment saturations and energy-efficient practices. However, due to the tremendous amount of energy consumption represented by large nonresidential facilities, and the limited amount of program audit data available, it is often necessary to conduct primary data collection at a sample of sites that represent the sub-sectors in the population.
- *Survey of retailers.* Retailers can provide important insight into the market share and saturation of many products, including programmable thermostats, water heaters, clothes washers, clothes dryers, and refrigerators.
- *Surveys of building code officials, builders, architectural and engineering firms, and other trade allies.* These data can also be used to characterize the equipment saturations in the new construction and retrofit markets if samples are carefully selected and appropriate surveys developed. Interviews with contractors, dealers, distributors, and other trade allies provide a cost-effective research approach, as business activity tends to be concentrated among relatively few of these market actors. Interviews can also be used to assess market share and saturation for multiple sectors.

Once equipment saturation and the prevalence of energy-efficient practices are understood, analysts can compare them against energy efficiency potential studies to determine the feasible level of investment opportunity available.

As an example of this kind of approach, imagine a state agency that is considering a new efficiency standard for air conditioning. Analysts at the agency could estimate electricity savings based on a variety of already available data, such as measure-specific electricity savings from a deemed savings database from another state (e.g., the California Database of Energy Efficiency Resources or the Michigan Energy Measures Database), and adjust the measure-specific savings to account for the weather zones present in the state, especially for weather-specific measures such as air conditioning with a high Seasonal Energy Efficiency Ratio (SEER). These adjustments might require the use of building simulation models (e.g., eQuest; see Section 2.4., "Tools and Resources") to get reasonably accurate estimates of electricity savings at the site level. These site-level savings would ideally be generated for each housing type, air conditioning rating level above federal standards, and weather zone. This can create a large matrix of possible combinations.

Determining historical baseline market penetration of the higher efficiency technology without conducting surveys of heating, ventilation, and air conditioning dealers can be accomplished by reviewing studies of market penetration rates from another state or states. These studies would need to be from states that had not already adopted a higher efficiency technology standard, and the results of the studies would need to be adjusted for demographic differences between the states.

Combined with some thoughtful analysis, these data can help define the potential electricity savings for the proposed air conditioning measures without incurring the time and expense of collecting all new data. Making choices about which data to use and how to adjust those data involves inherent trade-offs between the expected accuracy and the level of effort expended. Some analysis of the uncertainty surrounding each key variable is recommended to understand the relative accuracy of the estimates obtained through this method.

In a similar manner, an analyst looking to estimate of the potential renewable energy generation associated with a renewable portfolio standard (RPS) can use data from surrounding states and/or those that have adopted similar rules regarding the implementation of their RPS. For example, an analyst might look at adoption rates for roof-mounted solar PVs in other states that have similar net metering rules for solar systems and have established incentives for installation that reward end-users and developers in a similar manner financially.[10]

Assumptions regarding the electricity production of the system, financial discount rate, and other factors must be reviewed and projected to estimate attractive rates of return that will stimulate the market at the project level.

Extrapolating the project-level analyses to the statewide population requires demographic data, information on the current status of the solar industry in the state, and data on the current economic client to estimate a range of renewable energy generation levels that could be achieved over a given time period.

EXTRAPOLATING ENERGY EFFICIENCY DATA USING EXAMPLES FROM OTHER STATES

The Vermont Public Service Department updated its energy efficiency potential report in 2014. The report is designed to quantify the potential of electric energy efficiency to reduce both electricity consumption and peak demand in Vermont. The report updated previous assumptions on savings, cost, and useful life data using Technical Reference Manuals (TRMs) and evaluation from other states. Vermont used assumptions for other states that were relevant and applicable to its own economic and weather conditions. For example, Vermont modified the energy savings potential for weatherization and HVAC equipment measures based on Vermont-specific housing characteristics.

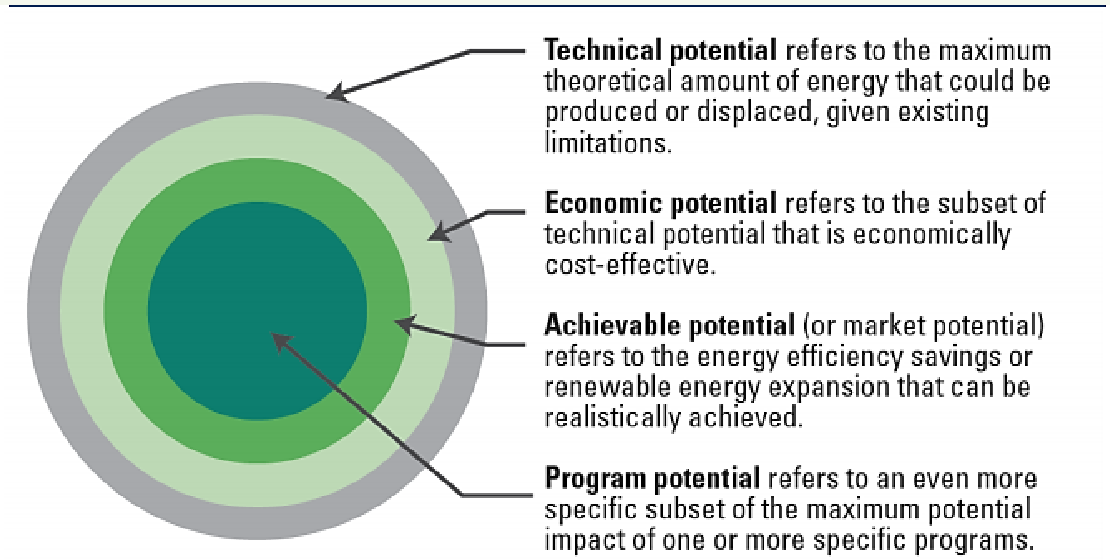
Conduct New Analyses

Analysts will typically conduct new analyses when no relevant or recent analyses are available or easily adaptable, or when they are seeking very localized or tailored detail about potential site-level or program-level impacts.

A new analysis of direct electricity impacts from a specific policy or program can involve the development of an energy efficiency or renewable energy potential study (see Figure 2-7) if a recent one is not available. A potential study can let the analyst know how much opportunity is available to pursue energy efficiency or renewable energy in the state so that they can make reasonable assumptions. Detailed guidance for energy efficiency potential studies is available in EPA's *Guide for Conducting Energy Efficiency Potential Studies*, at https://www.epa.gov/sites/production/files/2015-08/documents/potential_guide_0.pdf.

[10] If the comparison state's financial incentives took the form of an upfront rebate, and a future revenue stream based on renewable energy certificates is assumed for the state being analyzed, then a discounted cash flow analysis would be required to analyze the net present value of each approach to the project owner and solar developer to compare the costs of the two approaches fairly.

Figure 2-7: Using Energy Efficiency Potential Studies



To estimate the potential savings of energy efficiency and renewable energy measures, analysts can conduct simple analyses by extrapolating the results of existing energy efficiency or renewable energy potential studies. These studies may be sector-specific (residential, commercial, industrial), or aggregated at a geographic level (state or region). They may reflect technical potential, economic potential, achievable potential, program potential, or all four. If only the technical and economic potential are estimated, the analysis should consider what is achievable

EPA developed guidance in 2007 (still relevant today) on conducting an energy efficiency potential study. See the *Guide for Conducting an Energy Efficiency Potential Studies: A Resource of the National Action Plan for Energy Efficiency*, November 2007 at https://www.epa.gov/sites/production/files/2015-08/documents/potential_guide_0.pdf. U.S. DOE also provides a catalog of energy efficiency potential studies at http://energy.gov/eere/slsc/energy-efficiency-potential-studies-catalog.

A number of modeling and analytic tools are available to help analysts estimate potential site-level or program-level electricity impacts that can be aggregated up to the state level. For example, building simulation tools, such as EPA's ENERGY STAR® Portfolio Manager® or DOE's eQuest model, can be used to estimate energy savings per building and scale up to larger portfolios. The free RETScreen® model can evaluate energy production and savings, costs, risk, emissions reductions, and other characteristics of energy efficiency and renewable technologies. Section 2.4., "Tools and Resources," lists a number of these tools and related resources.

Analysis of a renewable energy policy or program would examine the costs and operation of eligible renewable resources and their interaction with the existing (and planned future) generation system. This type of analysis is often more complex, and may require a more sophisticated approach. Guidance for renewable energy potential studies is available in *A Framework for State-Level Renewable Energy Market Potential Studies*, published by the National Renewable Energy Laboratory, at https://www.nrel.gov/docs/fy10osti/46264.pdf.

As an example, imagine that a state agency wants to determine the energy impacts from a proposed lead-by-example policy of reducing energy consumption by 20 percent in all state-owned buildings by 2030. The first step in the process would be to gather historical baseline data on energy consumption for state-owned facilities, along with the square footage associated with each facility. These data may take some time and effort to gather, as they do not typically reside in one file or with one person. The baseline data will allow analysts to calculate target kilowatt-hour (and therm reductions) across all facilities. If the policy will reduce energy consumption in existing buildings alone, calculating the savings number is as simple as determining whether each facility will achieve 20 percent savings, or whether the portfolio as a whole will achieve a 20 percent reduction in annual consumption. Either way, it is a straightforward exercise to take 20 percent of the total kWh (and therms) consumed for the base year.

If the policy will include new construction as well, analysts would need to determine the baseline construction for new state facilities in the absence of the initiative, as well as the energy consumption associated with facilities built to that evolving standard multiplied by the square footage of planned additions.

To build a true bottom-up analysis of savings, analysts will need to find where the 20 percent savings are likely to come from. Individual building audits will provide the best data on where to achieve savings, and can be summed by end-use, facility, and organization up to the state level. This process is relatively expensive and time consuming; a first-level screening could involve benchmarking the facilities with national averages and best-practice energy consumption per square foot.[11]

After initial screening, walk-through audits can be used to confirm where to target the most cost-effective initial investments. Most cost-effective energy efforts start with lighting retrofits, as they are a proven energy savings that can be easily achieved. Heating, ventilating, and air conditioning (HVAC) improvements or control system upgrades will require a more detailed audit, often take longer to complete, and require less modular investments. Engineering algorithms or simulation models are used to estimate the savings from HVAC and other energy efficiency measures, and to estimate interactive effects that may decrease the combined savings of individual measures.

The level of detail desired may depend on the purpose of the estimates. If, for example, agency budgets were determined based on their energy savings, a more detailed analysis would provide better information about specific technology performance and payback than a screening-type of analysis. Regardless of the level of detail, the analyst would sum up the measure and building savings estimates across all facilities to assure that the 20 percent by 2030 statewide target can be met within the budgets allocated.[12]

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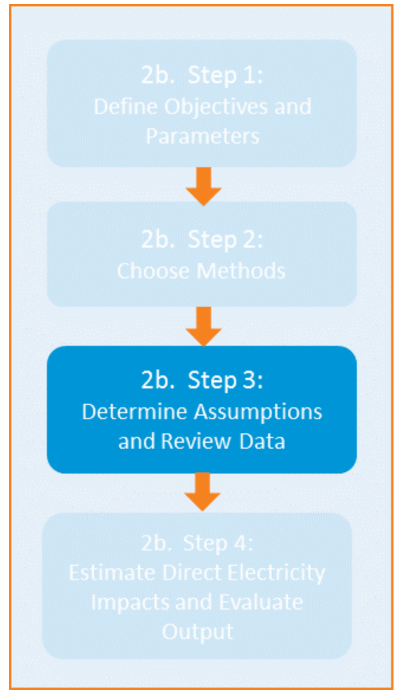
[11] When benchmarking facilities in this way, it is helpful to use benchmarks specific to that building type. For example, a hospital has a very different energy profile than does an office building, so only hospital-specific benchmarks would be useful for benchmarking a hospital. See ENERGY STAR's Portfolio Manager® at http://www.energystar.gov/benchmark.

[12] Of course, other financing mechanisms for energy efficiency are available, including bidding out the services to energy service companies. This chapter does not explore financing mechanisms, but focuses on energy savings calculation methods and mentions the budget implications only as a consideration for policy makers.

2b. Step 3: Determine Assumptions and Review Available Data



Determining potential direct electricity impacts attributable to energy efficiency and renewable energy programs and policies requires careful selection of assumptions based on state-specific demographic and climatic conditions. Several key assumptions should be considered when estimating the prospective energy savings of an energy efficiency and renewable energy initiative. Key assumptions to consider include:

- *Program period*: What year does the program start? End?
- *Program target:* What sector or consumer type is the focus of the program?
- *Anticipated compliance or penetration rate:* How many utilities will achieve the target or standard called for? How many consumers will invest in new equipment based on the initiative? How will this rate change over the time period?
- *Annual degradation factor:* How quickly will the performance of the measure installed degrade or become less efficient?
- *T&D loss:* Is there an increase or decrease in T&D losses that would require adjustment of the energy savings estimate?
- *Adjustment factor:* How should the estimate be adjusted to factor in any inaccuracies in the calculation process? For example, if a program estimates energy generation and capacity of a solar power system, it may adjust the estimates if it suspects there could be variations in system efficiency once implemented.[13]
- *Non-program effects*: What portion of the savings is due to factors outside of the initiative?
- *Funding and administration:* What is the budget for the program and how will it be administered? What are the administrative costs? How much will this reduce the amount of money available to directly obtain energy savings?
- *Energy efficiency and renewable energy potential*: How do the savings projected compare to the potential available? Are they realistic and consistent with other relevant studies?

To save time and ensure completeness, analysts can look to existing analyses to discover the assumptions others have made while analyzing similar programs.

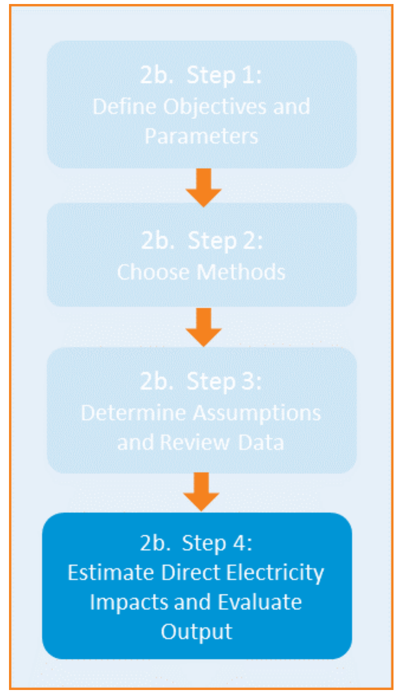
2b. Step 4: Estimate Direct Electricity Impacts and Evaluate Output

In this step, analysts use the assumptions they develop, apply the selected method to the energy efficiency and renewable energy initiative to estimate impacts, and evaluate the output. Factors analysts can consider when estimating the direct electricity impacts of specific programs or policies include:

- *Cost-effectiveness:* When estimating the potential direct electricity impacts, analysts should consider the cost-effectiveness of the measure or programs in the context of the avoided costs[14] of the utility system or region where they are implemented. To evaluate cost-effectiveness, they can conduct simple economic analyses such as project-level discounted cash flow analysis. Discounted cash flow analysis uses projections of future free cash flow (calculated by subtracting the cost of projected capital expenditures from projected operating cash flow)

[13] *To understand how an adjustment factor may be applied, see New Jersey's Clean Energy Program Energy Impact Evaluation at http://www.njcleanenergy.com/files/file/Library/CORE%20Evaluation%20Report%20-%20Draft%20July%2013%202009.pdf.*
[14] *For more information about avoided costs, see Chapter 3, "Assessing the Electricity System Benefits of Energy Efficiency and Renewable Energy."*

and applying a discount rate to estimate current value.[15] Using cash flow analysis, the analyst develops estimates of the discounted cash flow of alternative options reflecting any incentives available under the program or policy, and simply compares those with avoided costs (obtained from the public utility commission [PUC] or other entity, or estimated as discussed in Chapter 3, "Assessing the Electricity System Benefits of Energy Efficiency and Renewable Energy") in the region. For financial incentive-based programs, measures that are less than the avoided cost (considering the incentive) could be expected to enter the mix. For renewable mandates, technologies ranging from least-to-most cost could be considered part of the potential compliance set, up to the minimum amount of capacity required by the portfolio standard or goal.

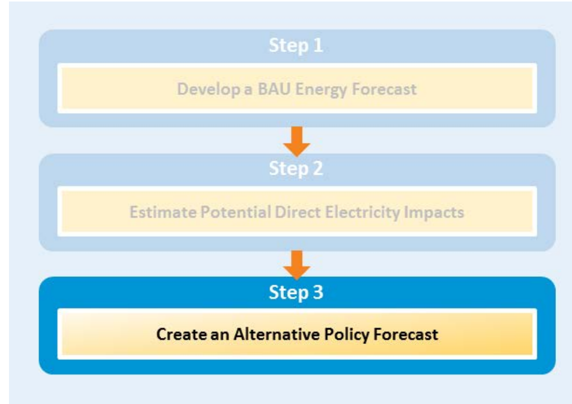


- *Non-compliance:* It is key to remember that there will be some degree of non-compliance for certain mandated programs. For example, building codes do not achieve 100 percent compliance and enforcement is not complete. Calculations should factor non-compliance into the equation.
- *Impacts of incentives*: Incentives associated with an energy efficiency and renewable energy policy can alter the energy savings estimates (e.g., a renewable tax credit could increase renewable energy production beyond RPS levels). If historical trends do not reflect these incentives, or non-economic based methods are used, analysts should attempt to reflect the potential response to these incentives.
- *Effective useful life and persistence of energy savings*: The effective useful life of energy efficiency measures refers to the length of time that they continue to save energy. Persistence refers to the change in savings throughout the functional life of an energy efficiency measure or activity. Both of these factors should be accounted for in calculations.
- *Methodological limitations*: There are limits to any methodology. For example, the revenue stream received by renewables will depend on when they are operative (especially in competitive markets). A basic method may miss the true distribution of costs that developers would face, and thus would provide only a rough estimate of the financial performance of these projects. More sophisticated methods may require this type of data for modeling the performance, economics, and penetration of these technologies.
- *Transparency*: As with all analyses, transparency increases credibility. Be sure to document all sources and assumptions.

Once potential electricity savings or generation impacts are estimated, the analyst can evaluate the output to ensure that the numbers are reasonable and meet the policy goals. If the results do not seem realistic, the analyst may need to review assumptions and reapply the approach or model in an iterative fashion to achieve reasonable electricity savings or renewable energy generation estimates. The resulting electricity estimates can be compared to an energy efficiency or renewable energy potential study, if available, to ensure that the policy analysis does not overestimate the possible savings or generation levels.

[15] *A basic description of discounted cash flow analysis is available at http://www.investopedia.com/terms/d/dcf.asp.*

2.2.3. Step 3: Create an Alternative Policy Forecast



Using the direct electricity impacts of energy efficiency and renewable energy estimated under Step 2, the analyst can then create an alternative policy forecast (using the same methods used to develop the BAU energy forecast under Step 1) that adjusts the BAU energy forecast to reflect the energy efficiency and renewable energy policy or program. In the case of efficiency, the electricity savings estimates would be subtracted from the BAU energy forecast to create a new alternative policy forecast; renewable energy generation estimates would be added to it.[16] The assumptions in the model would need to be adjusted to reflect any change in renewable energy supply expected from the initiative.

The impact estimates—and many of the same sophisticated demand-and-supply models—can also be used to assess impacts on the electric power system and project what generation is likely to be displaced that otherwise would have been in operation. This is discussed in more detail in Chapter 3, "Assessing the Electricity System Benefits of Energy Efficiency and Renewable Energy." The estimates can also be used to determine environmental and economic benefits as described in Chapter 4, "Quantifying the Emissions and Health Benefits of Energy Efficiency and Renewable Energy Initiatives," and Chapter 5, "Estimating the Economic Benefits of Energy Efficiency and Renewable Energy Initiatives."

2.3. CASE STUDIES

The following two case studies illustrate how estimating the direct electricity impacts associated with energy efficiency and renewable energy can be used in the state energy planning and policy decision-making process. Information about a range of tools and resources analysts can use to quantify these impacts, including those used in the case studies, is available in Section 2.4., "Tools and Resources."

2.3.1. Texas Building Code

Benefits Assessed in Analysis

- Electricity savings
- NO_x reductions

Energy Efficiency/Renewable Energy Program Description

The Texas Emissions Reduction Plan (TERP), initiated by the Texas Legislature (Senate Bill 5) in 2001 and authorized to run through 2019, establishes voluntary financial incentive programs and other assistance programs to improve air quality (i.e., ozone formed from nitrogen oxides (NO_x) and volatile organic compounds) in the state. One component of TERP recognizes the role of energy efficiency and renewable energy measures in contributing to a comprehensive approach for meeting federal air quality standards. Consequently, the legislation requires the Energy Systems Laboratory (ESL) at the Texas Engineering Experiment Station of the Texas A&M University System to submit an annual report to the Texas Commission on Environmental Quality estimating the historical and potential future energy savings from energy building code adoption and, when applicable, from more stringent local codes or above-code performance ratings. The report also includes estimates of the potential NO_x reductions resulting from these energy savings. ESL has

[16] *Alternatively, two forecasts may be produced, with and without the energy efficiency or renewable energy initiatives, and the difference would represent their impacts. This methodology would be more likely when using bottom-up economic-engineering approaches.*

conducted this annual analysis since 2002 and submits it in a report entitled *Energy Efficiency/Renewable Energy Impact in the Texas Emissions Reduction Plan*. ESL also provides assistance to building owners on measurement and verification activities.

Method(s) Used

ESL determined the energy savings and resulting NO_x emissions for new residential single- and multi-family construction and for commercial office buildings in Texas counties that have not attained federal air quality standards. A brief summary of the approach for estimating energy savings for both types of buildings is provided below.

Step 1: Develop BAU Forecast

- *Residential buildings.* First, ESL determined new construction activity by county. The baseline for estimating energy savings for single- and multi-family buildings uses published data on residential construction characteristics by the 2008 National Association of Home Builders, based on the International Energy Conservation Code (IECC) 2006 building code.
- *Commercial buildings*. The process to estimate energy savings begins with estimating the number of buildings and relative energy savings. ESL used Dodge Data and Analytics MarketShare, a proprietary database that provides construction start data, to gather the square footage of new commercial construction in Texas.

Step 2: Estimate Potential Direct Electricity Impacts

- *Residential buildings*. Annual and peak day energy savings (in kWh) attributable to the Texas building code are modeled using a DOE-2 simulation that ESL developed for the TERP. These estimates are then applied to National Association of Home Builders survey data to determine the appropriate number of housing types.
- *Commercial buildings*. Energy savings are estimated from code-compliant buildings (American Society of Heating, Refrigerating and Air-Conditioning Engineers [ASHRAE] Standard 90.1-2007) against pre-code buildings (ASHRAE Standard 90.1-2004), using data from the U.S. Department of Energy (U.S. DOE) and constructed square footage in Dodge data.

Step 3: Create Alternative Policy Forecast

After residential and commercial building savings are estimated, these savings are projected to 2020 by incorporating a variety of adjustment factors. These factors include:

- *Annual degradation factor:* This factor was used to account for an assumed decrease in the performance of the measures installed as the equipment wears down and degrades. With the exception of electricity generated from wind (which is assumed to have a degradation factor of zero), ESL used an annual degradation factor of 2 percent for single-family, multi-family, and commercial programs, and an annual degradation factor of 5 percent for all other programs. The 5 percent value was taken from a study by Kats et al. (1996).
- *T&D loss:* This factor adjusts the reported savings to account for the loss in energy resulting from the T&D of the power from the electricity producers to the electricity consumers. For this calculation, the electricity savings reported at the consumer level were increased by 7 percent to give credit for the actual power produced that is lost in the T&D system on its way to the customer. In the case of electricity generated by wind, it was assumed there was no net increase or decrease in T&D losses given that wind energy is displacing power produced by conventional power plants.
- *Initial discount factor*: This factor was used to discount the reported savings for any inaccuracies in the assumptions and methods employed in the calculation procedures. For the single-family, multi-family, and commercial programs, the discount factor was taken as 10 percent. For the savings and State Energy

Conservation Office (SECO) programs, the discount factor was 60 percent. The discount factor for SEER 13 single-family and SEER 13 multi-family program was 20 percent.

- *Annual growth factor*: These factors for single-family (3.3 percent), multi-family (1.5 percent), and for commercial (3.3 percent) construction are derived from recent U.S. Census data for Texas. The growth factor for wind energy (3.9 percent) is a linear projection based on the installed wind power capacity from 2009 to 2012 from the Public Utility Commission of Texas. No growth was assumed for PUC programs, SECO, and SEER 13 entries. The analysis assumed that the same amount of electricity savings from the code-compliant construction would be achieved for each year after 2013 through 2020.

Results

The ESL 2015 annual report on the energy efficiency and renewable energy impacts of the TERP, submitted to the Texas Commission on Environmental Quality in February 2017, describes prospective energy savings (compared with 2008 base-year levels) resulting from implementing the International Residential Code (IRC) and the IECC in residential and commercial buildings, respectively, through 2020. According to the report, the annual energy savings from code-compliant residential and commercial construction were estimated to be:

- 1,158,444 MWh of electricity/year in 2015 (3.9 percent of total electricity savings from TERP) and 2,454,765 MWh/year by 2020 (5.4 percent of total electricity savings from TERP)
- ESL divided the actual and projected energy savings into the different Power Control Authorities and, using EPA's eGRID emission factors, calculated the cumulative annual NO_x emissions reduction values as follows:
- 292 tons of NO_x/year in 2015 (3.6 percent of total NO_x savings from TERP)
- 620 tons of NO_x/year by 2020 (5 percent of total NO_x savings from TERP)

For More Information

Resource Name	Resource Description	URL Address
Texas Building Code Case Study		
Energy Efficiency/ Renewable Energy Impact in the Texas Emissions Reduction Plan	Annual Report to the Texas Commission on Environmental Quality (TCEQ) January 2015–December 2015, Volume I: Technical Report (submitted to TCEQ in February 2017).	http://oaktrust.library.tamu.edu/handle/1969.1/160308

2.3.2. Vermont – Energy Demand and Energy Savings Forecasting

Benefits Assessed in Analysis

- Electricity savings

Energy Efficiency/Renewable Energy Program Description

The Vermont Department of Public Service (DPS) forecasts energy demand and energy efficiency program savings as part of its long-term state energy policy and planning process. This process includes developing strategies and studies, including:

- The Comprehensive Energy Plan (required under statute to be conducted every 5 years)
- The 20-Year Electric Plan (also required every 5 years)

- The Vermont Energy Efficiency Potential Study (most recently updated in 2013 as a limited update to a more comprehensive study in 2011)
- A variety of other state planning initiatives, including a Total Energy Study released in 2014 (Vermont DPS, 2016)

The DPS uses these publications as tools to help manage the transition from traditional energy fossil fuel to cleaner energy supplies to benefit Vermont's economic and environmental future and to track progress toward the achievement of Vermont's renewable energy goals (see Table 2-4). These resources provide a means for them to show how energy demand and energy efficiency program forecasts fit into the bigger planning picture.

Table 2-4: Cumulative Annual Residential (MWh) Savings Potential for Vermont

Year	Statewide Cumulative Annual Savings – Max. Achievable (MWh)
2014	77,286
2015	159,651
2016	242,951
2017	319,935
2018	381,341
2019	439,261
2020	494,935
2021	467,060
2022	504,617
2023	538,433
2024	563,622
2025	588,142
2026	609,965
2027	631,020
2028	651,189
2029	668,674
2030	684,205
2031	698,925
2032	771,096
2033	723,116
Total	**10,215,424**

Source: GDS Associates, Inc., Electric Energy Efficiency Potential for Vermont (For VT DPS, 2013), http://publicservice.vermont.gov/sites/dps/files/documents/Energy_Efficiency/2013%20VT%20Energy%20Efficiency%20Potential%20Study%20Update_FINAL_03-28-2014.pdf.

Method(s) Used

For the 2013 update to the 2011 *Vermont Energy Efficiency Potential Study*, Vermont DPS collaborated with a team of consultants to estimate the state's potential to reduce electricity consumption and peak demand by implementing energy efficiency measures. The study relied on Vermont-specific cost estimates based on fuel and electricity cost projections, as well as assessments of building and equipment characteristics. One of the savings categories analyzed is the statewide cumulative annual residential energy savings potential in MWh. The process to forecast energy savings in Vermont required several steps:

Step 1: Develop BAU Energy Forecast

This step was completed under the original 2011 study; the 2013 study applied updated load forecasts.

Step 2: Estimate Potential Direct Electricity Impacts

- *Determine energy efficiency technical potential by measure* (i.e., retrofit, early retirement, and replace-on-burnout approaches to increase efficiency of a building, leading to savings in electricity, natural gas, and other fuels from a range of DSM programs). Measures analyzed in this report included appliances, electronics, HVAC, lighting, water heating, and fuel switching. The research team separated existing and new homes into single- and multi-family markets because of differences in energy consumption. The savings estimates were based on the most recent available residential electric sales forecasts for Vermont's service territories for 2014 through 2033.

- *Estimate the achievable, cost-effective potential for electric energy and peak demand savings.* The analysis relied on a bottom-up approach to calculate residential energy savings, using Vermont-specific conditions. This bottom-up approach started with the number of residential customers in each category (single- or multi-family, old or new construction). The equation used for residential sector technical potential was as follows: technical potential of efficient measure = (total # households x base case equipment end-use intensity x saturation share x applicability factor x savings factor).

Step 3: Create Alternative Policy Forecast

- *Develop a 20-year forecast of electric energy use.* DPS hired consultants to develop a baseline projection of energy demand given current trends and use patterns and a forecast of expected demand, assuming implementation of the new DSM measures, built up from estimates of energy use by appliance type and end-use category by sector (e.g., the number of refrigerators in the residential sector) and the savings potential for each. The level of maximum efficiency potential in Vermont by DSM programs was determined by using a market penetration scenario that aims for installation of energy efficiency measures in 80–90 percent of the remaining eligible market over a 20-year period. The potential energy efficiency efforts could reduce the residential winter peak demand by nearly 25 percent of the 2033 projected demand. Results presented in Table 2-4, above, show the statewide potential for cumulative annual residential energy savings (MWh) through 2033, but the analysis also reported results by energy efficiency measure, winter and summer peak demand potential by measure, incremental savings, benefits and cost associated with potential savings, and results by service territory. Metrics were also reported for commercial and industrial potential savings.

Results

- These projections and the analysis show that the cumulative savings potential over the next 20 years could be significant for households and commercial and industrial entities in Vermont.
- The report estimates a maximum achievable potential electricity savings of 1,450,000 MWh for the entire state, or a 23.4 percent reduction from projected 2033 electricity sales.
- A Vermont societal test[17] found that the benefit/cost ratio of implementing the maximum achievable potential energy savings was 3.6.
- Vermonters could benefit significantly from greater implementation of energy efficiency measures, and could save up to $3.6 billion in net present savings over the next two decades.

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[17] *The Vermont Societal Test, originally adopted by the PSC in 1997, includes a $.0070 per kWh saved adder to program electric energy benefits for environmental benefits, and a 10 percent reduction to program costs to account for the risk diversification benefits of energy efficiency measures and programs.*

- Important caveats include the fact that the savings realized by the people of Vermont will ultimately be determined by their participation in available DSM programs and state funding, and that the analysis assumed unconstrained budget amounts for Vermont's DSM programs through 2033; actual budget allocations determined by the state will affect the actual savings realized.
- The Vermont DPS can choose to use this analysis to target resources for energy efficiency programs over the next 20 years, enabling energy efficiency to play an increasingly critical role in the state's resource mix.

For More Information

Resource Name	Resource Description	URL Address
Vermont – Energy Demand and Energy Savings Forecasting Case Study		
Vermont Energy Efficiency Potential Study Update Final Report	This 2013 technical memorandum presents results from the evaluation of opportunities for energy efficiency programs in the service areas of Vermont's two energy efficiency utilities (EEU). The Vermont Public Service Board appointed the Burlington Electric Department as the EEU for the City of Burlington, and the Vermont Energy Investment Corporation as the EEU for the remainder of the State, under the name Efficiency Vermont. Prepared by for the Vermont DPS by GDS Associates, Inc.	http://publicservice.vermont.gov/sites/dps/files/documents/Energy_Efficiency/2013%20VT%20Energy%20Efficiency%20Potential%20Study%20Update_FINAL_03-28-2014.pdf
Vermont Comprehensive Energy Plan	This 2016 plan makes specific recommendations on ways in which the state can support, guide, expand, or take the critical next steps to help lead Vermont, the region, and the nation into a sustainable, affordable renewable-energy future. Developed by the Vermont DPS.	https://outside.vermont.gov/sov/webservices/Shared%20Documents/2016CEP_Final.pdf

2.4. TOOLS AND RESOURCES

This section lists and describes available data sources, tools, and other resources analysts can use to implement the methods described in this chapter, organized by step.

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

2.4.1. Tools and Resources for Step 1: Develop a BAU Forecast

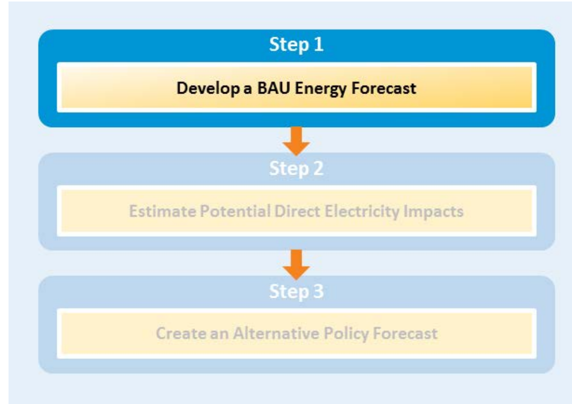
A range of baseline data resources and tools are available to analysts to develop a BAU energy forecast.

Sources for Baseline Data and Forecasts

Analysts can use a variety of data sources to develop their energy baseline and forecasts. Note that some of these sources provide historical data, some provide forecasted data, and some provide both.

Population Data

- The **U.S. Census Population Estimates Program** provides historical and projected population data. https://www.census.gov/programs-surveys/popest.html



Economic Variables

- The **Bureau of Economic Analysis** (http://www.bea.gov/), **Bureau of Labor Statistics** (http://www.bls.gov/), and the **U.S. Census Economic Census** (https://www.census.gov/programs-surveys/economic-census.html) all provide macroeconomic data on variables that analysts can use, such as full-time equivalent and short-term jobs created, dollar value of additional wages per year, job-years per dollar invested, dollar value of energy savings generated, dollar value of total value added, and dollar value of GSP generated.

Electricity and Fuel Prices

- EIA provides regional electricity and fuel price forecasts out to 2040 in the **Annual Energy Outlook** (http://www.eia.gov/forecasts/aeo/index.cfm). Price projections may also be available from PUCs and ISOs, although proprietary constraints may limit the amount available. Many private data providers may also be able to offer data that are more recent than those from publicly available sources.

State Sources

- **State Energy Offices and Departments of Transportation**. Most states collect historical and forecast data for both supply and demand information. Other agencies may have compiled similar energy information that could be used for this effort. Examples of state demand forecasts from California are provided below.
  - California Energy Commission. 2005. ***Energy Demand Forecast Methods Report***. Companion Report to the California Energy Demand 2006–2016 Staff Energy Demand Forecast Report. http://www.energy.ca.gov/2005publications/ CEC-400-2005-036/CEC-400-2005-036.PDF
  - CEC. 2007. ***California Energy Demand 2008-2018, Staff Revised Forecast***. http://www.energy.ca.gov/2007publications/CEC-200-2007-015/CEC-200-2007-015-SF2.PDF

Utility Sources

- **Consumer Energy Use Profiles by Sector**. Most utilities conduct audits or energy efficiency evaluation studies as part of energy efficiency programs' regular reporting. Data are customer-specific load profiles that can be used to build up total demand.
- **Independent System Operators (ISOs) or Regional Transmission Organizations (RTOs)**. Supply and total demand information to be used for planning purposes. Available from the Midwest Independent System Operator (MISO), ISO-New England, Pennsylvania-New Jersey Maryland Interconnection, Southwest Power Pool, California ISO, Electric Reliability Council of Texas, Florida Reliability Coordinating Council, and New York Independent System Operator.
- **North American Electric Reliability Corporation (NERC).** Capacity and demand, up to 10-year projections of electricity demand, electric generating capacity, and transmission line mileage. Generation data include unit-level statistics on existing generators, planned generator additions and retirements, and proposed equipment modifications. Free to government agencies. http://www.nerc.com/pa/RAPA/ESD/Pages/default.aspx
- **Public Utility Commissions (PUCs)**. Most PUCs collect historical and forecast data. These are usually supplied from utilities and studies and can be used to collect supply and demand data.

- **Regional Councils That Coordinate Energy Planning**. Regional councils, such as the Northwest Power and Conservation Council that covers Idaho, Montana, Oregon, and Washington, may be able to provide regional baseline and other data.
- **Utility Integrated Resource Planning Filings**. Most utilities collect historical and forecast data.

Federal Agency Sources

- DOE's Energy Information Administration (EIA)
- **EIA Annual Energy Outlook.** National forecast of supply and demand. http://www.eia.gov/forecasts/aeo/
- **EIA Electric Power Annual**. National, some regional and state level capacity and demand, margin, energy retail sales (MWh), revenue, emissions, short-term plans, etc. http://www.eia.doe.gov/cneaf/electricity/epa/epa_sprdshts.html
- **EIA Electric Sales, Revenue, and Price Tables or EIA Annual Electric Utility Data—EIA-860, 906, 861 Data File**. Annual data, peak, generation, demand/consumption, revenues, utility type, and state. http://www.eia.doe.gov/cneaf/electricity/epa/epa_sum.html http://www.eia.doe.gov/cneaf/electricity/page/eia861.html http://www.eia.doe.gov/cneaf/electricity/page/eia906_920.html
- **EIA Energy Consumption Surveys.** *EIA Manufacturing Energy Consumption Survey (MECS); Commercial (CBECS); Residential (RECS)***.** EIA's national surveys provide data on energy consumption in the manufacturing, commercial, and residential sectors. http://www.eia.doe.gov/emeu/mecs/contents.html; http://www.eia.doe.gov/emeu/cbecs/; http://www.eia.doe.gov/emeu/recs/contents.html
- **EIA State Electricity Profiles**. Detailed electricity data by state. https://www.eia.gov/electricity/state/
- **EIA State Energy Profile, State Energy Data (SEDS).** Annual production, consumption, prices, and expenditures by energy source. http://tonto.eia.doe.gov/state/ http://www.eia.doe.gov/cneaf/electricity/epm/table1_6_a.html http://www.eia.doe.gov/emeu/states/_seds.html
- **DOE's National Renewable Energy Laboratory (NREL).** Data on various renewable energy technologies and some costs. http://www.nrel.gov/rredc/
- **Baseline Cost of Energy for Renewable Energy Technologies**. NREL prepares annual input assumptions (e.g., technology and fuel costs) and scenarios to support and inform electric sector analysis in the United States. http://www.nrel.gov/analysis/data_tech_baseline.html
- **EPA's Emissions & Generation Resource Integrated Database (eGRID).** https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid
- **EPA's Energy-Environment Guide to Action.** A guide to state policies and best practices for advancing energy efficiency, renewable energy, and CHP. https://www.epa.gov/sites/production/files/2015-08/documents/guide_action_full.pdf
- **EPA's Webinar on Assessing Energy Efficiency Potential in Your State**, November 13, 2015. https://www.energystar.gov/index.cfm?c=partners.pt_state_resources

Table 2-5: Sample Energy Data Sources for Developing Baselines and BAU Forecasts

	Electric		Natural Gas		Other Fuels	
	Historic	Forecast	Historic	Forecast	Historic	Forecast
State Sources						
State Energy, Utility Commissions, Transportation, or Other Offices	X	X	X	X	X	X
Utility-Related Sources						
Utilities	X	X	X	X	X	X
Consumer Energy Profiles (Residential, Commercial, Industrial)	X		X		X	
Public Utility Commissions (PUCs)	X	X	X	X	X	X
Independent System Operators/ Regional Transmission Organizations (ISOs/RTOs)	X	X				
North American Electric Reliability Corporation (NERC) Electricity Supply and Demand Database	X	X				
Federal Agency Sources						
EIA Electric Power Annual	X					
EIA State Energy Profile, State Energy Data (SEDS)	X		X		X	
EIA Electric Sales, Revenue, and Price Tables or EIA Annual Electric Utility Data—EIA-860, 906, 861 Data File	X					
EIA Manufacturing Energy Consumption Survey (MECS); Commercial (CBECS); Residential (RECS)	X		X		X	
EIA Annual Energy Outlook	X	X	X	X	X	X
EPA Emissions & Generation Resource Integrated Database (eGRID)	X					
NREL	X		X	X	X	X

Models and Tools for Developing a Baseline Forecast

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

Economic Dispatch Models

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

- **GE Multi-Area Production Simulation (MAPS)™.** A chronological model that contains detailed representation of generation and transmission systems, MAPS can be used to study the impact on total system emissions that result from the addition of new generation. MAPS software integrates highly detailed representations of a system's load, generation, and transmission into a single simulation. This enables calculation of hourly production costs in light of the constraints imposed by the transmission system on the economic dispatch of generation. http://www.geenergyconsulting.com/practice-area/software-products/maps
- **Integrated Planning Model (IPM)®.** This model simultaneously models electric power, fuel, and environmental markets associated with electric production. It is a capacity expansion and system dispatch model. Dispatch is based on seasonal, segmented load duration curves, as defined by the user. IPM also has the capability to model environmental market mechanisms such as emissions caps, trading, and banking. System dispatch and boiler

and fuel-specific emission factors determine projected emissions. IPM can be used to model the impacts of energy efficiency and renewable energy resources on the electric sector in the short and long term. http://www.icf.com/resources/solutions-and-apps/ipm

- **PLEXOS®**. A simulation tool that uses linear programming/mixed integer programming optimization technology to analyze the power market, PLEXOS contains production cost and emissions modeling, transmission modeling, pricing modeling, and competitiveness modeling. PLEXOS allows the user to select emissions of interest (e.g., CO_2, NO_x, SO_2, etc.). The tool can be used to evaluate a single plant or the entire power system. http://www.energyexemplar.com
- **PROMOD IV®**. A detailed generator and portfolio modeling system, with nodal locational marginal pricing forecasting and transmission analysis, PROMOD IV can incorporate extensive details in generating unit operating characteristics and constraints, transmission constraints, generation analysis, unit commitment/operation conditions, and market system operations. http://new.abb.com/enterprise-software/energy-portfolio-management/market-analysis/promod
- **PROSYM (Zonal Analysis)™.** A chronological electric power production costing simulation computer software package, PROSYM is designed for performing planning and operational studies. As a result of its chronological nature, PROSYM accommodates detailed hour-by-hour investigation of the operations of electric utilities. Inputs into the model are fuel costs, variable operation and maintenance costs, and startup costs. Output is available by regions, by plants, and by plant types. The model includes a pollution emissions subroutine that estimates emissions with each scenario. http://new.abb.com/enterprise-software/energy-portfolio-management/market-analysis/zonal-analysis

Capacity Expansion Models

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

- **AURORA**. The AURORA model, developed by EPIS LLC, provides electric market price forecasting, estimates of resource and contract valuation and net power costs, long-term capacity expansion modeling, and risk analysis of the energy market. http://epis.com/aurora/
- **DOE's National Energy Modeling System (NEMS).** NEMS is a system-wide energy model (including demand-side sectors) that represents the behavior of energy markets and their interactions with the U.S. economy. The model achieves a supply/demand balance in the end-use demand regions, defined as the nine U.S. Census Bureau divisions, by solving for the prices of each energy product that will balance the quantities producers are willing to supply with the quantities consumers wish to consume. The system reflects market economics, industry structure, and existing energy policies and regulations that influence market behavior. https://www.eia.gov/outlooks/aeo/info_nems_archive.php
- **Electric Generation Expansion Analysis System (EGEAS).** EGEAS was developed by the Electric Power Research Institute, is a set of computer modules that are used to determine an optimum expansion plan or simulate production costs for a pre-specified plan. Optimum expansion plans are based on annual costs, operating expenses, and carrying charges on investment. http://eea.epri.com/models.html#tab=3
- **e7 Capacity Expansion.** e7 Capacity Expansion is an energy portfolio management solution from ABB covering resource planning, capacity expansion, and emissions compliance. It enables resource planners and portfolio managers to assess and develop strategies to address current and evolving RPSs and emissions regulations. http://new.abb.com/enterprise-software/energy-portfolio-management/commercial-energy-operations/capacity-expansion

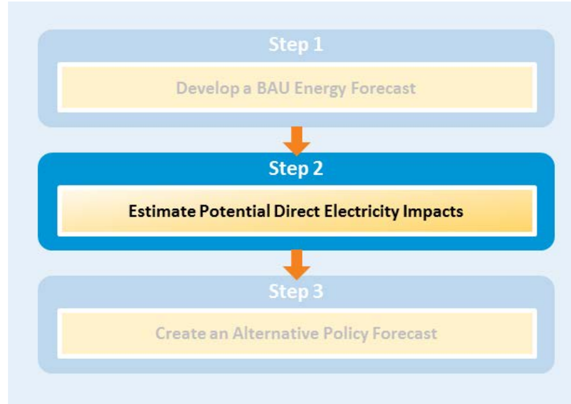
- **e7 Portfolio Optimization**. Portfolio optimization models unit operating constraints and market conditions to facilitate the analysis and simulation of scenarios. The model optimizes a combined portfolio of supply resources and energy efficiency or distributed generation assets modeled as virtual power plants. http://new.abb.com/enterprise-software/energy-portfolio-management/commercial-energy-operations/portfolio-optimization
- **ENERGY 2020**. Energy 2020 is a simulation model available from Systematic Solutions that includes all fuel, demand, and supply sectors and simulates energy consumers and suppliers. This model can be used to capture the economic, energy, and environmental impacts of national, regional, or state policies. Energy 2020 models the impacts of an energy efficiency or renewable energy measure on the entire energy system. User inputs include new technologies and economic activities such as tax breaks, rebates, and subsidies. It is available at the national, regional, and state levels. http://www.energy2020.com/
- **Integrated Planning Model (IPM)®.** This model simultaneously models electric power, fuel, and environmental markets associated with electric production. It is a capacity expansion and system dispatch model. IPM also has the capability to model environmental market mechanisms such as emissions caps, trading, and banking. System dispatch and boiler and fuel-specific emission factors determine projected emissions. IPM can be used to model the impacts of energy efficiency and renewable energy resources on the electric sector in the short and long term. http://www.icf.com/resources/solutions-and-apps/ipm
- **Long-Range Energy Alternatives Planning System (LEAP).** LEAP is an integrated, scenario-based modeling tool developed by the Stockholm Environment Institute. LEAP can be used to track energy consumption, production, and resource extraction in all sectors of the economy at the city, regional, state, or national scale. Beginning in 2018, LEAP includes the integrated benefits calculator, which can be used to estimate health (mortality), agriculture (crop loss) and climate (temperature change) impacts of scenarios. It can be used to account for both energy sector and non-energy sector greenhouse gas emissions sources and sinks, and to analyze emissions of local and regional air pollutants, and short-lived climate pollutants. www.energycommunity.org
- **NREL's Regional Energy Deployment System model (ReEDS).** This is a long-term capacity expansion model that determines the potential expansion of electricity generation, storage, and transmission systems throughout the contiguous United States over the next several decades. ReEDS is designed to determine the cost-optimal mix of generating technologies, including both conventional and renewable energy, under power demand requirements, grid reliability, technology, and policy constraints. Model outputs are generating capacity, generation, storage capacity expansion, transmission capacity expansion, electric sector costs, electricity prices, fuel prices, and carbon dioxide emissions. http://www.nrel.gov/analysis/reeds/
- **NREL's Resource Planning Model (RPM).** RPM is a capacity expansion model designed to examine how increased renewable deployment might impact regional planning decisions for clean energy or carbon mitigation analysis. RPM includes an optimization model that finds the least-cost investment and dispatch solution over a 20-year planning horizon for different combinations of conventional, renewable, storage, and transmission technologies. The model is currently only available for regions within the Western Interconnection, while a version for regions in the Eastern Interconnection is under development. https://www.nrel.gov/analysis/models-rpm.html

2.4.2. Tools and Resources for Step 2: Estimate Potential Direct Electricity Impacts

Analysts can use the tools described below to develop estimates of potential direct electricity benefits.

Tools for Estimating Direct Electricity Impacts

Internet-Based Methods



- **EPA's ENERGY STAR® Portfolio Manager® Portfolio of Buildings**. Free online, interactive tool that benchmarks the performance of existing commercial buildings on a scale of 1–100 relative to similar buildings. Tracks energy and water consumption for a building or portfolio of buildings and calculates energy consumption and average energy intensity. Analysts can use to evaluate potential energy savings of existing buildings by building type for an energy efficiency and renewable energy policy (e.g., a building code policy) and apply savings across the population. https://www.energystar.gov/buildings/facility-owners-and-managers/existing-buildings/use-portfolio-manager

  Level of analysis: Existing buildings

- **Roofing Savings Calculator**. Free calculator that estimates energy and cost savings from installing an ENERGY STAR® labeled roof product in a home or building. http://rsc.ornl.gov/

  Level of analysis: Buildings

- **EPA's ENERGY STAR® Target Finder Calculator**. Free tool that helps planners, architects, and building owners set aggressive, realistic energy targets and rate a building design's estimated energy use. Use the tool to determine: energy performance rating (1–100), energy reduction percentage (from an average building), source and site energy use intensity (kBTU/sf/yr), source and site total annual energy use (kBTU), and total annual energy costs. Analysts can use to evaluate potential energy savings of new/planned buildings by building type for an energy efficiency and renewable energy policy (e.g., a building code policy) and apply savings across the population. http://www.energystar.gov/targetfinder

  Level of analysis: New buildings

- **NREL's Wind Integration Data Sets**. Free datasets that can help users estimate power production from hypothetical wind power plants. http://www.nrel.gov/grid/wind-integration-data.html

  Level of analysis: Wind energy projects

- **PVWatts™**. A free solar technical analysis model available from NREL that produces an estimate of monthly and annual PV production (kWh) and cost savings. Users can select geographic location and use either default system parameters or specify parameters for their PV system. Data can be used to accumulate project-specific savings toward renewable energy policy goals for solar-related technologies. http://pvwatts.nrel.gov/

  Level of analysis: Grid-connected PV systems

Spreadsheet-Based Methods

- **CHP Spark Spread Estimator**. A free Excel-based tool used to evaluate a prospective CHP system for its potential economic feasibility. The CHP Spark Spread Estimator calculates the difference between the delivered electricity price and the total cost to generate power with a prospective CHP system. In addition to comparing a preliminary estimate of the cost to generate power onsite (in terms of $/kWh) to the retail price of power at the site, the estimator provides an approximate comparison of energy consumption and costs with and without CHP. https://www.epa.gov/sites/production/files/2015-09/spark_spread_estimator.xlsm

Level of analysis: CHP systems

- **EPA's ENERGY STAR Savings Calculators**. Series of free tools that calculate energy savings and cost savings from ENERGY STAR-qualified equipment. Includes commercial and residential appliances, heating and cooling, lighting, office products, and other equipment. https://www.energystar.gov/buildings/facility-owners-and-managers/existing-buildings/save-energy/purchase-energy-saving-products

  Level of analysis: Energy Efficiency measures

- **State and Utility Pollution Reduction Calculator Version 2 (SUPR2).** Free tool that provides high-level estimates of energy savings from various policies and technologies that could help an individual state meet its air quality goals. SUPR2's policy and technology options include energy efficiency, renewable energy, nuclear power, emissions control options, and natural gas. http://aceee.org/research-report/e1601

  Level of analysis: Energy efficiency measures

Software Methods

- **DSMore™**. Commercial model designed to evaluate the costs, benefits, and risks of DSM programs and services. Evaluates thousands of DSM scenarios over a range of weather and market price conditions. Although it requires detailed input data, the model uses these data to produce detailed outputs, including energy savings impacts associated with the type of fuel that is being saved (gas or electricity), and provides for expansive scenario analyses. http://www.integralanalytics.com/products-and-services/dsm-planning-and-evaluation/dsmore.aspx

  Level of analysis: DSM programs

- **eQuest®**. Free building simulation model for weather-dependent energy efficiency measures. Energy savings can be applied across the population. http://www.doe2.com/equest/

  Level of analysis: Buildings

- **EnergyPlus**. Free, whole-building energy simulation model from the U.S. DOE for modeling energy consumption—for heating, cooling, ventilation, lighting, and plug and process loads—and water use in buildings. https://energyplus.net/

  Level of analysis: Buildings

- **fChart and PV-fChart**. fChart Software produces the commercial programs fChart and PV-fChart for the design of solar thermal and PV systems, respectively. Both programs provide estimates of performance and economic evaluation of a specific design using design methods based on monthly data. http://www.fchart.com/pvfchart/

  Level of analysis: Solar PV or solar thermal systems

- **HOMER Energy**. Commercial software that evaluates design options for both off-grid and grid-connected power systems for remote, stand-alone, and distributed generation applications. http://homerenergy.com/

  Level of analysis: Microgrids and distributed generation

- **NREL System Advisor Model (SAM)**. A free model that predicts performance and estimates costs for grid-connected power projects based on installation and operating costs and system design parameters that the user specifies as inputs to the model. Projects can be either on the customer side of the utility meter, buying and selling electricity at retail rates, or on the utility side of the meter, selling electricity at a price negotiated through a power purchase agreement. https://sam.nrel.gov/

  Level of analysis: Renewable energy systems

- **RETScreen®**. Energy efficiency and renewable energy project analysis software. Use to evaluate the energy production and savings, costs, emissions reductions, financial viability, and risk for various types of energy efficiency and renewable energy technologies, including renewable energy, cogeneration, district energy, clean power, heating and cooling technologies, and energy efficiency measures. Free version will work for most uses; additional features are available in a paid version. http://en.openei.org/wiki/RETScreen_Clean_Energy_Project_Analysis_Software

  Level of analysis: Renewable energy and energy efficiency projects

- **WindPro.** Commercial Windows modular-based software suite for designing and planning single wind turbines and wind farms. http://www.emd.dk/windpro/

  Level of analysis: Wind turbines and wind farms

Resources for Predicting Load Profiles

Several resources are available to help predict the load profile of different kinds of renewable energy and energy efficiency projects:

- **The Connecticut Energy Efficiency Board** maintains a dashboard showing electricity and natural gas energy efficiency savings and spending data, broken out by utility, sector, and year. http://www.energizect.com/connecticut-energy-efficiency-board
- **Load impact profile data** for energy efficiency measures may be available for purchase from various vendors, but typically is not publicly available in any comprehensive manner.
- **NREL** provides solar insolation data and maps, from which solar power generation output can be modeled. Solar insolation data and maps provide monthly average daily total solar energy availability for any area of the country on a per kWh/m^2/day basis. These data sets are used in several publicly available tools, such as NREL's free PV Watts or Homer Energy's commercial microgrid software, where users can specify different solar PV project attributes and estimate the output of the solar generator. http://www.nrel.gov/analysis/
- **The Open PV Project**, also hosted by NREL, is a collaborative effort among government, industry, and the public to compile a database of available public data for PV installations in the United States. https://openpv.nrel.gov
- **State technical resource manuals (TRMs)** contain information on the features and energy savings of a wide range of energy efficiency measures. Approximately 20 states have published TRMs. For example, the California Database for Energy Efficient Resources provides estimates of energy and peak demand savings values, measure costs, and effective useful life of efficiency measures. http://www.deeresources.com/
- Some states or regions have **technology production profiles** in their efficiency and renewable energy potential studies (e.g., NYSERDA's report, *Energy Efficiency and Renewable Energy Resource Development Potential Study of New York State*, 2014. https://www.nyserda.ny.gov/-/media/Files/EDPPP/Energy-Prices/Energy-Statistics/14-19-EE-RE-Potential-Study-Summary.pdf
- **Wind profiles** can be obtained from many sources, including the **U.S. DOE's NEMS model** (https://www.eia.gov/outlooks/aeo/info_nems_archive.php), **NREL's Eastern and Western Wind Datasets** (https://www.nrel.gov/grid/eastern-western-wind-data.html), and the **American Wind Energy Association** (www.awea.org). All data will likely require some extrapolation or transposition for the intended use. Customized data and services are available for purchase from AWS Truepower (https://www.awstruepower.com/) and 3Tier (https://www.3tier.com), which NREL sources for its Eastern and Western Wind Datasets.

Resources and Protocols for EM&V

Use the EM&V resources and protocols below for assessing retrospective impacts of energy efficiency programs.

