engineers, and product manufacturers, distributors, and retailers can also provide information on the influences and motivations that determine the role of energy efficiency programs in the decision-making process. Particularly when working with professionals involved in the efficiency measure installation, individuals familiar with the program and projects should conduct the interviews, as long as they can eliminate or at least minimize any bias they may have.

- **Project analysis.** This can consist of two general types of reviews. The first is an analysis of the barriers to project installation and how the project addresses these barriers. The most common barrier is financial (project costs), so the common analysis is calculation of a project's simple payback. For example, if without any program-provided benefits the project a participant installed has a very short payback period, then the project may be considered as more likely to have been installed with or without the program.[2] The other type of analysis is a review of any documentation the participant may have of the decision to proceed with the project. Such documentation, for example internal memos or feasibility studies, can indicate the basis of the decision to proceed.

- **Non-specific market data collection.** Through the review of other information resources prepared for similar programs, the range of appropriate NTGRs can be estimated. Such resources might include analyses of market sales and shipping patterns, studies of decisions by participants and non-participants in other similar programs, and market assessment, potential, and/or effects studies. Market sales–based methods rely on aggregate data on total sales of a particular technology in a given jurisdiction, comparing this sales volume with a baseline estimate of the volume that would have been sold in the absence of the program. The accuracy of these methods depends on the completeness and accuracy of the sales data, as well as the validity of the baseline estimate.

All or some of these three types of data sources can be combined with the written or Web-based participant and non-participant self-surveys to triangulate on an estimate of the free ridership, spillover, and rebound rates for that program.

Net-to-Gross Ratio Calculation Using Equipment Sales Data

In 1992 Baltimore Gas and Electric (BGE) offered a number of conservation programs, including a residential HVAC program. This program was designed to give consumers who were in the market to replace their HVAC systems incentives to choose a more energy-efficient heat pump or central air conditioner. BGE conducted an impact evaluation including a net-to-gross analysis designed to quantify the portion of energy-efficient HVAC purchased that could be attributed to BGE's program. Several sources of data were used:

- A survey of participants in BGE's residential HVAC program.
- Two surveys of customers who did not participate in BGE's residential HVAC programs.
- A survey of HVAC contractors who reported their sales of HVAC equipment by SEER (seasonal energy efficiency ratio).
- Data from the Air Conditioning and Refrigeration Institute providing SEER levels for central air conditioners and heat pumps on an annual basis from 1981 through 1991.

These data provide a range of NTGRs from 0.74 to 0.92. An integrated approach provided what BGE considered the most reliable estimate:

Net-to-gross ratio =

Net increase in purchases of qualifying equipment due to the program divided by the number of units sold under the program in 1992

$$= (28{,}300 - 18{,}700) \div 10{,}400$$
$$= 0.92$$

Thus, BGE concluded that an initial NTGR of 0.90 was appropriate.

Case study provided by Baltimore Gas and Electric.

Ameren Ex 7.2

5.3.3 Econometric Models

Econometric models, in this context, are mathematical tools that apply quantitative or statistical methods to the analysis of NTGRs. Econometric methods are sometimes considered the most accurate approach to calculating NTGR when there are enough participants and truly comparable non-participants and when the program is large enough to justify the cost of such analyses. The econometric models are closely related to, and can be the same models as, those described in Section 4.3 for calculating gross energy savings.

Various econometric methods have been used, with varying advantages and disadvantages. The models use energy (and demand) data from participants and non-participants over the same period to estimate the difference between gross savings (participant savings) and simple net savings (participant savings minus non-participant savings). The models differ in their mathematical and statistical calculation methods, but also in how they address complicating factors of bias that differentiate true NTGRs from simple comparisons of participant and non-participant savings. One particular element of surveying that the econometric models attempt to address is self-selection bias.

5.3.4 Stipulated Net-to-Gross Ratio

This fourth approach, although not a calculation approach, is often used. NTGRs are stipulated in some jurisdictions when the expense of conducting NTGR analyses and the uncertainty of the potential results are considered significant barriers. In such a situation, a regulatory body sets the value, which are typically in the 80 to 95 percent range. Sources of stipulated NTGRs should be similar evaluations of other programs or, for example, what a public utility commissions mandates. Stipulated NTGRs should be updated periodically based on evaluations and review of other programs' calculated NTGRs.

5.4 Selecting a Net Savings Evaluation Approach

As mentioned in Chapter 4, selection of an evaluation approach is tied to the objectives of the program being evaluated, the scale of the program, the evaluation budget and resources, and specific aspects of the measures and participants in the program. Again, one criterion that works across all of the approaches is evaluator experience and expertise.