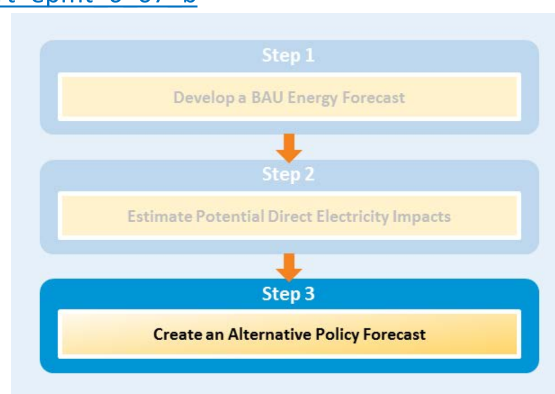
- **California Energy Efficiency Evaluation Protocols**. California Public Utility Commission. Requirements for evaluating energy efficiency programs in California. http://www.calmac.org/publications/EvaluatorsProtocols%5FFinal%5FAdoptedviaRuling%5F06%2D19%2D2006%2Epdf
- **Energy Efficiency Program Impact Evaluation Guide**. U.S. DOE and U.S. EPA. Describes common terminology and approaches used to determine electricity savings and avoided emissions from energy efficiency. https://www4.eere.energy.gov/seeaction/publication/energy-efficiency-program-impact-evaluation-guide
- **Regional EM&V Methods and Savings Assumptions Guidelines, 2010**. Northeast Energy Efficiency Partnerships. Includes methods in determining gross energy and demand savings, and savings assumptions for EE programs. http://www.neep.org/regional-emv-methods-and-savings-assumptions-guidelines-2010
- **Uniform Methods Project**. U.S. DOE. EM&V protocols for common efficiency programs and technologies. http://www.energy.gov/eere/about-us/ump-protocols

2.4.3. Tools and Resources for Step 3: Create an Alternative Policy Forecast

Resources for Determining Capacity Factors

The resources below can be helpful for determining capacity factors for renewables.

- **EIA Electric Power Monthly Capacity Factors for Utility Scale Generators Not Primarily Using Fossil Fuels** http://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_6_07_b



- **NREL System Advisor Model (SAM) Capacity Factor** https://www.nrel.gov/analysis/sam/help/html-php/index.html?mt_capacity_factor.htm
- Summary of Time Period-Based and Other Approximation Methods for Determining the Capacity Value of Wind and Solar in the United States http://www.nrel.gov/docs/fy12osti/54338.pdf

Resources for Energy Efficiency and Renewable Energy Retrospective Data and Potential Studies

- **American Council for an Energy-Efficient Economy (ACEEE).** Consumer resources on appliances, policy, potential study workshops, and technical papers such as the two examples provided below. http://www.aceee.org/
  - Elliott, R. Neal and Anna Monis Shipley. 2005. "Impacts of Energy Efficiency and Renewable Energy on Natural Gas Markets: Updated and Expanded Analysis." ACEEE. April. http://aceee.org/files/pdf/e052full.pdf
  - Elliot, R. Neal and Maggie Eldridge. 2007. "Role of Energy Efficiency and Onsite Renewables in Meeting Energy and Environmental Needs in the Dallas/Fort Worth and Houston/ Galveston Metro Areas." ACEEE. September. http://aceee.org/node/3078?id=93

- **California Database of Energy Efficiency Resources.** Provides documented estimates of energy and peak demand savings values, costs, and effective useful life. In this California Energy Commission and California Public Utilities Commission sponsored database, data are easy to research and could be used as input into internally developed spreadsheets on appliances and other energy efficiency measures, which can be adjusted for the circumstances of different states. http://www.deeresources.com/
- **Entergy Texas Deemed Savings Entergy**. This investor-owned utility provides deemed energy savings for energy efficiency measures, much as the other investor-owned utilities in Texas do. It accounts for the weather zone of the participants. These data could be used as input into internally developed spreadsheet regarding appliances and other energy efficiency measures for a bottom-up method. The data may have to be adjusted for a different state. http://www.entergy-texas.com/ content/Energy_Efficiency/ documents/HelperApplication_ HTR_Entergy_2006.xls
- **Lawrence Berkeley National Laboratory**. Technical resource that tests and invents energy-efficient technologies and provides publicly available research reports and case studies on energy efficiency and renewable energy. http://www.lbl.gov
- **Michigan Energy Measures Database.** Offers information on potential technologies or measures that could be used in an energy efficiency programs and for integrated resource planning, including customized measures for Michigan-specific weather conditions and loads. http://www.michigan.gov/mpsc/0,4639,7-159-52495_55129---,00.html
- **National Renewable Energy Laboratory (NREL).** Provides data on renewable energy and energy efficiency technology, market, benefits, costs, and other energy information. http://www.nrel.gov/analysis/
- **Regional Technical Forum (RTF) deemed savings database**. This was developed by the Northwest Planning Council staff, with input from other members of the RTF, which includes utilities in the four-state region of Oregon, Washington, Idaho, and Montana. Both residential and commercial energy efficiency measures are included. http://www.nwcouncil.org/ energy/rtf/supportingdata/ default.htm
- **Tellus Institute**. High-level reports presenting scenarios on increased efficiency and renewable energy standards, reporting on their impact on the environment. Also provides additional links to the software models used by the Institute, including LEAP (Long-range Energy Planning). http://www.tellus.org/

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PART TWO
CHAPTER 3

Assessing the Electricity System Benefits of Energy Efficiency and Renewable Energy

DOCUMENT MAP

CHAPTER 3 CONTENTS

ABOUT THIS CHAPTER

This chapter provides analysts and policy makers with information about a range of methods they can use to assess the electricity system-related benefits of energy efficiency and renewable energy. It first describes the methods and key considerations for selecting or using the methods. The chapter then provides case studies illustrating how the methods have been applied and lists a range of relevant tools and resources analysts can use to quantify electricity system impacts. Building off the direct electricity impacts discussed in Chapter 2, "Estimating the Direct Electricity Impacts of Energy Efficiency and Renewable Energy," the benefits quantified using methods discussed in this chapter can serve as inputs into subsequent economic assessments discussed in Chapter 5, "Estimating the Economic Benefits of Energy Efficiency and Renewable Energy." Several of the methods and tools described in this chapter can also be used to quantify the emissions impacts of energy efficiency and renewable energy, as discussed in Chapter 4, "Quantifying the Emissions and Health Benefits of Energy Efficiency and Renewable Energy."

3.1. OVERVIEW

Many energy efficiency and renewable energy programs and policies result in reduced demand for electricity from conventional generating resources on the grid. This delivers multiple benefits to the electricity system by:

- Lowering electricity costs for customers and utilities alike, particularly during periods of peak electricity demand[1]
- Improving the reliability of the electricity system and lowering the risk of blackouts, particularly when load is reduced in grid-congested areas
- Reducing the need for new construction of generation, transmission, and distribution capacity[2]

State legislatures, energy and environmental agencies, regulators, utilities, and other stakeholders (e.g., ratepayer advocates, environmental groups) can quantify and compare the electricity system benefits of energy efficiency and renewable energy resources to traditional grid electricity. This information can then be used in many planning and decision-making contexts, including:

- Developing state energy plans and establishing energy efficiency and renewable energy goals
- Conducting resource planning by state utility regulatory commissions or utilities
- Developing demand-side management (DSM) programs
- Conducting electricity system planning, including new resource additions (e.g., power plants), transmission and distribution (T&D) capacity, and interconnection policies
- Planning and regulating air quality, water quality, and land use
- Obtaining support for specific initiatives
- Designing policies and programs

STATES ARE QUANTIFYING THE ELECTRICITY SYSTEM BENEFITS OF ENERGY EFFICIENCY AND RENEWABLE ENERGY POLICIES

Several state policy makers have quantified the electricity system benefits from their energy efficiency and renewable energy measures and determined that the measures are providing multiple benefits, including avoiding the costs of electricity generation, reducing peak demand, and improving electricity system reliability.

The California Public Utility Commission (CPUC) published an evaluation report on the state's energy efficiency programs throughout 2010–2012. These programs resulted in:

- 7,745 Gigawatt-hours (GWh) of savings, enough to power 800,000 homes per year (direct electricity savings)
- Summer peak demand savings of 1,300 Megawatts (MW) (electricity system benefits)
- $5.5 billion in savings for California ratepayers, including the electricity system benefits described above (electricity system benefits and direct electricity savings)

California's energy efficiency programs were also cost-effective; for every dollar invested in energy efficiency programs, savings of $1.31 were achieved.

This chapter is designed to help analysts and decision makers in states and localities understand the methods, tools, opportunities, and considerations for quantifying the electricity system benefits of energy efficiency and renewable energy policies, programs, and measures. While most of the benefits and analytical approaches described in this *Guide* can apply broadly to all types of energy generation and use, the focus of this chapter is primarily on the electricity sector.

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[1] *Just as energy efficiency program economics can be evaluated from a variety of perspectives (total resource costs, program administration costs, and those of ratepayers, participants, and society) so too can the benefits of energy efficiency and renewable energy programs. For each perspective, the benefits of energy efficiency and renewable energy are defined differently. This* Guide *examines the equivalent of the total resource cost perspective, considering benefits (and costs) to the participants and the utility. While other perspectives (including utility costs) are valuable, this* Guide *focuses on those perspectives most significant to policy makers and energy efficiency and renewable energy program administrators. For more information about the different perspectives used to evaluate the economics of programs, see* Understanding Cost-Effectiveness of Energy Efficiency Programs: Best Practices, Technical Methods, and Emerging Issues for Policy Makers: A Resource of the National Action Plan for Energy Efficiency, *November 2008, at https://www.epa.gov/sites/production/files/2015-08/documents/cost-effectiveness.pdf.*

[2] *For an overview of the U.S. electricity system, see: https://www.epa.gov/energy/about-us-electricity-system-and-its-impact-environment.*

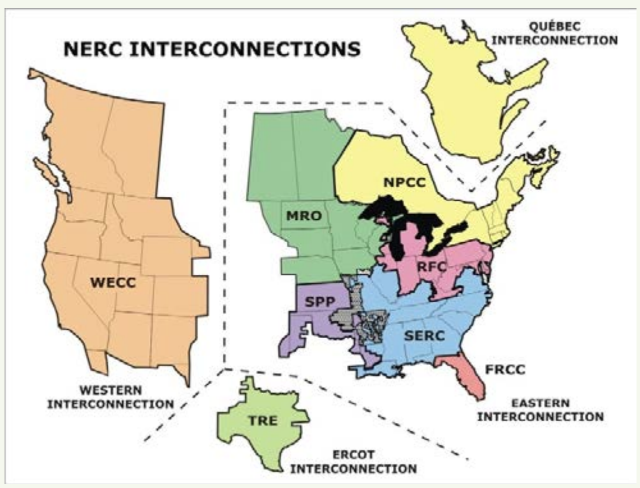
The range of methods and tools described is not exhaustive and inclusion of a specific tool does not imply EPA endorsement.

3.2. APPROACH

The U.S. electricity system is a complex, interconnected system made up of several components—including electricity generation, transmission, and distribution—and the markets by which electricity is bought and sold as described in the box "The U.S. Electricity System." Energy efficiency and renewable energy policies and programs can lead to quantifiable benefits across these multiple facets of the system. When planning an electricity system analysis, it's useful first to review the types of electricity system benefits described in this chapter, select the types of benefits of interest, and explore the ranges of methods available, considering the level of rigor desired and resources available for quantifying the relevant benefits.

THE U.S. ELECTRICITY SYSTEM

It is helpful to understand the nature and complexity of the electricity system before planning an analysis of how it may be affected by energy efficiency or renewable energy policies, programs, and technologies. The power grid is a complex, interconnected system in which most of the electricity is generated at centralized power plants, transmitted over long distances through high-voltage transmissions lines (sometimes across multiple states), and then delivered through local distribution wires to residential, commercial, and industrial end users. The system must generate enough electricity supply to meet demand from all end users and deliver supply through a network of T&D lines. This balancing act takes place in real time, as the grid is limited in its ability to store excess power for later use. Maintaining this balance is challenging because the need for electric services is dynamic, with demand fluctuating depending on the season, the time, and the weather. Supply may also fluctuate based on operating conditions for renewable resources such as solar and wind.



The North American electricity system acts essentially as four separate systems of supply and demand because it is divided into four interconnected grids in the continental United States and Canada: the Eastern, Western, Quebec, and Electric Reliability Council of Texas (ERCOT) Interconnections as depicted in the North American Electric Reliability Corporation (NERC) graphic above. Each interconnection contains power control areas that electricity can be imported or exported easily among numerous power control areas within each system. However, for reliability purposes, they have limited connections between them and are linked by direct current (DC) lines.

System operators across a region decide when, how, and in what order to dispatch electricity from each plant in response to the demand at that moment and based on the cost or bid process. In regulated electricity markets, dispatch is based on "merit order" or the variable costs of running the plants. In markets where regulatory restructuring is active or in wholesale capacity markets, dispatch is based on the generator's bid price into the market. Electricity from the power plants that are least expensive to operate (i.e., the baseload plants) is dispatched first. The power plants that are most expensive to operate (i.e., the peaking units) are dispatched last. The merit order or bid stack is based on fuel costs and plant efficiency, as well as other factors such as emissions allowances prices.

For more information about the electricity system, please see:

- EPA's Website, About the U.S. Electricity System and its Impact on the Environment: https://www.epa.gov/energy/about-us-electricity-system-and-its-impact-environment
- *2017 Electricity System Overview* (U.S. DOE, 2017): https://www.energy.gov/sites/prod/files/2017/02/f34/Appendix--Electricity%20System%20Overview.pdf

Graphic Source: NERC, 2018.

3.2.1. Understanding Primary vs. Secondary Electricity Benefits

For the purposes of this *Guide*, the electricity system benefits of energy efficiency and renewable energy are categorized as either primary or secondary, based on the current frequency of quantification and the prevalence of widely accepted quantification methods. Both categories include generation-related benefits and T&D-related benefits.

Primary Electricity System Benefits

Primary electricity system benefits are quantified often in analyses using methods and tools that are well understood and systematically applied as described in Section 3.2.4., Methods for Quantifying Primary Electricity System Benefits, of this chapter.

Generation-related benefits include:

- Short-run avoided costs of electricity generation or wholesale electricity purchases
- Long-run avoided costs of power plant capacity

T&D-related benefits include:

- Avoided electricity losses during T&D
- Avoided T&D capacity costs associated with building or upgrading T&D systems

Secondary Electricity System Benefits

Secondary electricity system benefits are less frequently assessed and can be more difficult to quantify than primary benefits. The methods for assessing them are less mature than methods for assessing primary benefits and can be diverse, qualitative, and subject to rigorous debate, as described in Section 3.2.5., Methods for Quantifying Secondary Electricity System Benefits, of this chapter.

Generation-related benefits include:

- Avoided ancillary service costs
- Reductions in wholesale market prices
- Avoided risks associated with long lead-time investments, such as the risk of overbuilding the electricity system
- Reduced risks from deferring investments in conventional centralized resources
- Improved fuel diversity and energy security

T&D-related benefits include:

- Increased reliability and improved power quality

USING NET PRESENT VALUE (NPV) WITH BOTH COSTS AND BENEFITS TO COMPARE ENERGY RESOURCES

Decision makers can compare the costs of different energy efficiency and renewable energy resources against each other and against more conventional generating resources by examining their NPV (i.e., the sum of discounted cash flows in terms of costs and savings over the life of the resource). For example, replacing a chiller in a food-processing factory with a more efficient unit incurs a higher capital cost upfront, but reduces annual electricity costs for the customer. Likewise, installing high-efficiency transformers in a new substation can be more expensive than standard equipment in terms of upfront costs, but will waste less electricity over time, thereby reducing variable operating and maintenance costs. The basic concept is to compare the net impact on the cost of power over the lifetime of each alternative that is technically capable of meeting the need. The alternative with the smallest net impact is typically the preferred choice, all other things being equal.

NPV analysis can incorporate multiple electricity system benefits described in this *Guide*, and enable comparison of various options on an equal basis.

Table 3-1 summarizes the traditional costs of generating, transmitting, and distributing electricity, and describes the primary and secondary energy efficiency and renewable energy benefits associated with each type of cost.

Table 3-1: Electricity System Costs and the Primary and Secondary Benefits of Energy Efficiency and Renewable Energy

Aspect of Electricity System	Timing of Costs/Benefits	Traditional Costs	Primary Benefits of Energy Efficiency and Renewable Energy	Secondary Benefits of Energy Efficiency and Renewable Energy
Generation	**Short run**[a]	▪ Fuel ▪ Variable O&M ▪ Emissions allowances	▪ Short-run avoided costs of electricity generation or wholesale electricity purchases	▪ Improved fuel diversity ▪ Improved energy security ▪ Avoided ancillary services costs ▪ Reductions in wholesale market clearing prices ▪ Increased reliability and power quality
	Long run	▪ Capital and operating costs of upgrades ▪ Fixed O&M[b] ▪ New construction to increase capacity	▪ Long-run avoided costs of power plant capacity	▪ Reduced risks from deferring investment in conventional, centralized resources pending uncertainty in future regulations ▪ Avoided risks associated with long lead-time investments (e.g., risk of overbuilding the electricity system)
T&D	**Short run**[a]	▪ Costs of energy losses	▪ Avoided electricity losses during T&D	▪ None
	Long run	▪ Capital and operating costs of upgrades ▪ Fixed O&M ▪ New construction to increase capacity	▪ Avoided T&D capacity costs	▪ Increased reliability and power quality

[a] *Note that short-run costs and benefits, which include the marginal costs of operating the system, also accrue in the long run.*

[b] *Fixed operation and maintenance (O&M) costs could also be impacted in the short run by large changes to the operation of generating units.*

3.2.2. Selecting What Benefits to Evaluate

Some state policy makers may not be interested in estimating all types of electricity system benefits, or they may be considering programs that deliver benefits in only some areas. It is generally common practice for most, if not all, policy makers to evaluate all of the primary benefits for energy efficiency and renewable energy projects or programs.

Secondary benefits, however, may be both harder to quantify and, in some cases, smaller than primary benefits. For these reasons, policy makers with limited time and resources may choose to devote the majority of their time to evaluating primary benefits.

For secondary benefits, the need for detailed estimation can vary depending on several factors, including:

- The type of energy efficiency or renewable energy resource being considered
- Regulatory or system operator study requirements
- Available resources (e.g., computers, staff, and data)
- Whether certain needs or deficiencies have been identified for the existing electricity system

Analysts often devote their limited staff and computing power to quantifying benefits that are likely to yield the most reliable and meaningful results, and address other benefits qualitatively.

3.2.3. Selecting a Method for Quantifying the Electricity System Benefits

When choosing a method for estimating electricity system benefits, analysts:

- Explore the types of methods or tools available for quantifying the specific benefit(s)
- Evaluate the rigor of analysis needed (e.g., screening level vs. regulatory impact analysis) plus any data needs, financial costs, or technical expertise required

Methods for Quantifying Electricity System Benefits

Analysts can use a range of mature methods—from basic to sophisticated—to quantify the electricity system benefits of energy efficiency and renewable energy policies and programs, as introduced below. As described earlier, however, the availability of mature, systematically applied methods for quantifying the electricity system benefits of energy efficiency and renewable energy depends on whether the analyst is quantifying primary or secondary electricity system benefits. When quantifying primary benefits, for example, analysts can choose from a range of well-established basic-to-intermediate and sophisticated approaches. When quantifying secondary benefits, however, analysts can find basic-to-intermediate quantification methods to assess most benefits but fewer applicable sophisticated methods.

Basic-to-Intermediate Methods for Quantifying Electricity System Benefits

Basic-to-intermediate methods typically include:

- Spreadsheet-based analyses
- Adaptation of existing studies or information

These methods generally rely on relatively simple relationships and analytic structures. Many are conceptually similar to sophisticated methods, but use additional simplifying assumptions (e.g., proxy plants, system averages).

For example, when estimating impacts of an energy efficiency or renewable energy resource, analysts may use simplifying assumptions (e.g., for generating units displaced or for emissions rates at the time of displacement) instead of a sophisticated economic dispatch model. While an economic dispatch model would identify specifically those units on the margin (i.e., the last units expected to be dispatched, which are most likely to be displaced by energy efficiency or renewable energy) in each time period, a basic method may pair impacts to the general type(s) of unit(s) expected to be on the margin given the existing units and/or past behavior.

When to use: Analysts can use estimation methods for preliminary assessments or screening exercises, such as comparing the cost of an energy efficiency or renewable energy option with a previous projection of avoided costs or the cost of a proxy plant. Although they are less robust than sophisticated modeling methods, basic methods require less data, time, and resources and can therefore be useful when time, budget, or data are limited.

Sophisticated Methods for Quantifying Electricity System Benefits

Sophisticated methods typically use dynamic, state-of-the-art electricity system models that:

- Simulate and project the response of electric generating units to actions that influence the level of energy efficiency and renewable energy resources.
- Calculate the resulting effects on metrics such as wholesale and retail prices, generation mix, fuel consumption, T&D system adequacy, emissions, and others.

These models have more complex structures and interactions than the basic methods, and are designed to capture the fundamental behavior of the power sector using techno-economic, sometimes referred to as engineering-economic, relationships or econometric methods. Sophisticated methods require additional input assumptions compared with basic methods, but they can generate more complex insights about the impacts on the electricity system.

For example, capacity expansion models can depict how the operations and/or capacity needs of the existing electric grid are likely to change with the adoption of an energy efficiency or renewable energy resource. Some models can also predict energy prices, emissions, and other market conditions.

These models are complex to set up and can be costly. Developing a detailed representation of the electricity system can involve many individual input assumptions, and it is helpful to validate, benchmark, or calibrate complex models against historical data and established forecasts such as those produced under the Energy Information Administration (EIA) Annual Energy Outlook (AEO). Access to confidential system data can also pose a challenge to conducting rigorous analysis of avoided costs. However, in many cases, datasets already exist for regional and utility planning analyses, and EIA datasets are free and publicly available. Furthermore, existing power sector models have the benefit of being well understood and mature.

When to use: Analysts can use sophisticated models when a high degree of precision and analytic rigor is required; when sufficient time, budget, and resources are available; and when sufficient data are available.

Table 3-2 describes the strengths and limitations of each method for quantifying electricity system benefits and examples of when each method is appropriate to use.

Table 3-2: Strengths and Limitations of Basic vs. Sophisticated Methods of Estimating Electricity System Benefits

Strengths	Limitations	When to Use
Basic-to-Intermediate Methods		
▪ Transparent assumptions ▪ Easy-to-understand method ▪ Modest level of time, technical expertise, and labor required ▪ Inexpensive ▪ Readily available for quantifying nearly all primary and most secondary electricity system benefits	▪ May be imprecise and less credible than other methods ▪ May be inflexible ▪ May not be able to reflect unique load characteristics of different energy efficiency and renewable energy programs ▪ Not applicable for long-term projections ▪ Does not typically account for imported power ▪ Does not account for myriad of factors influencing dispatch on a local scale, such as transmission constraints or reliability requirements	▪ For preliminary studies ▪ When time and/or budget are limited ▪ When limited data resources are available
Sophisticated Methods		
▪ May include representation of electricity system dispatch and, in some cases, optimally locate and determine capacity expansion ▪ More rigorous than other methods ▪ May be perceived as more credible than other methods, especially for long-term projections ▪ Allows for sensitivity analysis ▪ Readily available for quantifying most primary electricity system benefits	▪ May be less transparent than spreadsheet methods ▪ Labor- and time-intensive ▪ Often involves high software licensing costs ▪ Requires assumptions that have large impact on outputs ▪ May require significant technical experience ▪ Limited availability for quantifying secondary benefits	▪ When a high degree of precision and analytic rigor is required ▪ When sufficient time and budget resources are available ▪ When sufficient data resources are available

Choosing Between Methods for Quantifying Primary Electricity System Benefits

Choosing between methods involves considering:

- Range of methods available for the benefit(s) of interest
- Level of resources available
- Level of rigor required

Some benefits, particularly primary electricity system benefits, have numerous basic-to-sophisticated methods available for quantifying them while others, such as secondary electricity system benefits, may be more limited in what methods are available for analyses. For benefits where multiple types of quantification methods exist, it is helpful to note that basic and sophisticated methods are not mutually exclusive but may be used in a complementary way.

An influencing factor can be the breadth of the benefits quantified by a particular method. Many of the sophisticated models discussed in this chapter quantify several different benefit impacts (e.g., energy, emissions, economic, and others), and are accordingly mentioned multiple times throughout this *Guide.* Analysts interested in assessing benefits beyond electricity system impacts may consider methods that quantify additional benefits.

Assuming the availability of both basic and sophisticated methods, analysts often choose an approach based on the resources available and the level of rigor desired. The rigor with which decision makers can or may want to analyze the electricity system benefits of energy efficiency and renewable energy depends on:

- Type of benefit being analyzed
- Energy efficiency or renewable energy proposal's status in the development and design process
- Level of investment under consideration
- Regulatory and system operator requirements
- Resources (e.g., software, staff, time) available for the analysis
- Utility or region (for some benefits)

Section 3.2.4., "Methods for Quantifying Primary Electricity System Benefits" and Section 3.2.5., "Methods for Quantifying Secondary Electricity System Benefits," describe in greater detail the methods generally used in practice when quantifying primary and secondary electricity system benefits, respectively.

3.2.4. Methods for Quantifying Primary Electricity System Benefits

Many energy efficiency and renewable energy policies and programs reduce demand for electricity from conventional generating resources on the grid. This reduced demand can lead to benefits on the generation side of the electricity system, such as the avoided fuel or variable O&M costs in the short run and the avoided capital and operating costs associated with investments in new power plant capacity in the long run. This reduced demand can also lead to benefits on the T&D side of the electricity system. This includes the avoided losses (and costs) of electricity during T&D in the short run and the avoided capital and operating costs associated with investments in new T&D capacity in the long run.

The section "Generation Benefits: Avoided Costs," below, describes the methods for quantifying generation-related electricity system benefits and the section "Transmission and Distribution Benefits" describes methods for quantifying the T&D-related electricity system benefits. Analysts can use these methods to compare the impacts of their energy resources.

Generation Benefits: Avoided Costs

New energy efficiency and renewable energy resources may result in avoided electricity and capacity costs from generating units in both the short run (i.e., typically 5 years or fewer) and in the long run (i.e., typically 5 to 25 years).

- *Short-run avoided costs* consist of avoided fuel, variable O&M, and emissions allowances that can be saved at those generating units that would operate less frequently as a result of new energy efficiency and renewable energy resource additions.
- *Long-run avoided costs* consist largely of the capital and operating costs associated with new generation capacity and T&D capacity that are avoided or deferred by energy efficiency and renewable energy resources.[3,4]

Short-run and long-run avoided cost estimates generally depend on the comparison of two cases:

1. A baseline or reference case without the new resource
2. A case with the new resource, which when considering a demand-side resource includes a reduction in the load or load decrement

Both cases involve projections of future conditions and are subject to many uncertainties that influence electricity markets (e.g., fuel prices, construction costs, environmental regulations, and market responsiveness to prices). Avoided costs are calculated as the difference between these two cases and, consequently, they can be very sensitive to the underlying assumptions for either or both cases. The level of uncertainty is greatest in long-run avoided cost calculations that require projections far out into an uncertain future.

To address this uncertainty, analysts may want to consider performing sensitivity or scenario analyses on both the underlying business-as-usual (BAU) scenario (e.g., on demand growth, fuel prices) and on the key drivers of the case with the new resources (e.g., on the cost or timing of new resources) to gauge the potential range of results.

Short-Run Avoided Costs of Electricity Generation or Wholesale Electricity Purchases

The two types of methods for quantifying short-run avoided costs of electricity generation or wholesale electricity purchases are basic-to-intermediate and sophisticated. Basic-to-intermediate methods typically involve an active role for analysts in making assumptions, including deriving avoided cost characteristics of displaced generating units from a historical proxy unit or historical dispatch behavior for a group of units within a region. Sophisticated methods are usually more dynamic, using energy-related models that represent the interplay of future assumptions within the electricity or energy system. To calculate short-run avoided costs, sophisticated methods predict electricity generation responses in relation to multiple factors, including, but not limited to emissions controls, fuel prices, dispatch changes, and new generation resources.

> **SHORT-RUN AVOIDED COSTS**
>
> Short-run avoided costs of electricity generation are the operating costs of marginal units. Operating costs include fuel, variable O&M, and marginal emissions costs. In a competitive market, wholesale electricity prices will reflect the system's actual costs for operating marginal units in the bids that generators submit.

Quantifying the short-run avoided costs of energy efficiency and renewable energy initiatives, whether using basic-to-intermediate or sophisticated methods, involves the steps presented in Figure 3-1:

1. Estimate the energy efficiency or renewable energy operating characteristics.
2. Identify the marginal units to be displaced.

---

[3] *As noted earlier, in the long run, it is mostly energy efficiency and distributed renewable energy generation capacity that is deferring T&D costs as grid-scale renewable energy resources are adding capacity and their need for T&D infrastructure is similar to traditional generating units.*
[4] *Sometimes the short-term and long-term effects of energy efficiency and renewable energy measures are referred to as "operating margin" and "build margin," respectively (Biewald, 2005).*

3. Identify the operating costs of marginal units to be displaced.
4. Calculate the short-run avoided costs of electricity generation.

Basic-to-intermediate methods require analysts to make assumptions for each of the above steps, while sophisticated methods automate each step using an economic dispatch model once the analyst defines the energy efficiency or renewable energy resource. Each of these steps are described in greater detail below for both basic-to-intermediate and sophisticated methods.

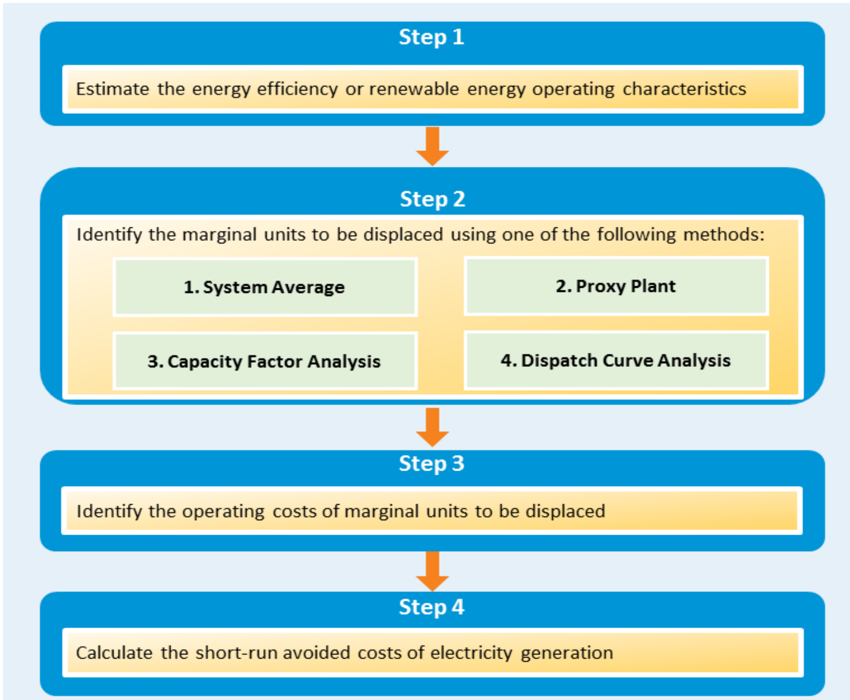
Basic-to-Intermediate Methods for Estimating Short-Run Avoided Costs

When estimating short-run avoided costs using basic-to-intermediate methods, analysts will make a variety of assumptions and/or choices within each step, as described below.

Step 1: Estimate the Energy Efficiency or Renewable Energy Operating Characteristics

The first part of estimating avoided costs of energy efficiency and renewable energy is to estimate the amount of electricity (in kilowatt-hours [kWh]) the energy efficiency measure is expected to save or that the renewable energy initiative is expected to generate over the course of a year and its lifetime. Methods for estimating this saved or generated electricity are described in Section 2.2., "Approach" of Chapter 2, "Estimating the Direct Electricity Impacts of Energy Efficiency and Renewable Energy."

Figure 3-1: Steps for Estimating Short-Run Avoided Costs



In addition to estimating annual impacts, it may be desirable to estimate the timing of impacts within a year, either hourly or on some less frequent interval. The impacts of energy efficiency and renewable energy resources that either reduce generation requirements or add additional generating capacity at the time of peak demand, when natural gas combustion turbines[5] may be operating, will differ from those that affect the system during periods of low demand when baseload plants may be the only plants operating.

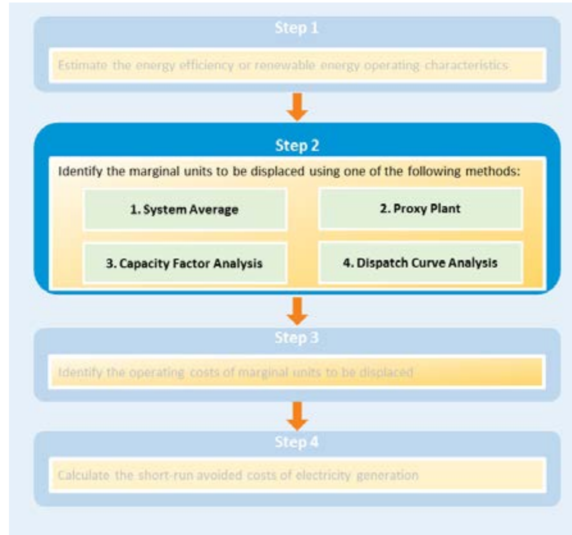
In the case of energy efficiency measures, load impact profiles describe the hourly changes in end-use demand resulting from the program or measure. In the case of renewable energy resources, the generation profiles (for wind or photovoltaics [PV], for example) are required. The time period can range from two- or three-hour intervals, such as peak, off-peak, and shoulder periods, to 8,760 hourly intervals. These data are used to identify more precisely what specific generation or generation types are displaced by the energy efficiency and renewable energy resources.

Several sources are available to help predict the generation or load profiles of different kinds of renewable energy and energy efficiency projects and are listed in Section 3.4., "Tools and Resources." In the absence of specific data on the

[5] *Natural gas combustion turbines are single cycle units which typically operate in times of peak demand, and are less efficient than natural gas combined-cycle units which run more frequently throughout the year (U.S. DOE, 2013a).*

load impact or electricity profile of the energy efficiency or renewable energy resource, analysts will need to use their judgment to assess the timing of that resource's impacts.

Step 2: Identify the Marginal Units to Be Displaced



The next step is to identify the units and their associated costs that are likely to be displaced by the energy efficiency or renewable energy resource(s). While this Step 2 section discusses different methods to estimate the marginal units specific to estimating avoided cost benefits, these same methods support the estimation of emissions benefits of energy efficiency and renewable energy discussed in Section 4.2.2., "Step 2: Quantify Emissions Reductions" of Chapter 4, "Quantifying the Emissions and Health Benefits of Energy Efficiency and Renewable Energy."

In each hour, electric generating units are generally dispatched from least to most expensive, on a marginal cost basis, until demand is satisfied. A host of complexities involved in dispatching the generating system include generator start-up and shut-down operating constraints and costs, and transmission and reliability considerations, among other factors. However, in concept, the unit that is displaced is the last unit to be dispatched, and is referred to as the "marginal" unit. Estimating the benefits of energy efficiency and renewable energy resources requires identifying marginal units and their avoided costs.

Identifying the marginal units can be estimated using basic-to-intermediate methods, such as spreadsheet analysis of market prices, marginal cost data, or inspection of regional dispatch information (i.e., fuel mix and capacity factor by fuel type). Non-modeling estimation methods, such as using a previously estimated avoided cost projection, may be more appropriate when time, budget, and access to data are limited, but they result in an approximation of the costs of avoided electricity generation. Consequently, analysts should consider whether the estimation method is an acceptable representation of the actual system. For example, already-available avoided costs may be out of date or may not match the timing of the impacts of the energy efficiency or renewable energy resource being considered. Reported or modeled avoided costs may not reflect some of the other complexities identified above, therefore looking at variable fuel and O&M may be misleading.

There are several basic-to-intermediate methods analysts can use to identify and evaluate the marginal units:

- *Basic Method 1: System Average* – Use an average of system costs of the generating units in the system to represent the marginal unit.
- *Basic Method 2: Proxy Plant* – Select one unit as a proxy for representing the marginal unit, typically correlated with what is expected to be on the margin during the time of day that the energy efficiency or renewable energy resource impacts would occur.
- *Basic Method 3: Capacity Factor Analysis (also known as Displacement Curve Analysis)* – Build and use a displacement curve using factors that are based on a unit or power plant's capacity factor or other characteristics that correlate with the likelihood of a unit type being displaced.
- *Intermediate Method 1: Dispatch Curve Analysis* – Couple the historical hourly generation of generating units in a region with the hourly load reduction profiles of energy efficiency and renewable energy resources to determine hourly generating cost characteristics of marginal units.

These four basic-to-intermediate methods are described in more detail in this section and are referenced below in Table 3-4. They are distinguished primarily by how they determine the characteristics of the units that are being displaced by the energy efficiency or renewable energy resource. For all methods, once the kWh impacts are mapped to the appropriate marginal generating units, then operating costs of the marginal units can be identified in "Step 3: Identify the Operating Costs of Marginal Units to Be Displaced" and cost savings (and emissions impacts described in Chapter 4) can then be estimated in "Step 4: Calculate the Short-Run Avoided Costs of Electricity Generation."

Basic Method 1: System Average

The simplest method that studies have used to estimate the impacts of the displaced unit, absent any detailed information on the regional electricity system, is to use an average of costs of the generating units in the system to represent the marginal unit.[6]

Most analysts recognize, however, that some types of generating units are almost never on the margin and therefore should not be included in the characterization of the marginal unit. For example, depending on the location, nuclear units and renewable resources may rarely be on the margin and unlikely to be displaced by energy efficiency or new renewable energy resources in the short run. Moreover, the average variable operating costs of the electricity system can differ greatly from the variable operating cost of the marginal source of generation.

To partially address this shortcoming, units that typically serve baseload and other units with low variable operating costs (e.g., hydro and other renewables) can be excluded from the regional or system average. This is an improvement over the system average, but due to the assumed average impacts regardless of the time the impacts are taking place, using "non-baseload" generating costs still do not capture the potential impact of a variety of energy efficiency and renewable energy resources, each with differing impact patterns. This method is an option despite these limitations.

Basic Method 2: Proxy Plant

Based on the expected operating characteristics of the energy efficiency or renewable energy resource determined in "Step 1: Estimate the Energy Efficiency and Renewable Energy Operating Characteristics," above, a single generating unit, or "proxy plant," can be determined to represent the short-run operating characteristics of the displaced generation. For example, for all impacts during the peak period, a natural gas-fired combustion turbine could be used as a proxy to estimate impacts. During baseload periods, a coal plant could be used, while in shoulder periods a natural gas combined-cycle (NGCC) plant might be used. The details would depend on the system being analyzed.

This method should only be used when the operating characteristics of the energy efficiency or renewable energy resource are likely to occur during a particular time period (e.g., peak hours during the summer) because the marginal generating unit will be more likely to be the same type of unit during similar periods. If there is minimal variability in when energy efficiency or renewable energy impacts are likely to occur, a user could create a weighted proxy plant (e.g., 60 percent of one plant's characteristics and 40 percent of another plant's characteristics), although advancing to one of the methods described next would yield a more robust analysis.

Basic Method 3: Capacity Factor Analysis (also called Displacement Curve Analysis)

One time-dependent method for estimating what will be displaced by energy efficiency or renewable energy involves displacement curves. Plants serving baseload can be generalized as operating 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. As a result, they would not be expected to be displaced

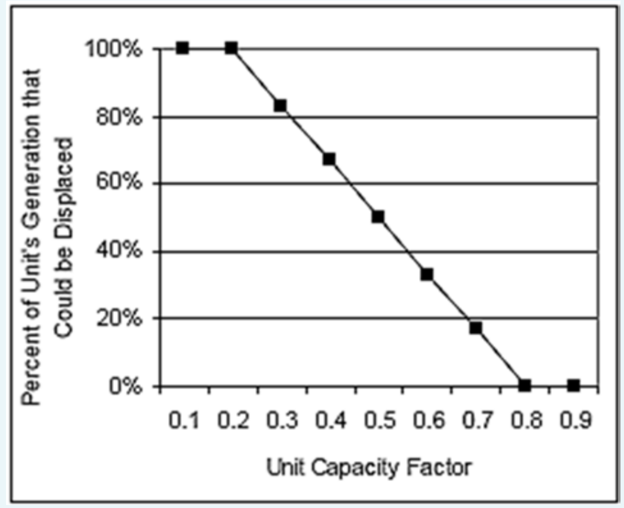
[6] *Analysts looking to quantify avoided costs and emissions reductions should consider one of the other methods.*

with any frequency. These plants would have high capacity factors (e.g., greater than 0.8 or 80 percent), which 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. Load-following plants, in contrast to baseload plants, can quickly change output, have much lower capacity factors (e.g., less than 0.3 or 30 percent) and are more likely to be displaced.

A location-specific displacement curve can be developed to identify what generation is likely to be displaced. The curve would reflect the likelihood of a unit being displaced, based on its expected place in the dispatch order. While many unit characteristics could be used to construct a displacement curve including unit type (e.g., coal steam, nuclear, combustion turbine), heat rate, or pollution control equipment in place, a unit's capacity factor is a reasonable representation of the likelihood of a generating unit to be displaced by an energy efficiency or renewable energy measure and is illustrated in Figure 3-2.

Figure 3-2: Displacement Curve Based on Capacity Factors

Sample curve for relating displacement to capacity factor.



Source: Keith and Biewald, 2005.

The following steps are used to construct a displacement curve based on capacity factor and to estimate the percentage of total hours each type of unit (e.g., coal-fired steam, oil-fired steam, combined-cycle gas turbine, etc.) is likely to be on the margin:

1. *Identify the generating unit types in your region and their associated capacity factors.* These capacity factor estimates can be based on an analysis of actual dispatch data, modeling results, or judgment.[7]

2. *Construct a displacement curve by determining the relationship between capacity factor and percent of time a unit or unit type will be displaced*. The relationship between capacity factor and percent of time it will be displaced could be determined analytically (e.g., examining historical data on the relationship between a unit's capacity factor and the time it is on the margin), or more likely a judgment could be made about this relationship, as depicted in Figure 3-2. When constructing the displacement curve, operating characteristics determined back in "Step 1: Estimate Energy Efficiency and Renewable Energy Operating Characteristics," should be used to make any adjustments to the unit capacity factor.

3. *Calculate the percentage of total hours each unit or unit type is likely to be on the margin.* Use the following calculations to estimate the percentage:

    a. Multiply each unit or unit type's historical generation for the representative time period determined in Step 1, above, by the percentage that could be displaced based on the displacement curve.

    b. Take the potential generation that could be displaced for each unit and divide it by the total potential generation that could be displaced to estimate the fraction of time (%) the unit or unit type will be on the margin.

[7] *For historical data on capacity factors for individual plants, see EPA's eGRID database at: https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid. For additional data sources, Section 3.4., Tools and Resources.*

Figure 3-2 illustrates this concept using capacity factors to build a displacement curve. Plants that serve baseload on the right side of the curve, such as nuclear units, are assumed to be very unlikely to be displaced by energy efficiency or renewable energy; peak load plants on the left, such as combustion turbines, are much more likely to be displaced.

A displacement curve may not perfectly capture all aspects of electricity system operations, however. Capacity factors are average statistics and therefore may not be truly representative of operations during specific times of day or times of the year. For example, during shoulder months (spring and fall), baseload generators can be shut down for maintenance. When this occurs, their capacity factor will fall, indicating in the displacement curve that they are on the margin, when they are actually not operating. In addition, certain types of units will be on the margin at different times of the day as load increases and falls. If displacement caused by the energy efficiency or renewable energy resource is expected to occur at a specific time of day, using average capacity factors may misrepresent the actual displacement that would occur during that time of day.

Intermediate Method 1: Dispatch Curve Analysis

While capacity factor analyses provide a way to estimate the characteristics of the marginal unit based on the relationship of a unit type's characteristic (e.g., capacity factor) with how often that unit type will be displaced, dispatch curve analyses estimate the characteristics and frequency of each generating unit on the margin by examining historical hourly dispatch data. Dispatch curves, also referred to as load duration curves, represent the regional electricity demand over a period of time in descending order. When combined with the dispatch characteristics of the marginal generating units serving the load for each unit of time, a load duration curve illustrates the generating unit types that are dispatched to meet that demand, effectively creating a dispatch curve.

Generating units are typically dispatched in a predictable order that reflects the demand on the system and 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 3-3 and Figure 3-3 provide a combined example of a load duration and dispatch curve that represents 168 hours (a 1-week period) during which a hypothetical energy efficiency or renewable energy resource would be operating. This hypothetical power system has 10 generating units, labeled 1 through 10. The third column shows the number of hours that each unit is on the margin.

Table 3-3: Hypothetical Load for 1-Week Period: Hours on Margin

Unit	Unit Name	Hours on Margin
1	Oil Combustion Turbine, Old	5
2	Gas Combustion Turbine	10
3	Oil Combustion Turbine, New	9
4	Gas Steam	21
5	Oil Steam	40
6	Gas Combined-Cycle, Typical	32
7	Gas Combined-Cycle, New	17
8	Coal, Typical	34
9	Coal, New	0
10	Nuclear	0

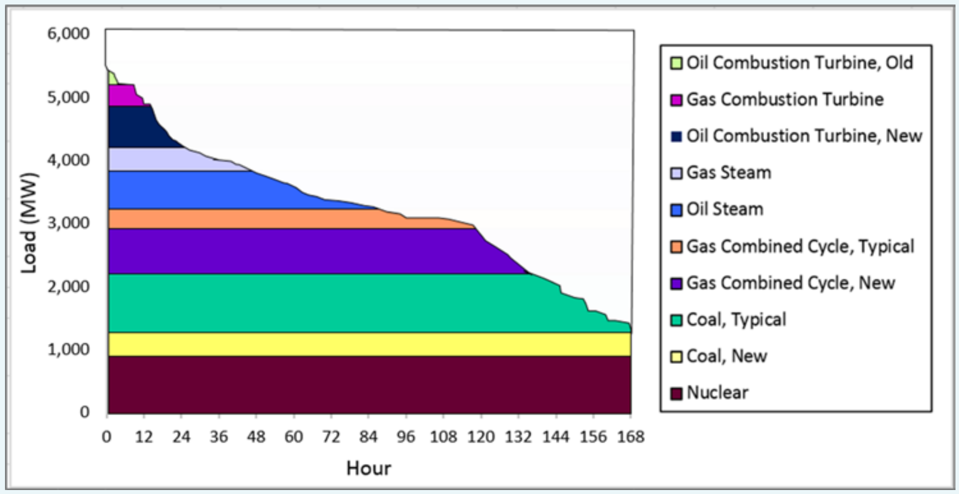
Date required for constructing a dispatch curve:

- Historical utilization of all generating units in the region of interest
- Operating costs and emissions rates (to support emissions estimation, as described in Chapter 4) of the specific generating units, for the most disaggregate time frame available (e.g., seasonally, monthly)
- Hourly regional loads
- Electricity transfers (If available) between the control areas of the region and outside the region of interest (because the marginal resource may be coming from outside the region)

See Section 3.4., "Tools and Resources," for data sources that can be used for obtaining operating costs, historical utilization data, and regional electricity transfers. When generator cost data are not available, capacity factors[8] for conventional 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 operating costs than fossil fuel or nuclear units.

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

Figure 3-3: A Hypothetical Hourly Dispatch Curve Representing 168 Hours by Generation Unit, Ranked by Load Level



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

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

When to use: Dispatch 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 non-modeling methods. However, this method can become labor-intensive relative to other non-modeling methods for estimating displaced emissions if data for constructing the dispatch curve are not readily available. Another limitation is that it is based on the assumption that only one unit will be on the margin at any given time; this generally is not true in most regions.

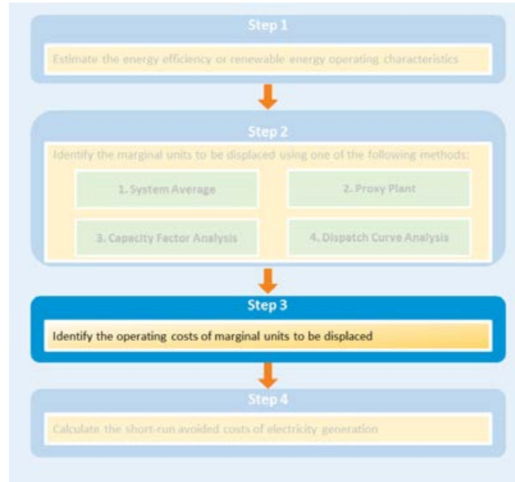
Relationship to basic methods: Methods described earlier, such as Basic Method 3: Capacity Factor Analysis, can support the development of a simplified dispatch curve. For example, capacity factors can be used to "fill" the horizontal segments on the curve as shown in Figure 3-3. One can assume that units with capacity factors greater than 80 percent can fill the baseload segments and that peaking units, with the lowest capacity factors, would fill the peak segments. Units with capacity factors between 80 and 60 percent would fill the next slice of the dispatch curve, and so on. The resolution would reflect available data or the ability to develop meaningful assumptions. The hope is that the level of aggregation is such that the units' characteristics are generally similar and, as such, the marginal unit would be approximated by the group average. If data allows, it is possible to take into account differences in units that drive their costs and emissions (e.g., general unit type and burner type, the presence of pollution control equipment, unit size, fuel type).

Forms of dispatch curves: Dispatch curves may take many forms, highlighting the various types of data listed above. For example, the dispatch curve in Figure 3-3 above plots demand for electricity over a period of time. Another type of dispatch curve used by planners plots system capacity to meet demand against variable operating costs of units. The

[8] *Capacity factors can be obtained from EPA's eGRID database at: https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid.*

curve depicted in the box "Estimating Short-Run Wholesale Market Price Effects: An Illustration," shown and discussed later in the "Reduction in Wholesale Market Clearing Prices" section of this chapter, is an example of this type of curve. Regardless of the form used, dispatch curves offer analysts a predictable way of discerning which units will be dispatched given a level of demand.

Step 3: Identify the Operating Costs of the Marginal Units to Be Displaced

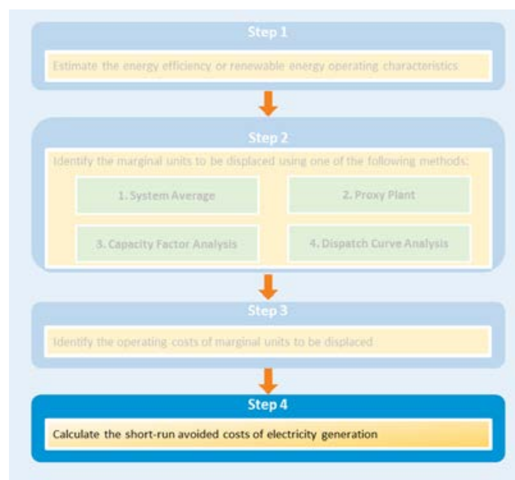


The third step of the analysis involves quantifying the avoided electricity costs (and as described in Chapter 4, Section 4.2.2., "Step 2: Quantify Expected Emissions Reductions") expected from displacing generation. The calculation process varies depending on whether the market is regulated or restructured:

- *In regulated markets,* short-run avoided electricity costs typically include fuel costs, variable O&M costs, and marginal emissions costs for the highest-cost generator in a given hour.[9]
- *In restructured markets,* where regional transmission organizations (RTOs) administer regional wholesale power markets, economic dispatch is conducted on the basis of bid prices rather than generators' marginal costs.[10] This information is available at each ISO's website (see Section 3.4., "Tools and Resources," at the end of this chapter for the websites of individual ISOs).

For longer-term analysis, it is necessary to forecast cost increases. Historical hourly operating costs for the marginal unit (i.e., regulated markets) or market prices (i.e., restructured markets) can be escalated using forward market electricity prices, although the forecast time frame is limited.[11, 12]

Step 4: Calculate the Short-Run Avoided Costs of Electricity Generation



Electricity impacts are mapped to the characteristics of the displaced marginal units to calculate the short-run avoided costs of electricity generation. For each hour or time-of-use period, multiply the cost of the marginal unit or hourly electricity market price by the reduction in load (for demand-side resources) or the increase in generation (for supply-side resources), as estimated using techniques described in Chapter 2. Typically, avoided costs are expressed as the annual sum of these avoided costs for each hour or other time period.

For basic-to-intermediate methods, the estimated electricity impacts (reduction in load or electricity supplied) are mapped to the displaced electricity information. For example, if hourly impacts are estimated, hourly kWh savings are multiplied by hourly avoided costs estimates. The

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[9] *For data sources for control area hourly marginal costs, see the U.S. Federal Regulatory Commission (FERC) form 714 at: https://www.ferc.gov/docs-filing/forms/form-714/view-soft.asp.*

[10] *In theory, bid prices are equivalent to a generator's marginal cost, but considerations such as the costs of starting up and shutting down the unit will also factor in.*

[11] *Forward electricity prices are available from energy traders and industry journals such as Platt's MegaWatt Daily, available at: https://www.platts.com/products/megawatt-daily*

[12] *Long-term electricity and fuel price projections can be found in EIA's Annual Energy Outlook (AEO), available at: https://www.eia.gov/outlooks/aeo/*

summation of these hourly values represents the impact of the energy efficiency or renewable energy resource on costs.[13] Once an analyst calculates the avoided costs (i.e., benefits), analysts can compare them to the costs of implementing energy efficiency and renewable energy measures to understand the net cost or benefit of those measures.

To illustrate how all four steps can be applied to estimate short-run avoided costs, the "Estimating Short-Run Avoided Costs" box depicts an example where the avoided costs are estimated after the capacity factor analysis method was used to identify the marginal units displaced.

Limitations of Basic-to-Intermediate Methods

These basic-to-intermediate methods have some limitations that should be considered when choosing a method:

- Methods that rely on historical data are more accurate when applied for similar conditions to those from when the data were collected. Substantial changes in costs or performance of generation, or other restrictions on their operations (e.g., climate legislation, requirements for a renewable portfolio standard) could fundamentally change the operation of the system and the implied dispatch curve.
    - Even without such fundamental changes, the system modifies over time as new units and energy resource types are added, existing units are retired, and units shift in dispatch order. Analyses based on historical data do not capture these shifts, so to the extent that estimates are being developed for the future, these types of basic-to-intermediate methods must be used with caution.
- These methods may not adequately account for benefits in cases where increases in energy efficiency or renewable energy result in reductions in generation outside the region of interest (e.g., in another state or region).

ESTIMATING SHORT-RUN AVOIDED COSTS

To illustrate the described approach for estimating short-run avoided costs, consider the case of a state that wishes to evaluate the potential benefits of an energy efficiency program. Sample calculations are illustrated in the accompanying table.

Step 1: The state estimates that the energy efficiency program would reduce electricity demand as shown in the Avoided Electricity column (based on an analysis of annual savings from the typical system and a typical load shape).

Step 2: Using a capacity factor analysis, the state estimates that natural gas combustion turbines are typically on the margin during peak periods for both summer and winter, a mix of NGCC units and natural gas-fired steam units (about 50 percent of each) are on the margin during shoulder periods, and existing coal-fired generators (pulverized coal) are typically on the margin during the off-peak periods.

Step 3: The hypothetical avoided costs associated with each of these marginal generating technologies are estimated based on typical variable operating and fuel costs for those types of units estimated to be on the margin. The results are show in the Avoided Electricity Cost for Time Period column.

Step 4: The Total Avoided Electricity Cost column shows the result of multiplying the Avoided Electricity column by the Avoided Electricity Cost for Time Period column. Summing across all periods yields the expected avoided costs for one year.

SAMPLE CALCULATION OF SHORT-RUN AVOIDED ELECTRICITY COSTS

Time Period	Avoided Electricity (MWh)	Avoided Electricity Cost for Time Period ($/kWh)	Total Avoided Electricity Cost ($)
Summer Peak (912 hours)	123,120	0.08	9,234,000
Summer Shoulder (1,368 hours)	153,900	0.06	8,772,300
Summer Off-Peak (1,368 hours)	20,520	0.03	513,000
Winter Peak (1,278 hours)	115,020	0.07	8,051,400
Winter Shoulder (1,917 hours)	143,775	0.06	8,195,175
Winter Off-Peak (1,917 hours)	19,170	0.03	479,250
Total	**575,505**		**35,245,125**

[13] *For sophisticated methods, this calculation may be a direct output of the modeling exercise.*

Sophisticated Methods for Estimating Short-Run Avoided Costs: Economic Dispatch Modeling

Sophisticated simulation modeling, such as simulation of economic dispatch decisions, automatically applies the four steps described above. It uses a detailed representation of the electricity system based upon a wide range of assumptions about technology characteristics and operation. Economic dispatch models (also commonly referred to as "production costing" models) incorporate load duration curves as described in the basic methods section previously, and calculate the types of generation necessary to meet demand for different deployment scenarios of energy efficiency and renewable energy. While developing a full input dataset for an economic dispatch simulation model can be a resource-intensive task, the output from a simulation model can provide more valid estimates than a basic-to-intermediate method, especially for energy efficiency and renewable energy resources with more availability at certain times and for projections of energy efficiency and renewable energy impacts in the future.

Economic dispatch models can also be employed to develop parameters that can be used to estimate the impacts of a large range of energy efficiency and renewable energy resources. For example, multiple model runs can be performed to estimate the impacts of changes in generation requirements at different seasons and times of day (e.g., winter peak, summer peak, base, etc.). These parameters, such as the marginal emissions rate and avoided costs, then can be applied to estimate of the impacts of energy efficiency and renewable energy resources at those same times.

Economic dispatch models simulate the dynamic operation of the electricity system given the characteristics of specific generating units and system transmission constraints. They typically do not predict how the electricity system will evolve but instead can indicate how the electricity system is likely to respond to a particular energy efficiency or renewable energy policy or measure. This is appropriate in the short run when the electricity system is more likely to react than to evolve due to energy efficiency and renewable energy measures. Economic dispatch models specifically replicate least-cost system dispatch and can be used to determine which generating units are displaced and when they are displaced based on economic and operating constraints.

Generally, this method involves modeling electricity dispatch without the new resource BAU case and then modeling dispatch with the new resource, on an hourly basis and typically for 1 to 5 years into the future. As with basic-to-intermediate estimation methods, it is essential to establish the specific operational profile of the energy efficiency or renewable energy resource. An hourly economic dispatch model can be used to determine hourly marginal costs and emissions rates (lbs./kWh), which can then be aggregated by time period and applied to a range of energy efficiency and renewable energy resources according to their production characteristics. Some models, described later in this chapter, simulate both capacity planning and dispatch although they may have a simpler representation of dispatch (e.g., seasonally, with multiple load segments). These models function in the same way as economic dispatch models that do not address capacity planning, but offer the ability to capture the differing marginal resources over load levels and time. Analysts can also use capacity expansion model outputs (e.g., related to expectations about new and retired units) as inputs to economic dispatch models that do not already address capacity planning to adjust the fleet of generation units and run detailed analyses. See the box "NREL Eastern Renewable Generation Integration Study" for an example.

When to use: Hourly economic dispatch modeling is generally used for near-term, highly detailed estimations. This method is appropriate for financial evaluations of specific projects, short-term planning, and regulatory proceedings. Sensitivity cases can be examined to explore

NREL EASTERN RENEWABLE GENERATION INTEGRATION STUDY

NREL's Eastern Renewable Generation Integration Study (ERGIS) analyzed the impacts of four wind and PV scenarios in the Eastern Interconnection region and found that integration of 30 percent renewables is technically feasible at a 5-minute interval. NREL used a combination of capacity expansion and economic dispatch modeling, using the ReEDS capacity expansion model to project future capacity additions to the grid. Once capacity additions and retirements were determined, NREL incorporated these results into PLEXOS, an economic dispatch model, to perform high-resolution economic dispatch modeling of the Eastern Interconnection, model the interactions of 5,600 generating units and over 60,000 transmission nodes at 5-minute intervals.

Source: NREL, 2016

how impacts respond to changes in input assumptions and scenario analysis can be conducted to more fully understand the range of impacts. While economic dispatch modeling is generally seen as very credible in these contexts, because of the limitations described below, agencies and stakeholders often rely on the results of economic dispatch modeling conducted by utilities and their consultants for regulatory proceedings rather than running dispatch models themselves.

Strengths of economic dispatch models*:*

- *Capture a high level of detail:* These models provide forecasts of wholesale electric prices for each hour (i.e., system marginal costs) and the hourly operations of each unit, typically up to a 5-year timeframe. This information has been the basis for plant financing decisions and the development of unit operating and bid strategies in markets. These same data also are necessary in estimating the emissions of specific units and the regional electricity system being modeled. By comparing the variable costs of each unit with the price forecasts, an analyst can estimate plant profitability.
- *Can run multiple cases:* Once the effort is taken to establish a BAU case, the incremental effort to add each additional sensitivity case is lower than establishing the BAU case. Running multiple cases can build up a range of impacts on various planning parameters (e.g., transmission, plant dispatch, and avoided variable costs), and may capture complex interactions and tradeoffs between these cases that basic approaches cannot.
- *Capture detailed operational and variable costs:* They are usually more detailed in their specification of operational and variable costs compared with capacity expansion models.

Limitations of economic dispatch models*:*

- *Do not capture avoided capacity costs:* Unlike capacity expansion models described later in this chapter, economic dispatch models cannot estimate avoided capacity costs from energy efficiency or renewable energy investments. These costs must be calculated outside the economic dispatch model using a spreadsheet model or other calculations.
- *Have significant data requirements to set up and run:* Some of these models require substantial detail on each unit in a regional electricity system and are typically full chronologic models (i.e., some data elements are needed for all 8,760 hours in a year). These models can also be labor-, time-, and cost-intensive.
- *Lack transparency:* Models may lack transparency. For example, economic dispatch models vary in terms of how they treat outage rates, heat rates, bidding strategies, transmission constraints, and reserve margins. Underlying assumptions about these factors may not be apparent to the model user, interested stakeholders, or an analyst examining the results.

Basic-to-intermediate and sophisticated methods each have strengths and limitations, as is illustrated in Table 3-4. Analysts can use these comparisons to help them determine the most appropriate method for their particular goals.

Table 3-4: Comparison of Basic-to-Intermediate and Sophisticated Methods for Quantifying Short-Run Avoided Costs of Electricity Generation or Wholesale Electricity Purchases

Methods	Strengths	Limitations	When to Use This Method	Tools
Basic-to-Intermediate Methods				
▪ System Average ▪ Proxy Plant ▪ Capacity Factor (i.e., Displacement Curve Analysis) ▪ Dispatch Curve Analysis	▪ Are simple ▪ May already be available	▪ Combine electricity use and capacity ▪ Not always relevant to a given policy if timing or costs are different ▪ Limited horizon (futures) ▪ May miss interactive effects (fuel and emissions markets) and reductions outside region of interest for significant energy efficiency and renewable energy investments over time	▪ When time, budget, and data are limited ▪ For rough estimates ▪ For preliminary assessments ▪ For overview-type policy assessments ▪ For small programs	▪ N/A
Sophisticated Method				
▪ Economic Dispatch Modeling[a]	▪ Represents electricity dispatch robustly and realistically ▪ Captures a high level of detail (e.g., operational and variable costs) ▪ Can run multiple scenarios (e.g., sensitivities)	▪ Is cost-intensive ▪ Is data- and time-intensive ▪ Is not transparent ▪ Does not capture avoided capacity costs	▪ When sufficient time, budget, and data resources are available ▪ When high degree of precision and analytic rigor is required ▪ When energy efficiency or renewable energy resource use will change system operations (e.g., energy efficiency and renewable energy resources change the marginal generating resource in a large number of hours)	▪ GE MAPS™ ▪ IPM® ▪ PLEXOS® ▪ PROMOD IV® ▪ PROSYM™

[a] *Economic Dispatch Modeling refers to unit commitment, security constrained unit commitment, and production cost models.*

Long-Run Avoided Costs of Power Plant Capacity

While the avoided cost of electricity generation is the major short-run benefit, avoided costs of adding new power plant capacity in the long run (typically 5 or more years) can be significant and are an important consideration for resource decisions.[14] For example, in the short run, energy efficiency and renewable energy policies and programs can enable electricity generators to operate less frequently and avoid fuel and variable O&M costs, or sell surplus generation capacity to other utilities in the region to meet their capacity needs. Over the long run, however, new energy efficiency and renewable energy initiatives typically avoid or defer both the cost of building new power plants and the cost of operating them.

[14] *For more information about establishing energy efficiency as a high-priority resource in long-term planning, see* National Action Plan for Energy Efficiency Vision for 2025: A Framework for Change, *November 2008.* https://www.epa.gov/sites/production/files/2015-08/documents/vision.pdf.

Methods for Estimating Long-Run Avoided Costs of Power Plant Capacity

The avoided cost of building and operating new power plants are the avoided costs of power plant capacity that can be estimated using either basic estimation or sophisticated simulation methods, each of which has strengths and limitations.[15]

Basic Methods for Estimating Long-Run Avoided Costs of Power Plant Capacity

Basic estimation methods involve the use of tools such as spreadsheets to estimate any long-run avoided costs of power plant capacity that may result due to an energy efficiency or renewable energy measure under consideration. One method for quantifying long-term savings of energy efficiency and renewable energy measures, the proxy plant method, relies on selecting a unit type as a proxy to represent the avoided costs of building future generating capacity.

Proxy Plant Method

Similar to how a proxy plant could be used to represent displaced generation from existing plants when estimating short-run avoided costs (i.e., Basic Method 2: Proxy Plant), an analyst can use a proxy plant method to estimate the costs that can be avoided in the long run by avoided the construction of a power plant in the future. Over the long term, proxy plant assessments are typically done using cost assumptions for the expected next addition.

Electricity cost estimates in this basic method would use a proxy plant's dispatch costs for future estimates and the capital costs. Depending on future expectations of capital costs, fuel prices, and environmental requirements, state policy makers can choose from a variety of generating units to represent their proxy plant. EPA has observed that many states use natural gas combustion turbines to represent the long-run avoided costs of electricity and capacity of energy efficiency and renewable energy initiatives. Forward capacity markets provide another resource for power plant capacity pricing expectations that may be integrated into these basic methods, as the results of their auctions should represent the market's opinion of future capacity costs in the region.

Data required for this method include:

- Cost and performance information for the proxy plant
- Capital cost escalation rates, a discount rate, and other financial data

See Section 3.4., "Tools and Resources," for potential data sources.

[15] *For more information about how utilities estimate avoided costs, see* The Guide to Resource Planning with Energy Efficiency: A Resource of the National Action Plan for Energy Efficiency, *November 2007,* https://www.epa.gov/sites/production/files/2015-08/documents/resource_planning.pdf.

USING PROXY POWER PLANT DATA TO ESTIMATE AVOIDED CAPITAL COSTS

To estimate avoided capital costs of an energy efficiency or renewable energy resource, a discounted cash flow analysis can first be conducted using data on initial construction costs, fixed and variable operating costs, and financial data. Once estimated, the NPV of the cost of owning the unit that reflects the full carrying costs of the new unit (including interest during construction, debt servicing, property taxes, insurance, depreciation, and return to equity holders) can be converted to annualized costs. The equation for calculating annual avoided capital costs is:

$$Annualized\ Costs\ \left(\frac{\$}{kWYear}\right) * Annual\ Capacity\ Savings\ (kW) = Avoided\ Capital\ Costs\ (\frac{\$}{Year})$$

The load profile information (reductions in demand at peak hours), discussed earlier would provide an estimate of displaced capacity, or simpler estimates can be used.

NREL's Jobs and Economic Development Impact (JEDI) model (http://www.nrel.gov/analysis/jedi/) is a free tool designed to allow users to estimate the economic costs and impacts of constructing and operating power generation assets. The tool provides plant construction costs, as well as fixed and variable operating costs. The following example shows avoided capital costs for an energy efficiency or renewable energy program that avoids the construction of a natural gas combustion turbine with the following characteristics:

- Construction cost = $1,250/kW
- Annual operation cost = $8.25/kW
- Energy efficiency program savings = 500 MW

The program would realize the following benefits:

- Avoided plant construction cost = $648 million
- Annual operating cost savings = $177 million

Source: NREL, 2015.

Sophisticated Methods for Estimating Long-Run Avoided Costs of Power Plant Capacity: Capacity Expansion Models

Sophisticated simulation methods, such as capacity expansion models (also called system planning models), can be used to quantify the long-run avoided capacity costs that result from implementing energy efficiency and renewable energy measures. Capacity expansion models project how the electricity system is likely to evolve over time, including what capacity will likely be added through the construction of new generating units and what units will likely be retired, in response to changes in demand and prices. Forecasts are based on numerous factors, including but not limited to: the costs of new technology, expected growth in electricity demand and changes in prices, regional electricity system operations, existing fleet of generating assets, the characteristics of candidate new units, environmental regulations (current and planned), and the deployment of energy efficiency and renewable energy measures. Models use this type of information, typically within an optimization framework, to select a future build-out of the system (e.g., multiple new units over a multi-decadal time frame) that has the lowest overall NPV, considering both capacity and variable costs of each unit.

Typical steps involved in estimating the avoided costs of power plant capacity using capacity expansion models:

1. Generate a BAU forecast of load and how it will be met.
2. Include the energy efficiency or renewable energy resource over the planning period and create an alternative forecast.
3. Calculate the avoided costs of power plant capacity.

Step 1: Generate a BAU Forecast of Load and How It Will Be Met

Some capacity expansion models use existing generating plants and purchase contracts to meet projected electricity demand over the forecast period, and the model (or the analyst) adds new generic plants when those resources do not meet the load forecast. The type of plants added depends on their capital and operating costs, as well as the daily and seasonal time-pattern of the need for power determined over the forecast period. Using these cost and time characteristics, the NPV of adding various power plant types can be compared using discounted cash flow analysis as mentioned earlier in the box "Using Proxy Power Plant Data to Estimate Avoided Capital Costs." Sophisticated capacity expansion models will run through an optimization process that chooses the least-cost solution to adding capacity. The model repeats this process until the load is served through the end of the forecast period and a least-cost solution is found. This BAU scenario contains a detailed schedule of resource additions that becomes the benchmark capital and operating costs over the planning period for later use in the long-run avoided cost calculation.

Step 2: Include the Energy Efficiency or Renewable Energy Resource Over the Planning Period and Create an Alternate Forecast

The following two methods can be used to incorporate the energy efficiency resource into the second projection:

- For a more precise estimate of the savings from an energy efficiency program, reduce the load forecast year-by-year and at more granular time-scales (e.g., daily or hourly) to capture the impact of energy efficiency resource, based on the program design and estimates of its electricity and capacity savings. This method would capture the unique load shape of the energy efficiency resource.
- For a less rigorous estimate (e.g., to use in screening candidate energy efficiency policies and programs during program design), reduce the load forecast by a fixed amount in each year, proportionally to load level. This method does not capture the unique load shape of the energy efficiency resource.

For renewable energy resources, add the resource to the supply mix. For some models and non-dispatchable resources, including distributed renewable energy resources, renewable energy could be netted from load in the same manner as is done for energy efficiency in the second bullet above.

Step 3: Calculate the Avoided Costs of Power Plant Capacity

The difference between the costs in the two projections created in Steps 1 and 2 represents the annualized or NPV costs that would be avoided by the energy efficiency or renewable energy resource. If a per unit avoided cost, such as the avoided cost per Megawatt-hour (MWh), is needed for screening energy efficiency and renewable energy resources or other purposes, it may be computed by taking the avoided cost (i.e., the difference between the cost in the two projections) for the relevant time period (e.g., a given year) and dividing that by the difference in load between the two projections. As noted above, analysts should compare the costs of implementing energy efficiency and renewable energy measures against the calculated avoided costs to understand the net cost or benefit of those measures

When to use: Capacity expansion or system planning models are typically used for longer-term studies (typically 5 to 40 years) where the impacts are dominated by long-term investment and retirement decisions. They are often used to evaluate large geographic areas and can examine potential long-term impacts on the electric sector or upon the entire energy system (e.g., fuels and emissions markets), which could also include the industrial, residential, commercial, and transportation sectors. In contrast, economic dispatch models focus on only the electricity sector.

Energy system capacity expansion models are generally used for projecting scenarios of how the energy system will adapt to changes in supply and demand or to new policies including emissions controls. They may consider the complex interactions and feedbacks that occur within the entire energy system, rather than focusing solely upon the electric sector impacts. This is significant because there can be tradeoffs and cross sector interactions that may not be captured by a model that focuses solely on the electricity sector. In addition to capturing the numerous interactions, energy system capacity expansion models can also model dispatch, although often not in as sophisticated a manner as a dedicated economic dispatch model (e.g., in a chronological, 8,760-hour dispatch).[16]

[16] *For more information about using capacity expansion models to estimate air and greenhouse emissions from energy efficiency and renewable energy initiatives, please see Section 4.2.2, "Step 2: Quantify Expected Emissions Reductions."*

Strengths of capacity expansion models:

- *Capture complex interactions:* They may capture the complex interactions and feedbacks that occur within the entire energy system, including many factors that are influenced by changing policies, regulatory regimes, or market dynamics (e.g., stricter emissions policy, introduction of a renewable portfolio standard).
- *Are designed for resource planning:* While both economic dispatch models and capacity expansion models are used in utility integrated resource planning proceedings, capacity expansion models are designed specifically for resource planning.
- *Capture avoided costs:* Capacity expansion models are able to estimate avoided capacity costs and usually also produce estimates of avoided variable costs.
- *Show system adaptability:* They can show how the electricity system is likely to adapt in response to new policies.
- *Cover a long timeframe:* The model selects optimal changes to the resource mix based on energy system infrastructure over the long term (typically 5 to 40 years).
- *Provide emissions reductions:* They provide estimates of emissions reductions from changes to generation mix.
- *Can layer in dispatch characteristics:* Some capacity expansion models may provide plant-specific detail and perform dispatch simultaneously (IPM).

Limitations of capacity expansion models:

- *Require many assumptions:* They require assumptions that have a large impact on outputs (e.g., future fuel costs). It is imperative to carefully consider key assumptions, such as fuel price forecasts and retirements, and the ability to accurately model the complex factors affecting the system including environmental and other regulatory requirements (e.g., renewable portfolio standards). These assumptions point to the need for model validation or calibration against actual data or another projection model. Most of the models are supported by their developers or other consultants who have available datasets. Some studies calibrate against the National Energy Modeling System (NEMS)-generated AEO produced by U.S. DOE's EIA.
- *Require technical expertise:* Capacity expansion models may require significant technical experience to run.
- *Lack transparency:* They often lack transparency due to their complexity and proprietary nature.
- *May require significant labor, time, and financial resources:* These types of models can be labor- and time-intensive, and may have high labor and software licensing costs.

Table 3-5 provides a simple comparison of the methods for estimating long-run avoided costs of power plant capacity.

Table 3-5: Comparison of Basic and Sophisticated Methods for Quantifying Long-Run Avoided Costs of Power Plant Capacity

Methods	Strengths	Limitations	When To Use This Method	Tools / Examples
Basic				
▪ Proxy Plant	▪ Are simple ▪ May provide cost assumptions	▪ Do not reflect opportunities to displace conventional baseload units in the long run	▪ For rough estimates ▪ For preliminary screening of demand response resources ▪ For overview-type policy assessments	▪ Natural gas combustion turbine (proxy plant method)
Sophisticated				
▪ Capacity expansion models	▪ Capture complex interaction to provide a robust representation of electrical system operation ▪ Are designed for resource planning ▪ Capture avoided costs ▪ Show system adaptability ▪ Cover a long timeframe ▪ Provide emissions reductions ▪ Can layer in dispatch characteristics	▪ Require many assumptions ▪ Require technical expertise ▪ Lack transparency ▪ May require significant labor, time, and financial resources	▪ When energy efficiency or renewable energy resource use will impact generation and investment in the capacity mix (e.g., resources avoid or defer building new power plants and operating them a large number of hours)	▪ AURORA ▪ U.S. DOE's NEMS ▪ EGEAS ▪ e7 Capacity Expansion Strategist ▪ e7 Portfolio Optimization ▪ Energy 2020 ▪ LEAP ▪ IPM® ▪ MARKAL, TIMES ▪ NREL's ReEDS ▪ NREL's RPM

Transmission and Distribution Benefits

In addition to avoiding electricity generation and power plant capacity additions, energy efficiency and renewable energy policies and programs that affect customers at the end-use (e.g., through residential or commercials measures) can help to avoid electricity losses during T&D and also avoid the capacity costs of building new T&D capacity. The following sections describe methods for quantifying these benefits.

Avoided Electricity Losses During Transmission and Distribution

Avoided T&D losses from energy efficiency and renewable energy policies and programs can be estimated by multiplying the estimated electricity and capacity savings located near or at a customer site by the T&D loss factor (i.e., the percent difference between the total electricity supplied to the T&D system and the total electricity taken off the system for delivery to end-use customers during a specified time period). A method for determining T&D losses is described below.

The two different types of T&D loss factors are generation-based factors and consumption-based factors. A generation-based factor is determined based on losses experienced at the individual generating facilities whereas consumption-based factors are calculated based on losses that occur throughout the generation, transmission, and distribution process, from the generation of the electricity to its point of consumption. A consumption-based T&D loss factor is appropriate to use for energy efficiency and distributed renewable energy programs a capture the T&D losses throughout the system.

A consumption-based T&D loss factor can be calculated using the following formula:

> *(Net Generation to the Grid + Net Imports – Total Electricity Sales) / Total Electricity Sales*

T&D losses in the range of 6 to 10 percent are typical, which means that for every 1 kWh saved at the customer's meter, 1.06–1.10 kWh are avoided at the generator. EIA estimates that the average consumption-based U.S. T&D loss factor was 8.38 percent in 2016 (EIA, 2018).[17] See Section 3.4., "Tools and Resources," for data sources that can be used to calculate a consumption-based T&D loss factor.

EXAMPLE OF T&D LOSS CALCULATIONS

Suppose a PG&E utility end-use energy efficiency program saves 500 MWh during the summer months of a given year.

In 2017, the CPUC calculated PG&E's generation to meter loss factors for summer peak and off-peak as 1.109 and 1.057, respectively (E3, 2017). Therefore, if 30 percent of energy is consumed during summer peak hours and 70 percent is consumed during summer off-peak hours, then the program savings during summer would total 536.3 MWh (1.109 * 30% * 500 MWh + 1.057 * 70% * 500 MWh).

T&D losses are typically higher when load is higher, especially at peak times when losses can be as great as twice the average value. The T&D loss reductions from energy efficiency, load control, and distributed generation are thus significantly higher when the benefits are delivered on peak than when they occur at average load levels, which greatly enhances the reliability benefits. The California Public Utilities Commission (CPUC) calculated the value of deferring T&D investments adjusted for losses during peak periods using the loss factors shown in Table 3-6 and Table 3-7 (E3, 2017). For example, an energy efficiency measure that saves 10.0 kWh of power at an SDG&E customer's meter would save 10.71 kWh once a T&D loss factor of 1.071 is factored in.

The significance of T&D losses in high load periods is further increased by the high marginal electricity costs and electricity prices experienced at those times. Due to the variation in loads over the course of the year, T&D loss estimates are more precise when developed for short time periods (e.g., less than 1 year).

Utilities routinely collect average annual energy loss data by voltage level (as a percentage of total sales at that level). RTOs and ISOs also provide loss data. Note that transmission loss, which is smaller than distribution loss, may be included in wholesale electricity prices in restructured markets.

Estimates of T&D losses can be applied to the electricity impacts estimated as described in Chapter 2, "Estimating the Direct Electricity Impacts of Energy Efficiency and Renewable Energy." If load profile information is available, then estimates can be used to distinguish between higher on-peak loss rates and lower off-peak loss rates. Once the total electricity impact is determined, see "Generation Benefits: Avoided Costs" in Section 3.2.4., Methods for Quantifying Primary Electricity System Benefits, for calculating avoided costs of generation from electricity impacts.

Table 3-6: Loss Factors for SCE and SDG&E T&D Capacity

	SCE	SDG&E
Distribution Only	1.022	1.043
T&D	1.054	1.071

Source: E3, 2017.

[17] *EIA also uses an alternative, generation-based method for calculating T&D losses that results in lower percentages (typically around 5 percent) based on losses reported at the individual facility level by utilities; see https://www.eia.gov/tools/faqs/faq.cfm?id=105&t=3 for details. Using this method as opposed to a consumption-based method would underestimate the T&D loss benefits of energy efficiency initiatives.*

Table 3-7: Loss Factors for PG&E T&D Capacity

	T&D	Distribution Only
Central Coast	1.053	1.019
De Anza	1.050	1.019
Diablo	1.045	1.020
East Bay	1.042	1.020
Fresno	1.076	1.020
Kern	1.065	1.023
Los Padres	1.060	1.019
Mission	1.047	1.019
North Bay	1.053	1.019
North Coast	1.060	1.019
North Valley	1.073	1.021
Peninsula	1.050	1.019
Sacramento	1.052	1.019
San Francisco	1.045	1.020
San Jose	1.052	1.018
Sierra	1.054	1.020
Stockton	1.066	1.019
Yosemite	1.067	1.019

Source: E3, 2017.

Avoided Transmission and Distribution Capacity Costs

Energy efficiency and renewable energy policies and programs that affect areas that are sited on or near a constrained portion of the T&D system can potentially:

- Avoid or delay costly T&D upgrades, construction, and associated O&M costs, including cost of capital, taxes and insurance.
- Reduce the frequency of maintenance, because frequent peak loads at or near design capacity will reduce the life of some types of T&D equipment.

Deferral of T&D investments can have significant economic value. The value of the deferral is calculated by looking at the present value difference in costs between the transmission project as originally scheduled and the deferred project. Most often, the deferred project will have a slightly higher cost due to inflation and cost escalations (e.g., in raw materials), but can have a lower present value cost when the utility discount rate is considered (which affects the utility's cost of capital). The difference in these two factors determines the value of deferring the project.

The avoided costs of T&D capacity vary considerably across a state depending on geographic region and other factors. Table 3-8 and Table 3-9 were developed for the CPUC in 2017 and illustrate how avoided costs of T&D capacity vary in California (in $/kW-year) by utility and climate zone. Using avoided cost estimates based on these differences, rather than on statewide system averages, enables state decision makers to better target the design, funding, and marketing of their energy efficiency and renewable energy actions (E3, 2017).

Table 3-8: 2016 Avoided T&D Capacity Costs for SCE and SDG&E

	SCE	SDG&E
Sub-transmission ($/kW-yr)	$30.52	–
Substation ($/kW-yr)	–	$22.05
Local distribution ($/kW-yr)	$101.90	$77.97

Source: E3, 2017.

Note: SCE capacity costs are based on 2015 filed values with 2 percent per year inflation. Sub-transmission lines are the part of the grid that interconnects the bulk transmission elements with the distribution elements and transfer electricity at lower voltages than transmission lines, while substations are used to scale up or down the voltage of power as it moves along the electricity system.

Table 3-9: 2016 T&D Capacity Costs for PG&E

Division	Climate Zone	Transmission $/kW-yr	Primary Distribution $/kW-yr	Secondary Distribution $/kW-yr
Central Coast	4	$36.27	$99.31	$8.19
De Anza	4	$36.27	$117.26	$4.66
Diablo	12	$36.27	$54.69	$7.43
East Bay	3A	$36.27	$62.73	$3.34
Fresno	13	$36.27	$31.53	$3.96
Kern	13	$36.27	$32.70	$4.50
Los Padres	5	$36.27	$42.52	$5.25
Mission	3B	$36.27	$20.67	$3.42
North Bay	2	$36.27	$18.46	$4.65
North Coast	1	$36.27	$43.93	$7.18
North Valley	16	$36.27	$37.52	$8.47
Peninsula	3A	$36.27	$40.18	$6.12
Sacramento	11	$36.27	$39.17	$4.37
San Francisco	3A	$36.27	$19.07	$2.62
San Joe	4	$36.27	$40.06	$5.06
Sierra	11	$36.27	$30.88	$6.77
Stockton	12	$36.27	$39.81	$4.72
Yosemite	13	$36.27	$47.63	$7.45

Source: E3, 2017.

Note: PG&E capacity costs are based on 2014 filed values with 2 percent per year inflation and peak capacity allocation factor. Primary distribution refers to the part of the distribution network that can deliver power to larger commercial and industrial users and operates with voltage levels in the tens of kilovolts. Secondary distribution refers to the lowest voltage level along the grid that delivers electricity directly to households and small commercial customers.

The benefit of avoided T&D costs is often overlooked or addressed qualitatively in resource planning because estimating the magnitude of these costs is typically more challenging than estimating the avoided costs of electricity generation and plant capacity. For example, the avoided T&D investment costs resulting from an energy efficiency or renewable energy program are highly location-specific and depend on many factors, including the current system status, the program's geographical distribution, and trends in customer load growth and load patterns. It is also difficult to estimate the extent to which energy efficiency and renewable energy measures would avoid or delay expensive T&D upgrades, reduce maintenance, and/or postpone system-wide upgrades, due to the complexity of the system.

Methods for Estimating Avoided Transmission and Distribution Capacity Costs

A common method to estimate avoided T&D costs is the system planning method. The system planning method uses projected costs and projected load growth for specific T&D projects based on the results from a system planning study—a rigorous engineering study of the electricity system to identify site-specific system upgrade needs. Other data requirements include site-specific investment and load data. This method assesses the difference between the present value of the original T&D investment projects and the present value of deferred T&D projects.[18] The system planning method uses projections and thus can consider future developments.

Projected embedded analysis is another method used to estimate avoided T&D costs. According to a New York State Energy Research and Development Authority (NYSERDA) report, to use this method, "utilities use long-term historical trends (more than 10 years) and sometimes planned T&D costs to estimate future avoided T&D costs. This approach often looks at load-related investment (as opposed to customer-related) and estimates system-wide (e.g., utility service territory) average avoided T&D costs" (NYSERDA, 2011).

The difference between the two methods is that projected embedded analysis provides a system average view, whereas the system planning method provides project-specific estimates. If analysts want to assess avoided costs for the system generally, projected embedded analysis will provide that information. However, this method will not be able to assess the impact of specific projects. To do that, analysts will need the system planning method.

CON EDISON EXPANDS ITS NON-WIRES ALTERNATIVES PROGRAM TO REDUCE LOAD

In December 2014, state regulators approved Con Edison's Brooklyn/Queens Demand Management (BQDM) Program to address a forecasted overload condition of the electric sub-transmission feeders serving two of their substations. The program is designed to reduce load by contracting for 41 MW of customer-side solutions and 11 MW of non-traditional utility-side solutions, such as distributed resource investments. Con Edison's operating budget for the program is $150 million and $50 million for the two different solutions, respectively.

Since launching the program, Con Edison has deferred a $1.2-billion substation upgrade by employing a strategy that harnesses a range of distributed resources and efficiencies rather than spending ratepayer funds on conventional utility solutions, such as construction of new substations and sub-transmission feeders. As of summer 2018, Con Edison had contracted for more than 52 MW of non-traditional solutions. The project was deemed successful and was re-authorized for extension by state regulators in July 2017. The extension allows the utility to obtain further demand reductions and defer additional traditional infrastructure investments, without any additional funding.

Sources: Con Edison, 2017; State of New York Public Service Commission, 2017.

Generally, it is difficult to be precise when calculating the avoided cost of T&D capacity because costs are very site specific and their quantification involves detailed engineering and load flow analyses. Other factors affecting location-specific T&D project cost estimates are system congestion and reliability.

During periods of high congestion, for example, interconnected resources that can be dispatched at these specific times are credited at time-differentiated avoided costs. In addition to region-specific annual avoided T&D capacity costs shown above in Table 3-8 and Table 3-9, the CPUC also uses time-differentiated avoided T&D capacity costs to estimate long-run avoided costs to support analyses of the cost-effectiveness of energy efficiency measures. For example, according to the CPUC, measures that reduce electricity consumption in August can have more than four times the

[18] The investment in nominal costs is based on revenue requirements that include cost of capital, insurance, taxes, depreciation, and O&M expenses associated with T&D investment (Feinstein et al., 1997; Orans et al., 2001; Lovins et al., 2002).

avoided costs of those that occur in January, due to the benefits of reducing peak demand during normally congested summer months. Furthermore, energy efficiency measures that reduce electricity consumption during hours of peak demand, such as mid- to late-afternoon, can potentially incur more than $10,000/MWh more in avoided costs than those that occur during non-peak times (depending on energy market prices) (E3, 2017).

Summary of Primary Electricity System Benefits

Table 3-10 outlines some of the factors that state decision makers can consider when deciding which primary electricity system benefits to analyze, including available methods and examples, strengths, limitations, and purpose of analysis.

Table 3-10: Primary Electricity System Benefits from Energy Efficiency and Renewable Energy Measures

Applicable Energy Efficiency and Renewable	Considerations for Determining Whether to Analyze	Who Usually Conducts, Commissions, or Reviews an Analysis?	When Is Analysis Usually Conducted or Made Available?
BENEFIT: Avoided electricity generation or wholesale electricity purchases			
▪ All resources ▪ Resources that operate during peak hours	▪ Traditionally analyzed in cost-benefit analysis ▪ Widely accepted methods ▪ Data generally available but expensive ▪ Sophisticated models available but complex, not transparent, and often expensive to use ▪ Many assumptions about technology, costs, and operation needed ▪ Long-term fuel price forecasts can be obtained from EIA's AEO, developed internally, or purchased	▪ Utilities conduct in-depth modeling ▪ State utility regulatory commissions and other stakeholders review utility's results and/or conduct own analysis ▪ RTO/ISO and the Independent Market Monitor conduct own analyses for planning, demand response programs, and market intelligence ▪ EIA and private consultancies provide economic dispatch and capacity expansion forecasts	▪ Resource planning and released regulatory proceedings ▪ Area-specific DSM program development ▪ RTO/ISO avoided cost estimates may be published on regular schedules
BENEFIT: Avoided power plant capacity additions			
▪ All resources ▪ Resources that operate during peak hours	▪ Traditionally analyzed in cost-benefit analysis ▪ Generally accepted methods for both estimation and simulation ▪ Some assumptions about technology, costs, and operation needed ▪ Data generally available	▪ Utilities conduct in-depth modeling ▪ State utility regulatory commissions and other stakeholders review utility's results and/or conduct own analysis ▪ RTO/ISO may publish capacity clearing prices ▪ EIA and private consultancies provide capacity expansion forecasts	▪ Resource planning and released regulatory proceedings ▪ Area-specific DSM program development ▪ RTO/ISO avoided cost estimates may be published on regular schedules
BENEFIT: Avoided T&D losses			
▪ Resources that are close to load, especially those that operate during peak hours	▪ Traditionally analyzed in cost-benefit analysis ▪ Straightforward; easy to estimate once avoided electricity has been calculated ▪ Loss factor for peak savings may need to be estimated	▪ Utilities collect loss data regularly and may conduct in-depth modeling ▪ State utility regulatory commissions and other stakeholders review utility's results and/or conduct own analysis	▪ Resource planning and released regulatory proceedings ▪ Area-specific DSM program development

Applicable Energy Efficiency and Renewable	Considerations for Determining Whether to Analyze	Who Usually Conducts, Commissions, or Reviews an Analysis?	When Is Analysis Usually Conducted or Made Available?
BENEFIT: Deferred or avoided T&D capacity			
▪ Resources that are close to load, especially those that operate during peak hours	▪ Traditionally analyzed in cost-benefit analysis ▪ Load flow forecast availability ▪ Unit cost of T&D upgrades can be estimated but may be controversial ▪ T&D capacity savings reasonably practical, but site-specific savings difficult to generalize	▪ Utilities conduct in-depth modeling ▪ State utility regulatory commissions and other stakeholders review utility's results and/or conduct own analysis ▪ RTO/ISO conduct own analyses for planning or reports	▪ T&D build planning ▪ Area-specific DSM program development ▪ RTO/ISO cost estimates may be published on regular schedules

3.2.5. Methods for Quantifying Secondary Electricity System Benefits

Energy efficiency and renewable energy policies and programs result in many additional electricity system benefits that affect the efficiency of electricity systems and energy markets, including:

- Avoided ancillary services costs
- Reductions in wholesale market clearing prices
- Increased reliability and power quality
- Avoided risks associated with long lead-time investments, such as the risk of overbuilding the electricity system
- Reduced risks from deferring investment in conventional, centralized resources pending uncertainty in future environmental regulations
- Improved fuel diversity
- Improved energy security

These secondary benefits have associated cost reductions, but the methodologies for assessing them are sometimes diverse, qualitative, and subject to rigorous debate.

The ability to estimate the secondary benefits of energy efficiency and renewable energy policies and programs and the availability of methods vary depending on the benefit. These methods are less mature than those for primary benefits, and as such, they tend to rely more on non-modeling estimation methods than do more sophisticated simulation models. Secondary electricity system benefits, and methods for estimating them, are described below.

Avoided Ancillary Services Costs

"Ancillary services" is a catchall term for electric generator functions needed to ensure reliability, as opposed to providing power, and include services such as operating reserves, voltage support, and frequency regulation.

RTOs and ISOs routinely report market prices for ancillary services such as voltage support and frequency regulation. In those regions with ancillary service markets, such as PJM, NYISO, ISO-NE, ERCOT, and the California ISO, services are provided at rates determined by the markets and thus are easily valued.[19] The avoided costs of ancillary services are typically smaller than other costs, such as avoided electricity, capacity, and T&D investment. For example, 2017 voltage support services were only 0.77 percent of the total PJM wholesale cost (PJM, 2018).

ANCILLARY SERVICES THAT ENERGY EFFICIENCY AND RENEWABLE ENERGY RESOURCES CAN PROVIDE TO THE SYSTEM

Operating Reserve – Spinning: Generation synchronized to the grid (i.e., "spinning") and usually available within 10 minutes to respond to a contingency event. For example, 50 MW of spinning operating reserve means that a generation unit can increase its output by 50 MW within 10 minutes.

Operating Reserve – Supplemental: Generation that is available within 30 minutes but is not necessarily synchronized to the grid.

Voltage Support: For reliable electricity flow on the transmission system, voltage must be maintained within an acceptable range. Voltage is regulated by reactive power which is absorbed or generated by different power system assets such as capacitors or generators.

Frequency Regulation: The ability to control the alternating current (AC) frequency so that it remains within a tolerance bound. Control can be maintained with generator inertia, ramping generation up or down, demand response, or storage.

Operating Reserves

Operating reserves are generation resources available to meet loads quickly in the event a generator goes down or some other supply disruption occurs. Energy efficiency programs avoid the need to procure additional capacity for operating reserves. Whereas energy efficiency programs typically do not affect the procurement of resources for operating reserves in the short term, they can affect long-run costs of avoiding building capacity to meet operating reserve requirements. The market value of a given MW of energy efficiency or renewable energy short-term reserve is equal to the operating reserve price, as posted by the RTO or ISO on its website. In regions with ancillary service markets, the RTO will set up a market where resources can bid to provide the service. Those that successfully bid are paid the clearing price by the RTO. An increased supply of low-cost energy efficiency will cause ancillary service markets to clear at a lower price. Methods for calculating long-run avoided costs are covered under "Long-Run Avoided Costs of Power Plant Capacity," in Section 3.2.4.

DIRECT EMISSIONS REDUCTIONS FROM DEMAND RESPONSE-PROVIDING ANCILLARY SERVICES

In a 2014 study on CO_2 reductions from demand response, the emissions reductions from demand response-providing ancillary services were estimated for the Electric Reliability Council of Texas (ERCOT). Without demand response, inefficient natural gas peaking units are kept on longer since they are able to respond quickly to sudden shifts in demand. In the ERCOT region, there is only a small amount of coal generation, so peaking units would run in place of more efficient, less polluting NGCC units. Also, the NGCC units would run less efficiently in this case because they would be forced to run at lower than full capacity. With demand response, NGCC units are able to operate at higher capacity levels because demand response resources are able to respond quickly to shifts in demand. This results in CO_2 reductions of greater than 2 percent in each hour where the load exceeds the summer peak average compared to when demand response is not deployed.

In some situations in which renewables need to be curtailed so that sufficient fossil fuel generation is available to provide ancillary services, demand response can instead provide the ancillary services. This prevents the curtailment of renewable resources.

Source: Navigant Consulting, 2014.

[19] *There can be opportunity costs associated with provision of operating reserve. Some regions allow demand response and other energy efficiency and renewable energy resources to bid directly into the electricity market.*

Voltage Support

Maintaining a certain voltage level on the transmission system is necessary to ensure reliable and continuous electricity flow. Electricity system assets, such as capacitors or generators, can help maintain voltage levels by absorbing or generating reactive power, which is a specific and necessary type of power that moves back and forth on the system but is not consumed by load.[20] In electricity markets, market mechanisms compensate utilities for resources that can provide voltage support. The amount of compensation they receive is typically published and can be used by analysts to estimate the avoided cost of voltage support. For instance, to find information on voltage support market mechanisms, analysts can use the reactive power provisions in Schedule 2 of the FERC pro forma open access transmission tariff, or an RTO or ISO's equivalent schedule for reactive support, such as the NY ISO's ancillary service prices for voltage regulation which are published in $/MWh on an hourly basis.[21] Alternately, the difference in reliability with and without the energy efficiency or renewable energy resource can also give some indication of voltage support benefits. (See the reliability metrics discussion in "Increased Reliability and Power Quality," below.)

Some energy efficiency and renewable energy measures can have direct beneficial effects on avoiding certain voltage support (i.e., reactive power) requirements. Reactive power ancillary services are local in nature, and energy efficiency and renewable energy policies and programs that reduce load in a load pocket area can minimize the need for local reactive power requirements. While solar and wind resources may require backup voltage support due to their intermittent nature, demonstrations have shown that large-scale solar PV projects equipped with smart inverters can provide voltage support and other reliability services similar to conventional generating resources (NREL, 2017).

Frequency Regulation

Frequency regulation is necessary to maintain proper grid frequencies within tight tolerance bounds (around 60 Hertz). It involves closely matching the interchange flows and momentary variations in demand within a given control area. Generating units that are ready to increase or decrease power as needed are used for regulation—when a shortfall or excess of generation exists, generation from these units increases or decreases, respectively (U.S. DOE, 2013b). Renewable and demand response resources can support frequency regulation when generating units need to quickly decrease power output. For example, a demand response program that actively reduces load by an end-user through price signals or directives from a master control center can help maintain proper grid frequencies and avoid problems associated with frequency variations below optimal levels (PNNL, 2012). PNNL concluded that proper frequency regulation through demand response can also increase power plant operating efficiencies and help integrate variable renewable energy sources.

COMPLIMENTARY VALUE OF DEMAND RESPONSE FOR VARIABLE RENEWABLE ENERGY

The integration of variable renewable energy can be assisted by demand response services. Increasing amounts of variable renewable energy on a system can increase the need to ramp conventional generating units up and down to meet demand. Demand response can help balance variable renewable energy and provide ancillary services by altering load as needed, reducing the need to ramp up spinning reserves.

Demand-side flexibility is used in practice to provide ancillary services and reliability services. For example, ERCOT obtains half its spinning reserves from demand response. The NYISO has several programs paying for load reductions when the grid is under stress (see http://www.nyiso.com/public/markets_operations/market_data/demand_response/index.jsp).

Source: Bird et al., 2013.

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[20] *Two types of power are active power (also called real or true power) and reactive power. Active power, measured in watts, is a function of voltage and current and performs useful work such as powering a lightbulb. In simple direct current (DC) systems, the relationship between voltage and current is constant but in alternating current (AC) systems, such as the power grid, the relationship between voltage and current can change. In order for active power to be consumed, voltage and current must be aligned to produce useful work and it is reactive power that enables this. Reactive power, measured in volt-amp reactive (VAR), is absorbed or produced by certain types of loads, such as motors, and changes the relationship between voltage and current.*

[21] *Note that the Schedule 2 payments are often uniform across a large region. As a result, they may not capture differences in the value of these services in load pockets. For more information about the NY ISO prices, see http://www.nyiso.com/public/markets_operations/market_data/pricing_data/index.jsp.*

Reductions in Wholesale Market Clearing Prices

In addition to the benefits of avoided wholesale electricity costs (i.e., avoided electricity and capacity costs described earlier), energy efficiency and renewable energy resources can lower the demand for electricity or increase the supply of electricity, causing wholesale markets to clear at lower prices, which can benefit consumers.

The methods for estimating short-run wholesale market price effects involve relatively well-understood data and are reasonably straightforward to apply. In contrast, wholesale market price effects over the long term involve relatively poorly understood relationships, and estimating these price effects can become quite complex. For this reason, this section presents the steps involved in estimating the magnitude of the price effects of resource additions in the short run using a basic method. For longer-term forecasts, a more sophisticated method such as an economic dispatch model may be preferred.

Analysts often use Demand Reduction Induced Price Effects (DRIPE) to assess the benefits of a reduction in wholesale market clearing prices from energy efficiency and demand response programs. DRIPE is a measure of the value of efficiency in terms of the reductions in wholesale prices in a given period. A number of states, including Massachusetts highlighted in the box below, recognize DRIPE as a real, quantifiable benefit of energy efficiency and demand response programs. For instance, an assessment of Ohio's Energy Efficiency Resource Standard showed that program activities for 2014 would result in wholesale price mitigation savings of $880 million and wholesale capacity price savings of $1,320 million for customers through 2020 (SEE Action, 2015).

PRICE EFFECTS OF ENERGY EFFICIENCY PROGRAMS IN THE NORTHEAST IN 2014

A 2015 Avoided-Energy-Supply Component Study (AESC) provides projections of marginal energy supply costs that will be avoided due to reductions in the use of electricity, natural gas, and other fuels resulting from energy efficiency programs throughout New England. AESC projects avoided costs for a future base case in which no new programs are implemented. Demand Reduction Induced Price Effect (DRIPE) refers to the reduction in wholesale market prices for capacity and energy due to energy savings resulting from efficiency and/or demand response programs. Energy reductions from these programs should translate to lower retail rates for customers depending on the T&D network and regulatory framework of the region.

This 2015 study projected the intrastate energy DRIPE in the West Central Massachusetts region in 2015 to be 1.1 cents/kWh. The study projected the capacity DRIPE to be zero since the New England Independent System Operator designed its capacity auctions to avoid purchasing surpluses, and because new natural gas power plants are expected to set the capacity market price.

Source: Hornby, R. et al., 2015.

In order to assess DRIPE savings, analysts can estimate the potential market price change attributable to a particular energy efficiency or renewable energy resource based on a dispatch curve analysis as follows.

- **Step 1: Determine the time period of the planned operation for the energy efficiency or renewable energy resource.** Time periods may be defined by specific seasons or at certain times of the day.
- **Step 2: Determine the size of the resource (typically in MW) and the hourly shape if relevant.** (For more information, see "Step 1: Estimate the Energy Efficiency or Renewable Energy Operating Characteristics," in Section 3.2.4.)
- **Step 3: Develop a dispatch curve.** The dispatch curve can be based upon either generating unit data (i.e., capacity ratings and operating costs) or market clearing price data, typically available from the ISO or control area operator. See Section 3.4., "Tools and Resources," for data sources which provide generating unit data and market clearing price data. For more information, also see "Step 2: Identify the Marginal Units to Be Displaced," in Section 3.2.4. This method constructs a supply curve of all generating sources that can be dispatched and at what cost.

- **Step 4: Examine expected electricity demand and costs without the program.** Examine the BAU curve developed in Step 3 to determine the expected demand for electricity—and the costs—during the relevant time period.
- **Step 5: Consider the expected changes of the energy efficiency or renewable energy resource on electricity demand and prices.** Analyze a case with the energy efficiency or renewable energy resource by reducing demand or adding supply to represent the energy efficiency or renewable energy resource.
- **Step 6: Compare the wholesale market price results under both scenarios.** The difference is the wholesale market price reduction benefit (expressed in $/MWh or total dollars for the time period).

An illustration of this method is in the box on the next page, "Estimating Short-Run Wholesale Market Price Effects: An Illustration."

This method for calculating the market price change can be applied to the electric energy market and capacity market, if one exists in the region. This benefit can be calculated using spreadsheets, an economic dispatch model (e.g., GE MAPS, PROMOD IV), or an energy system model for a more aggregated estimate. Another method, used by the CPUC in California's avoided cost proceeding, is to use historical loads and prices (CPUC, 2006).

Increased Reliability and Power Quality

An expansion in the use of energy efficiency and some distributed renewable energy resources can improve both the reliability of the electricity system and power quality by helping to avoid power outages, maintaining proper grid voltage levels, and avoiding the need for redundant power supply. For example, California's investments in energy efficiency and demand response played a role in averting rolling blackouts in the summer of 2001. Power quality problems, in particular, occur when there are deviations in voltage level supplied to electrical equipment. Some forms of energy efficiency and renewable energy resources, such as fuel cells, can provide near perfect power quality to their hosts.

Reliability

Electric grid reliability relies upon the adequacy (i.e., having enough electricity supply to meet peak demand) and the performance (i.e., the ability to respond to disturbances) of the system. Energy efficiency can generate multiple benefits to electric grid reliability. Efficiency programs reduce long-term electricity growth and promote resource adequacy. Efficiency programs can defer the need to build new power plants to maintain grid operating reserve margins, defined as the grid's backup generating capacity and usually required to be in the range of 10 to 20 percent. Energy efficiency and distributed generation can also alleviate transmission constraints in regions where transmission capacity becomes congested. Finally, energy efficiency and renewable energy can help to avoid over-reliance on single sources of energy, or "lock-in." (SEEA, 2015). While measuring these benefits can be difficult, there are methods available that analysts can use.

Metrics for Assessing Adequacy of the System

Probabilistic reliability metrics commonly used to assess the adequacy of the system include loss of load expectation (LOLE), loss of load probability (LOLP), loss of load hours (LOLH), and expected unserved energy (EUE) (CPUC, 2015).

- *LOLE* is defined as the number of days per year when a shortage in generation capacity is expected to occur, and is expressed as an expected value (the industry standard is 0.1 days per year).
- *LOLP* is nearly identical to LOLE and shows the probability of a range of reserve margins being met. It is expressed as a probability, or a percentage of the year for which there is insufficient reserve margin.
- *LOLH* measures the total number of hours of generation capacity shortfalls over a time period (e.g., 8 hours per year), and does not specify how long a given outage occurred.

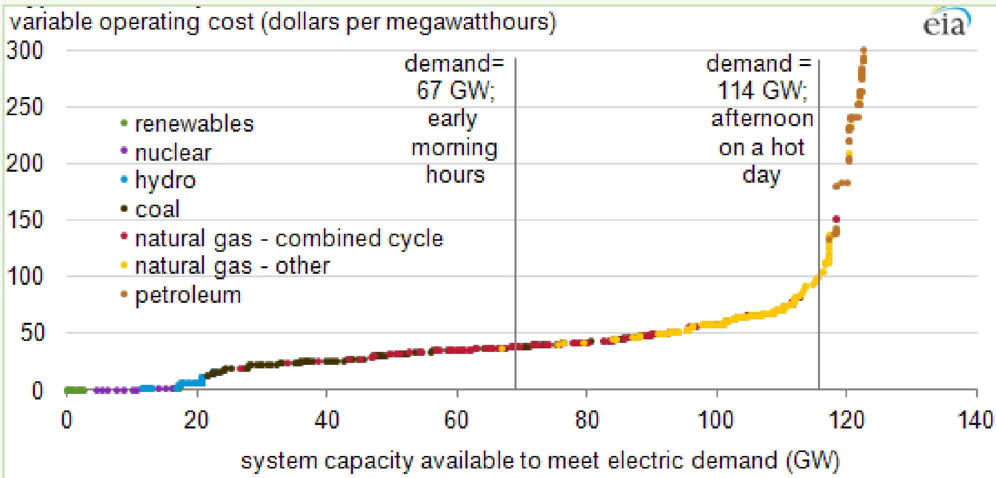
ESTIMATING SHORT-RUN WHOLESALE MARKET PRICE EFFECTS: AN ILLUSTRATION

To illustrate these steps with an example, assume a state decides to offer a rebate for residents who purchase ENERGY STAR certified air conditioners. Following the steps just outlined, the state can determine the potential effect of the rebate on wholesale electricity prices.

Step 1: The state determines that air conditioners in the region typically run on hot afternoons in the summer and so that is when the program would have the greatest impact.

Step 2: Based on the expected take-up rate of the rebate, the state calculates that the additional ENERGY STAR systems will lower demand by 4 GW.

Step 3: The state uses a curve constructed based on EIA-923 showing the variable operating costs for each dispatchable generator.



Source: EIA, 2012.

Step 4: Using the dispatch curve, the state finds that, in the absence of the rebate, the demand for electricity will be 114 GW, corresponding to a price of $100 per MWh.

Step 5: With the rebate program, the state expects demand to be reduced from 114 GW to 110 GW, which corresponds to a price of $75 per MWh in the dispatch curve.

Step 6: By lowering demand to 110 GW, the rebate program is expected to reduce wholesale prices by $25 per MWh (through a reduction in variable operating costs of the marginal generator, from $100 to $75) during hot summer afternoons.

The simplified equation for calculating savings from wholesale market price effects in this case is:

$$Savings\left(\frac{\$}{year}\right) = New\ Demand\ (in\ MW) * \#\ Hours\ of\ Demand\ Savings\ per\ Day * \#\ Days\ of\ Demand\ Savings\ per\ Year$$

$$* Reduction\ in\ Wholesale\ Prices\ from\ Displaced\ Marginal\ Generation\ \left(in\ \frac{\$}{MWh}\right) +$$

$$Demand\ Savings\ (in\ MW) * \#\ Hours\ of\ Demand\ Savings\ per\ Day$$

$$* \#\ Days\ of\ Demand\ Savings\ per\ Year\ * Wholesale\ Prices\ in\ Absence\ of\ Program\ \left(in\ \frac{\$}{MWh}\right)$$

If program savings of 4,000 MW (4 GW) were taking place over a 4-hour period each day for 90 summer days throughout the year, the program would save 110,000 MW * 4 hours per day * 90 days/year * $25/MWh + 4,000 MW * 4 hours per day * 90 days/year * $100/MWh = $1.044 billion each year in wholesale costs.

- *EUE* measures the amount of electricity shortfall during generation capacity shortages summed over a given time period, and also does not specify how long a given outage occurred. As a hypothetical example, the EUE for a 100-MW capacity shortage lasting one hour would equal 100 megawatt-hours (NERC, 2016).

As a general rule, the lower the LOLE, LOLP, LOLH, and EUE, the higher the reliability of the electricity system, and vice versa. See Section 3.4., "Tools and Resources," for potential resources on how to quantify reliability probabilistic metrics.

Metrics for Assessing Performance of the System

There are multiple indices to measure reliability from a performance perspective and they are relatively well established and straightforward to calculate. Some of the most common indices include:

- ***SAIFI (System Average Interruption Frequency Index):*** The average frequency of sustained interruptions per customer over a predefined area. It is calculated as the total number of customer interruptions divided by the total number of customers served.
- ***CAIDI (Customer Average Interruption Duration Index):*** The average time needed to restore service to the average customer per sustained interruption. It is calculated as the sum of customer interruption durations divided by the total number of customer interruptions.
- ***SAIDI (System Average Interruption Duration Index):*** Commonly referred to as customer minutes of interruption or customer hours, it provides information on the average time customers are interrupted. SAIDI = CAIDI * SAIFI, and represents the sum of the restoration time for each interruption event times the number of interrupted customers for each interruption event divided by the total number of customers.
- ***MAIFI (Momentary Average Interruption Frequency Index):*** Quantifies momentary interruptions resulting from each single operation of an interrupting device, such as a recloser. It is calculated as the total number of customer momentary interruptions divided by the total number of customers served.

Historical reliability data are often available. Converting reliability benefits into dollar values is complex, however, and the results of studies that have attempted to do so are controversial. For this reason, their use in support of resource decisions is less common than for other, well-established benefits, such as the avoided costs of generation, capacity, and T&D.[22]

Power Quality

Power quality refers to the consistency of voltage of electricity supplied to electrical equipment, usually meaning the voltage stays within plus or minus 5 percent. Maintaining consistent power quality is important; otherwise, electrical equipment can be damaged. Power quality improvements produce economic benefits for electricity consumers by avoiding damage to equipment and associated loss of business income and product, and, in some cases, the need for redundant power supply. For example, consumer and commercial electrical and electronic equipment is usually designed to tolerate extended operation at any line voltage within 5 percent nominal, but extended operation at voltages far outside that band can damage equipment or cause it to operate less efficiently. At the extreme, some commercial and industrial processes, such as silicon chip fabrication and online credit card processing, are so sensitive to outages or power quality deviations that customers take proactive steps to avoid these concerns, including construction of redundant transmission lines or installing diesel or battery backup power. The costs of such equipment could also be used to estimate the value of increased reliability and power quality.

The data needed to assess power quality benefits are neither consistently measured nor comprehensively collected and reported. Specialized monitoring equipment is typically necessary to measure power defects, and acceptable standards for power quality have been changing rapidly.

[22] The Interruption Cost Estimate Calculator (ICE) is a tool designed to estimate interruption costs (of events lasting longer than 16 hours) and benefits associated with reliability improvements (U.S. DOE, LBNL, and Nexant, 2015).

Avoided Risks Associated with Long Lead-Time Investments such as the Risk of Overbuilding the Electricity System

Energy efficiency and renewable energy options provide increased flexibility to deal with uncertainty and risk related to large, conventional fossil fuel resources. For example, in terms of resource planning, if one is unsure that long-term forecasts for load growth are 100 percent accurate, then energy efficiency and renewable energy resources offer greater flexibility due to their modular nature and relatively quick installation times relative to conventional resources.[23]

All other things being equal, a resource or resource plan that offers more flexibility to respond to changing future conditions is more valuable than a less flexible resource or plan. Techniques such as decision-tree analysis or real option analysis provide a framework for assessing this flexibility. These methods involve distinguishing between events within one's control (i.e., decision nodes) and those outside of one's control (i.e., exogenous events) and developing a conceptual model for these events as they would occur over time. Specific probabilities are generally assigned to the exogenous events. The results of this type of analysis can include the identification of the best plan on an expected value basis (i.e., incorporating the uncertainties and risks) or the identification of lower risk plans.

Beyond the expected value of the plan, certain resources may have some "option value" if they allow (or do not prevent) other resource options in the future. For example, a plan that involves implementing some DSM in the short run can have value above its simple short-run avoided cost. If conditions are sufficient, the resource develops the capability for expanded DSM deployment in the future, if conditions call for it.

Reduced Risks From Deferring Investment in Conventional, Centralized Resources Pending Uncertainty in Future Environmental Regulations

Energy efficiency and renewable energy can reduce the cost of compliance with current and future air pollution control requirements. Utilities and states also see these resources as a way to reduce their financial risk from future regulations. In order to account for uncertainty and risk in decision-making processes, utilities and states can consider multiple scenarios of future regulations and prices. Comparing energy efficiency and renewable energy to larger scale power projects under these different scenarios can result in an understanding of the specific risks that large investments might have compared to more flexible renewable energy and energy efficiency resources. A scenario analysis can identify a cost premium to be added to least-cost, high-risk energy resources being considered for development, allowing for full information when making decisions.