Another criterion—probably the most important—is cost. All four approaches can be used with any type of efficiency program, with the possible exception that the econometric modeling requires a program with a large number of participants. The lowest-budget approach is stipulated NTGR, followed by self-reporting surveys and enhanced surveys, and then the most expensive approach of econometric modeling (which incorporates the surveying activities). One way to keep costs down while using the more sophisticated approaches is to conduct an NTGR analysis every few years and stipulate NTGRs for the intervening years.

5.5 Notes

1. Provided courtesy of Quantec, LLC.
2. Note that the need to decide when a consumer would have installed an energy project, based on the economic payback associated with a project, is an example of the subjective nature of free ridership. The choice of a specific payback period—2, 3, 4, etc. years—to define who is and who is not a free rider has a clearly subjective nature.

Ameren Ex 7.2

6: Calculating Avoided Air Emission

Ameren Ex 7.2

Chapter 6 begins by describing two general approaches for determining avoided air emissions. It then presents several methods for calculating both direct onsite avoided emissions and reductions from grid-connected electric generating units. The chapter also discusses considerations for selecting a calculation approach. It is assumed that net energy savings have been calculated in a manner consistent with previous chapters in this document.

6.1 General Approaches for Calculating Avoided Air Emissions

Avoided air emissions are determined by comparing the emissions occurring after an efficiency program is implemented to an estimate of what the emissions would have been in the absence of the program—that is, emissions under a baseline scenario. In practice avoided emissions are calculated with one of two different approaches: emission factor or scenario analysis.

1. **Emission factor approach**—multiplying the program's net energy savings (as determined by one or more of the approaches defined in Chapter 5) by an emissions factor (e.g., pounds of CO_2 per MWh) that represents the characteristics of displaced emission sources to compute hourly, monthly, or annual avoided emission values (e.g., tons of NO_X per year). The basic equation for this approach is (t = time period of analysis):

   $$\textit{avoided emissions}_t = (\textit{net energy savings})_t \times (\textit{emission factor})_t \qquad (eq\ 6.1)$$

2. **Scenario analysis approach**—calculating a base case of sources' (e.g., power plants connected to the grid) emissions without the efficiency program and comparing that with the emissions of the sources operating with the reduced energy consumption associated with the efficiency program. This is done with sophisticated computer simulation dispatch models and is usually only used with electricity saving programs. The basic equation for this approach is:

   $$\textit{avoided emissions} = (\textit{base case emissions}) - (\textit{reporting period emissions}) \qquad (eq\ 6.2)$$

This chapter assumes that the net savings are calculated in a satisfactory manner, taking into account the issues raised in Section 3.8 with respect to quality of savings estimation, boundary areas, and additionality. Therefore, this chapter focuses on the various ways in which emission factors can be calculated and, for electricity efficiency programs, the basics of the scenario analysis approach. The first section of this chapter covers calculation of emission factors associated with avoided onsite fuel usage. The second section covers avoided grid-connected electricity-related emissions calculation approaches—both emission factors and scenario analysis. The final section provides brief comments on selecting a calculation approach.

6.2 Direct Onsite Avoided Emissions

Direct, onsite avoided emissions can result when efficiency programs save electricity that would have been produced at a project site or when efficiency reduces the need for heat or mechanical energy, reducing onsite combustion of natural gas, fuel oil, or other fuels. Identifying the appropriate emission factor is fairly straightforward for onsite emissions such as those from residential or commercial combustion equipment, industrial processes, or onsite distributed generation. The emission factors are commonly calculated in one of two ways:

- **Default emission factors.** Default emission factors, available from standard resources, are based on the fuel and emission source being avoided. This is the most common approach and a wide variety of resources provide emission factors per unit of fuel consumption, including: manufacturer's equipment performance data, state-certified performance data, emission permit data, and generic emission data compiled by regulators or industry groups. Some data sources are the International Energy Agency (<http://www.iea.org>), Energy Information Agency (<http://www.eia.doe.gov>), and U.S. EPA (<http://www.epa.gov/ttn/chief/ap42/ and http://cfpub.epa.gov/oarweb/index.cfm?action=fire.main>).

- **Source testing.** Source testing can determine the emission factors for a specific device (e.g., large-scale industrial boilers). Protocols for testing are available, but given the time and cost of such testing, this approach is usually only taken when required by environmental regulation. This may change if the value of avoided emissions makes source testing cost-effective as a part of, for example, a certification process.