When comparing new generation options in the face of stricter environmental regulations, some states and utilities are reducing financial risk by placing a higher cost premium on conventional resources relative to energy efficiency and renewable energy. For example, California's cap-and-trade program, which places a cost on each metric ton of carbon a

SCENARIO MODELING IN PACIFICORP'S 2013 INTEGRATED RESOURCE PLAN

Pacificorp's 2013 Integrated Resource Plan (IRP) considers 19 different future "core case" scenarios each with different assumptions including:

- Timing and level of CO_2 prices
- Natural gas and wholesale electricity prices
- Policy assumptions pertaining to federal tax incentives and RPS requirements
- Policy assumptions pertaining to coal unit compliance requirements driven by Regional Haze regulations
- Acquisition ramp rates for Class 2 DSM resource (from non-dispatchable, firm energy and capacity product offerings/programs) available and coal unit environmental investments
- By reviewing these scenarios, PacifiCorp is able to weigh options for the future of the utility systems under different potential regulations.

Source: PacifiCorp, 2013.

[23] *Nonetheless, energy efficiency and renewable energy resources carry their own risk of non-performance.*

utility emits, sends a price signal to utilities considering building new units. In February 2018, California auction settlement prices were $14.61 per metric ton of carbon dioxide equivalent (CARB, 2018).

Improved Fuel Diversity

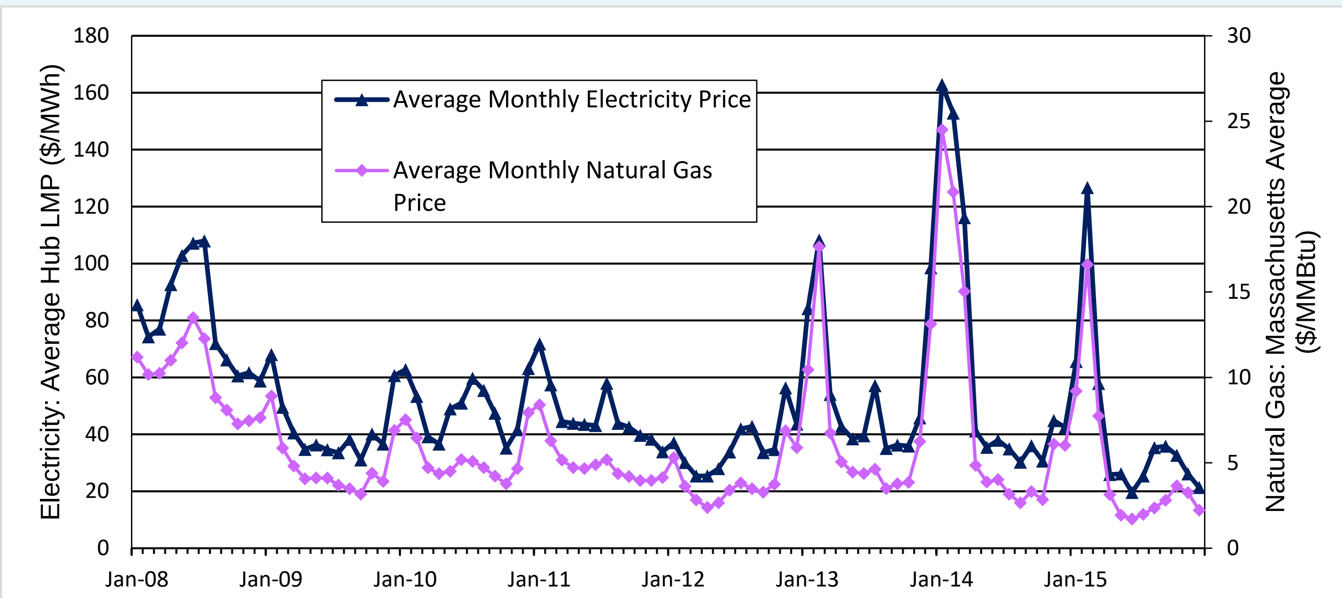
Portfolios that rely heavily on a few energy resources are highly affected by the unique risks associated with any single fuel source. In contrast, the costs of energy efficiency and renewable energy resources are not affected by fossil fuel prices and thus can hedge against fossil fuel price spikes by reducing exposure to this volatility.

Diversity in technology can also reduce the likelihood of supply interruptions and reliability problems. For example, while geothermal plants can be expensive to construct, they offer an almost constant supply of electricity and are best suited for baseload generation. Gas turbines, on the other hand, are relatively inexpensive to construct and can start quickly, but have a high operating cost and so are best suited for peaking generation. Figure 3-4 illustrates the relationship between electricity and natural gas prices in New England.

Two methods for estimating the benefits of fuel and technology diversification include market share indices and portfolio theory.

Figure 3-4: Natural Gas and Electricity Prices in New England

A large portion of New England's electricity is generated from natural gas. Due to this high dependence on one fuel source, and because fuel represents a large portion of the cost to produce electricity, natural gas and electricity prices are highly correlated.



Source: ISO New England, 2016.

Market Share Indices

- Market share indices, such as the Herfindahl-Hirschmann Index and Shannon-Weiner Index, identify the level of diversity as a function of the market share of each resource.[24] Use of these indices is appropriate for preliminary resource diversity assessment and as a state or regional benchmark.

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[24] *For more information about these indices, see U.S. Department of Justice and the Federal Trade Commission, Issued April 1992; Shannon, C. E. "A Mathematical Theory of Communication,"* Bell System Technical Journal *27: 379–423 and 623–656, July and October 1948. Market share indices are computationally simple, and the data required for the indices (annual state electricity generation by fuel type and producer type) are readily available from the EIA Form 923 database. Note that EIA Form 906 was superseded by EIA Form 923 starting in 2008. Both datasets are available at: https://www.eia.gov/electricity/data/eia923/index.html.*

- A limitation of these indices is that decisions on how to classify resources (e.g., calculating the share of all coal rather than bituminous and subbituminous coals separately) can have a large effect on the results. Another shortcoming is that the indices do not differentiate between resources that are correlated with each other (e.g., coal and natural gas) and thus can underestimate the portfolio risk when correlated resources are included.

Portfolio Theory

- The concept of portfolio theory suggests that portfolios of generation technologies should be assembled and evaluated based on the characteristics of the portfolio, rather than on a collection of individually assessed resources.

- Measures of the performance of a portfolio consider variance in load profile, whether the generator is dispatchable, and how quickly the generator can be dispatched. These measures account for risk and uncertainty by incorporating correlations between resources, as measured by the standard deviation of cost or some other measure of performance. The standard deviation can be calculated for a number of portfolios, each with a variety of different resources, to find portfolios that simultaneously minimize cost and risk. It is helpful to acknowledge this inherent trade-off between cost and risk; there is not a single portfolio that lowers both.

THE IMPORTANCE OF LOW PERFORMANCE CORRELATIONS

Similar resources (e.g., fossil fuels such as coal and oil) tend to face similar specific risks, and as a result their performances tend to be correlated. For example, coal and oil both emit CO_2 when burned and thus could be associated with future climate change regulatory risk, which in turn would likely increase costs and affect the performance of oil- or coal-fired generation. On the other hand, disparate resources (e.g., coal and wind) have lower performance correlations—and hence more value for offsetting resource-specific risks within the portfolio—than resources that have little disparity.

Improved Energy Security

While market share indices and portfolio analyses can estimate fuel and technology diversity, they do not readily incorporate the non-price and qualitative benefits of fuel diversity, such as energy independence, which can be a benefit of energy efficiency and renewable energy. Energy independence can improve energy security, for example when using domestic energy efficiency and renewable energy resources to reduce dependence on foreign fuel sources. Avoiding the use of imported petroleum may yield political and economic benefits by protecting consumers from supply shortages and price shocks. Energy and national security is also improved when the existence of one easily targeted large unit with onsite fuel is replaced with many smaller units that are located in a variety of locations. Care should be taken to consider price as well as factors that are not easily quantified when choosing among portfolios with different cost-risk profiles.

Summary of Secondary Electricity System Benefits

Table 3-11 outlines some of the factors that state decision makers can consider when deciding which secondary electricity system benefits to analyze, including available methods and examples, strengths, limitations, and purpose of analysis.

Table 3-11: Secondary Electricity System Benefits From Energy Efficiency and Renewable Energy Measures

Applicable Energy Efficiency and Renewable Energy Resources	Considerations for Determining Whether to Analyze	Who Usually Conducts or Commissions Analysis?	When Is Analysis Usually Conducted?
BENEFIT: Avoided ancillary services			
▪ Resources that can start during blackout, ramp up quickly, or provide reactive power ▪ Resources closer to loads	▪ Usually smaller benefits than traditionally analyzed benefits ▪ Market price data available for some services in some markets (e.g., PJM) ▪ Ancillary service savings from clean resources often site-specific and difficult to estimate ▪ Separating ancillary service value from capacity value in long-run analysis may be difficult	▪ Utilities conduct in-depth modeling ▪ State utility regulatory commissions and other stakeholders review utility's results and/or conduct own analysis	▪ Resource planning and released regulatory proceedings ▪ Area-specific DSM program development ▪ Policy studies
BENEFIT: Wholesale market price effects			
▪ All energy efficiency and renewable energy resources ▪ Resources that operate during peak hours	▪ Benefits depend on market/pricing structure and peaking resources and forecasted reserve margins ▪ Actual market price data generally available ▪ Studies to estimate benefits may be complex	▪ ISOs and utilities conduct in-depth modeling ▪ State utility regulatory commissions, other stakeholders review utility's results and/or conduct own analysis	▪ Resource planning and released regulatory proceedings ▪ Area-specific DSM program development ▪ Policy studies
BENEFIT: Increased reliability and power quality			
▪ Distributed renewable resources ▪ Energy efficiency and renewable energy resources close to load or with high power quality ▪ All resources that operate as baseload units ▪ All load-reducing energy efficiency resources that increase surplus generation and T&D capacity in region	▪ Historical reliability data often available ▪ Historical power quality data rare ▪ Studies for converting to dollar value complex and controversial ▪ Benefits especially valuable for manufacturing processes sensitive to power quality or regions where reliability is significant concern	▪ Utilities conduct in-depth modeling ▪ State utility regulatory commissions and other stakeholders review utility's results and/or conduct own analysis	▪ Usually ad hoc studies ▪ Policy studies

Applicable Energy Efficiency and Renewable Energy Resources	Considerations for Determining Whether to Analyze	Who Usually Conducts or Commissions Analysis?	When Is Analysis Usually Conducted?
BENEFIT: Avoided or reduced risks of overbuilding (associated with long lead-time investments, such as the risk of overbuilding the electricity system)			
▪ Distributed resources with short lead times ▪ Resources close to load ▪ All energy efficiency and renewable energy resources	▪ Historical load and load variability data often available ▪ Modeling varies from simple to complex	▪ Utilities conduct in-depth modeling ▪ State utility regulatory commissions and other stakeholders review utility's results and/or conduct own analysis ▪ Policy and risk management analysts conduct analysis	▪ Resource planning and released regulatory proceedings ▪ Policy studies
BENEFIT: Avoided or reduced risks of stranded costs (from deferring investment in conventional, centralized resources until environmental and climate change policies are implemented)			
▪ All energy efficiency and renewable energy resources	▪ Modeling varies from simple to complex ▪ Studies to estimate benefits may be complex ▪ Regulatory uncertainty adds to complexity of analysis	▪ Policy and risk management analysts conduct analysis	▪ Resource planning and released regulatory proceedings ▪ Policy studies
BENEFIT: Fuel and technology diversification			
▪ All energy efficiency and renewable energy resources	▪ Diversity metrics computable from generally available data ▪ Portfolio analysis of costs vs. risks adds complexity ▪ Ensuring inclusion of existing supply resources and incremental new resources	▪ State utility regulatory commissions conduct own analyses ▪ Utilities conduct in-depth modeling ▪ RTO/ISOs conduct own analyses	▪ State energy plans ▪ Resource planning and released regulatory proceedings ▪ Policy studies

3.3. CASE STUDIES

The following two case studies illustrate how assessing the electricity system benefits associated with energy efficiency and renewable energy can be used in the state energy planning and policy decision-making process. Information about a range of tools and resources analysts can use to quantify these benefits, including those used in the case studies, is available in Section 3.4., "Tools and Resources."

3.3.1. California Utilities' Energy Efficiency Programs

Benefits Assessed in Analysis

Electricity system benefits quantified in this case study include:

- Avoided electricity generation costs
- Avoided generation capacity costs
- Avoided ancillary services costs

- Avoided T&D capacity costs

Other benefits quantified in this case study include:

- Avoided environmental externality costs
- Avoided Renewable Portfolio Standard (RPS) costs

Energy Efficiency/Renewable Energy Program Description

In California, investor-owned utility (IOU) energy efficiency programs are funded by a small portion of electricity and gas rates included in customer bills, which provides over $1 billion per year. The programs span a variety of sectors encompassing residential homes and commercial buildings; large and small appliances; lighting and heating, ventilation, and air conditioning; industrial manufacturers; and agriculture. Within those sectors, IOUs take a number of approaches to efficiency programs, including:

- Financial incentives and rebates
- Research and development for energy efficiency technologies
- Financing mechanisms
- Codes and standards development
- Education, public outreach, and marketing

Four California IOUs, Pacific Gas and Electric Company (PG&E), Southern California Edison (SCE), San Diego Gas & Electric (SDG&E), and Southern California Gas Company, are the primary administrators of publicly funded energy efficiency programs. All of these programs are regulated by the CPUC to ensure they are meeting the goals and cost-effectiveness metrics set by the CPUC.

The primary benefits of demand-side resources, like energy efficiency, are the avoided costs related to generation and distribution of energy. In 2017, the CPUC approved an interim methodology developed by Energy and Environmental Economics, Inc. (E3) to calculate avoided costs, which is used to evaluate the cost-effectiveness of 2017–2040 utility energy efficiency programs in California. The updated methodology builds upon the previous avoided cost model that was used for estimating energy efficiency avoided costs since the 2011 cycle, and attempts to better reflect the expected future avoided costs for the California IOUs.

Methods Used

E3 conducted an analysis of IOU energy efficiency programs in 2017 to calculate the CPUC's avoided electricity generation costs, avoided generation capacity costs, avoided ancillary services costs, avoided T&D capacity costs, environmental externality costs, and avoided RPS costs. The analysts used the "Avoided Cost Calculator," an Excel-based spreadsheet model developed by E3 that incorporates CPUC-approved methods for use in demand-side cost-effectiveness proceedings. E3's methodology application for analyzing avoided costs is described in a detailed report issued in September 2017, *Energy Efficiency Avoided Costs 2017 Interim Update* (E3, 2017). The methodology accounts for six major cost benefits that are avoided when demand is reduced through installation of energy efficiency resources. To implement the methodology, E3 used the calculator to produce time- and location-specific cost estimates, and incorporate generation and T&D loss factors to reflect the fact that dispatched generation is greater than electricity delivered to customers due to electricity losses during transmission and distribution. It combines forecasts of the average value of each benefit with historical day-ahead and real-time energy prices, along with actual system loads reported by CAISO for 2015, to produce avoided costs with hourly granularity. Table 3-12 summarizes the methodology applied to each benefit to develop this level of granularity.

E3 used the calculator to develop location-specific results for the 16 California climate zones as defined by the Title 24 building standards to highlight the regional differences of electricity values in the state, which capture the effect of differences in climate on energy use.

Table 3-12: Summary of Methodology for Assessing Program Benefits

Benefit	Description	Basis of Annual Forecast	Basis of Hourly Shape
Avoided Electricity Generation Costs	The hourly wholesale value of avoided electricity	Forward market prices and the $/kWh fixed and variable operating costs of a combined-cycle gas turbine	Historical hourly day-ahead market price shapes from Market Redesign and Technology Upgrade (MRTU) Open Access Same-time Information System (OASIS)
Avoided Generation Capacity Costs	The avoided costs of building new generation capacity to meet system peak loads	Residual capacity value of a new simple-cycle combustion turbine	E3 Renewable Energy Capacity Planning (RECAP) model that generates outage probabilities by month/hour, and allocates the probabilities within each month/hour based on 2015 weather
Avoided Ancillary Services Costs	The avoided marginal costs of providing system operations and reserves for electricity grid reliability	Percentage of generation energy value	Directly linked with energy shape
Avoided T&D Capacity Costs	The avoided costs of expanding transmission and distribution capacity to meet peak loads	Marginal T&D costs from utility ratemaking filings	Hourly temperature data
Environmental Externality Costs	The cost of carbon dioxide emissions associated with the marginal generating resource	CO_2 cost forecast from the California Energy Commission's *2015 Integrated Energy Policy Report* mid-demand forecast, escalated at inflation beyond 2030	Directly linked with energy shape with bounds on the maximum and minimum hourly value
Avoided RPS Costs	The reduced purchases of renewable generation at above-market prices required to meet an RPS standard due to a reduction in retail loads	Cost of a marginal renewable resource less the energy market and capacity value associated with that resource	Flat across all hours

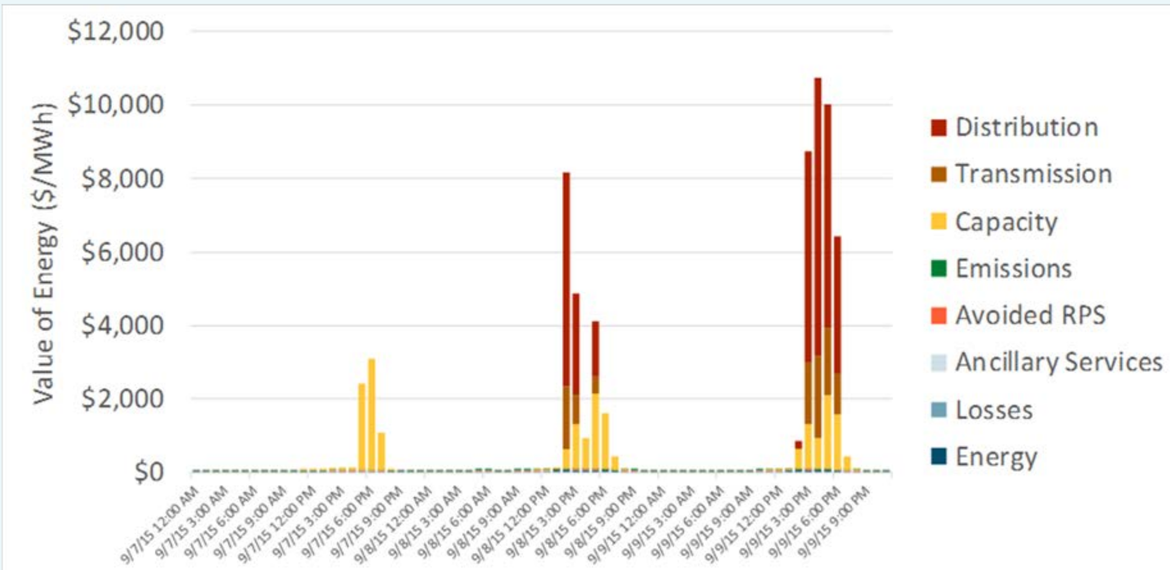
Source: E3, 2017.

Results

The results of E3's analysis demonstrate the value of estimating avoided costs in California using time- and location-specific data, which highlights the importance of reducing demand during peak hours. The study found that avoided costs (especially for distribution, but also for transmission and capacity) were particularly high during peak hours and the peak summer season.

Figure 3-5 breaks down avoided costs by type in PG&E's Sunnyvale territory over a three-day period. As shown, the marginal cost of energy is higher in the afternoons and evenings (peak hours) than in the morning. The highest peaks of total avoided cost shown in of over $10,000/MWh are driven primarily by avoided generation capacity *(yellow bars)* and avoided T&D capacity *(brown and red bars).* These types of avoided costs are concentrated during the peak hours of the day (the hours where electricity demand is highest and generation, transmission, and distribution capacity are most utilized) (E3, 2017).

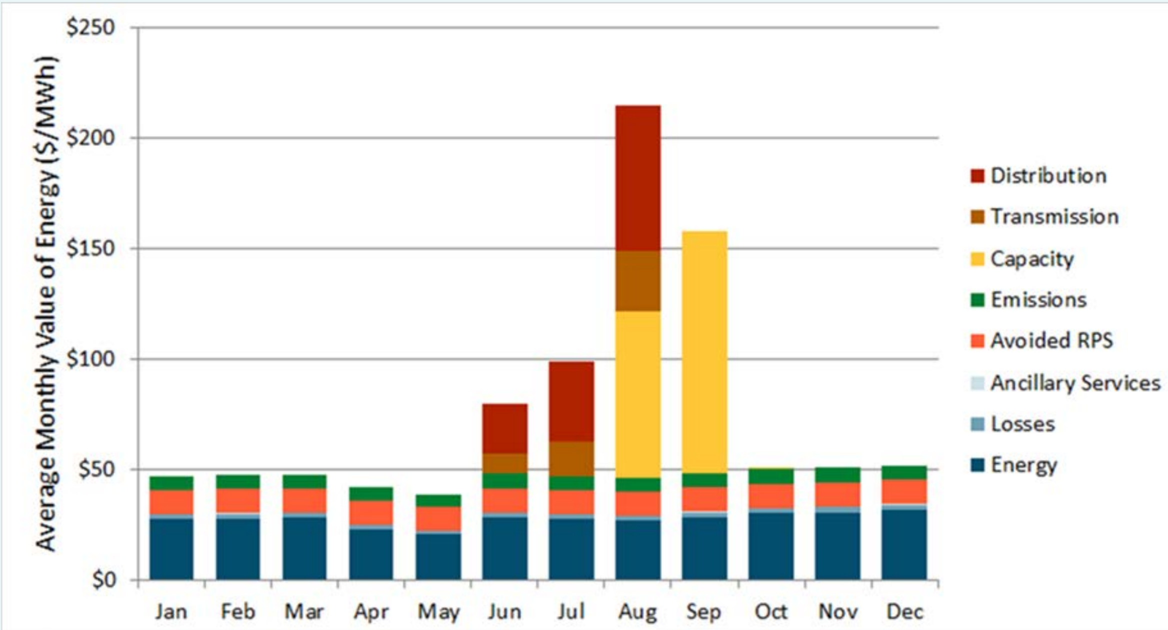
Figure 3-5: Three-Day Snapshot of Energy Values in Sunnyvale, CA (PG&E) in 2017



Source: E3, 2017.

Figure 3-6 demonstrates the value of electricity reductions in PG&E's Fresno territory by month. As shown, the average monthly value of energy is highest in the summer months when demand for electricity is highest and lower in other months. As a result, the value of generation capacity *(yellow bars)* and T&D capacity *(brown and red bars)* is concentrated in the summer months (E3, 2017).

Figure 3-6: Average Monthly Avoided Cost From Energy Efficiency in Fresno, CA (PG&E) in 2017



Source: E3, 2017.

Table 3-13 shows the costs and benefits to bill payers for each of California's four IOUs, as well as the whole state.[25] California's energy efficiency programs are estimated to have a total program lifetime benefit of $5.5 billion, 30 percent larger than the cost of the programs (CPUC, 2015).[26]

Table 3-13: Estimated Cost-Effectiveness Test Results for the California Investor-Owned Utilities' 2010–2012 Efficiency Programs ($Million)

Costs and Benefits	SDG&E	SoCalGas	SCE	PG&E	Total
Total costs to bill payers	$400	$379	$1,627	$1,825	$4,230
Total savings to bill payers	$404	$561	$2,329	$2,238	$5,532
Net benefits to bill payers	$4	$182	$702	$413	$1,302

Source: CPUC, 2015.

[25] *These estimates use a Total Resource Cost (TRC) test to assess cost-effectiveness. For more information, see http://www.cpuc.ca.gov/PUC/energy/Energy+Efficiency/Cost-effectiveness.htm*

[26] *As a result of the energy efficiency programs, California's investor-owned utilities project savings of about 7,745 GWh of electricity, 1,300 MW of peak summer demand, and 170,000 megatherms of natural gas from 2010 to 2012. Relative to a BAU baseline without the programs, the utilities expect to reduce carbon dioxide emissions by about 5,300,000 tons—the equivalent of the emissions of over one million cars over the same period.*

For More Information

Resource Name	Resource Description	URL Address
California Utilities' Energy Efficiency Programs Case Study		
Avoided Cost Calculator and *2017 Avoided Cost Interim Update*	This link leads to the Avoided Cost Calculator (updated in 217) as well as a detailed 2017 report that describes the methods used to calculate avoided costs for energy efficiency cost-effectiveness valuation for 2017–2040.	http://www.cpuc.ca.gov/General.aspx?id=5267
Energy Efficiency 2010–2012 Evaluation Report	This 2015 CPUC report describes the results of consumer-funded energy efficiency programs.	http://www.cpuc.ca.gov/General.aspx?id=6391

3.3.2. Energy Efficiency and Distributed Generation in Massachusetts

Benefits Assessed in Analysis

Electricity system benefits quantified in this case study include:

- Reduction in wholesale market clearing prices
- Reduction in avoided costs of electricity generation/wholesale electricity purchases
- Reduction in T&D costs
- Reduction in ancillary service costs
- Reduction in long-run avoided costs of power plant capacity

Other benefits quantified in this case study include:

- Increased economic activity
- Job creation
- Avoided greenhouse gas (CO_2) emissions

Energy Efficiency/Renewable Energy Program Description

The Green Communities Act (GCA), passed by the Massachusetts legislature in July 2008, created energy efficiency and renewable energy policies focused on increasing:

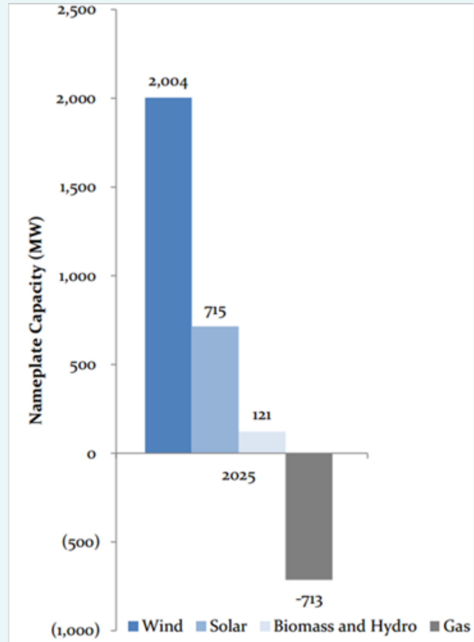
- Utility energy efficiency programs
- Solar deployment through net metering
- Grid-scale renewable energy development
- Massachusetts's Renewable Portfolio Standard (RPS) targets
- Funding for local energy efficiency and renewable energy projects

In 2014, Analysis Group released an evaluation of the economic and emissions impact of the GCA from 2010 through 2015 (see Figure 3-7).

Methods Used

The analysis compared the observed program impacts to a counterfactual scenario using modeled assumptions in which the GCA policies were not implemented. This comparison allowed Analysis Group to attribute costs and benefits properly to the GCA. The modeling only examined the impacts of energy efficiency and renewable energy projects implemented during the first 6 years of the GCA, from 2010 to 2015, but projected savings for these projects through 2025. The modeling assumes that energy efficiency savings expire after the end of their useful life (10 years) and that increased renewable generation resulting from the GCA generates energy through 2025.

Figure 3-7: Capacity Additions in New England Due to GCA in 2025



Source: "The Impacts of the Green Communities Act on the Massachusetts Economy: A Review of the First Six Years of the Act's Implementation" (Analysis Group, March 4, 2014).

The analysis used the PROMOD IV model to determine electricity system effects through 2025 resulting from lower consumer demand and increased renewable energy supply. The analysis also used the IMPLAN model to examine the net macroeconomic effects from increased costs due to energy efficiency programs and lost revenue from fossil fuel generators, as well as benefits from reduced consumer energy bills (lower avoided costs of electricity generation/wholesale electricity purchases, T&D costs, and ancillary service costs), lower power demand (lower long-run avoided costs of power plant capacity), construction and installation of energy efficiency and renewable energy measures, and increased renewable energy revenue. The analysis converts these impacts into inputs (in dollar terms) which are modeled in IMPLAN producing impacts on key output variables such as employment, income, and economic value-added. The impact of the GCA on these key output variables was calculated from the difference between two IMPLAN model runs: the counterfactual, non-GCA scenario and the observed GCA impact scenario.

Results

The analysis (see Table 3-14) shows that the GCA is projected to result in the following impacts by 2025:

- Addition of 2,800 MW of renewable capacity (over 2,000 MW of wind, 700 MW of solar)
- Over 700 MW of reduced natural gas capacity
- Over 10 Terawatt-hours (TWh) of reduced electricity generation
- Net economic benefit of over $1 billion ($600 million) at a 3 percent (7 percent) discount rate
- Nearly 16,400 jobs created

Table 3-14: Net Economic Impact of GCA by 2025

Scenario	3% Discount Rate		7% Discount Rate	
	Value Added ($bn)	Jobs	Value Added ($bn)	Jobs
Base	$1.2	16,395	$0.6	16,395
High Gas	$1.8	21,651	$1.1	21,651
Low Gas	$0.6	11,187	$0.2	11,187

Source: "The Impacts of the Green Communities Act on the Massachusetts Economy: A Review of the First Six Years of the Act's Implementation," (Analysis Group, March 4, 2014).

Policies created through the GCA reduce wholesale energy costs paid by Massachusetts customers through increased energy efficiency and distributed generation deployment. The study estimates, due to energy efficiency and renewable energy actions already completed, that the GCA is expected to reduce annual wholesale electricity prices by $2.51 per MWh in 2020, declining slightly to $1.47 per MWh in 2025.

The study also finds, due to energy efficiency and renewable energy actions already completed, that the GCA is expected to reduce annual greenhouse gas emissions by more than 2 million metric tons (MMT) CO_2 per year through 2025, when cumulative reductions exceed 30 MMT CO_2.

For More Information

Resource Name	Resource Description	URL Address
Energy Efficiency and Distributed Generation in Massachusetts Case Study		
The Impacts of the Green Communities Act on the Massachusetts Economy: A Review of the First Six Years of the Act's Implementation	This 2014 report by the Analysis Group describes economic impacts of the Massachusetts Green Communities Act.	http://www.analysisgroup.com/uploadedfiles/content/insights/publishing/analysis_group_gca_study.pdf

3.4. TOOLS AND RESOURCES

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

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

3.4.1. Tools and Resources for Quantifying Primary Electricity System Benefits

Analysts can use a range of available data sources, tools, and resources to estimate the primary electricity system benefits of energy efficiency and renewable energy initiatives.

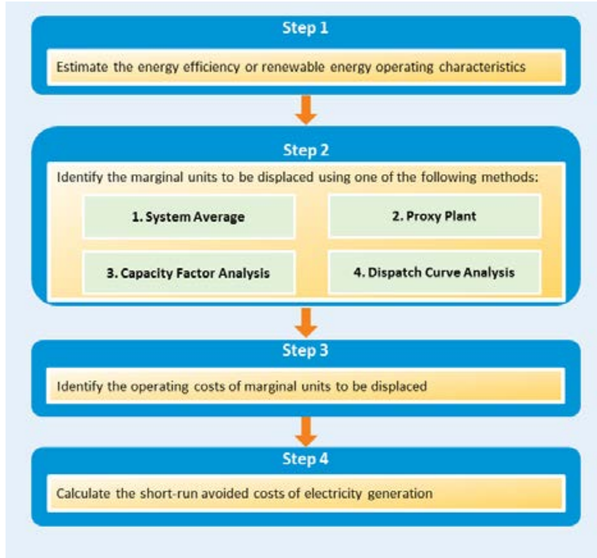
Tools and Resources for Estimating Avoided Costs of Electricity Generation or Wholesale Electricity Purchases

Resources detailed below serve as applicable data sources and tools for estimating avoided costs of electricity generation or wholesale electricity purchases.

Data Sources

Data Sources for Energy Efficiency and Renewable Energy Resource Operating Characteristics

In order to estimate avoided costs of electricity generation or wholesale electricity purchases, it is necessary to identify the operating costs of the marginal units to be displaced. Analysts can use the range of data sources listed below to identify the operating characteristics of the relevant energy efficiency and renewable energy resources. In addition to these data sources, load impact profile data for energy efficiency measures may be available for purchase from various vendors, but typically are not publicly available in any comprehensive manner.



- **3Tier**. This resource provides customized data and services that NREL sources for its Eastern and Western Wind Datasets. https://www.3tier.com
- **American Wind Energy Association**. This resource provides wind profiles. www.awea.org
- **AWS Truepower**. This resource provides customized data and services related to wind profiles for purchase. https://www.awstruepower.com/
- **California Database for Energy Efficient Resources (DEER).** DEER provides estimates of energy and peak demand savings values, measure costs, and effective useful life of efficiency measures. http://www.deeresources.com/
- **DOE's NEMS Model.** This resource provides wind profiles. https://www.eia.gov/outlooks/aeo/info_nems_archive.php
- **Homer's Energy Model**. This model can convert solar irradiation data to units of solar power. http://www.homerenergy.com/
- **New York State Energy Research and Development Authority's (NYSERDA) report, *Energy Efficiency and Renewable Energy Resource Development Potential in New York State, 2014***. This report on energy efficiency and renewable energy potential provides technology production profiles. Other states or regions may have similar reports. http://www.nyserda.ny.gov/-/media/Files/EDPPP/Energy-Prices/Energy-Statistics/14-19-EE-RE-Potential-Study-Vol1.pdf
- **Northeast Energy Efficiency Partnership's Regional Energy Efficiency Database (REED).** REED contains data on annual energy savings, peak demand savings, avoided air emissions, program expenditures, job creation impacts, cost of saved energy, program funding sources, and supporting information. http://www.neep.org/initiatives/emv-forum/regional-energy-efficiency-database
- **NREL's Eastern and Western Wind Datasets.** These datasets provide wind profiles. https://www.nrel.gov/grid/eastern-western-wind-data.html
- **NREL's Energy Analysis Site**. This site hosts Homer's Energy model and NREL's System Advisor Model. https://www.nrel.gov/analysis/
- **NREL's National Solar Radiation Database.** This database has a solar irradiation dataset with data in time intervals as small as half an hour. http://rredc.nrel.gov/solar/old_data/nsrdb/

- **NREL's System Advisor Model (SAM).** This model can convert solar irradiation data to units of solar power. https://sam.nrel.gov
- **NREL's Wind Prospector Tool.** This tool provides wind profiles. https://maps.nrel.gov/wind-prospector/
- **PV Watts**. This resource can convert solar irradiation data to units of solar power. http://pvwatts.nrel.gov/
- **Technical Resource Manuals (TRMs).** TRMs are documents used in 21 states to help estimate the impact of energy efficiency programs and can include hourly load profiles that display energy usage for different technologies throughout each hour of the day. For example, TRMs can be used to quantify the impact of light-emitting diode lighting installations on residential energy consumption, and contain generally applicable assumptions such as the number of hours in operation of different lighting technologies. TRMs are usually developed by public utility commissions (such as those in New York, Pennsylvania, and Vermont), as well as non-profit stakeholder groups (such as the Northeast Energy Efficiency Partnership). http://energy.gov/sites/prod/files/2013/11/f5/emvscoping_databasefeasibility_appendices.pdf

Data Sources for Dispatch Curve Analysis

Dispatch curve analyses examine historical hourly dispatch data to estimate the characteristics and frequency of each generating unit on the margin. Constructing a dispatch curve requires data on historical utilization of generating units; operating costs and emissions rates (if emissions are included in the analysis) for the most disaggregate time frame available; hourly regional loads; and electricity transfers between the control areas of the region and outside the region of interest. Sources for these required data are described below.

- **ABB's Velocity Suite**. Velocity Suite provides information on market participants and industry dynamics across commodities. http://new.abb.com/enterprise-software/energy-portfolio-management/market-intelligence-services/velocity-suite
- **EIA's Annual Energy Outlook.** This resource provides long-term electricity and fuel price projections. http://www.eia.doe.gov/oiaf/aeo/index.html
- **EIA's Electricity Data**. Operating cost and historical utilization data can typically be obtained from the EIA or the local load balancing authority. Often these sources can also provide generator-specific emissions rates for estimating potential emissions reductions from energy efficiency and renewable energy. http://www.eia.gov/electricity/
- **EIA's Form EIA-860.** This form provides generator-level information about existing and planned generators and associated environmental equipment at electric power plants with 1 MW or greater of combined nameplate capacity. https://www.eia.gov/electricity/data/eia860/
- **EIA's Form EIA-861**. This form provides information such as peak load, generation, electric purchases, sales, revenues, customer counts and DSM programs, green pricing and net metering programs, and distributed generation capacity. https://www.eia.gov/electricity/data/eia861/
- **EIA's Form EIA-923**. This form contains generator and fuel cost data by plant and can be used as an indicator for operating costs. https://www.eia.gov/electricity/data/eia923/
- **EPA's Air Market Program Data (AMPD).** AMPD is a web-based application that allows users easy access to both current and historical data collected as part of EPA's emissions trading programs. https://ampd.epa.gov/ampd/
- **EPA's eGRID Database.** This database provides historic data on or estimates of, capacity factors for individual plants which can be used in displacement curve analysis. https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid

- **FERC Form 1.** FERC Form 1 is the form filed annually by major electric utilities. This comprehensive financial and operating report can be used as a source of data for dispatch curve analysis. https://www.ferc.gov/docs-filing/forms/form-1/viewer-instruct.asp
- **FERC Form 423.** This form is a compilation of data for cost and quantity of fuels delivered to electric power plants. https://www.ferc.gov/docs-filing/forms.asp#423
- **FERC Form 714 (control area information).** This form can provide data on control area hourly marginal costs. http://www.ferc.gov/docs-filing/forms/form-714/data.asp
- **ISO New England**. ISO New England provides market clearing price data for northeastern states that can be used to develop a dispatch curve. https://www.iso-ne.com/markets-operations/markets/forward-capacity-market
- **Platts' MegaWatt Daily.** Platts publishes forward electricity market prices through this paid subscription newsletter. http://www.platts.com/products/megawatt-daily

Tools

Sophisticated Tools for Estimating Short-Run Avoided Costs: Economic Dispatch Models

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

- **GE Multi-Area Production Simulation (GE MAPS™).** GE MAPS, developed and supported by GE Energy and supported by other contractors, is a tool designed to model the interaction between generation and transmission systems, allowing users to assess the value of a portfolio of generating units and identify transmission bottlenecks constraining the electric grid. A chronological model that contains detailed representation of generation and transmission systems, GE MAPS can also be used to study the impact on total system emissions that result from the addition of new generation. GE MAPS software integrates highly detailed representations of a system's load, generation, and transmission into a single simulation. This enables calculation of hourly production costs in light of the constraints imposed by the transmission system on the economic dispatch of generation. http://www.geenergyconsulting.com/practice-area/software-products/maps
- **Integrated Planning Model (IPM)®.** IPM, developed and supported by ICF, simultaneously models electric power, fuel, and environmental markets associated with electric production. It is a capacity expansion and economic dispatch model. Dispatch is based on seasonal, segmented load duration curves, as defined by the user. IPM also has the capability to model environmental market mechanisms such as emissions caps, trading, and banking. System dispatch and boiler and fuel-specific emission factors determine projected emissions. IPM can be used to model the impacts of energy efficiency and renewable energy resources on the electric sector in the short and long term. http://www.icf.com/resources/solutions-and-apps/ipm
- **Market Analytics – Zonal Analysis, Powered by PROSYM.** PROSYM, owned by ABB, allows users to forecast market prices from periods ranging from 1 week to 40 years into the future and analyze the effects of fuel prices, plant outages, load uncertainty, hydro availability, and emissions on market prices. A chronological electric power production costing simulation computer software package, PROSYM is designed for performing planning and operational studies. As a result of its chronological nature, PROSYM accommodates detailed hour-by-hour investigation of the operations of electric utilities. Inputs into the model are fuel costs, variable O&M costs, and startup costs. Output is available by regions, by plants, and by plant types. The model includes a

pollution emissions subroutine that estimates emissions with each scenario. http://new.abb.com/enterprise-software/energy-portfolio-management/market-analysis/zonal-analysis

- **PLEXOS for Power Systems™.** PLEXOS, owned by Energy Exemplar, uses mathematical optimization techniques to create a simulation system for the electric power sector, allowing users to minimize future investment costs with respect to capacity expansion planning, examine scenarios involving expansion of renewable energy technologies, and model ancillary services. A simulation tool that uses LP/MIP (Linear Programming/Mixed Integer Programming) optimization technology to analyze the power market, PLEXOS contains production cost and emissions modeling, transmission modeling, pricing modeling, and competitiveness modeling. The tool can be used to evaluate a single plant or the entire power system. http://www.energyexemplar.com
- **PROMOD IV.** PROMOD IV, owned by ABB, is used for locational marginal price (LMP) forecasting, financial transmission right valuation, environmental analysis, asset valuations (generation and transmission), transmission congestion analysis, and purchased power agreement evaluations. A detailed generator and portfolio modeling system, PROMOD IV can incorporate details in generating unit operating characteristics and constraints, transmission constraints, generation analysis, unit commitment/operation conditions, and market system operations. http://new.abb.com/enterprise-software/energy-portfolio-management/market-analysis/promod-iv

Tools and Resources for Estimating Long-Run Avoided Costs of Power Plant Capacity

The avoided cost of building and operating new power plants are the avoided costs of power plant capacity that can be estimated using either basic estimation or sophisticated simulation methods. Data sources and relevant tools to assist with this process are described below.

Data Sources

Utilities are one possible source of data for estimating long-run avoided costs of power plant capacity and often provide this information to public utility commissions in resource planning and plant acquisition proceedings. Other data sources include:

- **EPA's Power Sector Modeling using the Integrated Planning Model (IPM).** This resource provides information and documentation on EPA's application of IPM to analyze the impact of air emissions policies on the U.S. electric power sector. https://www.epa.gov/airmarkets/clean-air-markets-power-sector-modeling
- **FERC Form 1**. This form can provide information for dispatch curve analyses. http://www.ferc.gov/docs-filing/forms/form-1/viewer-instruct.asp and http://www.ferc.gov/docs-filing/elibrary.asp
- **Regional Reliability Organizations***.* Organizations such as NERC can provide information on required reserve margins. http://www.nerc.com/pa/RAPA/ra/Pages/default.aspx
- **Regional Transmission Organizations, Independent System Operators, and Power pools***.* These sources maintain supply and demand projections by region and often sub-region.
- **SEC 10-Q Filings.** These quarterly filings provide company information on historical financial data and are available from the SEC EDGAR system. http://www.sec.gov/edgar.shtml
- **Securities and Economic Exchange Commission (SEC) 10K Filings.** These annual filings provide individual utility historical financial data. http://www.sec.gov/edgar/searchedgar/ companysearch.html

Tools

Electric Sector-Only Capacity Expansion Models

Capacity expansion models determine the optimal generation capacity and/or transmission network expansion in order to meet an expected future demand level and comply with a set of national, regional, or state specifications. Commonly used electric sector-only capacity expansion models for calculating long-run avoided costs of power plant capacity include:

- **AURORA**. The AURORA model, developed by EPIS LLC, provides electric market price forecasting, estimates of resource and contract valuation and net power costs, long-term capacity expansion modeling, and risk analysis of the energy market. http://epis.com/aurora/
- **EGEAS**. The Electric Generation Expansion Analysis System (EGEAS), developed by the Electric Power Research Institute, is a set of computer modules that are used to determine an optimum expansion plan or simulate production costs for a pre-specified plan. Optimum expansion plans are based on annual costs, operating expenses, and carrying charges on investment. http://eea.epri.com/models.html#tab=3
- **e7 Capacity Expansion.** e7 Capacity Expansion, developed by ABB, is an energy portfolio management solution covering resource planning, capacity expansion, and emissions compliance. It enables resource planners and portfolio managers to assess and develop strategies to address current and evolving RPSs and emissions regulations. http://new.abb.com/enterprise-software/energy-portfolio-management/commercial-energy-operations/system-optimizer-strategist
- **e7 Portfolio Optimization**. Portfolio Optimization models unit operating constraints and market conditions to facilitate the analysis and simulation of scenarios. The model optimizes a combined portfolio of supply resources and energy efficiency or distributed generation assets modeled as virtual power plants. http://new.abb.com/enterprise-software/energy-portfolio-management/commercial-energy-operations/portfolio-optimization
- **Integrated Planning Model (IPM)®.** IPM, developed by ICF, simultaneously models electric power, fuel, and environmental markets associated with electric production. It is a capacity expansion and economic dispatch model. IPM also has the capability to model environmental market mechanisms such as emissions caps, trading, and banking. System dispatch and boiler and fuel-specific emission factors determine projected emissions. IPM can be used to model the impacts of energy efficiency and renewable energy resources on the electric sector in the short and long term. http://www.icf.com/resources/solutions-and-apps/ipm
- **Long-Range Energy Alternatives Planning System (LEAP).** LEAP is an integrated, scenario-based modeling tool developed by the Stockholm Environment Institute. LEAP can be used to track energy consumption, production, and resource extraction in all sectors of the economy at the city, regional, state, or national scale. Beginning in 2018, LEAP includes the integrated benefits calculator, which can be used to estimate health (mortality), agriculture (crop loss) and climate (temperature change) impacts of scenarios. It can be used to account for both energy sector and non-energy sector greenhouse gas emissions sources and sinks, and to analyze emissions of local and regional air pollutants, and short-lived climate pollutants. www.energycommunity.org
- **NREL's Regional Energy Deployment System (ReEDS).** ReEDS, developed by NREL, is a long-term capacity expansion model that determines the potential expansion of electricity generation, storage, and transmission systems throughout the contiguous United States over the next several decades. ReEDS is designed to determine the cost-optimal mix of generating technologies, including both conventional and renewable energy, under power demand requirements, grid reliability, technology, and policy constraints. Model outputs are

generating capacity, generation, storage capacity expansion, transmission capacity expansion, electric sector costs, electricity prices, fuel prices, and carbon dioxide emissions. http://www.nrel.gov/analysis/reeds/

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

Whole Energy–Economy System Planning Models

Energy system-wide models with electricity sector capacity expansion capability include:

- **DOE's National Energy Modeling System (NEMS).** NEMS is a system-wide energy model (including demand-side sectors) that represents the behavior of energy markets and their interactions with the U.S. economy. The model achieves a supply/demand balance in the end-use demand regions, defined as the nine Census divisions, by solving for the prices of each energy product that will balance the quantities producers are willing to supply with the quantities consumers wish to consume. The system reflects market economics, industry structure, and existing energy policies and regulations that influence market behavior. The Electric Market Model, a module within NEMS, forecasts the actions of the electric power sector over a 25-year time frame and is an optimization framework. NEMS is used to produce the EIA's AEO, which projects the long-term future U.S. energy system and is used as a benchmark against which other energy models are assessed. https://www.eia.gov/outlooks/aeo/info_nems_archive.php
- **Energy 2020.** Energy 2020, developed by Systematic Solutions, is a simulation model that includes all fuel, demand, and supply sectors and simulates energy consumers and suppliers. This model can be used to capture the economic, energy, and environmental impacts of national, regional, or state policies. Energy 2020 models the impacts of an energy efficiency or renewable energy measure on the entire energy system. User inputs include new technologies and economic activities such as tax breaks, rebates, and subsidies. Energy 2020 uses emissions rates for NO_X, CO_2, SO_2, and particulate matter for nine plant types included in the model. It is available at the national, regional, and state levels. http://www.energy2020.com/
- **MARKet Allocation (MARKAL) Model.** MARKAL was originally developed by the U.S. DOE Brookhaven National Laboratory. Now, the model and its successor, *TIMES (The Integrated MARKAL-EFOM System)*, are developed and supported through the Energy Technology Systems Analysis Program of the International Energy Agency. These models are very similar, but TIMES includes functionality improvements and enhancements. Both MARKAL and TIMES determine the least-cost pattern of technology investment and utilization required to meet specified end-use energy demands (e.g., lumens for lighting, watts for heating, and vehicle miles traveled for transportation), while tracking the resulting criteria pollutant and greenhouse gas emissions. By adding constraints or changing various assumptions, these models can be applied to examine how those changes affect the optimal evolution of the energy system. For example, the requirement that greenhouse gases be reduced by 80 percent by 2050 could be added, and the models would determine the least-cost technological and fuel pathway for meeting this target. Similarly, a representation of an end-use energy efficiency requirement could be added, and the models used to evaluate its long-term system-wide impacts. MARKAL and TIMES have been applied by various groups in the United States and around the world for national, regional, and even metropolitan-scale applications. A dataset must be developed to represent current and future energy supplies, demands, and technologies for each application. For example, EPA has developed a U.S. Census-division level

MARKAL database that is available upon request (Lenox et al. 2013). http://iea-etsap.org/index.php/etsap-tools/model-generators/markal and http://iea-etsap.org/index.php/etsap-tools/model-generators/times

Other Tools for Estimating the Long-Run Avoided Costs of Power Plant Capacity

- **NREL's Jobs and Economic Development Impact (JEDI) model.** This free tool is designed to allow users to estimate the economic cost and impacts of constructing and operating power generation assets. The tool provides plant construction costs, as well as fixed and variable operating costs. http://www.nrel.gov/analysis/jedi/

Tools and Resources for Estimating Avoided Electricity Losses During Transmission and Distribution

Data Sources

- **EIA's Annual Energy Outlook (AEO).** Avoided U.S. T&D loss percentages for use in energy efficiency and distributed energy programs can be determined as *((Net Generation to the Grid + Net Imports – Total Electricity Sales)/Total Electricity Sales)*. This percentage considers all T&D losses that occur between net generation and electricity sales. The data for a particular year are available from the AEO, Table A8, available at: http://www.eia.gov/forecasts/aeo/

Resources

- **DOE's *Impacts of Demand-Side Resources on Electric Transmission Planning*.** This report assesses the relationship between high levels of demand-side resources (including end-use efficiency, demand response, and distributed generation) and investment in new transmission or utilization of existing transmission. http://energy.gov/epsa/downloads/report-impacts-demand-side-resources-electric-transmission-planning

Tools and Resources for Estimating Avoided Transmission and Distribution Capacity Costs

The follow resources support methods for estimating avoided T&D capacity costs:

Resources

- **DOE's *Impacts of Demand-Side Resources on Electric Transmission Planning*.** This report assesses the relationship between high levels of demand-side resources (including end-use efficiency, demand response, and distributed generation) and investment in new transmission or utilization of existing transmission. http://energy.gov/epsa/downloads/report-impacts-demand-side-resources-electric-transmission-planning

- **NYSERDA's *Deployment of Distributed Generation for Grid Support and Distribution System Infrastructure*:** This report provides an overview of avoided T&D costs that analysts can assess as well as case studies that highlight programs that have quantified avoided T&D costs. https://www.nyserda.ny.gov/-/media/Files/Publications/Research/Electic-Power-Delivery/Deployment-of-Distributed-Generation-for-Grid-Support.pdf

Tools

Specialized proprietary models of the T&D system's operation may be used to identify the location and timing of system stresses. Examples of such models include the following:

- **GridLAB-D.** Developed by the U.S. Department of Energy's Pacific Northwest National Laboratory, this is a power distribution system simulation and analysis tool to assist utilities in analyzing the impact of new end-use energy technologies, distributed energy resources, distribution automation, and retail markets on the electric distribution system. http://www.gridlabd.org/

- **OpenDSS.** Designed to simulate electric utility power distribution systems, this tool supports analyses of future increases in smart grid, grid modernization, and renewable energy technology. http://smartgrid.epri.com/SimulationTool.aspx
- **Power Transmission System Planning Software (PSS®E).** PSSE offers probabilistic analyses and dynamics modeling capabilities for transmission planning and operations. http://w3.siemens.com/smartgrid/global/en/products-systems-solutions/software-solutions/planning-data-management-software/planning-simulation/pages/pss-e.aspx
- **PowerWorld Simulator.** PowerWorld Corporation offers an interactive power systems simulation package designed to simulate high-voltage power systems operation on a variable time frame. https://www.powerworld.com/products/simulator/overview

General Resources for Quantifying Primary Electricity System Benefits

In addition to the data sources, tools, and other resources described above, analysts can refer to the following general resources to estimate primary electricity system benefits.

- **DOE's Grid Modernization Multi-Year Program Plan***.* The value of distributed energy resources, such as solar PV, community wind, energy storage, electric vehicles, microgrids, and demand response varies across both location and time. The Grid Modernization Initiative is developing an analytical framework and tools to help state decision makers value benefits, costs, and impacts of DER, including the changing impact of DER over time as more energy efficiency and distributed generation resources are added to the grid. https://energy.gov/sites/prod/files/2016/01/f28/Grid%20Modernization%20Multi-Year%20Program%20Plan.pdf
- **DOE's Grid Project Impact Quantification (Grid Project IQ) Screening Tool**. The Grid Project IQ screening tool provides insight into smart grid-related technology deployments. It helps users quickly explore the outcomes of adding a new project to an existing power system from a web browser. With Grid Project IQ, users can quantify changes in total energy, peak power, greenhouse gas and criteria air pollutant emissions, ramping rates, and generation fossil fuel costs. https://www.energy.gov/oe/activities/technology-development/grid-modernization-and-smart-grid/grid-project-impact
- ***Evolution of Wholesale Electricity Market Design with Increasing Levels of Renewable Generation*.** This 2014 NREL report focuses on characteristics of variable generation and its relevance to wholesale electricity market designs. https://www.nrel.gov/docs/fy14osti/61765.pdf
- ***Methods for Analyzing the Benefits and Costs of Distributed Photovoltaic Generation to the U.S. Electric Utility System*.** NREL's 2014 report provides information on methods for analyzing the benefits and costs of distributed photovoltaic generation. https://www.nrel.gov/docs/fy14osti/62447.pdf

3.4.2. Tools and Resources for Quantifying Secondary Electricity System Benefits

Analysts can use a range of available resources and tools to estimate secondary electricity system benefits.

Data Sources

The following data sources provide relevant information for quantifying secondary electricity system benefits.

- **EIA's Form EIA-906/920 (power plant database)**, **now EIA-923**. This database provides data on annual state electricity generation by fuel type and producer type that can be used in market share indices. This source is relevant for estimating improved fuel diversity benefits. http://www.eia.doe.gov/cneaf/electricity/page/eia906_920.html

- **ISO New England**. ISO New England provides market clearing price data for northeastern states that can be used to develop a dispatch curve. This source is relevant for estimating benefits from reduction in wholesale market clearing prices. https://www.iso-ne.com/markets-operations/markets/forward-capacity-market
- **NY ISO Ancillary Services Prices.** NY ISO publishes ancillary service prices for voltage regulation in $/MWh on an hourly basis for the state of New York. This source is relevant for estimating benefits from avoided ancillary services costs. http://www.nyiso.com/public/markets_operations/market_data/pricing_data/index.jsp

Resources

The following report scan be used to inform the quantification of reliability benefits.

- ***Probabilistic Assessment Technical Guideline Document.*** This report, put out by the North American Electric Reliability Corporation (NERC), details methodologies to probabilistically estimate reliability metrics. https://www.nerc.com/comm/PC/PAITF/ProbA%20Technical%20Guideline%20Document%20-%20Final.pdf
- ***State Approaches to Demand Reduction Induced Price Effects: Examining How Energy Efficiency Can Lower Prices for All***. This report, put out by SEE Action, reviews state applications of DRIPE and provides example methodologies that have been used to determine DRIPE estimates. https://www4.eere.energy.gov/seeaction/system/files/documents/DRIPE-finalv3_0.pdf

Tools

The following tools can be used to assess reliability benefits from energy efficiency and renewable energy measures.

- **GE Multi-Area Reliability Simulation (GE MARS).** GE MARS enables the electric utility planner to quickly and accurately assess the reliability of a generation system that comprises any number of interconnected areas. http://www.geenergyconsulting.com/practice-area/software-products/mars
- **Avoided Cost Calculator.** Developed by E3 for use in California, this tool helps users to estimate avoided costs of their demand-side program. Avoided costs measured in this calculator include electricity generation costs, generation capacity costs, ancillary services, T&D capacity costs, environmental costs (i.e., avoided greenhouse gases), and avoided RPS costs. http://www.cpuc.ca.gov/General.aspx?id=5267

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PART TWO
CHAPTER 4

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

DOCUMENT MAP

PART ONE
The Multiple Benefits of Energy Efficiency and Renewable Energy

PART TWO
Quantifying the Benefits: Framework, Methods, and Tools

CHAPTER 1
Quantifying the Benefits: An Overview of the Analytic Framework

CHAPTER 2
Estimating the Direct Electricity Impacts of Energy Efficiency and Renewable Energy

CHAPTER 3
Assessing the Electricity System Benefits of Energy Efficiency and Renewable Energy

CHAPTER 4
Quantifying the Emissions and Health Benefits of Energy Efficiency and Renewable Energy

CHAPTER 5
Estimating the Economic Benefits of Energy Efficiency and Renewable Energy

CHAPTER 4 CONTENTS

ABOUT THIS CHAPTER

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

4.1. OVERVIEW

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

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

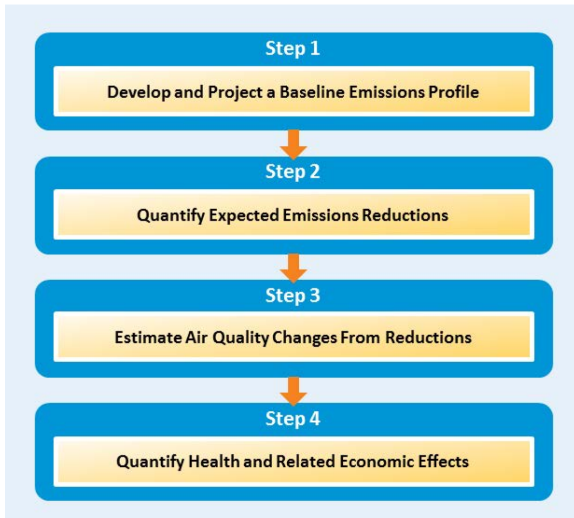
The range of methods and tools described is not exhaustive and inclusion of a specific tool does not imply EPA endorsement. Also, some regulatory programs may require the use of specific tools or approaches. A state or local analyst conducting an analysis to meet federal standards, for example, should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

4.2. APPROACH

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

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

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



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

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

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

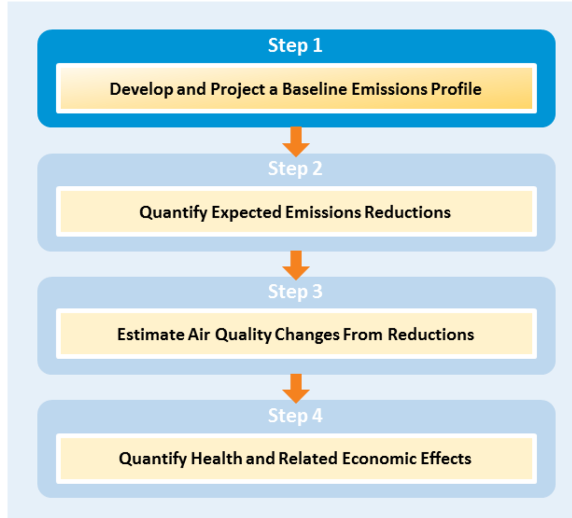
For each of the four basic steps, the remainder of this chapter describes a range of basic to sophisticated modeling methods, along with related protocols, data needs, tools, and resources that analysts can use to quantify the state and local emissions and health benefits of energy efficiency and renewable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

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

Step 1	Step 2	Step 3	Step 4
Develop and Project a Baseline Emissions Profile (Section 4.2.1.)	**Quantify Expected Emissions Reductions (Section 4.2.2.)**	**Estimate Air Quality Changes From Reductions (Section 4.2.3.)**	**Quantify Health and Related Economic Effects (Section 4.2.4.)**
Criteria Air Pollutants			
a. Determine preferred type of accounting framework and approach for developing and projecting an inventory. b. Compile criteria air pollutant emissions from available sources into inventory. c. Develop a projection using assumptions about the future and available tools.	a. Estimate criteria air pollutant reductions from energy efficiency and renewable energy using: ▪ Energy savings estimates and a profile of when these impacts are anticipated to occur ▪ Operating characteristics of energy efficiency or renewable energy resource (load profile) ▪ Emission factors ▪ Control technology data b. Compare against the baseline determined in Step 1.	Use criteria air pollutant data determined in Step 2 to estimate immediate changes in air quality with an air quality model.	a. Use data on air quality changes determined in Step 3 and epidemiological and population information to estimate immediate health effects. b. Apply economic values of avoided health effects to monetize benefits.
GHG Emissions			
a. Determine preferred type of accounting framework and approach for developing and projecting an inventory. b. Compile GHG emissions from available sources into inventory. c. Develop a projection using assumptions about the future and available tools.	a. Estimate GHG emissions reductions from energy efficiency or renewable energy using: ▪ Energy savings estimates and a profile of when these impacts are anticipated to occur ▪ Operating characteristics of energy efficiency or renewable energy resource (load profile) ▪ Emission factors ▪ Fuel data b. Compare against the baseline determined in Step 1.	*Assessing the longer-term air quality changes and resulting health and economic changes from GHG reductions involves a fuller assessment of the longer-term impacts of climate change, which are not covered in this* Guide.	

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

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



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

Determining Which Pollutants to Include in a Baseline Emissions Inventory

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

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

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

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

[3] *While state and local governments are not required by the federal government to submit GHG inventories, some emissions sources are required to report their GHG emissions to EPA. For example, EPA’s GHGRP generally requires annual reporting of GHG emissions and other relevant information from large fuel suppliers and facilities that emit 25,000 metric tons of CO_2 or more per year. EPA also generally requires electric generating units (EGUs) subject to the Acid Rain Program and with capacity greater than 25 Megawatts (MW) to report emissions and generation data to EPA. These data can be helpful for states and local governments creating own inventories.*

SOURCES OF AIR POLLUTION EMISSIONS

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

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

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

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

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

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

Source: U.S. EPA, 2008.

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

Deciding Between Production-Based or Consumption-Based Accounting

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

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

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

Methods for Developing and Projecting a Baseline Emissions Inventory

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

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

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

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

EMISSION FACTOR METHOD FOR INVENTORIES

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

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

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

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

Top-Down Inventory Development

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

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

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

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

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

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

Top-Down Data Needs

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

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

Some tools, such as EPA's State Inventory Tool, provide default values analysts can use. For a comprehensive list of available data sources and tools analysts can use to develop inventories, see Section 4.4., "Tools and Resources."

Bottom-Up Inventory Development

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

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

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

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

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

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

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

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

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

Bottom-Up Data Needs

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

Projecting Future Emissions

Emissions projections provide a basis for:

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

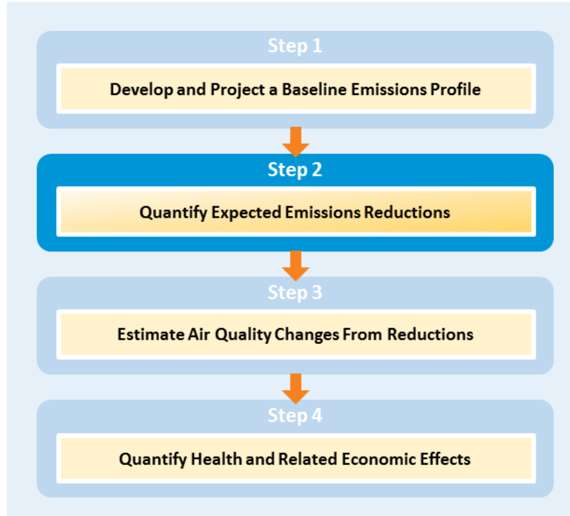
To conduct an analysis of potential emissions reductions from a future policy, an analyst will typically develop projected estimates of both the new policy case and the BAU case that does not include the new policy.

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

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

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

4.2.2. Step 2: Quantify Expected Emissions Reductions



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

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

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

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

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

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

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

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

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

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

Type of Method	Strengths	Limitations	When to Use This Method	Example Tools / Data Sources[a]
Basic				
▪ Methods that often assume consistent energy savings throughout the year and assign marginal emissions rates or specific emissions rates for proxy unit types	▪ Transparent assumptions ▪ Easy-to- understand method ▪ Modest level of time, technical expertise, and labor required ▪ Inexpensive	▪ May be imprecise and less credible than other methods ▪ Limited ability to customize unique load characteristics of different energy efficiency and renewable programs ▪ Not applicable for long-term projections ▪ Do not typically account for imported power ▪ Do not account for myriad of factors influencing dispatch on a local scale, such as transmission constraints or reliability requirements	▪ Screening analysis ▪ Voluntary programs ▪ Evaluating existing programs	▪ AVERT (preexisting marginal emission factors) ▪ ClearPath™ ▪ eCalc ▪ eGRID (preexisting marginal emission factors) ▪ Proxy Plant method ▪ SUPR2
Intermediate				
▪ Methods that can reflect time-of-day impacts throughout the year and use EGUs' dispatch patterns to assess impacts of EE/RE but do not account for detailed assumptions that sophisticated approaches can (e.g., fuel prices, emissions budget trading program effects, dispatch changes)	▪ Transparent assumptions and method ▪ Allow flexibility to adjust EGU fleet and reflect different energy efficiency and renewable energy assumptions and load shapes ▪ May be more credible than basic methods	▪ Require some technical expertise ▪ Do not represent small energy efficiency and renewable energy programs well ▪ Do not typically account for imported power ▪ Do not account for myriad of factors influencing dispatch on a local scale such as transmission constraints or reliability requirements	▪ Regulatory compliance for short-term plans (e.g., NAAQS) ▪ Energy plans ▪ County-level impacts ▪ Analysis of portfolio of energy efficiency and renewable energy programs ▪ Impacts comparison of different energy efficiency and renewable energy programs	▪ AVERT custom analysis ▪ ERTAC EGU forecasting tool ▪ LEAP ▪ Time-Matched Marginal Emissions Model
Sophisticated				
▪ Methods that can provide detailed forecasts of regional supply and demand impacts over time due to EE/RE policies and programs	▪ More rigorous than other methods ▪ May be perceived as more credible than other methods, especially for long-term projections ▪ Allow for sensitivity analysis ▪ May explicitly account for and quantitatively estimate imported power	▪ May be less transparent than spreadsheet methods ▪ Labor- and time-intensive ▪ Often involve high software licensing costs ▪ Require assumptions that have large impact on outputs ▪ May require significant technical expertise in energy modeling	▪ Emissions budget programs ▪ Resource planning ▪ Rate cases ▪ Financial/economic impacts projections ▪ Regulatory compliance and energy plans for short- and long-term time horizons ▪ Multi-sector analysis	▪ ENERGY 2020 ▪ e7 Capacity Expansion ▪ GE MAPS™ ▪ IPM® ▪ MARKAL/TIMES ▪ NEMS ▪ PLEXOS® ▪ PROSYM™ ▪ PROMOD IV® ▪ ReEDS ▪ RPM

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

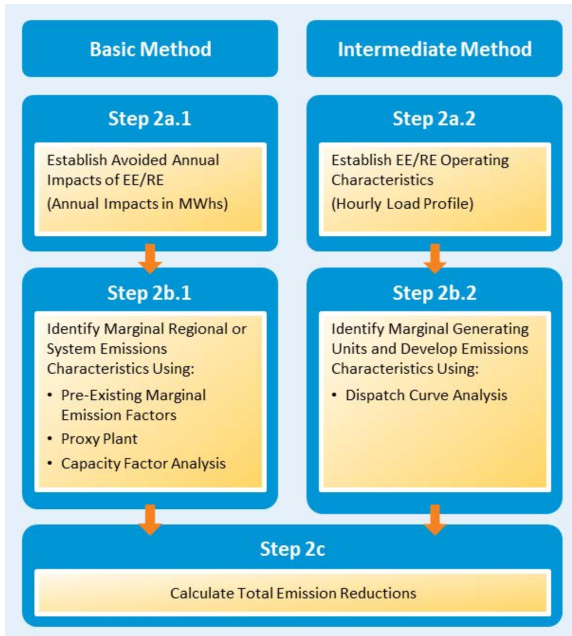
Basic-to-Intermediate Methods to Quantify Emissions Reductions

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

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

$$\boldsymbol{Total\ Emissions\ Reductions}\ (\mathbf{100}\ \boldsymbol{tons\ CO2}) = \boldsymbol{Avoided\ Electricity\ Generation}\ (\mathbf{200}\ \boldsymbol{MWh}) \times \boldsymbol{Emission\ Factor}\ \left(\mathbf{0.5}\ \frac{\boldsymbol{tons\ CO2}}{\boldsymbol{MWh}}\right)$$

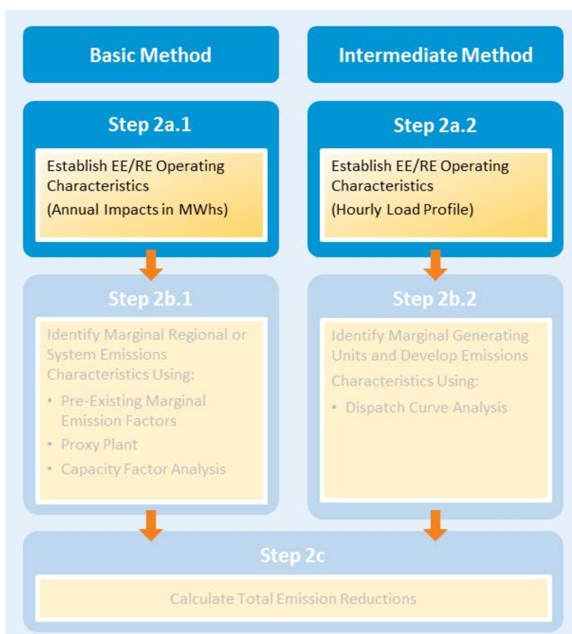
Figure 4-2: Basic and Intermediate Methods for Quantifying Emissions Reductions from Energy Efficiency and Renewable Energy



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

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

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



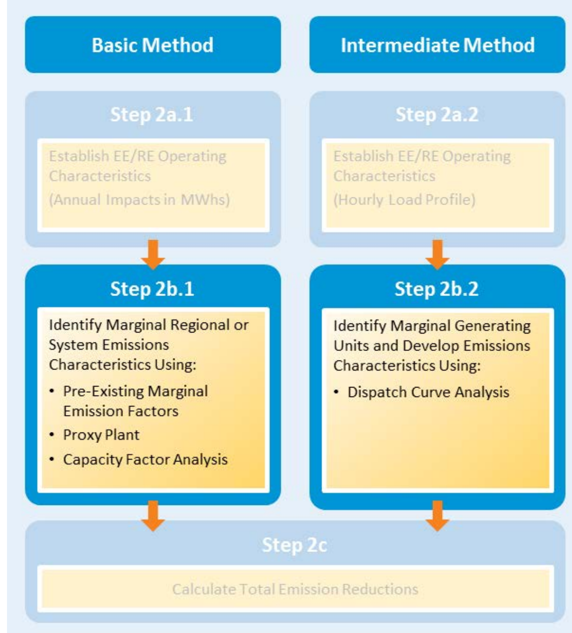
In addition to estimating annual impacts, analysts may want to estimate the timing of impacts within a year, either hourly or on some less frequent interval. The impacts of energy efficiency and renewable energy resources depend on the timing of their impact because marginal emissions rates of power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

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

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

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

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



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

Basic Methods

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

Intermediate Method

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

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

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

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

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

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

Method	Strengths	Limitations	When to Use This Method
		Basic Method	
Adopt Preexisting Marginal Emission Factors ▪ Preexisting marginal emission factors based on non-baseload (eGRID) or technology-specific load characteristics (AVERT)	▪ Computationally simple ▪ Requires less labor and data than unit type or dispatch curve analysis	▪ Somewhat insensitive to dispatch process ▪ Neglects power transfers between areas ▪ History may not be good indicator of future	▪ Rough estimates of energy efficiency or renewable energy benefits for displacing emissions ▪ When lacking energy efficiency or renewable energy operating characteristics
Proxy Plant ▪ Select a single unit type that represents the marginal unit	▪ Computationally simple ▪ Requires less labor and data than all other methods	▪ Uses simple assumption that only a single unit type is always on the margin ▪ There may actually be more than one unit on the margin because EE/RE has regional impacts on electric grid	▪ Rough estimates of energy efficiency or renewable energy benefits for displacing emissions ▪ When evaluating the avoidance of a future power plant ▪ When only one type of unit would be running at a specific time (e.g., peak hours during summer)
Capacity Factor Analysis ▪ Also called displacement curve analysis ▪ Estimates an emissions rate based on the relationship of a unit type's characteristic (e.g., capacity factor) with how often that unit type will be displaced	▪ Simpler and less labor required than dispatch curve analysis ▪ Considers generation resource characteristics	▪ Somewhat insensitive to dispatch process ▪ It may be inaccurate for baseload energy efficiency or renewable energy resources	▪ Preliminary planning and evaluation of energy efficiency and renewable energy resources, especially those that operate during peak times
		Intermediate Methods	
Dispatch Curve Analysis ▪ Examines historical hourly dispatch data to estimate the characteristics and frequency of each generating unit on the margin	▪ More reflective to dispatch merit order than basic methods ▪ Uses actual historical dispatch data ▪ Reflects time-of-day differences in EE/RE resources	▪ Higher data requirements than basic methods ▪ Assumptions may need to be updated regularly ▪ Typically relies on sophisticated algorithms to estimate the underlying emissions rates, leading to concerns over transparency and available technical expertise	▪ Planning and regulatory studies ▪ Analyzing the impacts of energy efficiency and renewable energy programs ▪ When the load shape of the energy efficiency or renewable energy resource is known

Basic Method 1: Adopt Preexisting Marginal Emission Factors

This method involves adopting a preexisting marginal emission factor (e.g., lbs. SO_2/MWh) that is suitable for the energy efficiency or renewable energy resource. Existing marginal emission factors typically represent the emissions profile of what is expected to be on the margin in a geographical region, but marginal emission factors have also been developed to represent specific technologies or a bundle of technologies. Available factors include:

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

APPLICABILITY OF SYSTEM AVERAGE EMISSION FACTORS

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

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

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

Basic Method 2: Proxy Plant

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

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

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

The capacity factor[13] analysis method uses displacement curves to estimate marginal units and their emissions characteristics. The curves used under this method reflect the likelihood of a unit being displaced, based on its expected place in the dispatch order. Compared to adopting an existing marginal emission factor, this method provides a more sophisticated way to customize the marginal emission factor based on the operating characteristics of the resource. Disaggregating the unit types as much as possible (e.g., by unit type, heat rate, and controls) makes capacity factor analysis more representative.

To implement this method, analysts develop a displacement curve to identify what generation is likely to be displaced. Some classes of units are more likely to be displaced than others by energy efficiency and renewable energy measures. For example, some coal, nuclear, and hydro plants typically provide constant baseload power, while the operating levels of higher-cost units (e.g., new gas-fired units) fluctuate, increasing their output during peak daytime hours. Older, less efficient, and more expensive coal, gas, and oil units or combustion turbines may only dispatch during the peak output periods. Due to the operating characteristics of many types of energy efficiency and renewable energy projects, the electricity produced or saved is likely to displace electricity from load-following[14] and peaking units in the short term, rather than from baseload units. Analysts will need to generalize the emissions characteristics of the generating unit type that is on the margin, which may vary considerably across different control areas and time periods. Historical unit capacity factors, representing the ratio of energy generated to the maximum potential for energy generation over a period of time, are typically used to construct a dispatch curve, as is illustrated in Figure 4-3.

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

1. *Estimate the percentage of total hours* that each unit type (e.g., coal-fired steam, oil-fired steam, gas combined-cycle, gas turbine, etc.) is likely to be on the margin. When a unit is on the margin, its output will be displaced by the new energy efficiency and renewable energy resource. This step is discussed in further detail in Chapter 3, in the section "Avoided Costs of Electricity Generation or Wholesale Electricity Purchases" under "Generation Benefits: Avoided Costs." Historical generation data for individual plants are available from EPA's eGRID database.

2. *Determine the average emissions rate* for each unit type (in pounds of emissions per MWh output). Use public data sources such as EPA's eGRID database or standard unit type emission factors from EPA AP-42, a compilation of air pollutant emission factors.[15]

3. *Calculate an emissions-contribution rate* for each unit type by multiplying the unit type average emissions (lbs./MWh) by the fraction of hours that the unit type is likely to be displaced.

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

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

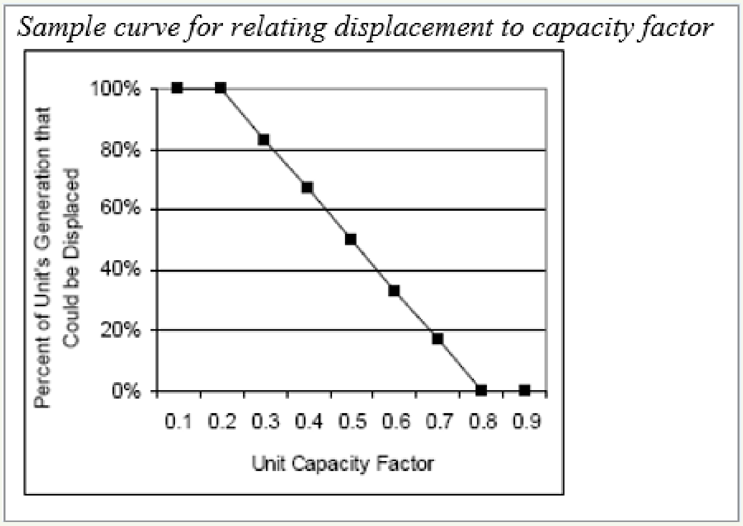
[15] *Note that AP-42 does not provide GHG emission factors; for GHGs, use fuel-specific emission factors from* EPA's Inventory of U.S. Greenhouse Gas Emissions and Sinks*. Also note that AP-42 factors are dependent on the air pollution controls that have been installed and this information would be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

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

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

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

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



Source: Keith and Biewald, 2005.
Note: In this chart, the unit capacity factor is used as an indicator for how likely a plant is to be displaced by an energy efficiency or renewable energy measure.

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

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

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

Source: Keith and Biewald, 2005.

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

Intermediate Method: Dispatch Curve Analysis

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

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

Table 4-5 and Figure 4-4 illustrate this process for a one-week period (168 hours). There are 10 generating units in this hypothetical power system, labeled 1 through 10. The units are presented in ascending order of the number of hours each unit generates electricity during this time period, which is shown in column 3 of the table and is reflected in the bars of the figure. Column 4 shows the number of hours that each unit is on the margin; this is represented in Figure 4-4 as the number of hours for each unit that the unit’s bar intersects the line, with hours being represented on the X-axis. Column 5 shows the unit’s SO_2 emissions rate. The hours on the margin and SO_2 emissions rate columns are then combined to come up with a weighted average SO_2 emissions rate of 5.59 lbs./MWh for these units, which would be used to determine SO_2 emissions benefits for the energy efficiency or renewable energy initiative.

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

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

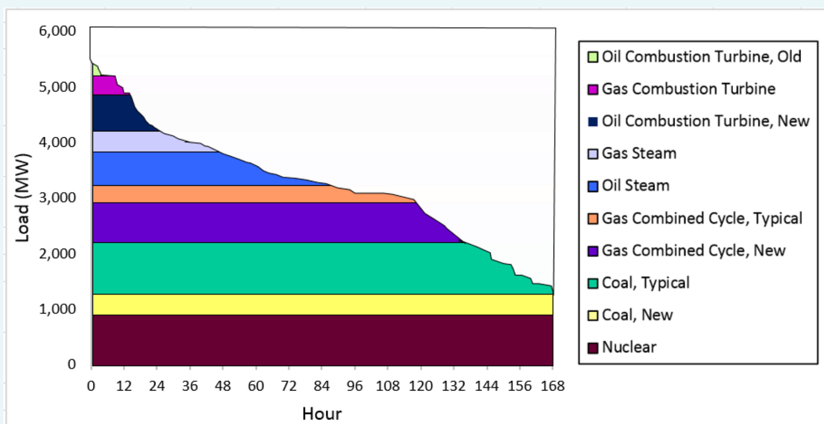
1	2	3	4	5
Unit	**Unit Name**	**Hours of Generation**	**Hours on Margin**	**SO_2 Emissions Rate (lbs./ MWh)**
1	Oil Combustion Turbine, Old	5	5	1.00
2	Gas Combustion Turbine	15	10	0.00
3	Oil Combustion Turbine, New	24	9	1.00
4	Gas Steam	45	21	0.10
5	Oil Steam	85	40	12.00
6	Gas Combined-Cycle, Typical	117	32	0.01
7	Gas Combined-Cycle, New	134	17	0.01
8	Coal, Typical	168	34	13.00
9	Coal, New	168	0	1.00
10	Nuclear	168	0	0.00

Note: Weighted average, SO_2 emissions (lbs./MWh): 5.59.

Constructing a dispatch curve requires data on:

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

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



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

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

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

When generator cost data are not available, the relative dispatch order for each unit or capacity factors for traditional[16] generating units can be used to approximate the relative cost of the unit (Those with the lowest cost operate more often throughout the year.) AVERT's statistical model is one example of a source where these data can be found.

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

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

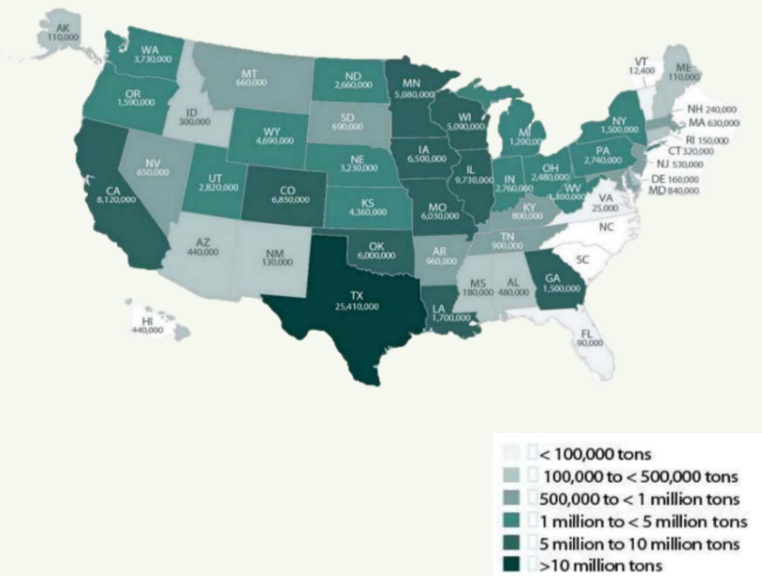
In May 2014, the American Wind Energy Association (AWEA) released a report detailing the state-by-state emissions benefits of deploying wind power throughout the country. To calculate the avoided NO_X, SO_2, and CO_2 emissions from wind generation, AWEA used EPA's AVERT tool. AWEA collected state-by-state wind electricity generation from DOE's Energy Information Agency (EIA) for the year 2013. AWEA then incorporated these data into AVERT and apportioned wind generation to the states. Since AVERT does not model Hawaii and Alaska, emissions benefits for these states were calculated independently using EIA fuel mix and generation data.

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

- 126.8 million short tons of CO_2 (5 percent of power sector emissions)
- 347 million pounds of SO_2
- 214 million pounds of NO_X

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

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



Source: AWEA, 2014.

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

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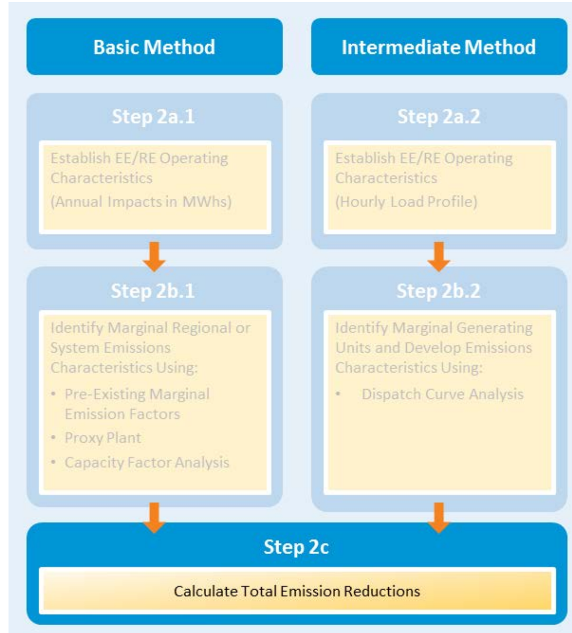
[16] *As an exception, variable power resources such as solar, wind, and hydropower are not available at all times of the day throughout the year but are assumed to have lower costs than fossil fuel or nuclear units.*

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

Step 2c: Calculate Total Emissions Reductions



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

In the final analysis of net emissions reduction estimates, it is important for analysts to consider any GHG or criteria air pollution emissions that might be produced during the production or generation, and use of, renewable fuels (e.g., landfill gas, biomass generation). For example, how biomass is produced, harvested, and consumed will determine the net biogenic CO_2 emissions associated with its use for energy. For more information on biomass, see the text box "Accounting for Biomass Emissions" on the next page.

Limitations of Basic-to-Intermediate Methods

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

- *They are best suited for estimating potential emissions reduction benefits in a relatively short time frame* (e.g., zero to 5 years). Longer-term analyses would require emission factors that account for the addition and retirement of energy sources over time and changes in market conditions including environmental requirements.
- *They do not typically account for imported power*, which may come from generating units with very different emissions characteristics than the units within the region or system. Basic-to-intermediate methods also do not account for future changes in electricity import and export patterns, which may change the marginal energy sources during operation of the energy efficiency or renewable energy measure.
- *They do not account for the numerous factors that influence dispatch on a local scale*. For example, the existence of transmission constraints on an area where an energy efficiency or renewable energy resource is deployed can affect which resources are dispatched. When the existing electricity system is not able to provide service in load pockets[18] that are served by local generators (typically due to transmission constraints), higher-cost units must be dispatched because energy cannot be imported from lower-cost units outside of the area. Reducing demand in these areas could reduce the need for these higher-cost units.

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

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

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

ACCOUNTING FOR BIOMASS EMISSIONS

Biomass is a fuel derived from organic matter, including, but not limited to, woody and agricultural crops and residues, or biogas (e.g., from landfills). These organic materials originate as part of the natural carbon cycle, meaning they sequester CO_2 and store it as carbon during growth and release it during decomposition, combustion, or other forms of conversion. To generate the same amount of energy, burning biomass for energy releases about the same amount of CO_2 or more as burning fossil fuels, largely due to the lower energy content of biomass and, in some cases, its moisture content. However, when considering the natural cycling of carbon in how the feedstock was produced, harvested, and used, some forms of biomass used for energy may have minimal net GHG emissions. Some programs and reporting tools may require biogenic CO_2 emissions to be reported, but not account for them in overall emissions totals, whereas others may not require biogenic emissions to be reported. When reporting and accounting for biomass emissions, analysts can follow state and/or other regulatory requirements or guidelines (see the description of the SEE Action Energy Efficiency Program Impact Evaluation Guide in the Section 4.3., "Tools and Resources," for an example guidance document). It is important to avoid double counting biomass emissions when conducting an economy-wide GHG emissions inventory (meaning it includes emissions across all sectors). In the IPCC inventory guidelines, carbon sequestration and CO_2 emissions within biological systems, including the growth and harvest of terrestrial biomass, are assigned to the Land Use, Land Use Change, and Forestry sector. Therefore, when biomass is burned for energy, the related biogenic CO_2 emissions are accounted for in the Land Use, Land Use Change, and Forestry sector—where the carbon was stored and initially emitted via harvest—not the Energy sector (IPCC, 2006).

For more information about assessing biogenic CO_2 emissions associated with the use of biomass for energy production, please see https://archive.epa.gov/epa/climatechange/carbon-dioxide-emissions-associated-bioenergy-and-other-biogenic-sources.html .

Sophisticated Methods to Quantify Emissions Reductions

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

Economic Dispatch Models

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

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

Capacity Expansion Models

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

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

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

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

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

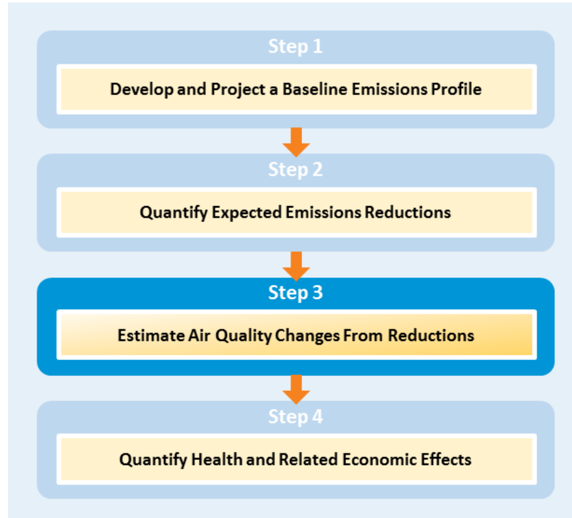
Table 4-6: Comparison of Sophisticated Modeling Methods for Quantifying Air and GHG Emissions Effects of Energy Efficiency and Renewable Energy Initiatives

Strengths	Limitations	When to Use This Method	Examples of Models[a]
Economic Dispatch			
▪ Provides very detailed estimations about specific plant and plant-type effects within the electric sector ▪ Provides highly detailed, geographically specific, hourly data ▪ Ideal for estimating wholesale electric prices and hours of operation and production	▪ Often lacks transparency ▪ Requires technical experience to apply ▪ May be labor-, data-, and time-intensive ▪ Often involves high labor and software licensing costs ▪ Requires establishment of a specific operational profile for the energy efficiency or renewable energy resource ▪ Cannot estimate avoided capacity costs from energy efficiency and renewable	Often used for evaluating: ▪ Specific projects in small geographic areas ▪ Short-term planning (0–5 years) and regulatory proceedings	▪ GE MAPS™ ▪ IPM® ▪ PLEXOS® ▪ PROMOD IV® ▪ PROSYM™
Capacity Expansion or Planning			
▪ Selects optimal changes to the resource mix based on energy system infrastructure over the long term (5–30 years) ▪ May capture the complex interactions and feedbacks that occur within the entire energy system ▪ Provides estimates of emissions reductions from changes to the electricity production and/ or capacity mix ▪ May provide plant-specific detail and perform dispatch simultaneously (IPM) ▪ Designed specifically for resource planning ▪ Can estimate avoided capacity costs	▪ Often lacks transparency due to complexity ▪ Requires significant technical experience to apply ▪ May be labor- and time-intensive ▪ Often involves high labor and software licensing costs ▪ Requires assumptions that have a large impact on outputs (e.g., future fuel costs)	Used for long-term studies (5–25 years) over large geographical areas such as: ▪ SIPs ▪ Late-stage resource planning ▪ Statewide energy plans ▪ GHG mitigation plans	▪ AURORA ▪ DOE's NEMS ▪ EGEAS ▪ e7 Capacity Expansion ▪ e7 Portfolio Optimization ▪ ENERGY 2020 ▪ IPM® ▪ LEAP ▪ MARKAL, TIMES[b] ▪ NREL's ReEDS ▪ NREL's RPM

[a] *For more information about individual tools, see Section 4.4., "Tools and Resources."*

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

4.2.3. Step 3: Estimate Air Quality Changes From Reductions



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

Ambient air concentration levels of pollutants that people breathe are the key measures of air quality. Ambient air concentration levels are based on the monitored amount of a pollutant in the air (e.g., in units of micrograms per cubic meter [µg/m3] or parts per million [ppm]). As noted under "Step 2: Quantify Expected Emissions Reductions," emissions levels are based on the amount of a pollutant released to the air (e.g., in units of tons) from various sources, such as vehicles and factories. Some emissions travel far from their source to be deposited on distant land and water; others dissipate rapidly over time and distance and/or are transformed into secondary pollutants through chemical reactions in the atmosphere. The health-based standards (NAAQSs) for criteria air pollutants are based on ambient air concentration levels and in some cases an averaging time period (e.g., there are both 24-hour and annual standards for particulate matter). The pollutant concentration to which a person is exposed is just one of the factors that determines if human health will be affected—and the severity of effects if they do occur (U.S. EPA, 2009).

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

Methods for Quantifying Air Quality Changes

Basic Methods

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

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

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

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

Sophisticated Methods

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

- *Dispersion models*. Dispersion models rely on emissions data, source and site characteristics (e.g., stack height, topography), and meteorological inputs to predict the dispersion of air emissions over time and distance and the impact on air concentrations at selected downwind locations. Although dispersion models can represent simple chemical degradation, these models do not include analysis of complex chemical transformations that occur in the atmosphere, and thus cannot assess the impacts of emissions changes on secondarily formed $PM_{2.5}$ and ozone. These models can be used for directly emitted particles (such as from diesel engines) and air toxics. EPA-recommended models and numerous other dispersion models are available as alternatives or for use in a screening analysis as described. https://www.epa.gov/scram/air-quality-dispersion-modeling-preferred-and-recommended-models

- *Photochemical models*. Photochemical models capture many of the complex physical and chemical processes that occur in the atmosphere as gaseous emissions of different chemicals react and form secondary $PM_{2.5}$ and ozone. These models perform complex computer simulations, and can be applied at a variety of scales from the local to the global level. A range of photochemical-type air quality tools are also available for use in assessing control strategies. They may not be air quality models per se, but they combine results from complex models with monitor data to calculate design values. http://www3.epa.gov/scram001/photochemicalindex.htm

- *Receptor models*. Receptor models can identify and quantify the sources of air pollutants at a specific location, called the "receptor" location. Unlike photochemical and dispersion air quality models, receptor models do not use pollutant emissions, meteorological data, and chemical transformation mechanisms to estimate the contribution of sources to receptor concentrations. Instead, receptor models use the chemical and physical characteristics of gases and particles measured at the source and receptor to identify source contributions to receptor concentrations. These models are a natural complement to other air quality models and are used as part of SIPs for identifying sources contributing to air quality problems. http://www3.epa.gov/scram001/receptorindex.htm

Examples of all three of these types of models are summarized in Section 4.4., "Tools and Resources."

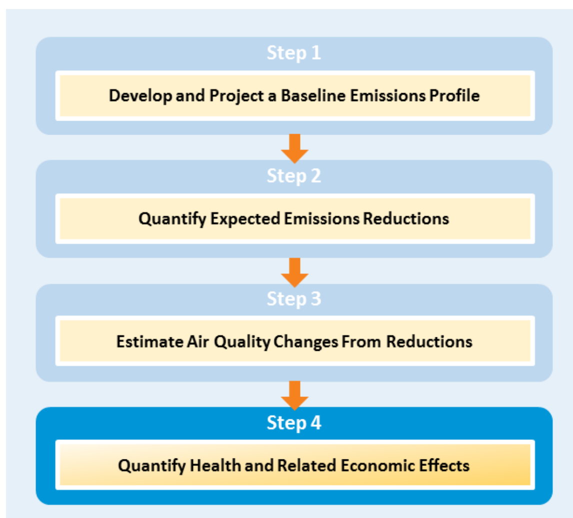
Key Considerations When Selecting a Method to Assess Air Quality Impacts

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

- *The pollutants for analysis*. Deciding what pollutants to model is a critical decision when selecting a model. Directly emitted primary pollutants—such as CO_2, SO_2, primary particulate matter (PM), and many air toxics—require models capable of modeling dispersion and transport (i.e., dispersion models). Secondary pollutants, such as ozone and most $PM_{2.5}$, are formed by chemical reactions occurring in the atmosphere among other pollutants. Secondary pollutants are considerably more difficult to model, requiring a model capable of handling complex chemical transformations (i.e., photochemical models), as well as short- and long-range transport.
- *Sources affected.* The number and types of sources that result in emissions directly affect the selection of an appropriate air quality model. A model that is appropriate for modeling the impact of a single generating facility with a tall smokestack would be inappropriate for analysis of an initiative that would affect electricity generation throughout the region.
- *Timeframe.* Pollutants have different relevant exposure timeframes for human health impacts. For some pollutants, human health impacts result from long-term exposure; for other pollutants, human health impacts result from short-term (e.g., daily or hourly) exposure. The impact assessment timeframe can be a key factor in determining appropriate methods for modeling air quality impacts of emissions reductions.
- *Data availability and resolution*. Sophisticated air quality models require large amounts of input data describing a variety of characteristics of the energy-environment system, including emissions inventory data, ambient air quality monitoring data, and meteorological data. Availability of required data is a key factor in selecting a method.
- *Geographic scope*. Selecting the most appropriate analytical tool to model air quality impacts depends on the geographic scope of the analysis. Modeling large geographic areas (e.g., a state or a group of states) often requires a different model than modeling smaller areas (e.g., a city).
- *Meteorological and topographical complexities*. When structuring an air quality impact analysis, it is important for analysts to consider regional meteorological and topographical conditions that may affect the transport and chemical reaction of pollutants within a region's atmosphere and which air quality models can account for these factors.

4.2.4. Step 4: Quantify Health and Related Economic Effects

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



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

Methods for Quantifying Health Impacts

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

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

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

Basic Method

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

- Relate changes in the emissions of a pollutant or changes in fossil fuel-based electricity generation to the number of avoided cases of premature death and illness to estimate the economic value of these avoided cases.
- Involve a type of "benefits transfer" analysis, where the results from comprehensive modeling (e.g., a regional control strategy for all coal-fired power plants within a region) are used to approximate the effects of a similar project that shares many of the same attributes.
- Are generally used to quantify fine particle- or ozone-related short-term health impacts but are also used to quantify the value of long-term climate damages avoided by reducing carbon dioxide (CO_2) (e.g., social cost of carbon); depending on the metric, they are multiplied against the change in:
  - Emissions (in tons) of each precursor of $PM_{2.5}$ (e.g., directly emitted $PM_{2.5}$, SO_2, NO_x) or ozone (e.g., NO_x, VOCs) or of each ton of CO_2
  - Fossil fuel-based electricity generation (in kWh)
- Represent a simplified composite of the air quality modeling, health impacts estimation, and valuation estimation steps used in more complex approaches described under the section, "Sophisticated Methods," below.

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

EPA BENEFIT PER-TON FACTORS

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

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

Strengths of using monetized health benefit factors:

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

Limitations of using monetized health benefit factors estimates:

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

Sophisticated Methods

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

Conducting a sophisticated analysis using a damage function method involves:

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

These two steps are described in greater detail below.[21]

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

   Analysts estimate health effects as follows:

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

   Where:

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

2. **Calculating the economic value of the avoided health effects**

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

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

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

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

Where:

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

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

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

Strengths of using sophisticated methods:

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

Limitations of using sophisticated methods:

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

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

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

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

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

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

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

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

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

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

4.3. CASE STUDIES

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

4.3.1. Regional Greenhouse Gas Initiative – Emissions and Health Benefits

Benefits Assessed in Analysis

- NO_x reductions
- SO_2 reductions
- Health benefits from reduced air pollution

Savings Metrics Assessed

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

Energy Efficiency/Renewable Energy Program Description

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

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

Methods Used

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

Abt estimated the change in NO_x and SO_2 emissions at each power plant based on the modeled change in electricity generation at each plant. The change in generation was multiplied by plant-specific NO_x and SO_2 emissions rates (lbs./MWh), which were derived from data from eGRID, the National Emissions Inventory, and EPA's Clean Air Markets Division. The emissions were calculated using the following equation:

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

The public health benefits were estimated using both COBRA and BenMAP-CE. COBRA was used to conduct the air quality modeling, and BenMAP-CE was used to estimate the incidence and value of the health impacts. The analysis used BenMAP-CE rather than COBRA for the health effects modeling because the analysis covered a 6-year period, and it was easier to analyze multiple years in BenMAP-CE than in the version of COBRA available at the time.[25] Abt developed revised emissions baselines for COBRA for each of the years from 2009 to 2014 based on data from EIA on the change in use of coal and natural gas in the electricity sector during that period. The baseline was also adjusted to account for other relevant regulations outside of RGGI, such as Maryland's Healthy Air Act of 2006, which resulted in the installation of SO_2 controls at some power plants starting in 2009.

Results

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

The analysis estimated positive health benefits in each state in the Northeast and Mid-Atlantic, including some states that do not participate in RGGI, such as Pennsylvania and New Jersey. However, the benefits were not evenly distributed throughout the region. The majority of the benefits in the region were due to SO_2 emissions reductions at a small number of coal plants in the Mid-Atlantic. Figure 4-6 shows a map of the distribution of benefits throughout the region.

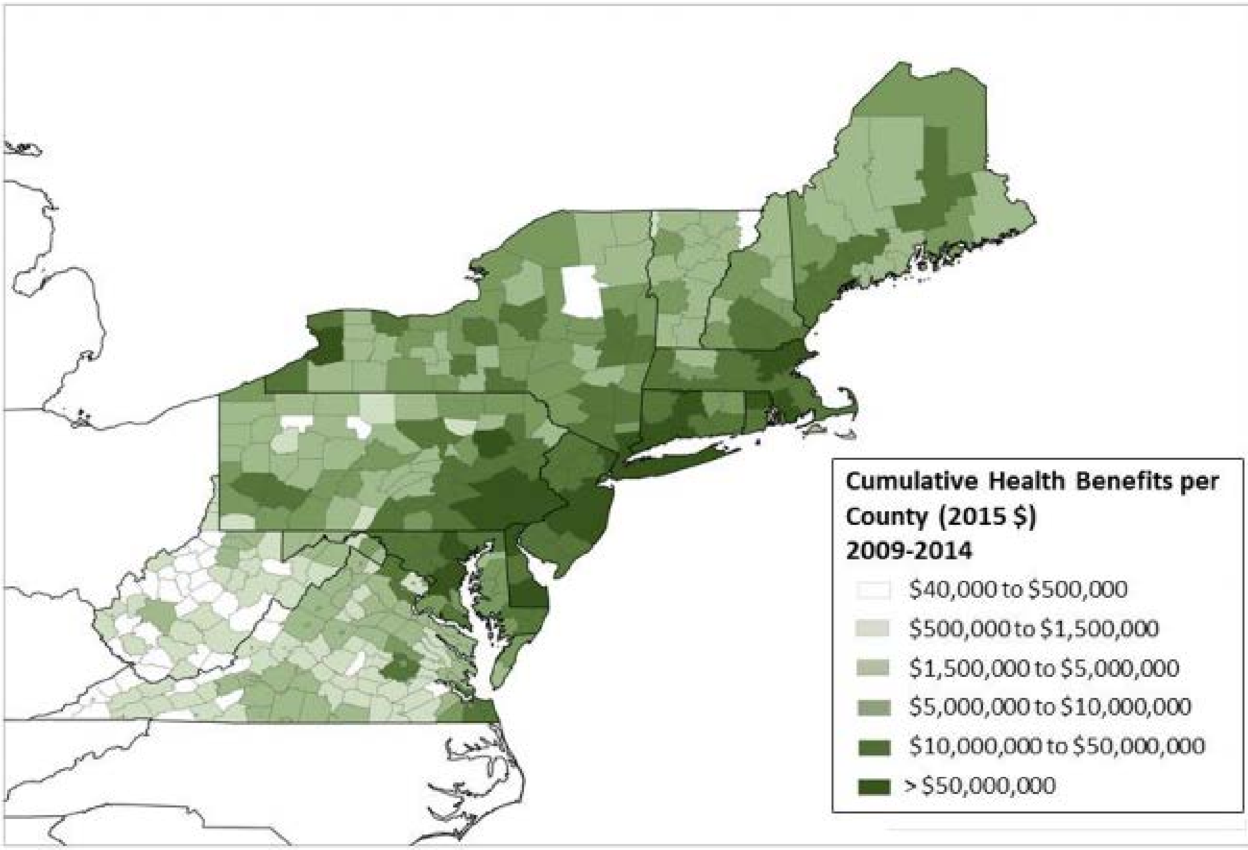
Note that the analysis did not account for ozone or any other co-benefits of RGGI, such as improved ecosystem services. The analysis also did not consider the ongoing health benefits associated with energy efficiency and renewable energy investments that persist beyond 2014. As such, the estimated health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

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

Avoided Health Effects	**Avoided Mortality**		
	▪ 300–830 premature adult deaths		
	Avoided Morbidity		
	▪ 35–390 nonfatal heart attacks ▪ 420–510 cases of acute bronchitis ▪ 8,200–9,500 asthma exacerbations ▪ 13,000–16,000 respiratory symptoms		
	Other Avoided Impacts		
	▪ 180–220 hospital admissions ▪ 200–230 asthma emergency room visits ▪ 39,000–47,000 lost work days ▪ 240,000–280,000 days of minor restricted activity		
Value of Avoided Health Effects	**Low**	**Central**	**High**
	$3.0 billion	$5.7 billion	$8.3 billion

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

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



Source: Abt Associates, 2017.

For More Information

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

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

Benefits Assessed in Analysis

- Air pollutant reductions (NO_x, SO_2, CO_2)
- Economic benefits
- Air quality benefits
- Human health benefits

Savings Metrics Assessed

- Value of annual health benefits for 2013 from reduced mortality ($, number of premature deaths per year)
- Value of CO_2 emissions reductions based on the social cost of carbon ($)
- Residential electricity savings (in terms of both terawatt-hours [TWh] and as a percent of residential electricity consumption)
- Tons of air pollution reduced

Energy Efficiency/Renewable Energy Program Description

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

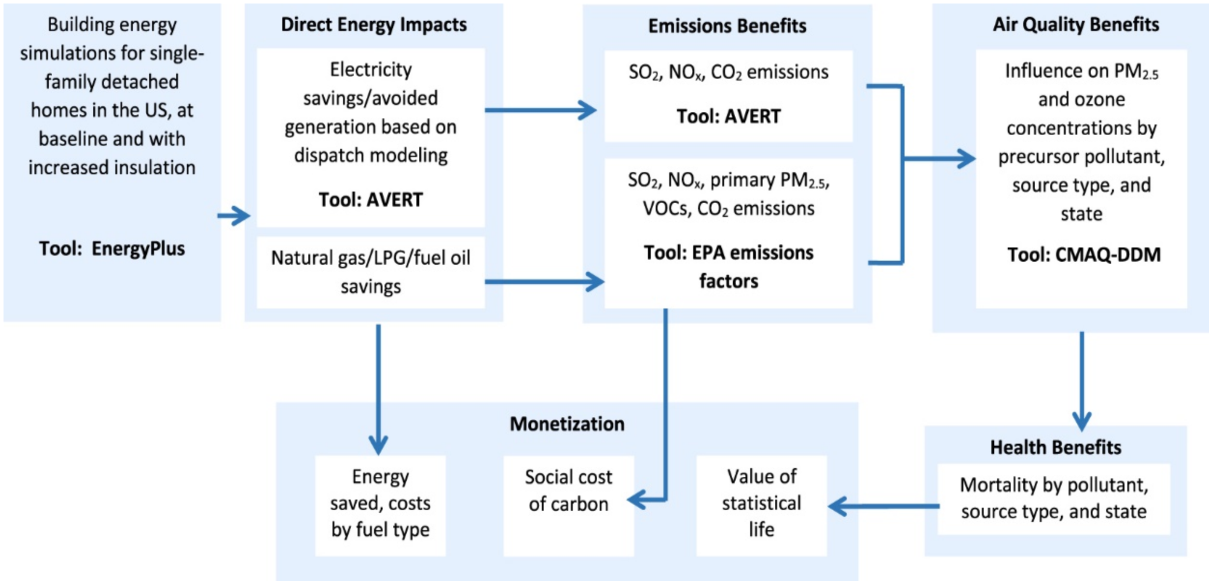
Methods Used

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

Energy Impacts

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

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



Source: Levy et al., 2016.

Emissions Impacts

- The analysts used EPA's AVERT tool to calculate reductions in SO_2, NO_X, and CO_2 by state and season for EGUs.[26] See the Dispatch Curve Analysis method described in Section 4.2.2., "Step 2: Quantify Expected Emissions Reductions" for more information on the method that AVERT uses. Electricity savings from the EnergyPlus model were matched to the dispatch regions used by AVERT based on the number of households in each region.

Air Quality Benefits

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

Estimating Health Benefits

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

Monetizing Benefits

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

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[26] *At the time of the analysis, AVERT did not include estimates of direct $PM_{2.5}$. The analysts, therefore, did not quantify direct $PM_{2.5}$ impacts but used the SO_2 and NO_X outputs to quantify changes in secondary $PM_{2.5}$. AVERT was updated in 2017 to include direct $PM_{2.5}$ enabling more comprehensive analyses of PM-related benefits.*

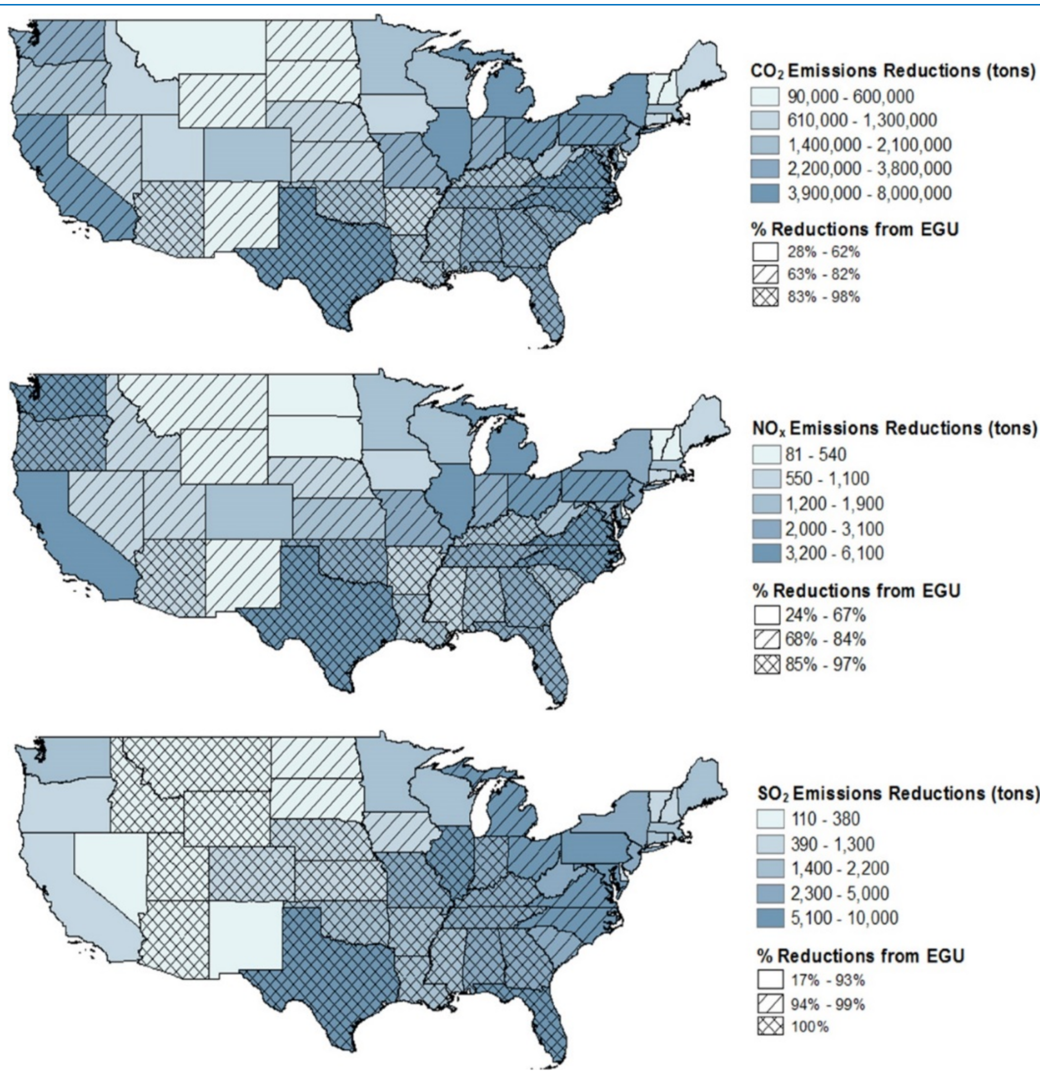
- The economic benefits of reduced CO_2 emissions are calculated using the social cost of carbon developed by the federal government's Interagency Working Group on the Social Cost of Carbon in 2013. A discount rate of 3 percent was used for the primary estimate, with other discount rates used for sensitivity testing.

Results

The analysts found that the improvement in residential energy efficiency measures would result in 320 fewer premature deaths per year due to the reduction in criteria pollutants nationally, representing $2.9 billion in health co-benefits. They estimated that the CO_2-related benefits would be $3.8 billion and that the scenario could result in $11 billion in economic benefits from reduced energy consumption. Based on their analysis, the researchers found that an increase of residential energy efficiency equivalent to the scenario modeled would result in national climate and health co-benefits of $49 per ton of EGU CO_2 emissions reduced, with a range across states from $12 to $390 per ton of EGU CO_2 reduced.