For direct onsite emissions, a typical emission factor is reported in units of emission per units of onsite fuel use. For example, a common CO_2 emission factor for natural gas is 117 pounds CO_2 per MMBtu (HHV). Such a value would be used with the quantity of avoided natural gas use to calculate emissions reductions, per the following equation:

avoided emissions = (*net avoided natural gas use*) × (*emission factor*) (*eq 6.3*)

For example, the following are the calculations for a project that reduces natural gas consumption from a large industrial boiler by 10,000 MMBtu/year.

- Displaced steam use due to efficiency project = 10,000 MMBtu/year
  Steam boiler HHV efficiency = 80 percent
- Displaced natural gas usage = 10,000 MMBtu/yr ÷ 0.80 = 12,500 MMbtu/yr
- Avoided CO_2 emissions = 12,500 MMbtu/yr × 117 lbs CO_2/MMBtu = 1,462,500 lbs/yr
- Avoided emissions in metric tons = 1,462,000 lbs/yr ÷ 2,000 lbs/ton = 731 tons of CO_2/yr

The program evaluator must select onsite emission factors that provide sufficient accuracy to meet the goals of the evaluation. This requires selecting different emission factors for different time periods, places, and technologies. In addition, emission factors based on historical emission rates may need to be adjusted to account for new, more stringent regulations. Accounting for changing environmental regulation is an important consideration in calculating emission benefits.

Avoided Emissions From Combined Heat and Power Projects

Calculating the avoided emissions associated with a new combined heat and power (CHP) system involves special considerations. CHP systems generate both electricity and thermal energy from a common fuel source. They can be significantly more efficient than separate generation of electricity and thermal energy. In order to calculate the efficiency and the emissions impacts, one must compare the onsite energy use and emissions of the CHP facility to the combined onsite and grid energy use and emissions of the conventional systems. The onsite emissions can be calculated as described in this section. See Section 6.3 for how to calculate grid emissions.

6.3 Emission Factors for Grid-Connected Electric Generating Units

Like the direct onsite case, emissions reductions from reduced electricity consumption occur because less fuel is combusted. However, calculating avoided grid emissions reductions is more complex because the fuel combustion in question would have occurred at many different existing or proposed electric generating units (EGUs), all connected to the electrical grid. Thus, emissions from displaced electricity depend on the dynamic interaction of the electrical grid, emission characteristics of grid-connected power plants, electrical loads, market factors, economics, and a variety of regional and environmental regulatory factors that change over time.

6.3.1 The Electricity Generation Mix

The electric grid is composed of a T&D system connecting a mix of generating plants with different emissions characteristics, which operate at different times to meet electricity demand. The mix of plants operating varies by region, and over time within regions—both as the demand changes from one hour to the next and as old plants are retired and new plants are built. A common way of looking at this varying generation mix is a load duration curve. The load duration curve shows the electricity demand in MW for a region for each of the 8,760 hours in the year. The hourly demand values are sorted from highest to lowest. Figure 6-1 shows a typical example, the load duration curve for an eastern electric utility.

Figure 6-1. Load Duration Curve

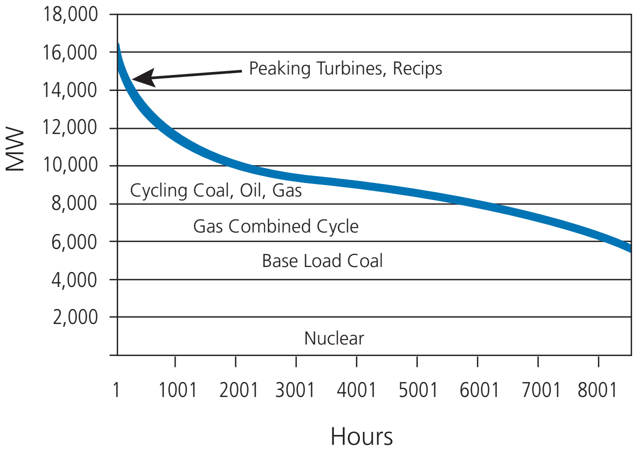

Figure 6-1 shows that the highest hourly electric demand was 16,216 MW and the lowest demand was 5,257 M. It also shows that the peaking turbines and reciprocating engines (recips) operated for only about 200 hours per year (in this case during very hot hours of the summer), while the base load coal and nuclear plants operated throughout the year.