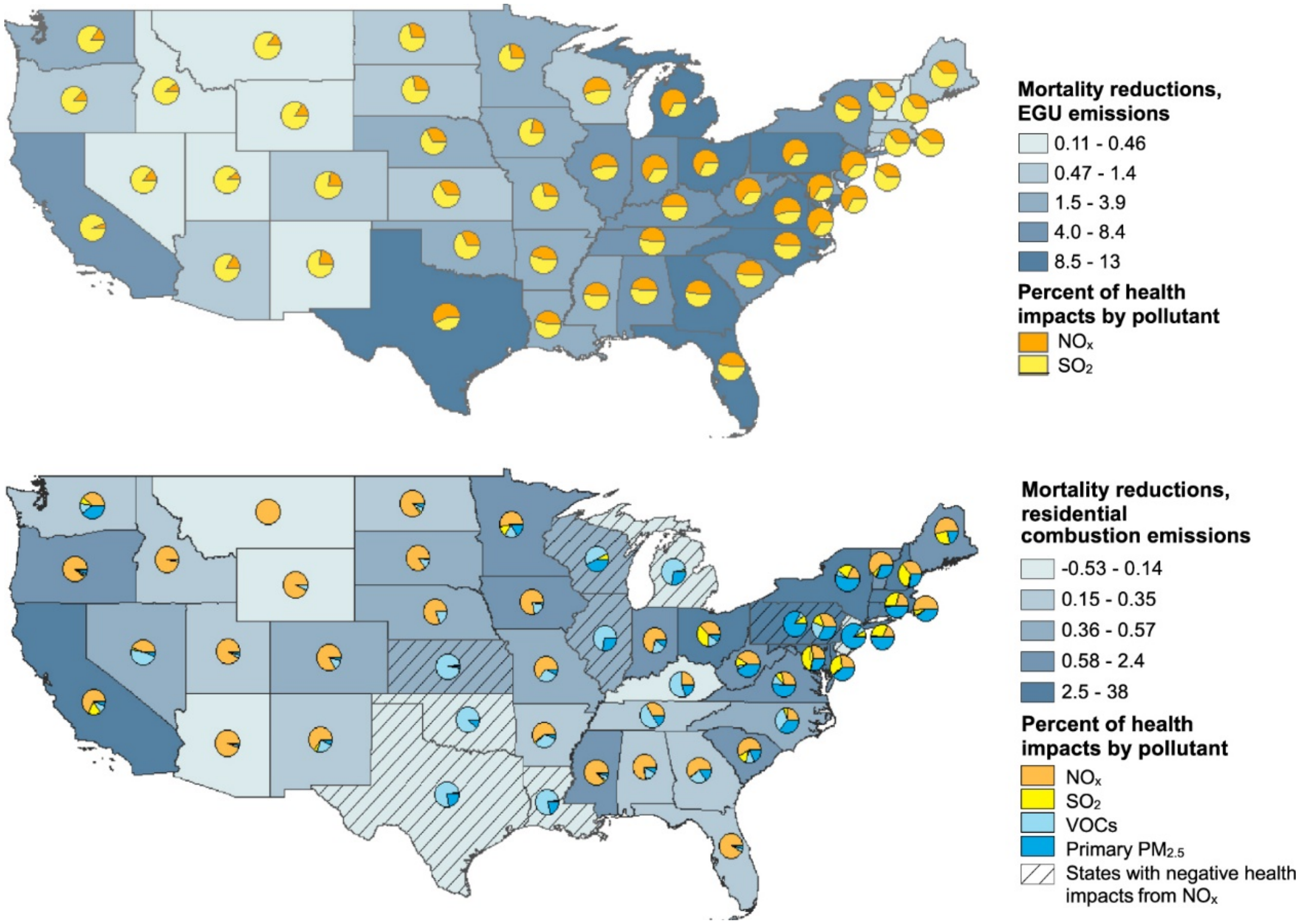
For a state-by-state breakdown of the results, Figure 4-8 shows emissions reductions by state for CO_2, NO_x, and SO_2, indicating the percent of reductions attributable to changes in generation from EGUs, while Figure 4-9 shows the change in premature deaths per year, with pie charts for each state indicating the contribution of specific emissions reductions to these changes.

Figure 4-8: Annual Emissions Reductions by State



Source: Levy et al., 2016.
Note: Emissions reductions represent the total reductions from both EGUs and residential combustion sources.

Figure 4-9: Annual Mortality Reductions by State



Source: Levy et al., 2016.
Note: Mortality reductions are shown as the change in the number of premature deaths per year.

For More Information

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

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

Benefits Assessed in Analysis

- SO_2 reductions
- PM reductions
- Mercury reductions (only a qualitative estimate of potential benefits)

Savings Metrics Assessed

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

Energy Efficiency/Renewable Energy Program Description

In 2012, Minnesota Power submitted an emissions reduction proposal, the *Boswell Unit 4 Environmental Improvement Plan*, under the state's Mercury Emissions Reduction Act of 2006. The Boswell generating station was built in the 1980s and is the largest power plant in Minnesota, with a capacity of 585 MW. The emissions reduction plan proposed replacing air pollution control equipment for Unit 4 at the Boswell plant with a $240 million scrubbing system that would reduce sulfur dioxide (SO_2), particulate matter (PM), and mercury emissions.

Methods Used

In 2013, the Minnesota Pollution Control Agency (MPCA) used air quality and air dispersion modeling to translate projected annual emissions reductions based on the Boswell Unit 4 plan into changes in air quality. The baseline emissions were taken from MPCA's Annual Emissions Inventory for Unit 4 for 2011. The emissions reduction projections were based on the proposal Minnesota Power submitted to MPCA in 2012 for the retrofit project. MPCA used the Comprehensive Air Quality Model with Extensions (CAMx), version 5.41, to translate the reductions in SO_2 and PM emissions from the Unit 4 retrofit to changes in ambient concentrations of fine particulate matter ($PM_{2.5}$).

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

Results

Since 2015, the Boswell Unit 4 retrofit reduced SO_2 by nearly 40 percent, PM by 80 percent, and mercury emissions by nearly 90 percent (Table 4-9).

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

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

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

	SO_2 (tons/year)	PM (tons/year)	Mercury (lbs./year)
Baseline, prior to plan implementation	1,061	1,275	228
After implementation of plan	647	259	26
Emissions decrease	414	1,016	202
Percentage change	-39%	-80%	-89%

Note: Based on 2011 emissions levels.

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

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

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

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

Table 4-11: Estimated Value of Benefits from Reductions in SO_2 and $PM_{2.5}$ at Boswell Energy Center Unit 4

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

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

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

For More Information

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

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

Benefits Assessed in Analysis

- SO_2 reductions
- NO_x reductions
- PM reductions

Savings Metrics Assessed

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

Energy Efficiency/Renewable Energy Program Description

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

Methods Used

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

The results of the PROMOD modeling were reductions in SO_2, NO_x, and $PM_{2.5}$ in the offshore wind scenario compared to the non-offshore wind scenario. These emissions reductions were entered into COBRA to estimate the health impacts in 2030.

Results

The analysis estimated that the offshore wind scenario would result in a reduction of 780 tons of SO_2, 1,800 tons of NO_x, and 180 tons of $PM_{2.5}$, beyond the scenario in which the Clean Energy Standard is met with other renewable technologies. The health impacts analysis estimated that these emissions reductions would result in 18 fewer premature deaths annually. The total health benefits of the offshore wind scenario were valued between $73 million and $165 million across all 15 states.

For More Information

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

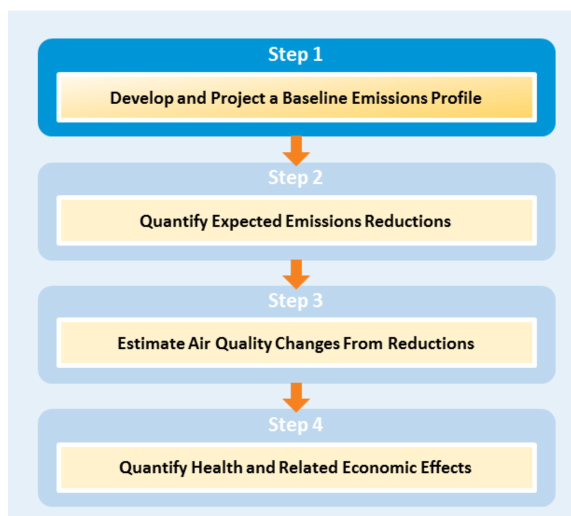
4.4. TOOLS AND RESOURCES

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

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

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

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



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

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

Potential Sources of Emissions Data

GHG Emissions (Only) Data Sources

- **EPA's State Energy CO_2 Emissions.** EPA maintains this website that provides state CO_2 emissions inventories from fossil fuel combustion by end-use sector (commercial, industrial, residential, transportation, and electric power). Pollutant types: CO_2. Scope coverage: Scope 1.[27] https://www.epa.gov/statelocalenergy/state-co2-emissions-fossil-fuel-combustion

- **EPA's U.S. Greenhouse Gas Reporting Program (GHGRP).** The GHGRP collects annual reporting of U.S. GHG emissions and other relevant information from large fuel suppliers and facilities that emit 25,000 metric tons or more per year. These data span a variety of sectors; facilities from 41 source categories are required to report. EPA publishes these data annually for download and through their interactive Facility Level Information on Greenhouse Gases Tool (FLIGHT). Pollutant types: CO_2, other GHGs. Scope coverage: Scope 1. https://www.epa.gov/ghgreporting
- **World Resources Institute Climate Analysis Indicators Tool 2.0***.* The Climate Analysis Indicators Tool (CAIT 2.0) is a free, comprehensive, and comparable database of GHGs and other climate-relevant indicators for U.S. states. Pollutant types: CO_2, other GHGs. Scope coverage: Scope 1. http://cait.wri.org/

Criteria Air Pollutant (Only) Data Sources

- **EPA's National Emissions Inventory (NEI).** Analysts can use the NEI to help establish an inventory of criteria air pollutants and hazardous air pollutants. The NEI is a national database of air emissions information prepared by EPA with input from numerous state and local air agencies, tribes, and industry. The database contains information on stationary and mobile sources that emit criteria air pollutants and their precursors, as well as hazardous air pollutants. The database also includes estimates of annual emissions, by source, of air pollutants in each area of the country. The NEI includes emissions estimates for all 50 states, the District of Columbia, Puerto Rico, and the Virgin Islands, and is updated every 3 years. Pollutant types: SO_2, NO_x, Hg. Scope coverage: Scope 1. https://www.epa.gov/air-emissions-inventories/national-emissions-inventory

Data Sources with Both Criteria Air Pollutant and GHG Emissions

- **EPA's Air Markets Program Data (AMPD).** EPA collects data in 5-minute intervals from continuous emissions monitor systems (CEMSs) at all large power plants in the country. The AMPD is a new system of reporting emissions data, monitoring plans, and certification data, and replaces the Emissions Tracking System that previously served as a repository of SO_2, NO_x, and CO_2 emissions data from the utility industry. Pollutant types: SO_2, NO_x, CO_2. Scope coverage: Scope 1. http://ampd.epa.gov/ampd/
- **EPA's Emissions & Generation Resource Integrated Database (eGRID).** This free, publicly available software from EPA has data on annual SO_2, NO_x, CO_2, and Hg emissions for most power plants in the United States. eGRID also provides annual average non-baseload emissions rates, which may better characterize the emissions of marginal resources. By accessing eGRID, analysts can find detailed emissions profiles for every power plant and electric generating company in the United States. Pollutant types: SO_2, NO_x, CO_2, other GHGs, Hg. Scope coverage: Scopes 1 and 2. https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid

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

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

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

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

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

- **EIA's State Energy Data System (SEDS).** This database has state energy-related data including electricity consumption and fuel consumption by sector. It includes annual data back to 1960. Pollutant types: CO_2. Scope coverage: Scopes 1 and 2. http://www.eia.gov/state/seds/
- **DOE's State and Local Energy Data (SLED).** DOE's SLED tool provides energy market data specific to individual cities and states. The tool provides an overview of the GHG emissions in each city, as well as national and state energy sources for electricity production. Pollutant types: CO_2. Scope coverage: Scope 2. http://apps1.eere.energy.gov/sled/#/
- **State or Local Governments.** In order to estimate emissions that arise from state or local government operations, an analyst would need to collect and compile data on energy and electricity use, process emissions, waste generated, and other emissions-generating activities. These data are often obtained from utility bills, fleet records, and similar records.

Other potential data sources:

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

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

Data Source	Type of Air Pollutant or GHG Emissions						Method		Scope	
	SO_2	NO_x	$PM_{2.5}$	CO_2	Other GHGs[a]	Hg	Top-Down	Bottom-Up	Scope 1	Scope 2
National Emissions Inventory (NEI)	x	x	x			x	x	x	x	
eGRID	x	x		x	x		x	x	x	x
Air Markets Program Data (AMPD)	x	x		x				x	x	
World Resources Institute Climate Analysis Indicators Tool (CAIT 2.0)				x	x		x		x	
EPA State CO_2 Emissions				x			x		x	
Local GHG Inventories				x	x		x		x	x
U.S. Greenhouse Gas Reporting Program (FLIGHT)				x	x			x	x	
DOE State and Local Energy Data (SLED)				x			x			x
EIA State Energy Data System (SEDS)				x			x		x	x
Universities	x	x	x	x	x	x	x	x	x	x

[a] *Other GHGs may include CH_4, N_2O, HFCs, PFCs, SF_6, and NF_3.*

Emission Factors for CO_2, NO_x, SO_2, and Other Pollutants

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

Resources that provide **emission factors for CO_2, NO_x, SO_2, and other pollutants:**

- **EPA's Clearinghouse for Inventories and Emissions Factors (CHIEF).** This site contains air emissions inventories, emission factors, modeling inputs, electronic reporting, and information on emissions monitoring techniques that are applicable to both statewide and community-wide emissions inventories. https://www.epa.gov/chief
- **EPA's Emissions & Generation Resource Integrated Database (eGRID).** eGRID is a comprehensive source of data on the environmental characteristics of almost all electric power generated in the United States. These environmental characteristics include emissions for NO_x, SO_2, CO_2, CH_4, and N_2O emissions rates. This database also includes data on net generation, resource mix, and many other attributes. The data are aggregated by state, North American Electric Reliability Corporation (NERC) region, eGRID sub-region, balancing authority area, and U.S. total. https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid
- **EPA's Power Profiler.** The Power Profiler is a web-based tool that allows users to enter in their zip code and utility, and it provides CO_2, NO_x, and SO_2 emission factors for the user's region based on eGRID data. http://oaspub.epa.gov/powpro/ept_pack.charts

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

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

Inventory Development Protocols and Tools

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

Protocols and Resources for Inventory Development

Developing an inventory that adheres to a comprehensive and detailed set of methodologies for estimating emissions is important because this helps ensure the inventory is created in a transparent manner using a consistent framework. Specific methods and protocols for developing top-down or bottom-up baseline emissions inventories are available at both the state and local levels. Guidance from the protocols vary depending on the type of inventory data a state collects.

For GHG (Only) Inventories

- **GHG Protocol Accounting and Reporting Standard for Cities.** The GHG Protocol is a joint effort of the World Resources Institute and the World Business Council on Sustainable Development. The GHG Protocol has developed many protocols for accounting for GHG emissions. The one that is most relevant to state and local governments is the Global Protocol for Community-Scale Greenhouse Gas Emissions Inventories. This protocol provides step-by-step instructions for setting boundaries and accounting for emissions from various emissions sources within the state or community. http://www.ghgprotocol.org/greenhouse-gas-protocol-accounting-reporting-standard-cities

- **GHG Protocol Corporate Accounting and Reporting Standard.** For measuring GHG emissions for state and local government operations, analysts can use the Corporate Accounting and Reporting Standard. This protocol was designed for corporate inventories, but can be adapted for use by state and local governments that want to quantify emissions from their own operations. The protocol provides step-by-step guidance on measuring, managing, and reporting GHG emissions from specific sources (e.g., stationary and mobile combustion, process emissions) and industry sectors (e.g., cement, pulp and paper, aluminum, iron and steel, and office-based organizations). http://www.ghgprotocol.org/corporate-standard

- **EPA's Center for Corporate Climate Leadership GHG Inventory Guidance.** The Center for Corporate Climate Leadership provides overall guidance to corporations on topics such as defining inventory boundaries, identifying GHG emissions sources, providing current emission factors, defining and adjusting a base year, reporting requirements, and goal setting. http://www.epa.gov/climateleadership/inventory/index.html

- **EPA's U.S. GHGRP Reporting Protocols.** The GHGRP program provides methodologies to estimate emissions from individual sources. These methodologies can help states estimate direct GHG emissions (both fuel combustion and process emissions) from direct-emitting facilities, suppliers, and carbon dioxide injection facilities. GHGRP also provides measures to verify emissions, as well as methods to directly monitor emissions, such as a CEMS. Factsheets: https://www.epa.gov/ghgreporting/ghgrp-methodology-and-verification. Methods: http://www.ecfr.gov/cgi-bin/text-idx?tpl=/ecfrbrowse/Title40/40cfr98_main_02.tpl

- **ICLEI U.S. Community Protocol.** ICLEI's U.S. Community Protocol is a technical document containing methodologies and best practices designed to provide guidance on top-down GHG emissions inventory development. http://icleiusa.org/publications/us-community-protocol/

- **IPCC Methodology Reports***.* The IPCC provides guidelines to inform GHG inventory preparation across all sectors. http://www.ipcc.ch/publications_and_data/publications_and_data_reports.shtml#4

- **Local Government Operations Protocol for the Quantification and Reporting of GHG Emissions Inventories.** The Local Government Operations Protocol was created in 2010 to help local governments develop consistent and credible emissions inventories based on internationally accepted methods. It allows users to select the level of disaggregation so that it can be used for top-down or bottom-up inventories. Developed in partnership by the California Air Resources Board, California Climate Action Registry, ICLEI – Local Governments for Sustainability, and The Climate Registry, it involved a multi-stakeholder technical collaboration that included national, state, and local emissions experts. http://icleiusa.org/ghg-protocols/

- **The Climate Registry Protocols (TCR).** TCR provides a set of protocols that detail best practices in GHG accounting, as well as voluntary reporting program requirements. Each protocol in TCR was developed by reaching a consensus among industry, environmental, and government stakeholders. https://www.theclimateregistry.org/tools-resources/reporting-protocols/general-reporting-protocol

Data Sources

- **DOE's State Energy Data (SEDS)**. EIA's state energy statistics are housed in the SEDS, which contains historical information on energy production, consumption, prices, and expenditures by state to aid in analysis and forecasting. https://www.eia.gov/state/seds/
- **DOE's State and Local Energy Database – City Energy Profiles***.* City energy profiles are intended to help cities perform planning exercises and implement clean energy projects. The profiles contain information on city energy use and activity data. Each city energy profile includes a range of summary information on GHG emissions; electricity generation; natural gas and other fuel source costs; renewable energy resource potential; transportation, buildings, and industry data; and applicable policies and incentives. https://apps1.eere.energy.gov/sled/#/
- **EPA's Facility Level Information on Greenhouse Gases Tool (FLIGHT).** FLIGHT gives access to GHG data reported to EPA by large emitters, facilities and inject CO_2 underground, and suppliers of products that result in GHG emissions when used in the United States. FLIGHT allows users to view data in several formats including maps, tables, charts, and graphs for individual facilities or groups of facilities. The database is searchable and allows comparison of emissions trends over time and download data. https://ghgdata.epa.gov/ghgp/main.do
- **EPA's State CO_2 Data.** EPA provides state CO_2 emissions inventories from fossil fuel combustion, by end-use sector (commercial, industrial, residential, transportation, and electric power), in metric tons of CO_2 from 1990 through 2015. https://www.epa.gov/statelocalenergy/state-co2-emissions-fossil-fuel-combustion

For Criteria Air Pollutant Inventories

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

Local-Scale Emissions Inventory Development

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

Tools for Inventory Development

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

Tools for Developing Top-Down GHG Inventories

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

Tools for Developing Bottom-Up GHG Inventories

For Buildings

- **EPA's ENERGY STAR® Portfolio Manager®**. Portfolio Manager is a free, interactive ENERGY STAR energy management tool that enables users to track and assess energy and water consumption for a single building or across a portfolio of buildings. The tool can be used to identify buildings with the most potential for energy efficiency improvements. A new feature of Portfolio Manager allows users to see how their buildings' CO_2 emissions compare with other buildings across the country, and to measure their progress in reducing emissions. The tool also has the functionality to compare the GHG performance of a user's facility against the performance of a building with energy efficiency equal to the nation median using data from DOE's national Commercial Building Energy Consumption Survey. Table 4-13 shows an example of this comparison for a hypothetical school. https://www.energystar.gov/buildings/facility-owners-and-managers/existing-buildings/use-portfolio-manager

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

Property Name	Year Ending	ENERGY STAR Score (1–100)	Total GHG Emissions (Metric Tons CO_2e)	National Median Total GHG Emissions (Metric Tons CO_2e)
Sample School	8/31/2017	60	112.2	123.6

Tools for Developing Bottom-Up Criteria Air Pollutant Inventories

For a Range of Sources

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

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

For Point Sources

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

- **EPA's Landfill Gas Emissions Model (LandGEM).** LandGEM is a free, automated estimation tool with a Microsoft Excel interface that can be used to estimate emissions rates for total landfill gas, methane, CO_2, non-methane organic compounds, and individual air pollutants from municipal solid waste landfills. *http://www.epa.gov/ttn/catc/dir1/landgem-v302-guide.pdf*

For Mobile Sources

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

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

Projecting Future Emissions: Protocols, Resources, and Tools

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

Protocols and Resources for Emissions Projections

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

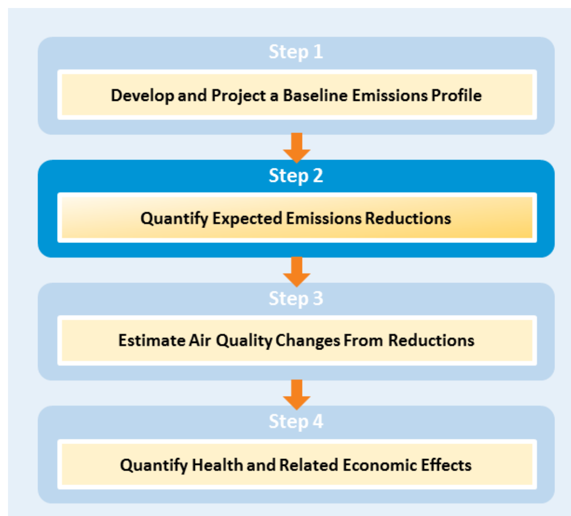
cost and emissions impacts of policies that limit SO_2, NO_x, CO_2, hydrogen chloride (HCl), and mercury (Hg). http://www.epa.gov/airmarkets/power-sector-modeling

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

Tools for Emissions Projections

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

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



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

Establishing Operating Characteristics/Data on Load Profiles

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

- **EPA's Air Markets Program Data (AMPD).** EPA collects data in five-minute intervals from CEMSs at all large power plants in the country. The AMPD is a new system of reporting emissions data, monitoring plans, and certification data, and replaces the Emissions Tracking System that previously served as a repository of SO_2, NO_x, and CO_2 emissions data from the utility industry. http://ampd.epa.gov/ampd/
- **EIA's Electricity Data.** This database contains statistics on electric power plants, capacity, generation, fuel consumption, sales, prices, and customers and can be used to assess generator-specific operating costs, historical utilization, and emissions rates. http://www.eia.gov/electricity/data.cfm
- **New York Independent System Operator (NYISO) Data.** NYISO, a regional grid operator, on hourly regional load data and transfer data between ISOs. http://www.nyiso.com/public/markets_operations/market_data/load_data/index.jsp

Emission Factors for CO_2, NO_x, SO_2, and Other Pollutants

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

Factors Specific to the Electric Generation Source Category (Only)

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

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

If You:	Use:
▪ Have been using eGRID already in your calculations and want to continue to use the same data source for consistency purposes ▪ Are interested in using a CO_2e value or want a factor for methane or nitrous oxide ▪ Are looking at a small level of disaggregation (20+ regions)	eGRID emission factors
▪ Are interested in using a CO_2 value from a previous recent year ▪ Want an emission factor for $PM_{2.5}$ emissions to estimate health impacts in COBRA ▪ Are looking for an emission factor that reflects a specific renewable energy resource, such as wind or solar ▪ Are interested in representing a portfolio of energy efficiency programs or a program that saves the same amount of energy throughout the year (e.g., street lighting or refrigerator change out)	AVERT emission factors

Factors Across Multiple Air Pollution Sources Categories

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

Tools for Quantifying Emissions Reductions

There are a range of tools, from basic to sophisticated, that analysts can use to quantify the emissions impacts of energy efficiency and renewable energy. The tools chosen should match the purpose and method as described in Section 4.2.2., "Step 2: Quantify Expected Emissions Reductions," of this chapter. The tools below apply the basic, intermediate, and sophisticated methods described earlier and are categorized accordingly.

Basic Tools

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

- **ClearPath™.** Analysts can use ClearPath™ to develop a top-down inventory of GHGs associated with electricity, fuel use, and waste disposal based on ICLEI's U.S. Community Protocol; track emissions progress over time; project scenarios; analyze benefits of reduction measures; and visualize alternative planning scenarios. http://icleiusa.org/clearpath/
- **Climate Action for URBan Sustainability (CURB) Scenario Planning Tool***.* This is an interactive scenario planning tool designed specifically to help cities identify and prioritize low-carbon infrastructure and other GHG reduction actions; understand the impact on emissions and financial performance of potential actions; and develop, compare, and explore multiple scenarios. It draws on built-in city, national and region-specific data. http://www.c40.org/programmes/climate-action-for-urban-sustainability-curb
- **DOE's Grid Project Impact Quantification (Grid Project IQ) Screening Tool**. The Grid Project IQ screening tool provides insight into smart grid related technology deployments. It helps users quickly explore the outcomes of adding a new project to an existing power system from a web browser. With Grid Project IQ, users can quantify changes in total energy, peak power, greenhouse gas and criteria air pollutant emissions, ramping rates, and generation fossil fuel costs. (Note: This tool uses EPA's AVERT model to estimate emission impacts.) https://www.energy.gov/oe/activities/technology-development/grid-modernization-and-smart-grid/grid-project-impact
- **EPA's Power Profiler.** The Power Profiler is a web-based tool that allows users to evaluate the air pollution and GHG impact of their electricity choices. The tool is particularly useful with the advent of electric customer choice, which allows many electricity customers to choose the source of their power. http://oaspub.epa.gov/powpro/ept_pack.charts
- **Metropolitan Washington Council of Governments' (MWCOG') Avoided Emissions Calculator.** With support from the DOE, this D.C.-based entity has developed the MWCOG Avoided Emissions Calculator, a tool to help state and local governments quantify climate and air quality benefits from energy efficiency and renewable energy programs. This spreadsheet-based emissions calculator gives users the ability to calculate the NO_x, ozone, SO_2, and CO_2 emissions benefits of selected energy efficiency and renewable energy measures. This tool has been customized using emissions rates for the Washington metropolitan region, and therefore is especially applicable for government entities in the area. https://www.mwcog.org/documents/2010/03/31/inclusion-of-energy-efficiency-and-renewable-energy-in-state-implementation-plans-for-air-quality-and-climate-change-air-quality-efficiency-energy-renewable-energy/
- **State and Utility Pollution Reduction Calculator Version 2** (**SUPR2)**. The SUPR2 tool provides high-level estimates of the costs and benefits of various policies and technologies that could help an individual state meet its air quality goals. SUPR2's policy and technology options include energy efficiency, renewable energy, nuclear power, emissions control options, and natural gas. http://aceee.org/research-report/e1601

Intermediate Tools

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

- **Eastern Regional Technical Advisory Committee's (ERTAC's) EGU Forecasting Tool.** ERTAC created the EGU Forecasting tool to project hourly air emissions inventories into the future, on both an annual and episodic peak basis. The tool uses data from EPA's Clean Air Markets Division, as well as fuel-specific growth rates and other information to calculate the projections. http://www.marama.org/2013-ertac-egu-forecasting-tool-documentation
- **EPA's AVoided Emissions and geneRation Tool** (**AVERT).** AVERT is used to estimate displaced generation from energy efficiency and renewable energy programs. Displaced generation is then used to estimate avoided emissions based on the historical hourly dispatch method described above, including differentiation of savings by the time of year and time of day. AVERT covers avoided emissions from SO_2, NO_x, $PM_{2.5}$ and CO_2 and splits the contiguous U.S. into ten regions. AVERT can be used to estimate emissions reductions in the current year or near future, but it is based on historical behavior and does not incorporate future variables on fuel or electricity market prices. https://www.epa.gov/statelocalenergy/avoided-emissions-and-generation-tool-avert
- **Long-Range Energy Alternatives Planning System (LEAP).** LEAP is an integrated, scenario-based modeling tool developed by the Stockholm Environment Institute. LEAP can be used to track energy consumption, production, and resource extraction in all sectors of the economy at the city, state, national or regional scale. Beginning in 2018, LEAP includes the Integrated Benefits Calculator, which can be used to estimate health (mortality), agriculture (crop loss) and climate (temperature change) impacts of scenarios. It can be used to account for both energy sector and non-energy sector greenhouse gas (GHG) emission sources and sinks, and to analyze emissions of local and regional air pollutants, and short-lived climate pollutants. www.energycommunity.org
- **Time-Matched Marginal Emissions Model.** Resource Systems Group's Time-Matched Marginal Emissions Model calculates avoided emissions from regional energy efficiency and renewable energy measures on an hourly basis. The model calculates marginal grid emissions rates from fossil fueled units for every hour of the year, and matches them to the corresponding energy efficiency or renewable energy measure in that same hour to calculate avoided emissions. https://www.epa.gov/sites/production/files/2016-03/documents/using_a_time-matched_hourly_marginal_emissions_tool_in_metropolitan_washington.pdf

Sophisticated Tools

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

Economic Dispatch Models

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

- **GE Multi-Area Production Simulation (MAPS™).** A chronological model that contains detailed representation of generation and transmission systems, MAPS can be used to study the impact on total system emissions that result from the addition of new generation. MAPS software integrates highly detailed representations of a system's load, generation, and transmission into a single simulation. This enables calculation of hourly production costs in light of the constraints imposed by the transmission system on the economic dispatch of generation. http://www.geenergyconsulting.com/practice-area/software-products/maps

- **Integrated Planning Model (IPM)®.** This model simultaneously models electric power, fuel, and environmental markets associated with electric production. It is a capacity expansion and system dispatch model. Dispatch is based on seasonal, segmented load duration curves, as defined by the user. IPM also has the capability to model environmental market mechanisms such as emissions caps, trading, and banking. System dispatch and boiler and fuel-specific emission factors determine projected emissions. IPM estimates emissions for NO_x, SO_2, CO_2, and Hg. IPM can be used to model the impacts of energy efficiency and renewable energy resources on the electric sector in the short and long term. http://www.icf.com/resources/solutions-and-apps/ipm
- **PLEXOS®**. A simulation tool that uses Linear Programming/Mixed Integer Programming optimization technology to analyze the power market, PLEXOS contains production cost and emissions modeling, transmission modeling, pricing modeling, and competitiveness modeling. PLEXOS allows the user to select emissions of interest (e.g., CO_2, NO_x, SO_2, etc.). The tool can be used to evaluate a single plant or the entire power system. http://www.energyexemplar.com
- **PROMOD IV®**. A detailed generator and portfolio modeling system, with nodal locational marginal pricing forecasting and transmission analysis, PROMOD IV can incorporate extensive details in generating unit operating characteristics and constraints, transmission constraints, generation analysis, unit commitment/operation conditions, and market system operations. http://new.abb.com/enterprise-software/energy-portfolio-management/market-analysis/promod
- **PROSYM (Zonal Analysis)™.** A chronological electric power production costing simulation computer software package, PROSYM is designed for performing planning and operational studies. As a result of its chronological nature, PROSYM accommodates detailed hour-by-hour investigation of the operations of electric utilities. Inputs into the model are fuel costs, variable operation and maintenance costs, and startup costs. Output is available by regions, by plants, and by plant types. The model includes a pollution emissions subroutine that estimates emissions with each scenario. http://new.abb.com/enterprise-software/energy-portfolio-management/market-analysis/zonal-analysis

Capacity Expansion Models

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

- **AURORA**. The AURORA model, developed by EPIS LLC, provides electric market price forecasting, estimates of resource and contract valuation and net power costs, long-term capacity expansion modeling, and risk analysis of the energy market. http://epis.com/aurora/
- **DOE's National Energy Modeling System (NEMS).** NEMS is a system-wide energy model (including demand-side sectors) that represents the behavior of energy markets and their interactions with the U.S. economy. The model achieves a supply/demand balance in the end-use demand regions, defined as the nine U.S. Census Bureau divisions, by solving for the prices of each energy product that will balance the quantities producers are willing to supply with the quantities consumers wish to consume. The system reflects market economics, industry structure, and existing energy policies and regulations that influence market behavior. NEMS tracks emissions levels for CO_2, SO_2, and NO_x. https://www.eia.gov/outlooks/aeo/info_nems_archive.php

- **Electric Generation Expansion Analysis System (EGEAS).** This tool was developed by the Electric Power Research Institute, is a set of computer modules that are used to determine an optimum expansion plan or simulate production costs for a pre-specified plan. Optimum expansion plans are based on annual costs, operating expenses, and carrying charges on investment. http://eea.epri.com/models.html#tab=3
- **e7 Capacity Expansion.** e7 Capacity Expansion is an energy portfolio management solution from the consulting firm ABB that covers resource planning, capacity expansion, and emissions compliance. It enables resource planners and portfolio managers to assess and develop strategies to address current and evolving RPSs and emissions regulations. http://new.abb.com/enterprise-software/energy-portfolio-management/commercial-energy-operations/capacity-expansion
- **e7 Portfolio Optimization**. Portfolio Optimization models unit operating constraints and market conditions to facilitate the analysis and simulation of scenarios. The model optimizes a combined portfolio of supply resources and energy efficiency or distributed generation assets modeled as virtual power plants. http://new.abb.com/enterprise-software/energy-portfolio-management/commercial-energy-operations/portfolio-optimization
- **ENERGY 2020***.* Energy 2020 is a simulation model available from Systematic Solutions that includes all fuel, demand, and supply sectors and simulates energy consumers and suppliers. This model can be used to capture the economic, energy, and environmental impacts of national, regional, or state policies. Energy 2020 models the impacts of an energy efficiency or renewable energy measure on the entire energy system. User inputs include new technologies and economic activities such as tax breaks, rebates, and subsidies. Energy 2020 uses emissions rates for CO_2 and other GHGs, as well as NO_x, SO_2, and $PM_{2.5}$ for nine plant types included in the model. It is available at the national, regional, and state levels. http://www.energy2020.com/
- **Integrated Planning Model (IPM)®.** This model simultaneously models electric power, fuel, and environmental markets associated with electric production. It is a capacity expansion and system dispatch model. IPM also has the capability to model environmental market mechanisms such as emissions caps, trading, and banking. System dispatch and boiler and fuel-specific emission factors determine projected emissions. IPM estimates emissions for NO_x, SO_2, HCl, CO_2, and Hg. IPM can be used to model the impacts of energy efficiency and renewable energy resources on the electric sector in the short and long term. http://www.icf.com/resources/solutions-and-apps/ipm
- **MARKAL/TIMES.** MARKAL and TIMES determine the least-cost pattern of technology investment and utilization required to meet specified end-use energy demands (e.g., lumens for lighting, watts for heating, and vehicle miles traveled for transportation), while tracking the resulting criteria air pollutant and GHG emissions. By adding constraints or changing various assumptions, these models can be applied to examine how those changes affect the optimal evolution of the energy system. The MARKAL model estimates emissions for CO_2, SO_2, and NO_x. http://iea-etsap.org/index.php/etsap-tools/model-generators/times
- **NREL's Regional Energy Deployment System model (ReEDS).** This is a long-term capacity expansion model that determines the potential expansion of electricity generation, storage, and transmission systems throughout the contiguous United States over the next several decades. ReEDS is designed to determine the cost-optimal mix of generating technologies, including both conventional and renewable energy, under power demand requirements, grid reliability, technology, and policy constraints. Model outputs are generating capacity, generation, storage capacity expansion, transmission capacity expansion, electric sector costs, electricity prices, fuel prices, and carbon dioxide emissions. ReEDS tracks emissions of CO_2, SO_2, NO_x, and Hg. http://www.nrel.gov/analysis/reeds/

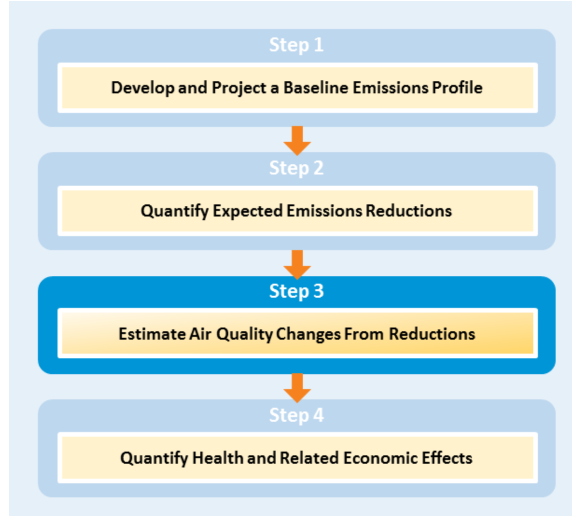
- **NREL's Resource Planning Model (RPM).** RPM is a capacity expansion model designed to examine how increased renewable deployment might impact regional planning decisions for clean energy or carbon mitigation analysis. RPM includes an optimization model that finds the least-cost investment and dispatch solution over a 20-year planning horizon for different combinations of conventional, renewable, storage, and transmission technologies. The model is currently only available for regions within the Western Interconnection, while a version for regions in the Eastern Interconnection is under development. RPM tracks power sector emissions for CO_2, SO_2, NO_x, and Hg. https://www.nrel.gov/analysis/models-rpm.html

General Resources for Quantifying Emissions Reductions

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

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

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



General Resources for Quantifying Air Quality Impacts

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

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

Tools for Quantifying Air Quality Impacts

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

Screening and Reduced-Form Tools and Resources

- **EPA's Response Surface Modeling (RSM).** RSM is based on a method known as air quality metamodeling, which aggregates pre-specified individual air quality modeling simulations into a multi-dimensional air quality "response surface." RSM is a metamodel of an air quality model developed using the CMAQ Modeling system. It is a reduced-form prediction model using statistical correlation structures to approximate model functions through the design of complex multi-dimension experiments. https://www3.epa.gov/scram001/reports/pmnaaqs_tsd_rsm_all_021606.pdf
- **EPA's Source-Receptor (S-R) Matrix.** The S-R Matrix is a reduced-form model based on the Climatological Regional Dispersion Model, which provides the relationship between emissions of $PM_{2.5}$, NO_x, SO_2, ammonia (NH_3), or VOCs and county-level $PM_{2.5}$ ambient concentrations. The S-R Matrix is used to evaluate $PM_{2.5}$ in the COBRA screening model. To obtain the COBRA model, visit https://www.epa.gov/statelocalenergy/co-benefits-risk-assessment-cobra-screening-model. To learn more about the S-R Matrix, see Appendix A of the COBRA User Manual: https://www.epa.gov/sites/production/files/2015-08/documents/cobra-manual.pdf

Sophisticated Modeling Tools

When quantifying the air quality impacts of emissions changes, more sophisticated tools are available that provide a finer level of resolution than what is possible with the screening tools. These types of tools include photochemical models, dispersion models and receptor models as described below. EPA recommends the models depicted in Table 4-15 for air quality modeling to assess control strategies and source impacts.

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

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

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

Photochemical Modeling

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

General Resources About Photochemical Models

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

Photochemical Models

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

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

Dispersion Modeling

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

General Resources About Dispersion Models

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

Dispersion Models

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

Receptor Modeling

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

General Resources About Receptor Modeling

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

Receptor Models

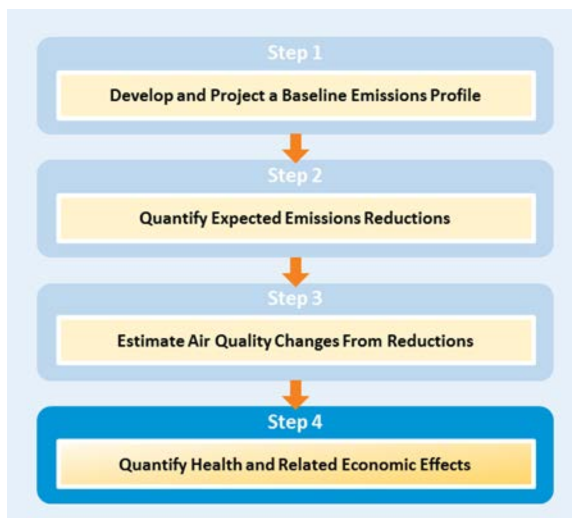
- **EPA's Chemical Mass Balance.** The EPA-CMB Version 8.2 uses source profiles and speciated ambient data to quantify source contributions. Contributions are quantified from chemically distinct source types rather than from individual emitters. Sources with similar chemical and physical properties cannot be distinguished from each other by Chemical Mass Balance. Many of the source profiles, however, are outdated. https://www3.epa.gov/ttn/scram/receptor_cmb.htm

- **EPA's Unmix 6.0 Model.** The EPA Unmix 6.0 model "unmixes" the concentrations of chemical species measured in the ambient air to identify the contributing sources. https://www.epa.gov/air-research/unmix-60-model-environmental-data-analyses

- **Positive Matrix Factorization (PMF).** PMF is a form of factor analysis where the underlying co-variability of many variables (e.g., sample to sample variation in PM species) is described by a smaller set of factors (e.g., PM sources) to which the original variables are related. The structure of PMF permits maximum use of available data and better treatment of missing and below-detection-limit values. https://www.epa.gov/air-research/positive-matrix-factorization-model-environmental-data-analyses

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

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



Health Benefit Factors

- **EPA's Benefit-per-kWh (BPK) Factors***.* EPA is developing a set of factors to estimate the monetized public health benefits per kWh of energy efficiency or renewable energy projects, policies, or programs. EPA expects to release BPK factors for different regions of the country and different project types (wind, solar, and energy efficiency) in August 2018. Analysts will be able to multiply the BPKs by the estimated amount of kWh of electricity produced or reduced by the project or program to estimate the value of health benefits in dollars. https://www.epa.gov/energy/quantifying-health-and-economic-benefits-energy-efficiency-and-renewable-energy-policies

- **EPA's Response Surface Model (RSM)-based Benefit-per-Ton Estimates.** EPA used a reduced-form modeling approach to develop tables reporting the PM-related benefits of reducing directly emitted $PM_{2.5}$ and $PM_{2.5}$ precursors from certain classes of sources to an estimate of the monetized $PM_{2.5}$-related health benefits. Applying these estimates simply involves multiplying the emissions reduction by the relevant benefit per-ton metric. https://www.epa.gov/benmap/response-surface-model-rsm-based-benefit-ton-estimates

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

Tools for Quantifying Health Impacts and Related Economic Values

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

COBRA

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

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

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

COBRA HEALTH OUTPUTS

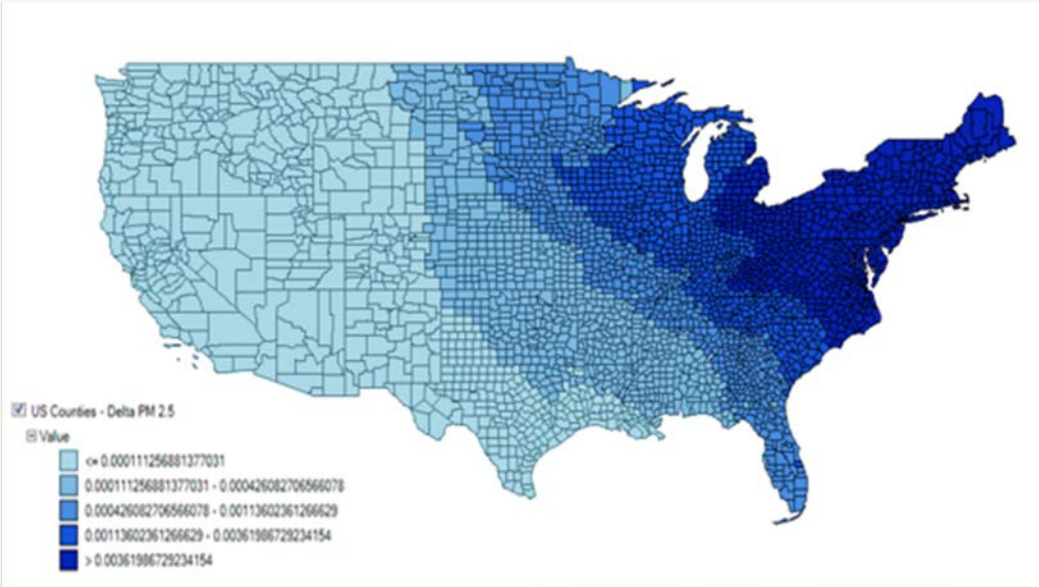
- Mortality
- Chronic and acute bronchitis
- Non-fatal heart attacks
- Respiratory or cardiovascular hospital admissions
- Upper and lower respiratory symptom episodes
- Asthma emergency room visits
- Asthma attacks: Shortness of breath, wheezing, and coughing
- Minor restricted activity days
- Work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

How Does COBRA Work?

- Users select the time period for the analysis. The model contains detailed emissions estimates for 2017 and 2025, developed by EPA.
- Users can create their own scenarios by making changes to the emissions estimates specified by the chosen baseline. Changes in $PM_{2.5}$, SO_2, NO_x, NH_3, and VOC emissions can be specified at the county, state, or national level.
- COBRA incorporates the user-defined emissions changes into a reduced-form air quality model, the S-R Matrix, to estimate the effects of emissions changes on $PM_{2.5}$ concentrations. The user-defined NO_x and SO_2 emissions changes may be generated using tools such as EPA's AVERT.

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

Figure 4-10: Sample COBRA Results



COBRA provides data on emissions reductions, health impacts, and economic impacts resulting from various policy options. This map shows changes in health effects for $PM_{2.5}$ broken out by U.S. region for a hypothetical emissions reduction policy.

Source: EPA, 2015b.

Strengths and Limitations of COBRA

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

BenMAP-CE

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

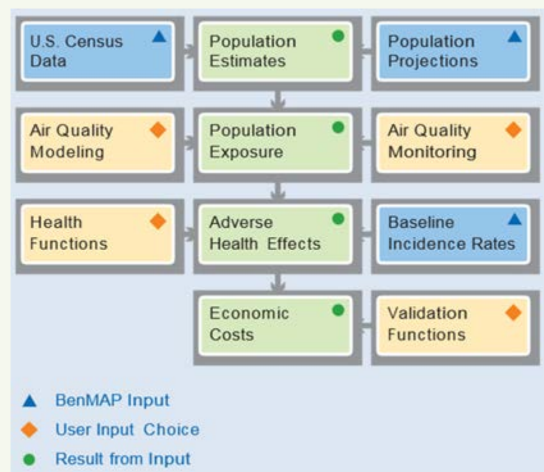
- Estimate the effects on numerous health endpoints associated with changes in ambient ozone and PM concentrations.
- Monetize the value of health effects.
- Visually inspect results with maps of air pollution, population, incidence rates, incidence rate changes, economic valuations, and other types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

The BenMAP-CE tool is an open-source tool used by civil servants, risk assessors, and public health experts throughout the world. The BenMAP-CE tool is designed to be both flexible and transparent. Users can perform an analysis using built-in U.S. and China data, or incorporate their own air quality, health, and economic data. Novice users can apply a simple tool that draws upon data from the Global Burden of Disease study (Brauer et al., 2015) to estimate the benefits of reducing fine particle levels in any country of the world. Users typically run BenMAP-CE to estimate the health impacts of a policy scenario, specifying both baseline and post-policy air quality levels. BenMAP-CE then estimates the changes in population exposure.

How Does BenMAP-CE Work?

- Air quality information for the baseline and scenario runs need to be generated externally, either from monitor-based air quality data, model-based air quality data, or both.[28] BenMAP-CE includes monitoring data for ozone, PM, NO_2, and SO_2 for a number of years.
- BenMAP-CE then calculates the changes in health effect incidence associated with the change in population exposure by using C-R functions derived from the epidemiological literature and pooling methods specified by the user.[29] Ben-MAP-CE uses the estimate of statistical error associated with each C-R function to generate distributions of incidence estimates, as well as a central point estimate. These distributions are helpful for characterizing the uncertainty associated with each component of the health impact assessment.
- BenMAP-CE also calculates the economic value of the avoided or incurred health effects based on valuation methods from published economics literature. The estimated economic value of an avoided health outcome is multiplied by total change in events to determine the monetized health benefits of air quality improvements. As with the C-R functions described above, the valuation functions include estimates of statistical error that BenMAP-CE uses to generate distributions of results (U.S. EPA, 2015a).
- The BenMAP-CE modeling method is illustrated in Figure 4-11.

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



Strengths and Limitations of BenMAP-CE

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

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

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

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

In 2013, the Minnesota Pollution Control Agency (MPCA) used BenMAP-CE to estimate the benefits of an emissions reduction proposal for Minnesota Power's coal-fired power plant Boswell Unit 4. Their plan was designed to achieve mercury (Hg) reductions by the Mercury Emissions Reduction Act, but also led to lower emissions of SO_2 and PM.

MPCA analyzed the expected impact of pollution control technologies, such as scrubbers and filters, on Unit 4. They estimated that, by the 2016 compliance deadline and compared to 2011 levels, the plan would reduce SO_2 by 39 percent, PM by 80 percent, and Hg by 89 percent.

MPCA then quantified the impact of these emissions reductions on pollution concentrations using photochemical air quality modeling. Air quality changes were entered into BenMAP-CE to estimate monetized health benefits of SO_2 and PM, which were valued between $14 and $31 million.

Source: Minnesota Pollution Control Agency, 2013.

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

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

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

- **"Assessing Emission Benefits of Renewable Energy and Energy Efficiency Programs."** This 2015 paper was presented at U.S. EPA's International Emissions Inventory Conference. It presents an approach embodied in EPA's AVoided Emissions and geneRation Tool (AVERT), to assist state and local air quality managers and stakeholders in estimating avoided CO_2, NO_x, and SO_2 emissions from EGUs due to the implementation of energy efficiency and renewable energy policies and resources. https://www3.epa.gov/ttn/chief/conference/ei21/session9/deyoung.pdf
- **"Carbon Reductions and Health Co-benefits from U.S. Residential Energy Efficiency Measures."** This 2016 paper, published in *Environmental Research Letters*, examined the climate, economic, and health benefits of increased residential insulation regarding fossil fuel powered electricity generating units. The analysis used the AVERT model to estimate emissions reductions resulting from reduced electricity demand. http://iopscience.iop.org/article/10.1088/1748-9326/11/3/034017/meta
- **Clark County, NV's Paths Forward Submissions under U.S. EPA's Ozone Advance Program.** The Clark County Department of Air Quality (DAQ) enrolled in the U.S. Environmental Protection Agency (EPA) Ozone Advance program, June 2013. As a part of their annual "path forward" submissions, Clark County (DAQ) uses EPA's AVoided Emissions and geneRation Tool (AVERT) to calculate emissions reductions attributable to renewable energy and energy efficiency programs implemented in Nevada. https://www.epa.gov/advance/program-participants-nevada
- **"The Clean Air Benefits of Wind Energy."** As detailed in this 2014 white paper, wind energy is widely available across the country and is already playing a significant role in reducing carbon emissions in nearly every state, as well as emissions of other air pollutants. This paper provides state-by-state numbers, calculated using EPA's Avoided Emissions and generation Tool (AVERT), for the emissions reductions attributable to the currently installed wind turbine fleet in the United States. http://awea.files.cms-plus.com/FileDownloads/pdfs/AWEA_Clean_Air_Benefits_WhitePaper Final.pdf

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

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

- **"Staff White Paper on Benefit-Cost Analysis in the Reforming Energy Vision Proceeding**." In 2015, the New York Department of Public Service proposed a general framework for evaluating the benefits and costs of alternative utility investments. The paper lists proposed components of a benefit-cost analysis framework and a methodology for valuing benefits and costs, including using COBRA to estimate the health impacts of SO_2 and NO_x emissions. https://www3.dps.ny.gov/W/PSCWeb.nsf/96f0fec0b45a3c6485257688006a701a/c12c0a18f55877e785257e6f005d533e/$FILE/Staff_BCA_Whitepaper_Final.pdf
- **"Controlling Episodic Air Pollution with a Seasonal Gas Tax: The Case of Cache Valley, Utah**." This 2015 paper published in *Environmental & Resource Economics* used longitudinal data to establish a relationship between particulate matter ($PM_{2.5}$) concentrations and vehicle trips. The authors also analyzed the benefits and costs of a seasonal gas tax and found that the social net benefit of the gas tax depended on the type of benefit analysis used. https://link.springer.com/article/10.1007/s10640-015-9968-z
- **"Public Health Impact and Economic Costs of Volkswagen's Lack of Compliance with the United States' Emission Standards."** This 2016 paper, published in the *International Journal of Environmental Resources and Public Health*, used COBRA to quantify the health impacts of extra NO_x emissions from Volkswagen's non-compliant vehicles in the United States. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5036724/
- ***Standardized Regulatory Impact Assessment: Computers, Computer Monitors, and Signage Displays*.** This 2016 report analyzed the economic impacts of California Energy Commission's proposed efficiency standards for computers, computer monitors, and signage displays. The analysis used COBRA to monetize the health benefits from potential emissions reductions from the proposed standard. http://www.dof.ca.gov/Forecasting/Economics/Major_Regulations/Major_Regulations_Table/documents/SRIA_APPEFF_2016_All.pdf
- **"The Climate and Air Quality Benefits of Wind and Solar Power in the United States."** This 2017 article, published in *Nature Energy*, examined the cumulative air quality and climate benefits of solar and wind electricity generation from 2007 to 2015. The analysis considered avoided emissions, avoided damages, comparisons with incentives and market prices, and the impact of cap-and-trade programs. The analysis used COBRA, AP2, and EASIUR to estimate the health benefits of solar and wind generation throughout the United States. https://www.nature.com/articles/nenergy2017134
- ***Benefit-Cost Evaluation of U.S. DOE Investment in HVAC, Water Heating, and Appliance Technologies.*** This 2017 report, commissioned by U.S. DOE, included a rigorous benefit-cost impact evaluation of the one of DOE's long-standing R&D portfolios within the Building Technology Office's Emerging Technologies Program: R&D investments in heating, ventilation, and air conditioning (HVAC), water heating, and appliance technologies. It used EPA's COBRA model to quantify the health benefits associated with the program investments. https://www.energy.gov/sites/prod/files/2017/09/f36/DOE-EERE-BTO-HVAC_Water%20Heating_Appliances%202017%20Impact%20Evaluation%20Final.pdf

- **Virginia Department of Planning and Budget Economic Impact Analysis for 9 VAC 5-140 Regulation for Emissions Trading.** In 2017, the Virginia Department of Environmental Quality used COBRA to estimate the air quality related health co-benefits from SO_2 and NO_x reductions likely to occur under Virginia's proposed CO_2 Budget Trading Program. http://townhall.virginia.gov/L/GetFile.cfm?File=C:%5CTownHall%5Cdocroot%5C1%5C4818%5C8130%5CEIA_DEQ_8130_v2.pdf

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

- **The Health and Environmental Benefits of Wind and Solar Energy in the United States, 2007–2015.** In 2017, the Lawrence Berkeley National Laboratory published a study that evaluated how a subset of wind and solar energy's health and environmental benefits evolved over time. The study considers benefits in absolute terms and on a dollar-benefit-per-kWh basis. The study used EPA's AVERT model to generate estimates of avoided emissions of CO_2, SO_2, NO_x, and $PM_{2.5}$, and it used COBRA (along with other health benefits models, including EASIUR and AP2) to estimate health impacts from emissions reductions. https://emp.lbl.gov/publications/health-and-environmental-benefits
- ***A Retrospective Analysis of the Benefits and Impacts of U.S. Renewable Portfolio Standards.*** This 2016 report, produced by Lawrence Berkeley National Laboratory and the National Renewable Energy Laboratory, analyzes historical benefits and impacts of all state RPS policies, in aggregate. It uses EPA's AVERT models to quantify retrospectively the greenhouse gas and air pollution impacts of state RPS. The analysis uses three different approaches to quantify the health impacts of changes in air pollution, including EPA's COBRA model. http://www.nrel.gov/docs/fy16osti/65005.pdf
- ***Saving Energy, Saving Lives: The Health Impacts of Avoiding Power Plant Pollution with Energy Efficiency.*** This 2018 ACEEE report used AVERT and COBRA to quantify the state and local emissions and health impacts, respectively, of achieving a 15-percent reduction in annual electric consumption evenly across the country in a single year. They used the outputs to rank states and the 50 largest U.S. cities based on where the scenario's energy savings could have the greatest positive impact on the health of people living there. http://aceee.org/sites/default/files/publications/researchreports/h1801.pdf

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PART TWO
CHAPTER 5

Estimating the Economic Benefits of Energy Efficiency and Renewable Energy

DOCUMENT MAP

PART ONE
The Multiple Benefits of Energy Efficiency and Renewable Energy

PART TWO
Quantifying the Benefits: Framework, Methods, and Tools

CHAPTER 1
Quantifying the Benefits: An Overview of the Analytic Framework

CHAPTER 2
Estimating the Direct Electricity Impacts of Energy Efficiency and Renewable Energy

CHAPTER 3
Assessing the Electricity System Benefits of Energy Efficiency and Renewable Energy

CHAPTER 4
Quantifying the Emissions and Health Benefits of Energy Efficiency and Renewable Energy

CHAPTER 5
Estimating the Economic Benefits of Energy Efficiency and Renewable Energy

ABOUT THIS CHAPTER

This chapter provides policy makers and analysts with information about a range of methods they can use to estimate the economic benefits of energy efficiency and renewable energy. It first describes the methods and key considerations for selecting or using the methods. The chapter provides case studies illustrating how the methods have been applied and then lists examples of relevant tools and resources analysts can use.

CHAPTER 5 CONTENTS

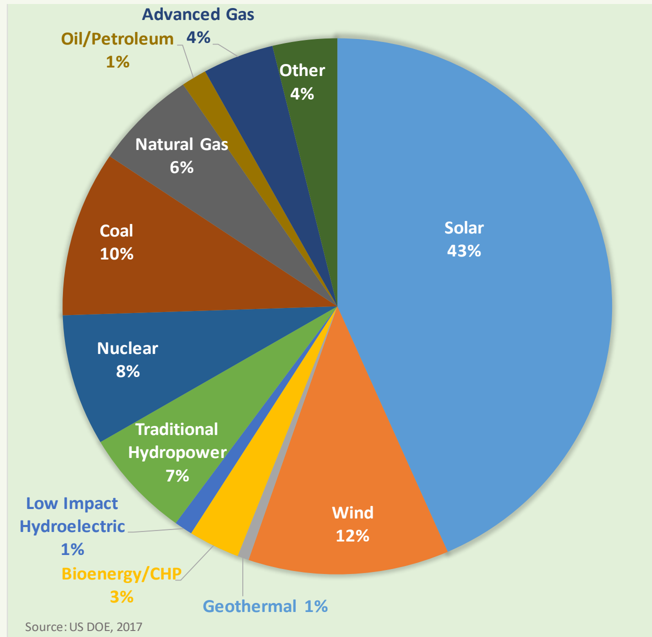
5.1. OVERVIEW

The benefits of cost-effective investments in energy efficiency and/or renewable energy can span the economy by lowering energy costs for consumers and businesses, increasing productivity for businesses, and creating jobs. According to the U.S. Department of Energy (U.S. DOE), the production, installation, and servicing of energy efficiency and renewable energy resources and technologies provide a growing number of economic benefits to and employment for millions of Americans (U.S. DOE, 2017; see Figure 5-1). Many state and local energy efficiency and renewable energy programs and policies are sustaining and enhancing these trends, generating numerous economic benefits along the way.

Quantifying the economic impacts of energy efficiency and renewable energy policies and programs can illustrate how the investments can spread economic value across the broader community. For example, a 2011 analysis of spending $44.4 million in a single future year on efficiency in Vermont results in a net increase of close to 1,900 jobs-years,[1] nearly $100 million in additional personal income, approximately $350 million in output, and $220 million in gross state product over the next 20 years. (For more information, see "Quantifying the Economic Benefits of Energy Efficiency Policies in Vermont" in Case Studies, Section 5.3.4.) Quantifying this type of information can help analysts and decision makers identify opportunities where meeting today's energy or environmental challenges can also serve as an economic development strategy.

This chapter is designed to help analysts and decision makers in states and localities understand the methods, tools, opportunities, and considerations for assessing the economic impacts of energy efficiency and renewable energy policies, programs, and measures. It is intended to help those who request analyses, those who conduct their own analyses, and those who review others' analyses to understand the types of questions to consider when planning, conducting, and/or reviewing an analysis. The range of methods and tools described is not exhaustive and inclusion of a specific tool does not imply EPA endorsement.

Figure 5-1: U.S. Electric Power Generation Employment in 2016, As a Percentage of Total, By Sub-Technology



As shown in Figure 5-1:

- U.S. solar employment in 2016 accounted for more than 350,000 jobs, or 43 percent of the electric power generation workforce—the largest share of workers in the electric power generation sector. This was an increase from 2015 levels by 25 percent.
- U.S. wind employment in 2016 represented just over 100,000 jobs, or 12 percent of the electric power generation workforce, an increase of 32 percent compared to 2015 numbers.

More than 2 million people were employed in the production or installation of energy efficiency products in 2016, a 7 percent increase from 2015 levels. Compared to expected growth rates in the electric power generation and the transmission, distribution, and storage sectors of 7 percent and 6 percent, respectively, solar and wind employment were expected to grow in 2017 by 7 percent and just under 4 percent, respectively, and energy efficiency was expected to grow by 9 percent in 2017 (U.S. DOE, 2017).

[1] *Job-years are not the same as number of jobs. For example, 5 job-years can mean one job that lasts for 5 years or it can mean five jobs that last for 1 year. Additional information about jobs vs. job-years can be found in the box "Alternative Measures of Employment: Jobs vs. Job-Years vs. Wages."*

5.2. APPROACH

Estimating the state- or local-level economic impacts of energy efficiency and renewable energy initiatives involves projecting likely changes in the flow of goods, services, and income, and then estimating the resulting economic benefits measured by key economic indicators, including employment, gross state product, economic growth, and personal income/earnings.[2] Economic impact models are used by many state agencies to measure the effects of energy efficiency and renewable energy policies (Sumi et al., 2003).

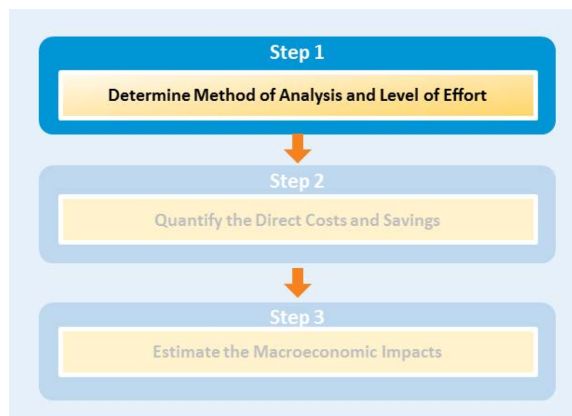
An analyst typically follows several basic steps to analyze the economic impacts of energy efficiency and renewable energy initiatives:

1. Determine the method of analysis and level of effort, including the appropriate level of rigor and the desired level of detail about geographic and industrial sectors.
2. Quantify the direct costs and savings associated with the initiative.
3. Apply the costs and savings using the chosen method to estimate the macroeconomic impacts associated with the initiative.

Each of these steps, depicted in Figure 5-2, is discussed in greater detail below.

Figure 5-2: Steps for Analyzing the Macroeconomic Impacts of Energy Efficiency and Renewable Energy

5.2.1. Step 1: Determine the Method of Analysis and Level of Effort



Several methods are available for quantifying the macroeconomic effects of energy efficiency and renewable energy initiatives. These methods range in complexity from applying basic rules of thumb for screening purposes to using sophisticated tools for dynamic modeling. Analyses may also involve multiple methods or models, such as the combination of an economic model with an energy model.

In selecting the most appropriate method or combination of methods, analysts can consider many factors, including time constraints, cost, data requirements, internal staff expertise, and overall flexibility and applicability. For example, a state or locality looking to quickly compare many policy options to get an approximate sense of their costs and benefits would select a different tool than one chosen by a state or locality interested in determining the sector-specific impacts of a particular policy or strategy. Consequently, it is useful for state policy makers to understand the basic differences between the broad types of available models and methods, their strengths and weakness, and their underlying assumptions. The following section introduces the foundational concepts associated with a range of methods and models that analysts can use to assess the state and local macroeconomic impacts of energy efficiency and

[2] *These indicators are described as benefits for the state and local-level analyses described in this chapter. For analysis of national regulations, some of these economic indicators may be described as either benefits, costs, or distributive impacts (Executive Order 12866, Federal Register Vol. 58, No. 190, 1993).*

renewable energy initiatives. It also describes some key considerations related to reviewing the baseline assumptions in any method chosen.

ALTERNATIVE MEASURES OF EMPLOYMENT: JOBS VS. JOB-YEARS VS. WAGES

Studies present employment estimates in terms of various measures of labor, including jobs, job years, and total wages. It is important to understand what a study is showing in terms of potential job impacts.

Sometimes employment-related results are presented as net jobs, jobs, job-years, or total wage income (or earnings):

- The term *jobs* is the least precise measure of labor: estimates of jobs typically do not distinguish between full-time and part-time employment, or by wages, benefits, or other details.
- If an analysis of an energy efficiency or renewable energy program refers to *net jobs*, it means the study factored in any job losses that may have occurred in non-energy efficiency or renewable energy-related sectors due to the policy (e.g., decrease in demand for coal) and presents the impacts on jobs after those losses have been subtracted from any increase.
- Estimates of *job years* include the time dimension, generally assuming a 40-hour week. For example, a study may predict the creation of 15 job years. Fifteen job years can mean one job that lasts for 15 years or it can mean 15 jobs that last for 1 year.
- Some approaches measure changes in terms of *total wage income* or *earnings*. This measure is more comprehensive, generally reflecting both time and labor market adjustments.

Table 5-1 lists the methods or models analysts can consider for different types of analysis. Table 5-2, later in the chapter, lists in greater detail the strengths and limitations of each method, along with key considerations for appropriate use.

Table 5-1: Types of Methods and Models and Their Typical Uses

States Might Consider This Type of Method or Model	For This Type of Analysis
Rules of thumb factors	High-level screening analysis
Input-output models	Short-term analysis of policies with limited scope and impact
Econometric models	Short- and long-term analysis of policies with economy-wide impact
Computable general equilibrium models	Long-term analysis of policies with economy-wide impact
Hybrid models	Short- and long-term analysis of policies with limited or economy-wide impact

Methods for Estimating Impacts

Rules of Thumb

Generic rules of thumb factors for economic impact analysis are simplified factors that represent relationships between key policy or program characteristics (e.g., financial spending, energy savings) and employment or output. They are typically drawn from other sources or analyses and provide first-order approximations of the direction (i.e., positive or negative) and magnitude of the impacts upon the economy. They require less precise data than those needed for more complex, dynamic models.

Table 5-2 lists a sampling of rules of thumb factors that states or national laboratories have developed, based on analyses of actual projects that can be used to estimate the income, output, and employment impacts of energy efficiency and renewable energy programs. For example, RTI International developed employment and energy savings factors for energy efficiency programs in North Carolina, where annual investments in clean energy increased twentyfold between 2007 and 2013. Through a retrospective analysis, the study was able to develop a high-

KEY CONSIDERATIONS WHEN PLANNING AN ECONOMIC ANALYSIS

- All methods involve predictions, inherent uncertainties, and many assumptions.
- The approach selected should match the question being asked. For example, simple tools should not be used to answer sophisticated, complex questions.
- The models, assumptions, and inputs used in the analysis should be transparent and well documented.
- Expert input on the analytic process and assumptions as well as expert peer review of the final results can enhance the credibility and usefulness of the analysis.

level relationship showing that for every $1 billion of investment in clean energy projects in North Carolina, up to 37,100 jobs (full-time equivalent) were supported and about 11 million Megawatt-hours (MWh) were saved (RTI, 2014). In this example, the analysis started with a large-scale assessment of the program's impacts and then simplified the results into output per billion dollars invested, creating rule of thumb factors that could be used in subsequent screening analyses. Additional information about these factors listed in the table can is available in Section 5.4., "Tools and Resources."

Table 5-2: Sample Rules of Thumb Factors for Estimating Income, Output, and Employment Impacts of Energy Efficiency and Renewable Energy Activities

Rule of Thumb Factor	Geographic Scope	Source
Type of Impact: Output		
$1 of spending on weatherization programs in Arkansas in 2009, generated a total of $2.09	Arkansas	Arkansas Advanced Energy Foundation, 2014. *http://www.arkansasadvancedenergy.com/files/dmfile/TheEconomicImpactofEnergyEfficiencyProgramsinArkansas.FINAL.pdf*
$1 spent on energy efficiency programs in Florida produces $1.9 value added	Florida	Southeast Energy Efficiency Alliance, 2013. *http://www.seealliance.org/wp-content/uploads/SEEA-EPS-EE-Report.pdf*
$1 spent on energy efficiency projects in North Carolina results in $1.67 in output	North Carolina	La Capra Associates, Inc., 2013. *https://www.rti.org/publication/economic-utility-portfolio-and-rate-impact-clean-energy-development-north-carolina-final*
Type of Impact: Employment		
$1 million dollars invested in residential and commercial energy efficiency generates about 11 jobs	National	Anderson et al. 2014. *http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-23402.pdf*
$1 million spent on low-income weatherization yields 8.9 person-years of employment	National	Goldman, C. et al. 2010. *https://emp.lbl.gov/sites/all/files/presentation-lbnl-3163e.pdf*
$1 million saved on energy spending by retrofit building owners creates 6.5 direct jobs	National	Garrett-Peltier, 2011. *http://www.peri.umass.edu/fileadmin/pdf/research_brief/PERI_USGBC_Research_Brief.pdf*
$ 1 million spent on energy efficiency technology manufacturing and installation creates an average of 5.7 direct jobs	National	Garrett-Peltier, 2011. *http://www.peri.umass.edu/media/k2/attachments/PERI_USGBC_Research_Brief.pdf*
$1 million spent on commercial building retrofits generates 8.0 direct jobs	National	Garrett-Peltier, 2011. *http://www.peri.umass.edu/media/k2/attachments/PERI_USGBC_Research_Brief.pdf*
$1.04 billion in direct output from energy efficiency sector spending in Arkansas creates over 11,000 total full-time jobs	Arkansas	Arkansas Advanced Energy Foundation, 2014. *http://www.arkansasadvancedenergy.com/files/dmfile/TheEconomicImpactofEnergyEfficiencyProgramsinArkansas.FINAL.pdf*
$1 billion spent on renewable energy projects creates 37,100 full-time equivalents over a 7-year period	North Carolina	North Carolina Sustainable Energy Association, 2014. *http://www.rti.org/sites/default/files/resources/ncsea_2013_update_final.pdf*
$1 million spent on energy efficiency generates 18.5 jobs	Georgia	Southeast Energy Efficiency Alliance, 2013. *http://www.seealliance.org/wp-content/uploads/SEEA-EnergyPro3-Report.pdf*

When to Use

Rules of thumb factors are most applicable for use as screening-level tools for developing preliminary benefit estimates and for prioritizing potential energy efficiency and renewable energy activities. At the simplest level, rules of thumb provide rough approximations and can be used for quick, low-cost analyses of policies.

Strengths and Limitations

A key strength of rules of thumb factors:

- *Efficiency* and *convenience*, especially when time and resources are limited, or when many options are under consideration and limited resources are available to conduct advanced comparisons. For example, a state considering a lengthy list of energy efficiency or renewable energy options can use rules of thumb to help rank the candidates and create a short list of options that warrant further analysis. Rules of thumb are often derived from actual projects, can be broadly applied, and do not require significant project data or technical understanding.

Limitations of rules of thumb factors:

- *Fixed underlying* assumptions that may not currently apply. It is important to understand the assumptions and limitations inherent in a rule of thumb before using it. For example, rules of thumb may be based on outdated information, such as construction and material costs that have changed since the factor was derived.
- *Overly simplistic.* The simplicity of rule of thumb factors may mask important considerations, such as whether funds are likely to have come from elsewhere in the economy, shifting economic activity away from alternatives and toward energy efficiency and renewable energy activities.

Input-Output Models

Input-output models, also known as multiplier analysis models, can also be used to conduct analyses within a limited budget and timeframe, but provide more rigorous results than those derived from rules of thumb. Analysts can use these models to estimate the short-term economic impacts of their energy efficiency and renewable energy projects.

Input-output models depict relationships and interdependencies among industries in a state, regional, or national economy. At the core of any input-output model is an input-output table, which describes the flow of goods and services from producers to intermediate and final consumers. The input-output table in the most commonly used input-output models in the United States comes from national and regional public data sources such as the Bureau of Economic Analysis' national input-output table and regional economic accounts. Economic impacts in input-output models are driven by changes in demand for goods and services resulting from the policy being analyzed.

WHAT IS AN ECONOMIC MULTIPLIER ("RIPPLE EFFECT")?

A change in spending by governments, businesses, or individuals can have an impact on the overall economy that exceeds the original amount spent. The effect of the change in spending thus multiplies or ripples through the economy. For example, a boost in spending on energy efficient equipment can benefit the equipment manufacturers. Increased revenue for the manufacturers support investments by the manufacturers in equipment and labor to meet rising demand, make more sales, or install more equipment. This raises revenue for upstream equipment suppliers and increases worker earnings, which are then spent in different areas of the economy.

In economic analyses, an economic multiplier, usually expressed as a ratio, captures how much additional economic activity is generated in one industry from an expenditure (or change in demand) in another industry. It includes the initial direct economic impact of the stimulus (such as an increase in sales of energy efficient products above) as well as the indirect or ripple effects (such as expansions in manufacturing, sales, and installation jobs).

In input-output models, multipliers estimate the size of sector-specific indirect effects, as well as the economy-wide totals. Multipliers can be derived separately for employment, income, and economic output.

In Montana, for example, a study found that for each megawatt (MW) of renewable energy capacity added, small photovoltaic projects would add 9.2 jobs and large photovoltaic projects would add 5 jobs. Wind and energy efficiency projects would add 1.5 and 1.2 jobs, respectively, for each additional MW (Comings et al., 2014).

When to Use

Input-output models are most suitable for analyzing detailed sectoral impacts of regional, state, or local policies in the short term.

Strengths and Limitations

Key strengths of input-output models:

- *Ability to reveal high-level impacts*. They can quantify the total economic effects of a change in the demand for a given product or service.
- *Capture relationships and interdependencies*. They use a set of industry relationships that describe changes in employment, output, or income in one industry given a demand change in another industry.

Limitations of input-output models:

- *Static*. The multipliers derived from input-output models only represent a snapshot of the economy at a given point in time (i.e., they are static). Due to their static nature, input-output models generally assume fixed prices and do not account for substitution effects and changes in competitiveness or other demographic factors that occur over the longer run (RAP, 2005).
- *May overestimate employment impacts*. The absence of resource constraints or substitution effects over time means that input-output models tend to overestimate the employment effects of a policy (U.S. EPA, 2010).

Models for Comprehensive Analyses

Development and implementation of energy efficiency and renewable energy initiatives at the state level may require a more comprehensive analysis of the macroeconomic effects of alternative clean energy initiatives over time than what has been described up to this point. Although the approaches above are straightforward, and results can be produced relatively quickly, rules of thumb and input-output models may not provide the analytical rigor needed to evaluate long-term substantial investments in energy efficiency and renewable energy initiatives. Several well-established types of models, including macroeconometric models, computable general equilibrium models, and hybrid models, can be used to quantify more comprehensively the nature and magnitude of the economic effects of energy efficiency and renewable energy investments.

Macroeconometric Models

Macroeconometric models use mathematical and statistical techniques to analyze economic conditions both in the present and in the future. Macroeconometric models find relationships in the macro-economy and use those relationships to forecast how energy efficiency and renewable energy initiatives might affect income, employment, gross state product, and other common output metrics. For example, energy demand may be related to the price of fuel, the number of households, and/or the weather, but not to individual income levels. These models use historical data to project future outcomes.

Macroeconometric models are more complex than input-output models, as they include additional economic relationships beyond industry purchasing relationships. For example, macroeconometric models include representations of consumer and producer behavior, which allow these models to interpret the impact to the economy of changes in energy prices, changes to the production costs of an industry, or changes to household budgets.

Macroeconometric models generally have an aggregate supply component with fixed prices, and an aggregate demand component. Regression coefficients within the models' equations describe how one component of the economic system changes in response to a change in some other component of the economic system. Most macroeconometric models use a combination of coefficients, some of which are estimated from historical data, and others that are coefficients obtained from other sources.

When to Use

Macroeconometric models can be used for both short- and medium-term analyses where there is need for more sectoral and regional detail than can be provided by input-output models or rules of thumb.

Strengths and Limitations

Key strengths of macroeconometric models:

- *Dynamic capabilities*. They can estimate the effects of state or local policy impacts over time.
- *High level of detail and flexibility*. Macroeconometric models are based on an overarching economic theory but can have thousands of equations estimating the relationships between different economic variables using historical data. As a result, the level of detail they can achieve is much higher than that of computable general equilibrium (CGE) models (see below), which are restricted by using model equations derived from economic theory.
- *Data-driven, rather than theoretical, assumptions*. They are not restricted by some of the potentially unrealistic assumptions in many CGE models, such as perfect competition, complete foresight, or rational economic behavior.

A major limitation of macroeconometric models:

- *Heavy reliance on historical data as the pattern for future behavior*. As a result, the projected future behavior may be unrealistic because it neglects changes in consumer and business conduct or investments that may occur when future policies and price changes are anticipated. For example, if a state carbon policy standard were proposed today for implementation in 5 years, one might expect that firms would begin making decisions about investments in energy sources and carbon-efficient technology that would prepare them for when the mandatory provisions take effect. This limitation leads to macroeconometric models being best suited for short and medium-term length analyses.

Computable General Equilibrium and Hybrid Models

CGE models use equations derived from economic theory to trace the flow of goods and services throughout an economy and solve for the levels of supply, demand, and prices across a specified set of markets. CGE models use a framework based on the tenets of microeconomic general equilibrium theory: when the baseline equilibrium is shifted by, for example, an energy efficiency or renewable energy tax incentive, a new market equilibrium is created. This new equilibrium includes prices and output adjustments throughout the economy. In this way, CGE models can be useful for assessing the economy-wide impacts of an energy efficiency or renewable energy policy.

CGE models fall into two broad categories: static and dynamic. Static models lack a time element. They compare two “equilibrium” conditions, one before the policy and one after. The adjustment period could be weeks or, for large policy changes, decades. Dynamic models trace each variable over time (e.g., from policy initiation through each of the 10 subsequent years) and more explicitly capture interactions and complex relationships in the market. Static models are simpler to run but potentially less informative.

CGE models are calibrated using data from a Social Accounting Matrix, which is an extension of an input-output table that includes additional information such as the distribution of income and the structure of production. Unlike input-output models, CGE models are able to account for substitution effects, supply constraints, and price adjustments in the economy snapshot.

Hybrid models typically combine aspects of CGE modeling with those of macroeconometric models, and may be based more heavily on one or the other. They are able to achieve a high level of detail through many econometrically derived equations while retaining the consumer and producer theoretical components of CGE models. As a result, they can be complicated and expensive models to use.

When to Use

CGE models estimate what the economy will resemble in the new "steady state," or equilibrium, once all impacts of a policy or program have been fully realized. CGE models are thus best used for long-term analyses: they may not accurately depict the impacts an economy experiences on its way to the new equilibrium. Particularly when compared with a static CGE model, which only looks at a snapshot in time, macroeconometric models are typically better at capturing interim economic changes that will occur between the policy stimulus and the new equilibrium. Hybrid models are able to combine the best aspects of both CGE and macroeconometric models, and can depict pathways to a new equilibrium.

Strengths and Limitations

Strength of CGE models:

- *The theoretical foundation.* This provides an advantage in estimating the long-term impacts of policies because economic theory has been developed over hundreds of years of research in a variety of conditions.

Limitations of CGE models:

- *Limited availability for* subnational *analysis.* They are more readily available at the national level than at the state level, and most CGE models are highly aggregated. Some state agencies, however, have developed and/or used state-specific CGE models to analyze the impacts of energy efficiency and renewable energy initiatives.[3] State-level CGE models are often developed by universities, private consulting firms, or nonprofit organizations. In California, for example, the University of California at Berkeley developed a dynamic CGE model, the Berkeley Energy and Resources (BEAR) model.
- *Limited energy sector representation*. It is important to examine how the energy sector is treated within any specific CGE model. Although it may allow for substitution effects, it may not include an option for consumers or firms to switch to renewable energy or energy efficiency as a way to meet energy demand. Individual models will handle this differently depending upon the details (e.g., number of sectors) of the model (For more information, see the box "The Importance of Accurate Energy Data and Representation" below).

Hybrid models have the advantage of having the strong theoretical foundations of a CGE model combined with the greater detail of macroeconometric models. In addition, they are able to perform well in both the short and long term. The drawbacks to hybrid models are that they tend to be more of a "black box" (i.e., they do not readily reveal the internal mechanisms that underlie relationships depicted in the model) due to their complexity, and they tend to be the most expensive model type.

[3] *RTI International developed a CGE model (the Applied Dynamic Analysis of the Global Economy [ADAGE] Model) that can be used to explore dynamic effects of many types of energy, environmental, and trade policies, including climate change mitigation policies. For more information on CGE models and their application for macroeconomic impact analysis, see Sue Wing (2004).*

Comparison of Models Commonly Used to Assess Energy Efficiency and Renewable Energy Initiatives

Table 5-3 summarizes key aspects of the most common methods and some sample models that are used for energy-related policy analyses.[4] State or local analysts may find this information useful in determining which model will best suit the needs of their particular analysis.

Table 5-3: Methods and Models for Quantifying Economic Impacts of Energy Efficiency and Renewable Energy Initiatives

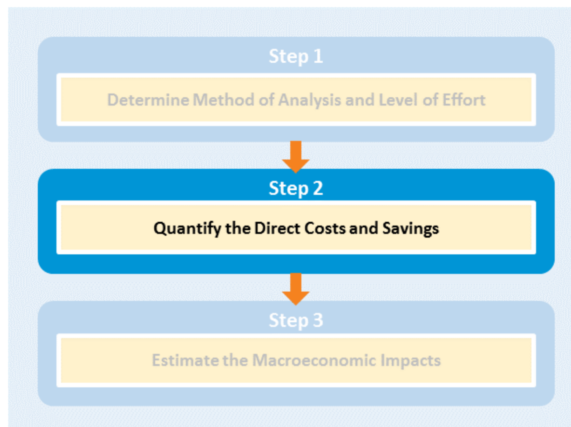
Type of Method	Strengths	Limitations	Typically Used For	Sample Tools or Resources[a]
Rules of Thumb	▪ May be transparent ▪ Require minimal input data, time, technical expertise, and labor ▪ Inexpensive, often free	▪ Overly simplified assumptions ▪ Approximate results ▪ May be inflexible ▪ Assume linearity in effects: e.g., if $1 million creates 10 jobs, then $1 billion will create 10,000 jobs	▪ High-level, screening analyses when time, budget, and technical expertise are limited	▪ Rules of thumb (e.g., impact per kWh, MMBtu or dollars spent as shown in Table 5-2)
Input-Output Models	▪ Can be inexpensive to purchase and to run ▪ Provide rich sectoral detail based on North American Industry Classification System ▪ Can be used to model regional interactions ▪ Can be linked to sophisticated energy models	▪ Assume fixed prices and wages (i.e., they do not account for price and wage changes that may result from increased demand) ▪ Typically do not account for substitution effects, opportunity costs, supply constraints, and changes in competitiveness or demographic factors ▪ Assume linearity in effects (see rules of thumb above)	▪ Short-term analyses ▪ Policies with limited scope and impact	▪ DEEPER ▪ IMPLAN ▪ Job and Economic Development Impact (JEDI) Model ▪ REAL models ▪ RIMS II
Macroeconometric Models	▪ Usually dynamic; can estimate and/or track changes in policy impacts over time ▪ Highly detailed due to the large number of equations that can be statistically estimated ▪ Can account for substitution effects, supply constraints, wage effects and price effects ▪ Can be used to model regional interactions	▪ Historical patterns may not be best indicator or predictor of future relationships ▪ Some do not allow foresight (i.e., the model assumes society does not plan for policies), leading to potentially unrealistic projected impacts	▪ Best used for short- and medium-term analysis; dynamic models with foresight are best for long-term analyses ▪ Generally, most appropriate for policies with economy-wide impact ▪ More comprehensive estimates of cost and benefits than those provided by simpler models	▪ ADAGE ▪ Cambridge Econometrics E3ME ▪ EViews ▪ IHS Markit Global Link ▪ Oxford Economics' Global Economic Model

[4] *Based on the sample of state analyses listed at the end of this report.*

Type of Method	Strengths	Limitations	Typically Used For	Sample Tools or Resources[a]
Computable General Equilibrium (CGE) and Hybrid Models	▪ Account for substitution effects, supply constraints, and price adjustments ▪ Strong theoretical foundations ▪ Can be used to model regional interactions ▪ Hybrid models can achieve high levels of detail	▪ CGE models are not widely available at state level and, when available, often are static or highly aggregated ▪ Energy sector may not allow for fuel substitution (e.g., may not include renewables) ▪ May not be feasible or practical to use when data and resources are limited ▪ Hybrid models can be cost-prohibitive	▪ CGE models best suited for long-term analysis; hybrid models able to perform in short- and medium-term as well ▪ Generally, most appropriate for policies with economy-wide impact	CGE: ▪ ADAGE ▪ BEAR ▪ ENERGY 2020 ▪ ILIAD and LIFT ▪ IPM® ▪ ReEDS ▪ STAMP Hybrid ▪ REMI Policy Insight+

[a] *For more information, see Section 5.4., "Tools and Resources" for Step 1.*

5.2.2. Step 2: Quantify Direct Costs and Savings from the Energy Efficiency or Renewable Energy Initiative



The second step in analyzing state- or local-level macroeconomic effects is to quantify the direct costs and savings from implementing the energy efficiency or renewable energy initiative. These direct costs and savings will serve as the primary inputs to the analysis (in Step 3) to quantify the macroeconomic effects on income, employment, and output. The specific expenditures and savings that analysts need to consider in this step may vary, but they generally include estimates of energy cost savings associated with the initiative, along with data on costs spent by participating entities to administer the program. An important element of this step is to review the baseline assumptions used in the model or method chosen to quantify costs and savings, to ensure they are reasonable for the analysis.

What Are the Direct Costs and Savings?

Part One of this *Guide*, "The Multiple Benefits of Energy Efficiency and Renewable Energy," describes the direct effects of state and local demand-side (e.g., energy efficiency) and supply-side (e.g., renewable energy) initiatives. These costs and savings will serve as inputs to the economic analysis.

Demand-side energy efficiency initiatives lead to direct costs and savings, including:

- *Household and business costs:* Costs for homeowners and businesses to purchase and install more energy-efficient equipment. For policies supported by a surcharge on electric bills, the surcharge is an included cost.
- *Program administrative costs:* Dollars spent operating the efficiency initiative—including labor, materials, and paying incentives to participants.
- *Energy cost savings:* The money saved by businesses, households, and industries resulting from reduced energy costs (including electricity, natural gas, and oil cost savings), reduced repair and maintenance costs, deferred

equipment replacement costs, and increased property values. Energy cost savings are typically reported in total dollars saved.

- *Sector transfers:* Both the increased flow of money to companies that design, manufacture, and install energy-efficient equipment and the reduced flow of dollars to other energy companies, including electric utilities, as demand for electricity and less-efficient capital declines.

The direct costs and savings of renewable energy, combined heat and power (CHP), and distributed generation (DG) initiatives include:

- *Construction costs:* Money spent to purchase the renewable energy, CHP, and DG equipment; installation costs; costs of grid connection; and onsite infrastructure construction costs (such as buildings or roads).
- *Operating costs:* Money spent to operate and maintain the equipment during its operating lifetime and the cost of production surcharges applied to consumers.
- *Program administrative costs:* Money spent operating the initiative—including labor, materials, and paying incentives to participants.
- *Displacement savings:* Money saved by utilities from displacing traditional generation, including reducing purchases (either local or imports) of fossil fuels and lowering operation and maintenance costs from existing generation resources.
- *Waste heat savings:* Savings accrued by utilities or other commercial/industrial businesses that use waste heat from CHP for both heating and cooling.

Additional savings, in the form of avoided costs, can occur under both demand-side and supply-side initiatives and can be used as inputs to an economic analysis. These avoided costs include, but are not limited to:

- *Avoided health-related costs*: Energy efficiency and renewable energy policies that reduce criteria air pollutants can improve air quality and avoid illnesses and deaths, as described in Chapter 4, Quantifying the Emissions and Health Benefits of Energy Efficiency and Renewable Energy. Fewer illnesses mean fewer sick days taken by employees or students, better productivity, and fewer hospitalizations associated with respiratory illnesses and cardiac arrest. These impacts can result in fewer lost wages and lower medical expenditures. Fewer worker deaths can result in continued economic benefits to the state
- *Avoided electricity system-related costs*: Energy efficiency and renewable energy initiatives can result in avoided capacity or transmission and distribution (T&D) costs to the electricity generators and/or distributors, as described in Chapter 3, Assessing the Electricity System Benefits of Energy Efficiency and Renewable Energy. Energy efficiency and renewable energy initiatives that reduce in criteria air pollutants can reduce the costs of complying with air quality standards when compared to more expensive technological options (e.g., scrubbers).

Some studies have monetized other benefits, including avoided environmental damages from CO_2 or economic benefits from avoiding electricity bill arrearages. The box below, "Quantifying the Economic Value of Energy Efficiency to Enhance Cost-effectiveness Assessments," describes one study conducted for the state of Maryland.

QUANTIFYING THE ECONOMIC VALUE OF ENERGY EFFICIENCY TO ENHANCE COST-EFFECTIVENESS ASSESSMENTS

EmPOWER Maryland is a state-wide energy efficiency initiative that was created by the legislature initially to reduce energy consumption by 15 percent by 2015. Participating utilities must evaluate their energy efficiency programs to ensure they are cost-effective. A study by Itron, Inc. (Itron, 2015) developed estimates of selected non-energy impacts (i.e., costs and benefits that are not related just to the utility) that could be included in a cost-effectiveness analysis of the program. The study analyzed four impacts: air emissions, comfort, commercial operations and maintenance (O&M), and utility bill arrearages (i.e., unpaid bills; this measure would be used to assess the cost-effectiveness of EmPOWER Maryland's low-income programs).

Itron assessed the feasibility of incorporating air emissions as an environmental externality into costs. The study calculated dollar damages per kWh, broken down by damages associated with NO_x, SO_2, and CO_2 emissions, for differing levels of emission reductions achieved by EmPOWER programs. It also calculated unit damage costs and hidden costs in the form of human health effects. Itron found that EmPOWER programs saved 1.1 cents per kWh in 2013 (with a range of 0.2 to 2.9 cents depending on the scenario considered) by reducing NO_x, SO_2, and CO_2 emissions.

The study quantified and monetized comfort benefits using a model created for an energy efficiency program in Massachusetts that was comparable to EmPOWER residential programs. It quantified comfort benefits through a survey that asked participants to value the comfort impacts of energy programs relative to bill savings. Applying this simple model, Itron determined that a comfort benefit of $136 should be applied to every participant in the EmPOWER program.

The study inventoried potential sources of O&M benefits, such as occupancy sensors and lamp replacements. Itron calculated labor hours, wage rate, and cost per lighting replacement and occupancy sensor, concluding that if these programs were included into the existing benefit-cost ratios the benefits would increase by up to 13%.

Finally, the study estimated benefits associated with avoiding arrearages. Utilities can reduce arrearages by offering programs that reduce customers' energy bills, making them more affordable for customers (particularly low-income customers). Based on the most recent available data, Itron found that EmPOWER low-income program participants saved an average of $253 annually, which translates (using a 5% discount rate) to a lifetime arrearage financing benefit of $55 per participant or 2% per kWh saved over the life of the energy efficiency measures.

The authors of the study concluded that all four non-energy related areas should be incorporated into cost-effectiveness calculations for the EmPOWER Maryland program, as they identify real costs and benefits associated with operating the program.

In July 2015, the Maryland Public Service Commission found that "the inclusion of these specific NEBs in … (cost-effectiveness) tests … will enhance the parity of cost-effectiveness screening" and ordered that these values be used by utilities for cost-effectiveness testing beginning in the 2015 program cycle (MD PSC, 2015).

Methods for Quantifying Direct Costs and Savings

States can use a wide range of methods to quantify the expected direct costs and savings associated with the efficiency or renewable energy initiative. Using the most straightforward approach, states can adapt and project results from existing initiatives in other states to their own conditions. This approach can be especially useful for estimating program costs. If an initiative has already been implemented, the direct costs and savings can be calculated based on actual expenditure and/or savings data from the program. Including actual expenditures and savings in a model or tool for projecting future direct effects likely will require some data manipulation and application of assumptions, such as mapping the actual costs or savings to defined economic sectors (e.g., by North American Industry Classification System or Standard Industrial Classification) and geographic regions, before entering them into the model.

Because the outputs of Step 2 will be used as inputs for Step 3, the choice of methods and data for quantifying costs and savings will be influenced by the economic analysis method selected in Step 1 and its associated data requirements. If a static model (such as input-output model or a static CGE model) is used, the analyst will calculate an annualized value for the year in which the direct program or policy activity occurred. For dynamic models that analyze direct activity and other changes due to a policy intervention on a year-by-year basis, the input values will be entered as nominal values in the year or years in which they occur.

Tools and methods for quantifying many of these direct costs, savings, and monetized benefits that can be used as inputs to a comprehensive economic analysis are described in the other chapters of this *Guide*:

- *To quantify the potential economic savings* from reductions in electricity demand due to energy efficiency, electricity savings from electricity supply options, such as CHP and DG, and increases in electricity generated from renewable sources, the analyst should translate the direct electricity impacts into dollars that can be input into the model. This monetization can be accomplished by applying projections of prices for different energy types (e.g., oil, gas, electricity) to the profile of expected energy savings. Estimates of expected energy savings need to account for the useful life of products and services, along with assumptions about the persistence of energy savings over time. For more information on persistence and other factors involved in calculating energy savings, see Chapter 2, "Assessing the Potential Electricity Impacts of Energy Efficiency and Renewable Energy Initiatives."

- *To quantify the direct economic savings of electricity system benefits* (e.g., avoided electricity generation, avoided capacity additions, avoided T&D losses), see the methods described in Chapter 3, "Assessing the Electricity System Benefits of Energy Efficiency and Renewable Energy."
- *To quantify emissions and air quality-related health benefits in economic terms*, see the methods described in Chapter 4, Step 4, "Quantifying the Emissions and Health Benefits of Energy Efficiency and Renewable Energy."

Key Considerations for Reviewing Baseline Assumptions

All methods and models include specific underlying assumptions that affect results. Many of these assumptions change over time and it is helpful to explore the baseline assumptions used in the specific rule of thumb or model selected to ensure they are reasonable for the current analysis. Even the most sophisticated model projections, when applied to an unrealistic or unrepresentative baseline, will be misleading.

At a minimum, an analyst can explore the following key assumptions within the method or model:

- *Population*: are the size and distribution across age categories accurate?
- *Economic growth rate:* is the expected rate of growth in line with current projections for the region?
- *Consumer behavior*: do the model's assumptions about how consumers change behavior in response to a change (i.e., elasticities) seem realistic?
- *Rate of technological change*: do the model's assumptions seem in line with reality?
- *Energy prices*: are they current?

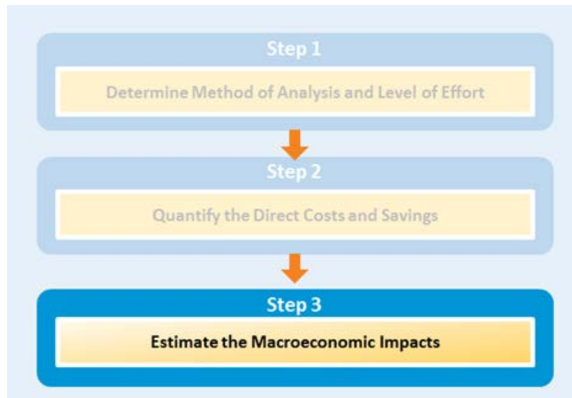
If the assumptions are out-of-date or not aligned with the geographic focus of the current analysis region, analysts can explore their ability to refine or calibrate the baseline to current conditions. If the baseline is not adjustable (e.g., in a rule of thumb factor), however, analysts can assess how the different assumptions might affect the current analysis. For example, a rule of thumb that assumes lower energy prices than are expected in the current analysis may yield more conservative (i.e., lower) estimates about the positive impacts of energy efficiency spending on jobs. By reviewing the underlying assumptions in any method or model, analysts can identify biases or data in need of updating.

The task of reviewing baseline assumptions becomes more complicated as the complexity of the tool increases, as described below.

- *Rules of thumb* estimates are specific to a geography, technology, and time so they are inherently limited. It is important to evaluate whether the factors and key assumptions used to derive the estimate are consistent with the current evaluation. If they are not, it may not be appropriate to apply that rule of thumb. For example, a rule of thumb estimate developed for a solar initiative in California will likely not be applicable to a wind initiative in Massachusetts, where the resource availability and cost may be very different. Applying a rule of thumb approach to an initiative with consistent scope/technology but similar geographies, however, might be sufficient for screening purposes, even if the initiatives were developed in different years.

- *Input-output models* compare the policy or project to a no-initiative base case. These models require calibration of the project scenario but do not allow much customization to the baseline, other than setting the year of impact and the geographic area under consideration. Baseline assumptions are typically tailored to a region, but the analyst should examine them to ensure they are still current. Because the assumptions cannot be customized, some analysts adjust their inputs if they believe the baseline assumptions will produce inaccurate estimates, or they treat the model's estimates as upper bounds (Bess and Ambargis, 2011).
- *More complex models*, such as macroeconometric, CGE, and hybrid models, allow for multiple scenarios of analysis and may require the construction of a base case scenario, or the updating of a default base case. Typically, the baseline scenario characterizes a business-as-usual forecast and may require updating the model's assumptions about energy use patterns, population, and economic growth within the region to ensure they reflect on-the-ground reality. The base case should be developed according to specifications associated with the particular method of analysis chosen.

5.2.3. Step 3: Apply the Method to Estimate Macroeconomic Impacts



Once the direct costs and savings of an energy efficiency or renewable energy initiative have been quantified, the final step is to use the data developed in Step 3 as inputs to the screening tool or model selected in Step 1 to estimate the state- or local-level macroeconomic effects of the initiative. Quantifying the macroeconomic effects provides an aggregate measure of the magnitude and direction (positive or negative) of the initiative's impacts. This full picture of costs and benefits can help decision makers choose among options.

The procedures involved in applying the screening tool or model depend on the method chosen and the type of initiative being analyzed. For example, the direct costs and savings estimates developed in Step 3 could be simply applied to a rule of thumb for screening purposes, or could be used as inputs to run an input-output model. The steps involved in entering inputs and running a more sophisticated model vary by model. For sophisticated analyses, it can also be helpful to test the sensitivity of key assumptions as part of the analysis. Analysts can do this by running alternative scenarios that vary parameters or detail "best case"/"worst case" outcomes (for more information, see the box "Sensitivity Analyses").

When interpreting and sharing the results of these analyses, it is important to consider the analytic method and program being analyzed, to explain the context for the assessment, to be transparent about any assumptions that were made, and to identify any experts who reviewed or contributed to the analysis.

SENSITIVITY ANALYSIS

A sensitivity analysis investigates the ways in which changes in assumptions affect a model's outputs. All models include assumptions that are subject to uncertainty and error, such as assumptions about future energy prices, discount rates, population and demographic characteristics, or the expected lifetime of energy efficiency measures. Sensitivity analyses explore the extent to which the model's outputs are influenced by assumptions about inputs.

Sensitivity analyses begin by selecting the variable or variables to be tested, and then selecting a range of alternative values for those variables. For sensitivity analyses of a single variable, analysts typically test the effect of extremely low and extremely high values on the model's output (e.g., 5^{th} and 95^{th} percentile values). More complex analyses will vary several inputs simultaneously to simulate interrelationships among variables.

While conducting a sensitivity analysis is an important step in economic modeling, there are several key limitations to keep in mind. First, the range of predictions that result from testing extremely low and extremely high values for a selected input may not fully capture the range of uncertainty: they will miss any changes in relationships that may occur at different points along the range. Second, a sensitivity analysis cannot reveal flaws in the model itself (Kann and Weyant, 2000).

Some key questions to consider when describing the methodology and results include:

- What are the specific strengths and limitations of the model or method used?
- How and for how long will costs and savings of the program flow through the economy?
- Are both costs and benefits included? Are any key ones missing?
- Are future costs or benefits discounted? If so, what is the discount rate?
- Does the study account for changes in conditions and technologies over time?
- What are the sources of funds that will be used to pay for the program? Where does the money come from (e.g., electricity surcharges) and go (e.g., rebates)?
- How many people will likely be reached through the program?
- How long will any energy savings likely last?
- Households, businesses, and/or utilities will be spending money on clean energy equipment or services that they are no longer spending on something else. What expenses are they cutting back? Where is it now going instead?
- Are the assumptions (and sources) regarding costs and benefits clear in terms of what the results do and do not include?
- If estimating jobs, are the estimates net or gross? Job-years or jobs? Is it a rough estimate or a reasonably sophisticated one?

USING IMPLAN TO MODEL JOB AND LABOR INCOME IMPACTS OF A BUILDING CODE

The Pacific Northwest National Laboratory (PNNL) undertook an analysis in 2013 to assess the potential impact of a proposed new residential building energy code in the state of Minnesota (PNNL, 2013). The analysis focused on average annual job creation and labor income impacts under two scenarios, comparing estimates of the annual incremental cost associated with building single-family and multifamily housing units in Minnesota that are compliant with the proposed new code, with estimates of costs under the then-current code. The number of housing starts was a key factor in determining the annual direct costs, so the study explored results using both a high and low housing-start scenario.

To estimate short-term job impacts of the incremental costs, the study used the IMPLAN model. IMPLAN provides results for direct and indirect job impacts with a high degree of sector granularity. The results of the IMPLAN analysis demonstrated that adoption of a new building code in Minnesota would generate significant positive annual impacts on employment. Under the high housing start scenario, for example, each year of code-compliant construction in Minnesota would support up to an additional 1,310 short-term jobs and up to an additional $64 million in short-term labor income per year.

The remainder of this chapter provides an overview of the tools and resources for conducting an economic analysis, along with case studies to illustrate how analysts have quantified the macroeconomic effects of energy efficiency and renewable energy policies, programs, and projects.

5.3. CASE STUDIES

The following case studies illustrate how estimating the economic benefits associated with energy efficiency and renewable energy can be used in the state energy planning and policy decision-making process. Information about a range of tools and resources analysts can use to quantify these benefits, including those used in the case studies, is available in Section 5.4., "Tools and Resources."

5.3.1. Energy Efficiency and Renewable Energy Investments in Montana

Benefits Assessed

Economic benefits estimated in this case study include:

- Job-years per million dollars spent

- Jobs-years per average Megawatt (MW)
- Annual jobs per average MW

Energy Efficiency/Renewable Energy Program Description

This study analyzed employment impacts associated with the construction, operation, and maintenance of four resources likely to play a role in Montana's energy efficiency and renewable energy future:

- Large-scale wind
- Large-scale solar photovoltaic (PV)
- Small-scale solar PV (e.g., rooftop)
- Energy efficiency

Methods(s) Used

The 2014 study estimated Montana-specific direct costs for the capital and ongoing operations and maintenance expenses associated with each of the four resources. Publicly available project cost estimates as well as National Renewable Energy Laboratory (NREL) data were used to calculate the wind and solar cost estimates. The study estimated the costs associated with energy efficiency projects based on a review of current programs offered by state utilities and on research of efficiency spending in other states.

The researchers used both the IMPLAN and JEDI input-output models to estimate the direct and indirect jobs associated with project costs by resource type. Specifically, they:

1. Customized IMPLAN's default spending pattern assumptions for each resource using NREL data found in JEDI, because IMPLAN groups all electricity generation into one sector automatically.
2. Ran IMPLAN to assess the in-state indirect impacts using the industry relationships and local purchase coefficients.
3. Translated direct and indirect impacts into construction and installation job-years and operations and maintenance job-years per average MW for each resource and per million dollars spent on each resource.
4. Calculated a cumulative employment impact per average MW generated by resource. They assumed that the operating life of each resource was 20 years and divided the construction jobs by that number and then combined the results with the annual operations and maintenance jobs per average MW.

Results

Assessing the impact in job-years per average MW generated or saved, the study found that more jobs are created during the initial construction and installation stage than during ongoing operations and maintenance across all resources. When assessed on a per average MW generated basis, it concluded that small PV supports the most job-years in either stage, followed by large-scale PV.

When evaluating the jobs impact on the basis of per million dollars spent, the study found that energy efficiency supports the most job-years during the construction and installation phase (see Figure 5-3) whereas PV supports the most job-years during the operations and maintenance phase. Energy efficiency supports nearly the same number of job-years per million spent in either the construction and installation stage or the ongoing operations and maintenance phase whereas solar and wind support more jobs during the operations and maintenance period than they supported during the earlier period. The study also estimated the average annual job impacts by resource and per average MW generated over a 20-year period and found that PV resources, small and large, support more construction, installation, operations, and maintenance jobs than wind or energy efficiency resources (see Figure 5-3 and Figure 5-4). Specific estimates are listed below.

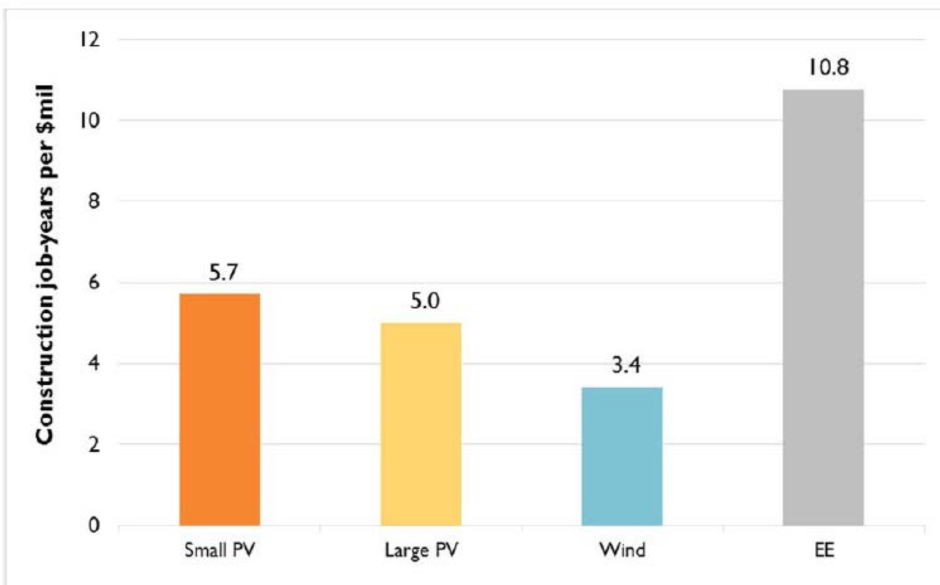
Construction and installation-related job-years

- Job-years per average MW generated (PV, wind) or saved (energy efficiency)
  - Small PV supports an estimated 136 total construction and installation job-years per average MW.
  - Large PV supported 69 job-years per average MW, followed by 19 for energy efficiency and 14 job-years for wind.

Annual operations and maintenance job-years

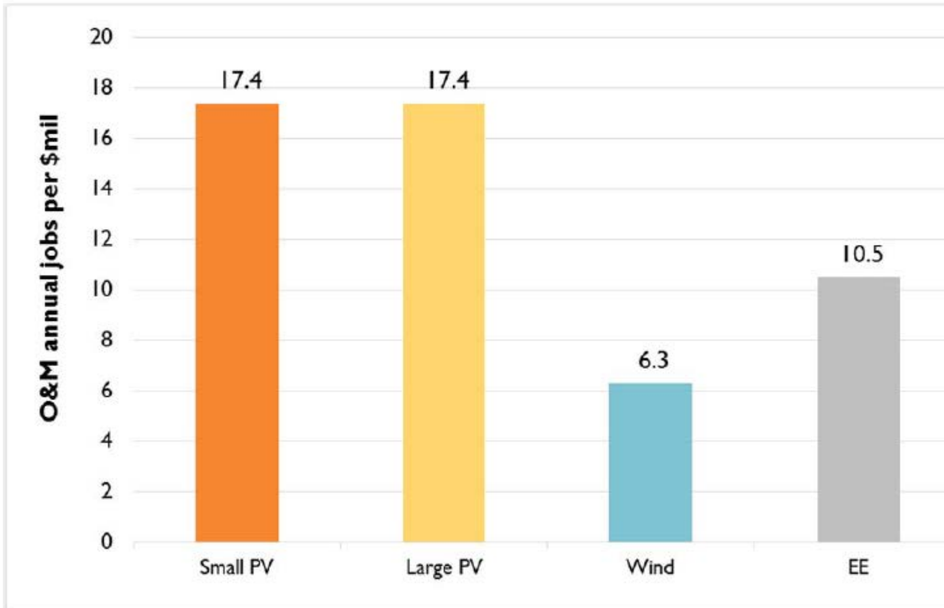
- Job-years per average MW generated (PV, wind) or saved (energy efficiency)
  - Small PV supports the most, 2.4, annual operations and maintenance jobs per average MW generated.
  - Large PV supports 1.5 annual operations and maintenance jobs per average MW generated, followed by wind and with 0.7 and 0.2 jobs annually per average MW generated or saved, respectively.

Figure 5-3: Construction and Installation Job-Years per Million Dollars Spent



Source: Synapse and NREL JEDI Model (industry spending patterns), IMPLAN (industry multipliers).

Figure 5-4: Operations and Maintenance Jobs per Million Dollars Spent



Source: Synapse and NREL JEDI Model (industry spending patterns), IMPLAN (industry multipliers).

For More Information

Resource Name	Resource Description	URL Address
Energy Efficiency and Renewable Energy Investments in Montana Case Study		
Employment Effects of Clean Energy Investment in Montana	This 2014 report from Synapse Energy presents an analysis of the employment impacts associated with the construction, operation, and maintenance of four resources likely to play a role in Montana's clean energy future: large-scale wind, large-scale solar photovoltaic (PV), small-scale solar PV (e.g., rooftop), and EE. It focuses on clean energy resources, and does not evaluate coal or natural gas generation.	http://www.synapse-energy.com/sites/default/files/SynapseReport.2014-06.MEIC_.Montana-Clean-Jobs.14-041.pdf

5.3.2. Southeast Region: The Impact of Energy Efficiency Investments Under DOE's Better Buildings Neighborhood Program

Benefits Assessed

Economic benefits estimated in this case study include:

- Jobs
- Labor income
- Total value added
- Output impacts

Energy Efficiency/Renewable Energy Program Description

The Southeast Energy Efficiency Alliance (SEEA) was one of 41 organizations across the United States that participated in the U.S. DOE Better Buildings Neighborhood Program (BBNP) from 2010 to 2013. BBNP aimed to develop sustainable programs to increase innovation and investment in energy efficiency and create new jobs. Under BBNP, SEEA assembled a consortium of 15 communities in the Southeast and managed 13 energy efficiency programs, primarily in the residential market but targeting multifamily and commercial markets as well.

Over the 3 years and with a $20.2 million budget, the communities in SEEA's consortium conducted 10,200 building audits and completed more than 6,200 energy efficiency building retrofits.

Method(s) Used

In 2014, the IMPLAN I/O model was used for an analysis to assess the economic impacts of SEEA's energy efficiency investments in the Southeast region under the BBNP.

Inputs for the study were based on funding from BBNP, delivered to states in the SEEA region through U.S. DOE Energy Efficiency and Conservation Block Grants and State Energy Programs. SEEA allocated the funds to residential, multifamily, and commercial investments for energy efficiency retrofit projects.

The analysts calculated the following inputs for the study:

1. Program spending, based on SEEA's line-item program budgets
2. Utility avoided fuel and capacity costs, based on utility data collected by SEEA
3. Incentives offered by local utilities and lenders, modeled as positive cash flows to households
4. Customer contributions to project costs, using financial incentive data wherever possible (and assumptions based on program descriptions and rules in cases where data were not available)

The IMPLAN model is driven by final demand, capturing how changes in final demand in one economic sector can affect other industries. Model assumptions derive from 2011 economic data relating local and regional industries to one another.

The IMPLAN model output includes three types of effects:

- *Direct effects:* production changes due to increases in demand
- *Indirect effects:* changes in the demand due to "factor inputs" (primary goods and operations necessary for operations) caused by program activities
- *Induced effects:* changes in the way households or individuals spend their additional funds on goods or services

Results

The analysis produced estimates of the direct, indirect, and induced net effects on jobs, labor income, total value added (i.e., gross state product or gross regional product) and total output as a result of the $20.2 million investment in energy efficiency in the Southeast, as shown in Table 5-4.

Table 5-4: Economic Impact Summary, Southeast Region

Type of Effect	Key Indicator			
	Jobs (#)	Labor Income ($)	Total Value Added ($)	Output ($)
Direct Effect	240	16,256,217	27,584,611	55,689,601
Indirect Effect	106	6,191,403	10,120,715	22,223,316
Induced Effect	3	131,923	265,598	366,471
Total Effect	349	22,579,544	37,970,924	78,279,388

Note: Columns may not add up to totals due to rounding.

Because of the rich sectoral detail available in the IMPLAN model, the analysis explored which sectors would be affected by the energy efficiency investments. Not surprisingly, at the regional level, the study found that the greatest increase in employment would be experienced by the sector classified as “Maintenance and repair construction of residential structures.”

The study further assessed the return on investment to the Southeast region from the BBNP’s energy efficiency investments. It found that every $1 million invested would yield 17.28 jobs, $1.1 million in labor income, $1.9 million in total value added, and $3.9 million in output. It compared these impacts against investing the same amount of money in five other sectors: trade and services, construction, renewable energy, manufacturing, and energy. As shown in Table 5-5 a $1 million investment would have positive economic impacts in all sectors. However, investment in an energy efficiency program, as demonstrated by the Southeast BBNP, had the greatest impact on job creation and overall economic output. Trades and services had the second-highest return on all factors, but yielded only $830,000 in labor income, $1.2 million in total value added, and $1.9 million in output. Construction showed the third highest return on investment, followed by renewable energy, manufacturing, and then energy.

Table 5-5: Summary of Returns on Investment, by Model

Model	Return per Million Dollars Invested			
	Jobs (#)	Labor Income ($)	Total Value Added ($)	Output ($)
BBNP Initiatives	17	1,117,099	1,878,571	3,872,789
Trade and Services	17	827,687	1,199,223	1,934,823
Construction	14	728,869	1,044,395	2,009,925
Renewable Energy	10	550,798	902,409	1,923,806
Manufacturing	9	510,495	790,710	1,921,881
Energy	8	549,817	768,785	2,077,489

The study also ran the model for multiple states, and concluded that not only did BBNP-funded initiatives produce net positive economic outcomes in the SEEA region, but the production of jobs, total value added, and output were similar across states in the region.

Key assumptions and limitations of the analysis:

- Results are static in time, meaning the multipliers represent only a snapshot of the economy at a given point in time.
- IMPLAN assumes fixed prices.
- IMPLAN does not account for opportunity costs, substitution effects, supply constraints, and changes in competitiveness or other demographic factors.

For More Information

Resource Name	Resource Description	URL Address
Southeast Region: The Impact of Energy Efficiency Investments Under U.S. DOE’s Better Buildings Neighborhood Program Case Study		
Better Buildings Neighborhood Program	The BBNP from SEEA aims to help 41 competitively selected state and local governments develop sustainable programs to upgrade the energy efficiency of more than 100,000 buildings nationwide. These communities, including the 13 programs that SEEA managed in the Southeast, used innovation and	http://seealliance.org/resource-center/project-archive/better-buildings/

Resource Name	Resource Description	URL Address
	investment in energy efficiency to expand their building improvement industry, test program delivery business models and create new jobs.	
The Economic Impact of EE Investments in the Southeast	This report provides a detailed description of the methodology used by the Cadmus Group to evaluate the economic performance of SEEA's 16-city, U.S. DOE-funded energy efficiency retrofit consortium from 2010 to 2013. It includes regional and state-level findings that are presented in the form of a total economic impact summary, employment impacts and return on investment, by region and by state. Participant states include Alabama, Florida, Georgia, Louisiana, North Carolina, South Carolina, Tennessee, and Virginia.	http://seealliance.org/wp-content/uploads/SEEA-EPS-EE-Report.pdf
Energy Pro3: Productivity, Progress and Prosperity for the Southeast	This 2013 report from SEEA describes results from the SEEA Southeast Community Consortium formed to implement community-based energy efficiency retrofit programs across the Southeast. The report found that $1 million invested in energy efficiency programs in Tennessee generated $1.3 million in labor income.	http://www.seealliance.org/wp-content/uploads/SEEA-EnergyPro3-Report.pdf
The Impact of Energy Efficiency Investments: Benchmarking Job Creation in the Southeast	This 2014 report from SEEA describes a macroeconomic analysis of the U.S. DOE BBNPs. The analysis found that in Florida, each $1 spent on energy efficiency programs in Florida produced $2.6 value added and $4.1 in output.	http://www.seealliance.org/wp-content/uploads/SEEA_EPS_EE_JOBReport_FINAL.pdf

5.3.3. The Economic Impacts of the Regional Greenhouse Gas Initiative 2015–2017

Benefits Assessed

Economic benefits estimated in this analysis include:

- Net economic impact (i.e., net present value, or NPV) of the Regional Greenhouse Gas Initiative (RGGI)
- Changes in payments to out-of-region power plant providers
- Energy bill savings
- Net employment impact in job-years

Energy Efficiency/Renewable Energy Program Description

RGGI is a market-based CO_2 cap-and-trade program for the power sector that first launched in 2009. As of 2018, nine northeast and mid-Atlantic states participate in RGGI, including Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New York, Rhode Island, and Vermont. Each year, CO_2 allowances are made available through centralized auctions and the revenue is redistributed to the participating states. Since 2009, almost $2.8 billion in revenue has been raised through the auction of allowances, with nearly $1.0 billion raised from 2015–2017. The states disburse the money in a variety of ways, including to support energy efficiency, renewable energy, greenhouse gas emissions reduction measures, direct bill assistance, and education and job training programs. Electric generating units must demonstrate compliance every 3 years.

Methods(s) Used

The 2018 study, by The Analysis Group, used two models to analyze the economic impacts associated with the 3-year compliance period from 2015 to 2017.

First, analysts used the PROMOD electric system model to estimate the impacts on power system operations and outcomes. They simulated two scenarios, one "With RGGI" and the other "Without RGGI." The difference between these two scenarios was used to represent the direct incremental impacts on the power system. The "With RGGI" scenario was derived from the actual system operations from 2015 to 2017. The "Without RGGI" included the "same inputs in terms of fuel prices, power plants available to be dispatched, power plant operational characteristics, NO_x and SO_2 allowance costs, baseline load levels" as the "With RGGI" scenario but it removed the costs and impacts attributable to RGGI (e.g., cost of CO_2 allowances, energy efficiency savings from EE investments, and additions of renewable resources resulting from RGGI investments).

Next, analysts used the IMPLAN input-output model to quantify value added and employment impacts based on changes in the movement of dollars (i.e., spending) throughout the economy. IMPLAN quantified the overall economic impacts of RGGI based on:

- *Direct effects*, including the direct effects on the owners of power plants, on consumer of energy who purchase electricity and fuels, and of the spending of RGGI auction allowance proceeds
- *Indirect effects*, including new demand for goods, services, and jobs from the spending of RGGI proceeds
- *Induced effects*, from increased spending by workers

Results

The Analysis Group concluded that RGGI has provided positive economic gains to the participating states overall, even after accounting for net losses to power plant owners. The overall drop in electric market revenue from a net present value perspective was just under $350 million. These impacts did not affect all power plant owners in the same manner, however. In general, carbon-emitting power plant owners lost revenue while zero-carbon or low-carbon power plant owners gained during this compliance period.

The impacts of spending the RGGI proceeds rippled through the state economies, generating benefits that exceeded the losses to power plant owners.

Estimates of specific benefits between 2015 and 2017 are listed below.

Net economic impact for the region

- $1.4 billion of net positive economic activity
  - Equivalent to $34 in net positive value added per capita

Reduced payments to out-of-region providers of fossil fuels

- Nearly $1.37 billion in NPV

Energy bill savings

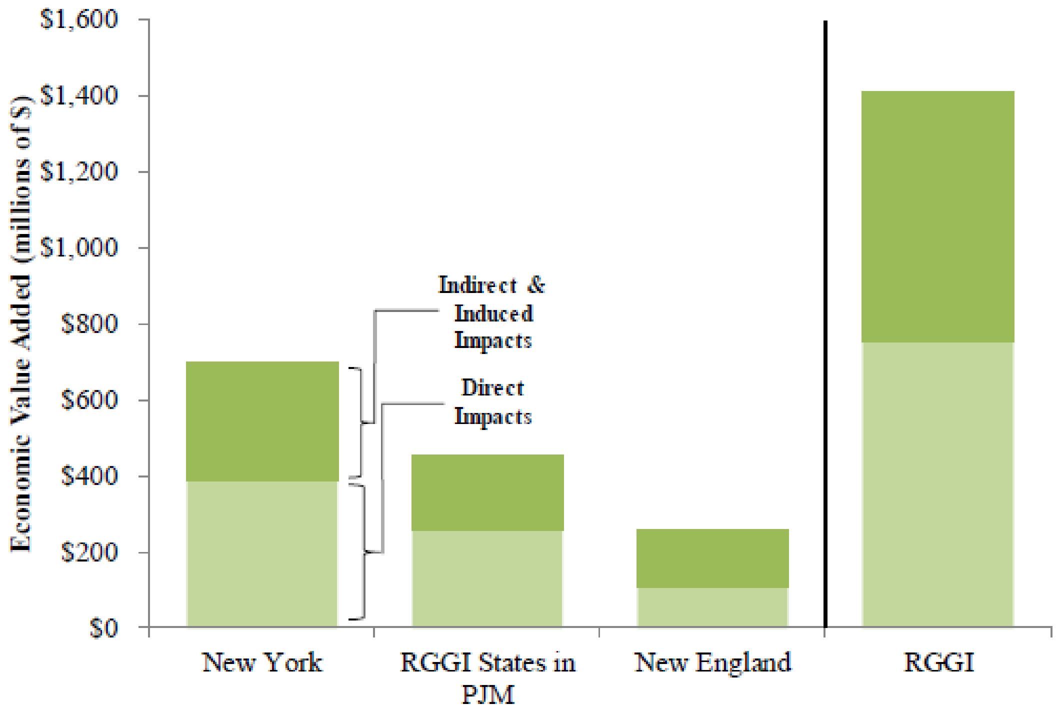
- Electricity consumers saved $99 million
- Natural gas and heating oil customers saved $121 million

Net employment impact in cumulative job-years

- Over 14,5000 new job-years for RGGI states between 2015 and 2017 as a result of RGGI implementation, including:
  - More than 6,000 new job-years for New York
  - More than 3,000 new job-years for the RGGI states in PJM
  - More than 4,000 new job-years for New England

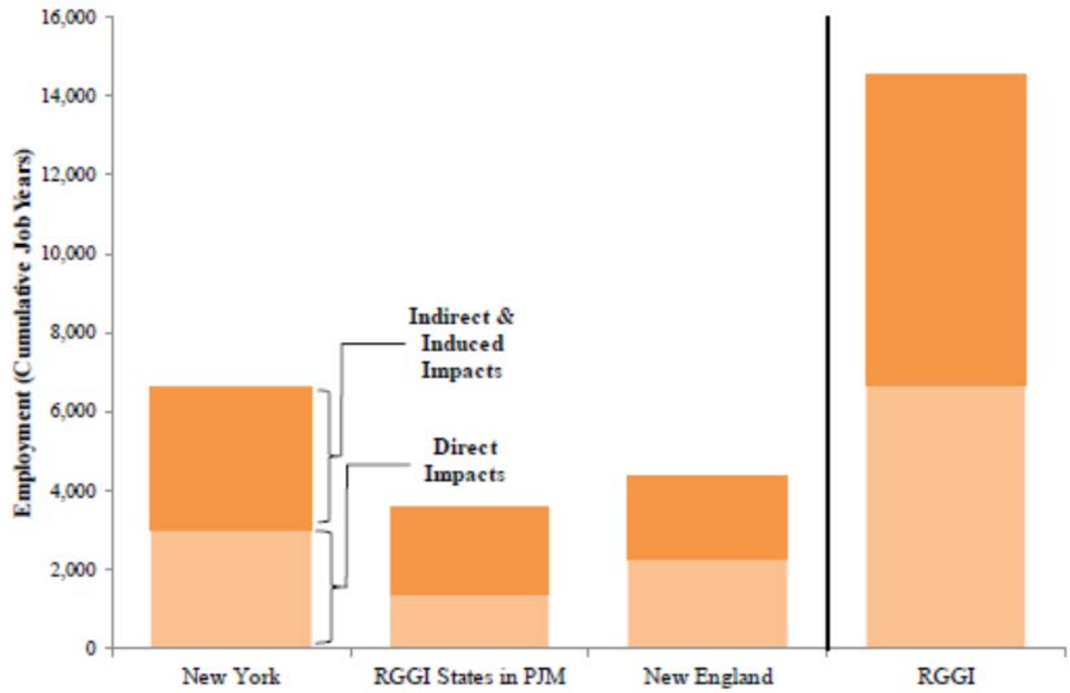
The Analysis Group previously conducted economic impact analyses of the first two compliance periods and compared the results across the studies. Although the numbers cannot be added due to differences in the years analyzed and how NPVs are reported, they show net economic benefits of RGGI over time. The 2015–2017 economic and employment impacts are presented in Figure 5-5 and Figure 5-6. Comparisons to previous compliance period impacts are shown in Table 5-6.

Figure 5-5: Net Economic Impact of the Implementation of RGGI During the 2015–2017 Period (NPV, $2018)



Source: Analysis Group, 2018.

Figure 5-6: Net Employment Impact to RGGI States as a Result of RGGI Implementation During the 2015–2017 Period (Cumulative Job Years)



Source: Analysis Group, 2018.

Table 5-6: Comparing Results of RGGI Economic Impact Analyses Across Compliance Periods

	2011–2013	2014–2016	2015–2017
Net Economic Impact (NPV, 201X$)	$1.6 billion (NPV, 2011$)	$1.3 billion (NPV, 2015$)	$1.4 billion (NPV, 2018$)
Job-Years (as of 201X)	16,000 (as of 2011)	14,200 (as of 2015)	14,500 (as of 2018)

For More Information

Resource Name	Resource Description	URL Address
The Economic Impacts of the Regional Greenhouse Gas Initiative 2015–2017 Case Study		
The Economic Impacts of the Regional Greenhouse Gas Initiative on Nine Northeast and Mid-Atlantic States: Review of RGGI's Third Three-Year Compliance Period (2015–2017)	This 2018 report from The Analysis Group presents an analysis of the economic impacts of the RGGI program between 2015–2017, including the net economic impacts, changes in power plant revenue, changes in payments to out-of-region power providers, energy cost savings, and the net employment impacts.	http://www.analysisgroup.com/uploadedfiles/content/insights/publishing/analysis_group_rggi_report_april_2018.pdf
The Economic Impacts of the Regional Greenhouse Gas Initiative on Nine Northeast and Mid-Atlantic States: Review of RGGI's Second Three-Year Compliance Period (2012–2014)	This 2015 report from The Analysis Group presents an analysis of the economic impacts of the RGGI program between 2012–2014, including the net economic impacts, changes in power plant revenue, changes in payments to out-of-region power providers, energy cost savings, and the net employment impacts.	http://www.analysisgroup.com/uploadedfiles/content/insights/publishing/analysis_group_rggi_report_july_2015.pdf
The Economic Impacts of the Regional Greenhouse Gas Initiative on Ten Northeast and Mid-Atlantic States Review of the Use of RGGI Auction Proceeds from the First Three-Year Compliance Period	This 2011 report from The Analysis Group presents an analysis of the economic impacts of the RGGI program between 2009–2011, including the net economic impacts, changes in power plant revenue, changes in payments to out-of-region power providers, energy cost savings, and the net employment impacts.	http://www.analysisgroup.com/uploadedfiles/content/insights/publishing/economic_impact_rggi_report.pdf
The Regional Greenhouse Gas Initiative website	The RGGI program website includes overview information about the program, materials for participants in RGGI, and current information about the status of RGGI auctions and state rules.	https://rggi.org/

5.3.4. California: Analyzing Economic Impacts of the California's American Recovery and Reinvestment Act Programs

Benefits Assessed

Economic benefits estimated in this case study include:

- Net jobs and job-years
- Personal income
- Gross state product
- Tax and fee revenue

Energy Efficiency/Renewable Energy Program Description

The California Energy Commission (CEC) oversaw a number of energy efficiency programs with $257.6 million in funding the state received from the American Recovery and Reinvestment Act of 2009 (ARRA) between 2010 and 2012. Programs included:

- California Comprehensive Residential Retrofit
- Clean Energy Business Finance Program

- Clean Energy Workforce Training Program
- Energy Conservation Assistance Act-ARRA Program
- Energy Efficiency and Conservation Block Grant Small Cities and Counties Program
- Energy Efficient State Property Revolving Loan Fund Program
- Municipal and Commercial Targeted Measure Retrofit Program

Method(s) Used

A 2014 study examined the employment impacts associated with the spending on these programs from 2010 to 2012 and projected impacts out to 2026. This study used a seven-region Regional Economic Models, Inc. (REMI) Policy Insights Plus model to specifically calculate direct, indirect, and induced employment impacts, income effects, gross state product and gross state revenue for the programs.

For each of the seven California regions defined in the model, the researchers analyzed two distinct cases. A baseline case assumed no program spending, whereas the other case incorporated program expenditures and energy bill changes related to the programs. To assemble the direct model inputs, the researchers relied on CEC's program expenditure data and project-level data for information about regional spending, incentives, and energy savings. The analysis used monitoring and verification data from onsite energy efficiency and renewable energy projects.

The study presented results retrospectively (looking back to 2010) and prospectively (estimating impacts out to 2026). By using the REMI model, the researchers could define results at both the regional level and the program level, enabling a comparison of job impacts across programs to determine which subset of ARRA funding generated the most significant impacts.

Results

According to the study, ARRA-supported investments in energy efficiency programs in California from 2010–2012 have generated or are expected to generate:

- 3,723 full-time or part-time jobs from 2010 to 2012
- 16,946 full-time or part-time jobs from 2010 through 2026 including:
    - Direct jobs from the delivery of the program
    - Indirect jobs through purchases of equipment from suppliers, distributors, and manufacturers
    - Induced jobs that result from consumer spending made possible by energy bill reductions
- $1.27 billion of incremental personal income from additional wages and salaries from 2010 through 2026
- $2.04 billion in gross state product cumulatively over 16 years
- Approximately $243 million in additional revenue from taxes and fees

For More Information

Resource Name	Resource Description	URL Address
California: Analyzing Economic Impacts of the California's American Recovery and Reinvestment Act Programs Case Study		
Employment and Economic Effects from the CEC's American Recovery and Reinvestment Act of 2009 Programs	This 2014 report from DNV Kema Energy & Sustainability investigates the economic and employment effects of the American Recovery and Reinvestment Act of 2009.	http://www.energy.ca.gov/2014publications/CEC-400-2014-016/CEC-400-2014-016.pdf

5.3.5. Quantifying the Economic Benefits of Energy Efficiency Policies in Vermont

Benefits Assessed

Economic benefits in this study include:

- Jobs
- Personal income
- Total output in business sales
- Gross state product

Energy Efficiency/Renewable Energy Program Description

Efficiency Vermont (EVT) was created as the nation's first statewide energy efficiency utility in 1999. It "advances sustainable energy solutions for all Vermonters through education, services, and incentives, and promotes efficiency as a clean, cost-effective, and local fuel source." The utility is funded by an energy efficiency charge that appears on Vermonters' electricity bills and was $0.01/kWh or less in 2016 for residential, industrial, and commercial electricity customers. Funding for EVT also comes from RGGI revenues and EVT's sale of energy efficiency savings to the Forward Capacity Market.

In 2016, EVT reported that its programs had already increased Vermont ratepayers' discretionary incomes, *s*upported 55 contracting businesses in the state, and *s*trengthened the bottom lines of its retail partners. As shown below, savings of approximately $9 million were realized by both households and businesses, with every dollar invested in efficiency producing $2 in savings.

Sources: Optimal Energy and Synapse Energy, 2011; State of Vermont Public Service Board, 2016, 2017.

This 2011 study analyzed the potential state economic and employment impacts from 1 year of planned energy efficiency investments that were to be made by EVT and the Burlington Electric Department (BED) in 2012.

Methods(s) Used

Prepared by Optimal Energy and Synapse Energy for the Vermont Department of Public Service (DPS), the 2011 study examined the economic and employment impacts of proposed program spending to be made in 2012 by EVT and BED over a 20-year period from 2012 to 2031. The 2012 spending figures used in the analysis were sourced from the DPS budget proposal for that year and included both planned investments in electric efficiency and heat and process fuels (HPFs) efficiency.

The study used the Regional Economic Models, Inc. Policy Insights Plus (REMI PI+) model to estimate the direct, indirect, and induced impacts from the energy efficiency programs on employment, personal income, gross state product, and output in terms of business sales in 2012 compared to a scenario with no spending in that year. To assemble the inputs to the model, researchers relied on electricity efficiency measure-level data from the 2011 Demand Resource Planning Project conducted for DPS. Researchers modified the measure assumptions from the Demand Resource Planning Project to match targeted yields for 2012 programs and made adjustments to include the BED (which was not considered in the Demand Resource Planning Project). Researchers also accounted for geotargeting, which lowered the estimated energy savings realized from program spending.

Optimal Energy then used its Portfolio Screening Tool to calculate savings for program participants from electricity efficiency investments, and used 2012 projections from the Vermont Energy Investment Corporation to estimate efficiency savings for HPFs. To calculate benefit to end users, the researchers multiplied annual sector estimates of electricity and non-electricity savings by average retail rates.

They then used data on program and participant spending, net energy savings, and ratepayer effects from the energy efficiency charges on utility bills as inputs to the REMI PI+ model to estimate the economic stimulus from 2012 spending. The model assumed that only a certain portion of demand was met locally, so that only benefits to Vermont were included in the results.

Results

Over the 20-year period between 2012 and 2031, the study found that the total expected impacts of the energy efficiency programs on the Vermont economy include:

- A net increase of nearly 1,900 job-years
- $98 million in additional personal income (in 2011$)
- $351 million in additional output (in 2011$)
- $220 million in gross state product (in 2011$)

The analysis also presented the results in terms of value per program dollar spent based on the planned 2012 program budget of $44.4 million (in 2011 dollars). Researchers found that every $1 million in program spending would create a net gain of 43 job-years, while every $1 of program spending generated a net increase of nearly $5 in cumulative gross state product, an additional $2 in Vermonters' income over 20 years, and more than $6 in gross energy savings.

For More Information

Resource Name	Resource Description	URL Address
Quantifying the Economic Benefits of Energy Efficiency Policies in Vermont Case Study		
Economic Impacts of Energy Efficiency Investments in Vermont – Final Report	This 2011 study from Optimal Energy and Synapse Energy presents an analysis of the employment and economic impacts associated with energy efficiency spending that was considered as part of the Vermont DPS's 2012 budget proposal. This analysis focuses on benefits from electricity efficiency as well as heating and process fuel efficiency spending in the state.	http://publicservice.vermont.gov/sites/dps/files/documents/Energy_Efficiency/EVT_Performance_Eval/Economic%20Impacts%20of%20EE%20Investments_2011.pdf
Efficiency Vermont Annual Report for 2016	This report provides detailed information on Efficiency Vermont's activities in 2016.	https://www.efficiencyvermont.com/Media/Default/docs/plans-reports-highlights/2016/efficiency-vermont-annual-report-2016.pdf

5.3.6. Analyzing the Impacts of the Massachusetts Green Communities Act Using Two Different Models

Benefits Assessed

Economic benefits in this study include:

- Jobs
- Economic value added

Energy Efficiency/Renewable Energy Program Description

Signed into law in 2008, Massachusetts designed the Green Communities Act (GCA) to enable municipalities to overcome barriers to the implementation of energy efficiency and renewable energy programs and projects. The GCA strengthens the Commonwealth's renewable portfolio standard to rely on more renewable energy sources, and aims to expand renewable energy opportunities and promote energy efficiency throughout Massachusetts. Funding to implement the GCA comes from a variety of sources, including ratepayer funds.

A 2014 study quantified the economic impacts of GCA spending and implementation in total, accounting for both economic costs and benefits during its first 6 years of implementation from 2010 to 2015. It also estimated economic impacts of GCA programs and investments through 2025.

Methods(s) Used

To provide a comprehensive and robust perspective of the GCA's impacts in Massachusetts, the 2014 study relied on two modeling methods.

- First, once the researchers estimated how energy efficiency and technology investments spurred by the GCA would result in changes to electricity demand and supply, they used Ventyx's PROMOD model to analyze the impact of these changes on the electricity sector.
- Second, they used IMPLAN to perform a macroeconomic analysis using the dollar values derived from each PROMOD scenario. IMPLAN modeled the impact of GCA-related positive and negative changes in demand on the electricity sector and other industry sectors.

Direct inputs to the models were based on actual data for implemented GCA programs, covering past monitoring and verification activity, consumer energy costs, energy use reductions, generation capacity of new energy sources, revenue and ratepayer information, and fiscal investments in programs.

Each segment of the analysis considered a scenario with activities related to implementation of the GCA, along with an alternative counterfactual scenario modeling the impacts that would occur if the GCA had never been enacted. To compare the "with" and "without" GCA scenarios, factors such as power system infrastructure, fuel prices, emission allowance prices, and peak load forecasts were held constant.

The analysis also recognized sensitivities to key assumptions, including the discount rate and fuel prices. Specifically, it explored impacts of the first 6 years of GCA implementation on value added through 2025 by applying a "public" 3 percent discount rate and a "private" 7 percent discount rate to all dollar flows, converting them into 2013 net present value dollars. It also modified the scenario to assess changes in value added or jobs impacts if natural gas prices were 30 percent higher or lower than in the base scenario. The sensitivity analysis results in a range of values as shown below.

Results

The researchers found that, when fully implemented in 2016, efficiency measures supported by the GCA would achieve the following results annually (relative to the scenario without the GCA):

- Reduce electricity consumption by 3,617 GWh
- Reduce gas consumption by 4.6 MMBtu

As shown in Table 5-7, under the base scenario, researchers estimated that implementation of the GCA would generate 16,395 full-time job-years. It would also add between $0.63 and $1.17 billion (2013 dollars) in total economic value to the state, including between $113 and $155 million in additional state and local tax revenues. Expected job creation and economic value added were higher under the high gas price scenario and lower under the low gas price scenario, indicating that these results were sensitive to natural gas price assumptions.

Table 5-7. Massachusetts Economic Value Added and Jobs Created Resulting From the GCA

Description	3% Discount Rate		7% Discount Rate	
	Value Added[a]	Jobs[b]	Value Added[a]	Jobs[b]
Base Scenario	$1.17 billion	16,395	$0.63 billion	16,395
High Gas Price (+30%)	$1.80 billion	21,651	$1.13 billion	21,651
Low Gas Price (-30%)	$0.60 billion	11,781	$0.18 billion	11,781

Note: Reflects base case and alternative scenarios discounted at private and public discount rates.

[a] Economic Value Added reflects the total economic value added to the economy, which reflects the gross economic output of the area less the cost of the inputs. The reported numbers reflect net present value of economic value added.

[b] Jobs reflect the number of full-time job-years over time, and are not discounted.

Source: Analysis Group, 2014.

For More Information

Resource Name	Resource Description	URL Address
Analyzing the Impacts of the Green Communities Act Using Two Different Models Case Study		
The Impacts of the Green Communities Act on the Massachusetts Economy: A Review of the First Six Years of the Act's Implementation	This 2014 study from Analysis Group assesses the economic and employment impacts from Massachusetts' Green Communities Act from its first 6 years of implementation between 2010 and 2015.	http://www.analysisgroup.com/uploadedfiles/content/insights/publishing/analysis_group_gca_study.pdf

5.3.7. Applying the Steps in a Macroeconomic Analysis: Wisconsin's Focus on Energy Program

Benefits Assessed

Economic benefits in this study include:

- Jobs
- Economic value added
- Personal income
- Sales generated

Energy Efficiency/Renewable Energy Program Description

Wisconsin's Focus on Energy Program advances cost-effective energy efficiency and renewable energy projects in the state through information, training, energy audits, assistance, and financial incentives. Its efforts are designed to help Wisconsin residents and businesses manage rising energy costs, promote in-state economic development, protect the environment, and control the state's growing demand for electricity and natural gas over the short and long term.

A 2015 study set out to quantify the net economic impacts of the Focus on Energy program for five periods, including the 2011, 2012, 2013, and 2014 program years, and for a quadrennial period from 2011 to 2014.

Methods(s) Used

Wisconsin performs periodic analyses of Focus on Energy's economic impacts based on actual and projected outcomes. The analyses attempt to capture how program-specific investments circulate through Wisconsin's economy, and how they continue to affect the economy over time. Focus on Energy has used Regional Economic Models, Inc.'s REMI Policy Insight (REMI PI+) model for its economic analyses since 2003.

For the 2015 study, analysts estimated the economic benefits from the Focus on Energy program for each program year and for the 25-year future period following these years. The study used the REMI PI+ model to estimate the direct, indirect, and induced economic impacts for Wisconsin in terms of employment, industry sales generated, value added, and disposable income. Using data from the Wisconsin Public Services Commission, the analysis team assembled the following inputs for the model:

- Program spending by Focus on Energy, including from administration, implementation, incentives, and participant spending on program goods and services
- Ratepayer payments from the surcharge on energy bills that supports the program

- Participant energy bill savings
- Avoided costs by utilities
- Reduced energy sales to utilities

The study methodology used a regional baseline scenario that models economic activity that would have occurred if the program were not implemented, and compared it with activity that resulted from changes in energy use and demand for products and services introduced by Focus on Energy programs. It also modeled the flow of program-related funds among stakeholders. The analysis team used the standard regional control scenario as the baseline.

Results

The results indicate that the Focus on Energy program provides net benefits to the State of Wisconsin. Specifically, the analysis of program effects for the quadrennial period from 2011 to 2014 estimated that between 2011 and 2038 Focus on Energy is expected to:

- Create more than 19,000 job-years
- Increase value added or gross state product by around $2.8 billion (2015 dollars)
- Increase disposable income for residents by more than $1.4 billion (2015 dollars)
- Generate sales for Wisconsin businesses of more than $5.5 billion (2015 dollars)

Table 5-8: Cumulative Economic Development Impacts in Wisconsin

Economic Development Impact	Program Calendar Year(s)				
	2011	2012	2013	2014	Quadrennial (2011–2014)[a]
Employment (job-years)	4,631	5,911	4,606	4,618	19,291
Economic Benefits (millions of 2015 dollars)	$571	$826	$685	$756	$2,854
Personal Income (millions of 2015 dollars)	$340	$497	$298	$320	$1,435
Sales Generated (2015 dollars)	$1,076	$1,593	$1,346	$1,454	$5,502

[a] *Individual program year values do not sum to quadrennial impacts due to differences between modeling runs.*

Source: Cadmus Group, 2015.

For More Information

Resource Name	Resource Description	URL Address
Applying the Steps in a Macroeconomic Analysis: Wisconsin's Focus on Energy Program Case Study		
Focus on Energy Economic Impacts 2011–2014	This 2015 study from the Cadmus Group analyzes the economic impacts of Wisconsin's Focus on Energy Program for each year from 2011 to 2014, and for a quadrennial period from 2011 to 2014.	https://focusonenergy.com/sites/default/files/WI%20FOE%202011%20to%202014%20Econ%20Impact%20Report.pdf

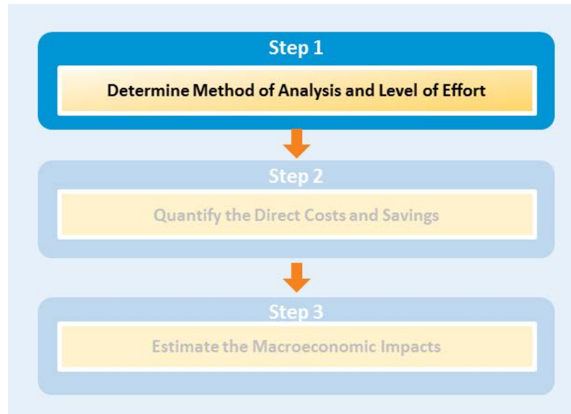
5.4. TOOLS AND RESOURCES

A number of data sources, protocols, general resources, and tools are available for analysts to implement the methods described in this chapter. This section organizes resources by the high-level steps in the analytical process.

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

5.4.1. Tools and Resources for Step 1: Determine the Method of Analysis and Level of Effort

Analysts can use a range of resources to determine the method of economic analysis and level of effort, as described in Step 1 in this chapter.



Resources for Conducting Economic Impact Analyses Using Rules of Thumb

This section lists rules of thumb from a variety of studies, organized by type of impact. Generic rules of thumb for economic impact analysis are simplified factors that represent relationships between key policy or program characteristics and employment or output. Examples listed in this section use rules of thumb that states or national laboratories have developed, based on analyses of actual projects, which can be used to estimate the income, output, and employment impacts of energy efficiency and renewable energy programs.

Type of Impact: Economic Output

- ***The Economic Impact of Minnesota's Weatherization Programs: An Input-Output Analysis***. This 2010 report from the University of Minnesota Extension Center for Community Vitality describes an economic impact analysis in Minnesota. The analysis found that each $1 of spending on weatherization programs in Minnesota in 2009 generated $2.09 in output. http://www.waptac.org/data/files/Website_Docs/Recovery_Act/Success_Stories/MN/eia-mn-wap-success-story.pdf

- ***The Economic, Utility Portfolio, and Rate Impact of Clean Energy Development in North Carolina****.* This 2013 report from La Capra Associates, Inc. describes an economic, utility, and rate impact analysis of clean energy development for the North Carolina Sustainable Energy Association. The analysis found that in North Carolina, each $1 spent on energy efficiency projects results in $1.67 in output. https://www.rti.org/publication/economic-utility-portfolio-and-rate-impact-clean-energy-development-north-carolina-final

- ***The Impact of Energy Efficiency Investments: Benchmarking Job Creation in the Southeast****.* This 2014 report from the Southeast Energy Efficiency Alliance describes a macroeconomic analysis of the U.S. DOE BBNPs. The analysis found that in Florida, each $1 spent on energy efficiency programs in Florida produced $2.6 value added and $4.1 in output. http://www.seealliance.org/wp-content/uploads/SEEA_EPS_EE_JOBReport_FINAL.pdf

Type of Impact: Employment

- ***Assessing National Employment Impacts of Investment in Residential and Commercial Sector Energy Efficiency: Review and Example Analysis*****.** This 2014 report from the U.S. DOE Pacific Northwest National Laboratory focuses on job creation from increased levels of energy efficiency in the buildings sector. The analysis found that nationally, $1 million invested in residential and commercial energy efficiency generates about 11 jobs. https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-23402.pdf

- ***Economic Impact Analysis of Clean Energy Development in North Carolina – 2014 Update*.** This 2014 report from the North Carolina Sustainable Energy Association analyzes direct and secondary effects associated with major energy efficiency initiatives and the construction, operation, and maintenance of renewable energy projects. The analysis found that in North Carolina, $1 billion spent on renewable energy projects creates 37,100 full-time equivalents over a 7-year period. https://www.rti.org/sites/default/files/resources/ncsea_2013_update_final.pdf
- ***The Economic Impact of Energy Efficiency Programs in Arkansas: A Survey of Contractor Activity in 2013*.** This 2014 report from Arkansas Advanced Energy Foundation describes the results of a study of job creation, economic, growth, and other benefits from the energy efficiency resources standard program in Arkansas. The study found that $1.04 billion in direct output from energy efficiency sector spending in Arkansas creates over 11,000 total full-time jobs. https://www.arkansasadvancedenergy.com/files/dmfile/TheEconomicImpactofEnergyEfficiencyProgramsinArkansas.FINAL.pdf
- ***Employment Estimates for Energy Efficiency Retrofits of Commercial Buildings***. This 2011 report from the University of Massachusetts Amherst Political Economy Research Institute presents estimates of spending and employment that could results from a federal program to incentivize energy efficiency in commercial buildings. The analysis found that nationally, $1 million saved on energy spending by retrofit building owners creates 6.5 direct jobs, $1 million spent on energy efficiency technology manufacturing and installation creates an average of 5.7 direct jobs, and $1 million spent on commercial building retrofits generates 8.0 direct jobs. http://www.peri.umass.edu/fileadmin/pdf/research_brief/PERI_USGBC_Research_Brief.pdf
- ***Energy Efficiency Services Sector: Workforce Size, Expectations for Growth, and Training Needs***. This 2010 presentation from Lawrence Berkeley National Laboratory describes a study to determine the requirements for growing the energy efficiency services workforce. The study found that nationally, $1 million spent on low-income weatherization yields 8.9 person-years of employment. https://emp.lbl.gov/sites/all/files/presentation-lbnl-3163e.pdf
- ***The Impact of Energy Efficiency Investments: Benchmarking Job Creation in the Southeast****.* This 2014 report from SEEA describes a macroeconomic analysis of the U.S. DOE BBNPs. The analysis found that in Georgia, $1 million spent on energy efficiency generates 18.5 jobs. http://www.seealliance.org/wp-content/uploads/SEEA_EPS_EE_JOBReport_FINAL.pdf

Type of Impact: Labor Income

- ***Energy Pro3: Productivity, Progress and Prosperity for the Southeast****.* This 2013 report from SEEA describes results from the SEEA Southeast Community Consortium formed to implement community-based energy efficiency retrofit programs across the Southeast. The report found that $1 million invested in energy efficiency programs in Tennessee generated $1.3 million in labor income. http://www.seealliance.org/wp-content/uploads/SEEA-EnergyPro3-Report.pdf

Tools for Conducting Economic Impact Analyses Using Models

Analysts can use a range of software tools to conduct economic impact analyses to estimate the short-term and/or long-term economic impacts of their energy efficiency and renewable energy policies, programs, projects.

Input-Output Models

- **DEEPER.** The Dynamic Energy Efficiency Policy Evaluation Routine (DEEPER), developed by the American Council for an Energy-Efficient Economy (ACEEE), is a 15-sector input-output model of the U.S. economy that draws on social accounting matrices from the Minnesota IMPLAN Group, energy use data from the U.S. Energy Information Administration's Annual Energy Outlook, and employment and labor data from the Bureau of Labor Statistics. It includes a macroeconometric module. http://aceee.org/fact-sheet/deeper-methodology
- **IMPLAN Model**. The IMPLAN model, from the Minnesota IMPLAN Group, Inc., pairs classic input-output analysis with regional social accounting matrices to create economic models using data collected for a defined region. IMPLAN's analytical software uses data to allow users to model custom economic impacts, learn how economies function, and quantify contributions to them. http://www.implan.com/
- **Jobs and Economic Development Impact (JEDI) Model.** This free tool, developed by NREL, is designed to allow users to estimate the economic cost and impacts of constructing and operating power generation assets. It provides plant construction costs, as well as fixed and variable operating costs. http://www.nrel.gov/analysis/jedi/
- **Regional Economics Applications Laboratory (REAL).** The University of Illinois REAL focuses on the development and use of regional econometric input-output models for urban and regional forecasting and economic development. REAL has developed regional models for seven U.S. states and four U.S. metropolitan regions. http://www.real.illinois.edu/products/
- **RIMS II Model***.* The Regional Input-Output Modeling System (RIMS II) is a regional economic model used by investors, planners, and government agencies to assess the potential economic impacts of projects. This model produces multipliers that are used in economic impact studies to estimate the total impact of a project on a region. https://bea.gov/regional/rims/

Macroeconometric Models

- **Cambridge Economics E3ME.** E3ME is a global, macroeconometric model designed to address major economic and economy-environment policy challenges. The model provides a high level of sectoral and geographic disaggregation, covering 59 global regions. It provides social impact outputs, including unemployment levels and distributional effects. https://www.camecon.com/how/e3me-model/
- **EViews Econometric Modeling Software***.* EViews, from IHS Markit, is an econometric modeling software that allows the user to create statistical and forecasting equations. Functionality includes analysis of time series, cross section, and longitudinal data; statistical and econometric modeling; creation of graphs and tables; and budgeting strategic planning, and academic research. https://www.ihs.com/products/eviews-econometric-modeling-analysis-software.html
- **IHS Markit Global Link Model.** The Global Link Model is a global macroeconomic model designed for forecasting and scenario planning. The model provides baseline forecasts updated quarterly and 30-year outlooks that allows the user to assess changes in commodity prices, exchange rates, monetary and financial policy, energy prices, demographics and establishment-level performance. https://ihsmarkit.com/products/global-link-economic-model-and-scenarios.html
- **Oxford Econometrics Global Economic Model**. The Global Economic Model is a globally integrated macroeconomic model covering 80 countries; it links assumptions about trade volume and prices, competitiveness, capital flows, interest and exchange rates, and commodity prices. https://www.oxfordeconomics.com/global-economic-model

Computable General Equilibrium and Hybrid Models

- **Applied Dynamic Analysis of the Global Economy (ADAGE) Model***.* RTI International's ADAGE model is a dynamic CGE model capable of examining many types of economic, energy, environmental, climate change mitigation, and trade policies at the international, national, U.S. regional, and U.S. state levels. To investigate proposed policy effects, the model combines a consistent theoretical structure with economic data covering all interactions among businesses and households. ADAGE has three distinct modules: International, U.S. Regional, and Single Country. Each module relies on different data sources and has a different geographic scope, but all have the same theoretical structure, which allows for detailed regional and state-level results that incorporate international impacts of policies. The model is developed and run by RTI International for EPA. https://www.rti.org/publication/applied-dynamic-analysis-global-economy-rti-adage-model-2013-us-regional-module-final
- **Berkeley Energy and Resources (BEAR) Model***.* The BEAR model is a detailed and dynamic economic simulation model that traces the complex linkage effects across the California economy as they arise from changing policies and external conditions. https://policyinstitute.ucdavis.edu/uc-berkeley-energy-resources-bear-model/
- **ENERGY 2020***.* ENERGY 2020 is a simulation model available from Systematic Solutions that includes all fuel, demand, and supply sectors and simulates energy consumers and suppliers. This model can be used to capture the economic, energy, and environmental impacts of national, regional, or state policies. Energy 2020 models the impacts of an energy efficiency or renewable energy measure on the entire energy system. User inputs include new technologies and economic activities such as tax breaks, rebates, and subsidies. It is available at the national, regional, and state levels. http://www.energy2020.com/
- **ILIAD and LIFT Models***.* Inforum's ILIAD (Interindustry Large-scale Integrated and Dynamic) model is a 360-sector model of the U.S. economy, forecasting all components of final demand and value added, as well as prices and employment. ILIAD also forecasts employment, value added components, and prices. The ILIAD model currently relies on the Inforum LIFT (Long-term Interindustry Forecasting Tool) model for more aggregate drivers. LIFT is a dynamic general equilibrium representation of the U.S. national economy. Users of ILIAD can employ LIFT variables to directly index the growth of the corresponding detailed sectors in ILIAD, or use existing equations to forecast the detailed industries, and then control them to LIFT growth rates or levels. http://www.inforum.umd.edu/services/models/iliad.html
- **Integrated Planning Model (IPM)®.** IPM, developed and supported by ICF, simultaneously models electric power, fuel, and environmental markets associated with electricity production. It is a capacity expansion and system dispatch model. Dispatch is based on seasonal, segmented load duration curves, as defined by the user. IPM also has the capability to model environmental market mechanisms such as emissions caps, trading, and banking. System dispatch and boiler and fuel-specific emission factors determine projected emissions. IPM can be used to model the impacts of energy efficiency and renewable energy resources on the electricity sector in the short and long term. http://www.icf.com/resources/solutions-and-apps/ipm
- **Regional Economic Modeling, Inc. REMI Policy Insight+ Model.** REMI's Policy Insight+ model generates year-by-year estimates of the regional effects of policy initiatives. The model is available in single- and multi-area configurations with calibrated economic, demographic, and policy variables. REMI also offers the E3 model, which can be used to analyze the economic impacts of policies to reduce emissions. http://www.remi.com/
- **Regional Energy Deployment System (ReEDS).** ReEDS, developed by NREL, is a long-term capacity expansion model that determines the potential expansion of electricity generation, storage, and transmission systems throughout the contiguous United States over the next several decades. ReEDS is designed to determine the

cost-optimal mix of generating technologies, including both conventional and renewable energy, under power demand requirements, grid reliability, technology, and policy constraints. Model outputs include generating capacity, generation, storage capacity expansion, transmission capacity expansion, electric sector costs, electricity prices, fuel prices, and carbon dioxide emissions. https://www.nrel.gov/analysis/reeds/

- **State Tax Analysis Modeling Program (STAMP)**. The STAMP model, developed by the Beacon Hill Institute, is a 5-year dynamic CGE model that simulates changes in taxes, costs (general and sector-specific) and other economic inputs to provide a mathematical description of the economic relationships among producers, households, governments and the rest of the world. Models are available for individual U.S. states. http://www.beaconhill.org/STAMP_Web_Brochure/STAMP_EconofSTAMP.html

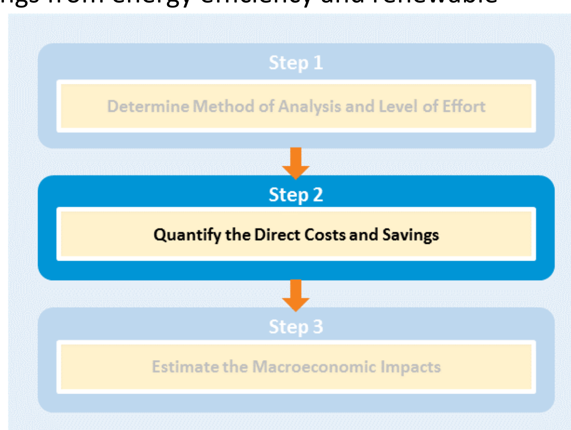
General Resources for Evaluating Baseline Assumptions When Conducting Economic Impact Analyses

Analysts can use a range of available resources to review baseline assumptions as outlined in Step 2 in this chapter.

- **Bureau of Economic Analysis Regional Economic Accounts***.* The Bureau of Economic Analysis provides a number of resources on regional economic accounts, including data and maps of gross domestic product and personal income and employment. http://www.bea.gov/regional/index.htm
- **Census Bureau***.* The Census Bureau mission is to serve as the leading source of quality data about the nation's people and economy. The Census Bureau conducts censuses and surveys and provides populations estimates and projections. http://www.census.gov/
- **EIA's Annual Energy Outlook.** This resource provides long-term electricity and fuel price projections. https://www.eia.gov/outlooks/aeo/
- **EPA's *Guidelines for Preparing Economic Analyses, Chapter 5***. This report chapter describes factors that should be considered in developing baseline analyses and assumptions. https://www.epa.gov/sites/production/files/2017-09/documents/ee-0568-05.pdf

5.4.2. Tools and Resources for Step 2: Quantify Direct Costs and Savings from the Energy Efficiency or Renewable Energy Initiative

Most of the tools and resources for quantifying the direct costs and savings from energy efficiency and renewable energy initiatives are described in other chapters of this *Guide* (as outlined in Section 5.2.2., "Step 2: Quantify Direct Costs and Savings from the Energy Efficiency and Renewable Energy Initiative"). Additional resources that may be useful in this step are described below.

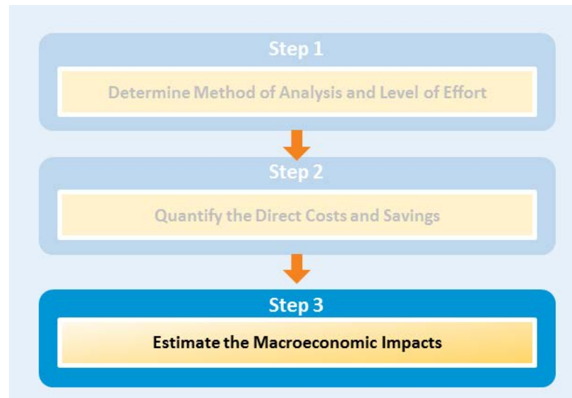


- **The American Council for an Energy-Efficient Economy (ACEEE).** ACEEE focuses on energy policy (federal, state, and local), research (including programs on buildings and equipment, utilities, industry, agriculture, transportation, behavior, economic analysis, and international), and outreach. ACEEE has developed reports, data compilations, and other resources that may be useful in quantifying direct costs and savings from energy efficiency programs. http://www.aceee.org/
- **DOE's Argonne National Laboratory Long-Term Industrial Energy Forecasting (LIEF) Model***.* The LIEF model is designed for convenient study of future industrial energy consumption, taking into account the composition of production, energy prices, and certain kinds of policy initiatives. The model enables direct comparison

econometric approach with conservation supply curves from detailed engineering analysis. It also permits explicit consideration of a variety of policy approaches other than price manipulation. https://www.osti.gov/scitech/biblio/10169987

- **DOE's Lawrence Berkeley National Laboratory DOE-2.2 Model***.* DOE-2 is a building energy analysis program that can predict the energy use and cost for all types of buildings. DOE-2 uses a description of the building layout, constructions, usage, conditioning systems (lighting, HVAC, etc.) and utility rates provided by the user, along with weather data, to perform an hourly simulation of the building and to estimate utility bills. http://www.doe2.com/

5.4.3. Tools and Resources for Step 3: Estimate the Macroeconomic Impacts



In Step 3, the direct costs and savings from Step 2 are entered into the tools and resources described in Step 1 to quantify macroeconomic impacts. Additional resources that may be useful in the analysis are described below.

- ***Alternative Measures of Welfare in Macroeconomic Models*.** This working paper from EIA describes several methods of calculating impacts, costs, and benefits of policies. https://www.eia.gov/workingpapers/pdf/welfare-vipin-wappendix.pdf
- ***An Evaluation of Macroeconomic Models for Use at EIA***. This working paper reviews macroeconomic models used by EIA to create forecasts and to evaluate the impact of different government policies. https://www.eia.gov/workingpapers/pdf/macro_models-vipin-wappendix.pdf
- ***EPA's Guidelines for Economic Analysis****.* EPA's Guidelines for Preparing Economic Analyses establish a sound scientific framework for performing economic analyses of environmental regulations and policies. They incorporate recent advances in theoretical and applied work in the field of environmental economics. The Guidelines provide guidance on analyzing the benefits, costs, and economic impacts of regulations and policies, including assessing the distribution of costs and benefits among various segments of the population. https://www.epa.gov/environmental-economics/guidelines-preparing-economic-analyses

5.4.4. Examples of State-Level Economic Analyses Performed with Commonly Used Tools

Examples of state energy efficiency and renewable energy analyses are provided below, organized by type of tool. The examples below employed some of the most commonly used tools to conduct this type of analysis.

Input-Output Models

State-Level Energy Efficiency and Renewable Energy Analyses That Used ACEEE's DEEPER Model

Note that DEEPER is an input-output model that includes a macroeconometric module, so the examples below could be considered examples of input-output and macroeconometric analyses.

- ***Advancing Energy Efficiency in Arkansas: Opportunities for a Clean Energy Economy*.** This 2011 report from ACEEE examines the potential electricity, natural gas, and fuel savings that could be realized in Arkansas through the implementation of a suite of 11 energy efficiency and nine transportation policies and quantifies the growth in gross state product and employment that would result from these investments. http://aceee.org/research-report/e104

State-Level Energy Efficiency and Renewable Energy Analyses That Used IMPLAN

- ***Economic Analysis of Nevada's Renewable Energy and Transmission Development Scenarios*.** This 2012 report from Synapse Energy Economics, Inc. explores topics surrounding the development of new generation and transmission within Nevada, and between Nevada and neighboring areas; derives the levelized costs of transmission additions using appropriate economic assumptions for the cost of capital, the annual revenue requirement and the expected energy generation and utilization of the lines from the generation projects; and provides the estimates for the costs of delivered energy. http://energy.nv.gov/uploadedFiles/energynvgov/content/Synapse%20Nevada%20RE%20Report%20w%20Disclaimer%20and%20Comments%20112812.pdf

- ***Economic Impact Analysis of Clean Energy Development in North Carolina – 2014 Update*.** This 2014 report from the North Carolina Sustainable Energy Association analyzes direct and secondary effects associated with major energy efficiency initiatives and the construction, operation, and maintenance of renewable energy projects. The analysis found that in North Carolina, $1 billion spent on renewable energy projects creates 37,100 full-time equivalents over a 7-year period. https://www.rti.org/sites/default/files/resources/ncsea_2013_update_final.pdf

- ***The Economic Impact of the Renewable Energy Production Tax Credit in New Mexico.*** This 2017 report from O'Donnell Economics & Strategy used IMPLAN to estimate the economic impact of New Mexico's Renewable Energy Production Tax Credit from 2013 through 2016. http://familybusinessesforaffordableenergy.org/wp-content/uploads/2017/03/EconImpactStudy-022817-1.pdf

- ***The Impact of Energy Efficiency Investments: Benchmarking Job Creation in the Southeast.*** This 2014 report from SEEA describes a macroeconomic analysis of the U.S. DOE BBNPs. The analysis found that in Florida, each $1 spent on energy efficiency programs in Florida produced $2.6 value added and $4.1 in output. http://www.seealliance.org/wp-content/uploads/SEEA_EPS_EE_JOBReport_FINAL.pdf

- ***Potential Job Creation in Minnesota as a Result of Adopting New Residential Building Energy Codes*.** This 2013 report from the U.S. DOE Pacific Northwest National Laboratory describes whether jobs would be created in Minnesota based on their adoption of model building energy codes. http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-21538.pdf

- ***Projected Job and Investment Impacts of Policy Requiring 25 Percent Renewable Energy by 2025 in Michigan*.** This 2012 report from Michigan State University assesses the investment and job impacts that would be the result of increasing Michigan's renewable energy generation to 25 percent of total electricity by 2025. https://www.canr.msu.edu/cea/uploads/files/25by25Report_Final_081012.pdf

State-Level Energy Efficiency and Renewable Energy Analyses That Used JEDI

- ***An Assessment of the Economic, Revenue, and Societal Impacts of Colorado's Solar Industry*.** This 2013 report from the Solar Foundation describes a comprehensive economic analysis of the jobs, economic, and environmental impacts of the Colorado solar industry. This report identifies a number of benefits resulting from solar photovoltaic (PV) development in Colorado and includes projections of future magnitude and value of these benefits under a scenario in which Colorado realizes the goal of the Colorado Solar Energy Industries Association's "Million Solar Roofs" campaign: 3 gigawatts (GW) of total solar capacity by 2030. http://solarcommunities.org/wp-content/uploads/2013/10/TSF_COSEIA-Econ-Impact-Report_FINAL-VERSION.pdf

- ***A Clean Energy Economy for Indiana: Analysis of the Rural Economic Development Potential of Renewable Resources.*** This 2010 report from the National Resource Defense Council examines the potential of Indiana's renewable resources and finds unprecedented opportunity for long-term economic growth in rural communities as well as new income sources for farmers from an array of emerging clean energy technologies, particularly wind, biofuels, biopower, and biogas. https://www.nrdc.org/sites/default/files/cleanenergyindiana.pdf

- ***Economic Development Opportunities for Arizona in National Clean Energy and Climate Change Legislation.*** This 2010 report from the Landsward Institute at Northern Arizona University analyzes the potential economic impacts on Arizona of a United States clean energy and climate change mitigation policy similar to that contained in several proposed pieces of legislation in the United States Congress. http://www.landsward.nau.edu/energy_climate_change_legislation_page.html
- ***Economic Impact Potential of Solar Photovoltaics in Illinois.*** This 2013 report from the Center for Renewable Energy at Illinois State University examines the jobs and total economic impact of technical potentials and examines the existing and potential PV supply chain in the State of Illinois. http://renewableenergy.illinoisstate.edu/downloads/publications/FINAL%20Solar%20Economic%20Impact%20Report%20Dec%202013.pdf
- ***Potential Economic Impacts from Offshore Wind in the Southeast Region.*** This 2013 report from the U.S. DOE focuses on the employment opportunities and other potential regional economic impacts from offshore wind developed in four regions of the United States. The studies use multiple scenarios with various local job and domestic manufacturing content assumptions. Each regional study uses the new offshore wind Jobs and Economic Development Impacts (JEDI) model, developed by the National Renewable Energy Laboratory. https://www.nrel.gov/docs/fy13osti/57565.pdf

CGE Models

State-Level Energy Efficiency and Renewable Energy Analyses That Used STAMP

- ***The Cost and Economic Impact of Delaware's Renewable Portfolio Standard.*** This 2011 report from the American Tradition Institute estimates the economic effects of the Delaware Renewable Portfolio Standard mandate. The study estimates the cost of the Delaware state renewable portfolio standard (RPS) accounting for different cost and capacity factor estimates for electricity-generating technologies from the academic literature. http://www.caesarrodney.org/pdfs/RPS_Delaware.pdf
- ***The Economic Impact of Arizona's Renewable Energy Standard and Tariff.*** This 2013 report from the Beacon Hill Institute at Suffolk University estimates the economic impacts of the Arizona Renewable Energy Standard and Tariff (REST) rule. This study bases estimates on EIA projections and also provide three estimates of the cost of Arizona's REST mandates using different cost and capacity factor estimates for electricity-generating technologies from the academic literature. http://www.beaconhill.org/BHIStudies/AZ-REST/AZ-BHI-REST-2013-0403FINAL.pdf
- ***The Economic Impact of the Kansas Renewable Portfolio Standard.*** This 2012 report from the Beacon Hill Institute at Suffolk University estimates the economic impacts of the Kansas RPS mandates. Specifically, the study provides three estimates of the cost of Kansas' RPS mandates using different cost and capacity factor estimates for electricity-generating technologies. http://www.protecttheflinthills.org/information/the_economic_impact_of_the_kansas_rps[1].pdf

State-Level Energy Efficiency and Renewable Energy Analyses That Used REMI

- ***The Economic Impacts and Macroeconomic Benefits of Energy Efficiency Programs in Oregon***. This 2016 report, sponsored by member companies of the Northwest Energy Efficiency Council and written by ECONorthwest, describes and updates a 2014 analysis about the economic effects of energy conservation in Oregon using IMPLAN to estimate short-run impacts and REMI for projections to 2021. https://www.neec.net/wp-content/uploads/2017/10/neec-econ-oregon-update-aug2016.pdf

- ***The Economic Impacts of Energy Efficiency in the Midwest.*** This 2016 analysis, conducted by Cadmus, uses the REMI model to estimate the economic effects expected to occur between 2014 and 2038 due to Midwestern energy efficiency investments made in 2014. http://www.neo.ne.gov/neq_online/mar2017/Midwest-Report-FINAL.pdf

- ***Employment and Economic Effects from the CEC's American Recovery and Reinvestment Act of 2009 Programs****.* This 2014 report from DNV Kema Energy & Sustainability investigates the economic and employment effects of the American Recovery and Reinvestment Act of 2009. http://www.energy.ca.gov/2014publications/CEC-400-2014-016/CEC-400-2014-016.pdf

- ***Focus on Energy Economic Impacts 2011–2014****.* This 2015 report from the Cadmus Group summarizes the statewide economic development impacts of Focus on Energy's 2011–2014 energy efficiency and renewable energy programs. Cadmus analyzed these economic impacts using Regional Economic Models, Inc.'s Policy Insight+ model (REMI PI+), an economic forecasting tool that models the annual and long-term effects of different spending choices on multiple components of the state economy. https://focusonenergy.com/sites/default/files/WI%20FOE%202011%20to%202014%20Econ%20Impact%20Report.pdf

- ***New York Solar Study: An Analysis of the Benefits and Costs of Increasing Generation from Photovoltaic Devices in New York****.* This 2012 report from the New York State Energy Research and Development Authority describes the results of a study regarding policy options that could be used to achieve goals of 2,500 MW of installed capacity operating by 2020 and 5,000 MW operating by 2025. https://www.nyserda.ny.gov/About/Publications/Solar-Study

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