The area under the curve is the generation needed to meet load plus line losses, in this case about 79.7 million MWh. This varying electric load is met with a large number of different types and sizes of generating units. Figure 6-1 also indicates a typical mix of generating technologies. The generating units are dispatched based on a number of factors, the most important usually being the unit's variable cost—the cost of fuel, consumable items, and operation and maintenance directly related to production. Base load units are run as much as possible because they are the least expensive; peaking and intermediate (cycling) units are used only when needed because of their higher costs. The type of units—base load, peaking, etc—that are the most "polluting" can vary from one region to another.

Compared to the base case, energy efficiency displaces a certain amount of generation during each hour that it operates. Efficiency essentially takes a "slice" off the top of the load curve for the hours that it occurs, displacing the last unit of generation in each of these hours. The displaced emissions can be estimated by multiplying the displaced generation by the specific emission rate of that unit or by preparing scenario analyses.

Depending on the hour of the day or year and the geographical location of the avoided electricity use, the displaced unit could be a cycling coal, oil, or steam unit; a combined cycle unit; a central station peaking turbine; or a reciprocating engine unit—or even a zero-emissions unit. The first challenge in calculating the avoided emissions for electricity generation is defining the mix of technologies displaced by the efficiency programs for the specific program location and during specific times of the year.

6.3.2 Calculating Avoided Emission Factors and Scenario Analyses

The methods for determining avoided emissions values for displaced generation range from fairly straightforward to highly complex. They include both spreadsheet-based calculations and dynamic modeling approaches with varying degrees of transparency, rigor, and cost. Evaluators can decide which method best meets their needs, given evaluation objectives and available resources and data quality requirements. Designers of programs or regulations that use these estimates may also wish to specify a method at the outset, and a process for periodic review of that method.

The emission rates of the electricity grid will vary over time. Thus, it is generally recommended that the emissions analyses be conducted annually for each year of the evaluation-reporting period for electricity saving programs. Emissions rates can also vary hour by hour as the mix of electricity plants operating changes to meet changing loads. For natural gas and fuel oil programs, annual savings and hourly analyses are probably less critical. Whether an annual average analysis, an hourly analysis, or some time period of analysis in between is used is up to the evaluator to decide based on evaluation objectives and available resources.

6.3.3 Emission Factors Approach

This section describes two methods for calculating avoided emission factors:

- Calculating emissions rates using a simple "system average" displaced emissions rate obtained from an emissions database. This generally produces less precise estimates.
- Calculating emissions rates using a "medium effort" calculation method, such as estimating regional or state average emission rates for marginal generators or matching capacity curves to load curves. This generally results in moderately precise avoided emission estimates.

Section 6.3.3 further describes these two methods, beginning with a discussion about approaches for calculating emission factors for new and existing power plants.

Operating and Build Margin Emissions Rate

The load duration curve in Section 6.3.1 depicts an existing generation mix. However, efficiency could also prevent the need for future power plant construction. Even if gas-fired generation is currently what is avoided, if energy efficiency can avoid the construction of a new power plant, then the emissions from that plant will be avoided as well. For most energy efficiency program activity in the United States, it is safe to assume that only existing generator emissions are avoided in the short term of two to five years. However, if the analysis is estimating impacts over a longer period of time and/or the scale of the programs being evaluated is large enough, then new units could be considered as well.

The emission factor from a generating unit that would not be run due to energy efficiency is called the operating margin (OM). The emission factor from a generating unit that would not be built is called the build margin (BM). In general terms, avoided emissions can be estimated by determining the extent to which an efficiency program or portfolio affects the BM and OM and either (a) determining appropriate emission factors for the BM and OM using the emission factor approach or (b) accounting for new and existing generating units when using the base case and efficiency scenario approach.

The general formula for calculating emission rates for determining avoided emissions rates is:

$$ER = (w) \times (BM) + (1 - w) \times (OM) \qquad (eq\ 6.4)$$

where: ER is the average emission rate (e.g., tons of CO_2-equivalent / MWh)

BM is the build margin emission factor (e.g., t CO_2-equivalent / MWh)

OM is the operating margin emission factor (e.g., t CO_2-equivalent / MWh)

w is the weight (between 0 and 1) assigned to the build margin

Time is explicit in this equation. That is, the emissions reduction can vary from year to year (or in theory from hour to hour) as the variables w, BM, and OM change over time. In this formula, w indicates where the generation produced (or reduced) by the project activity would have come from in the baseline scenario. A weight of 1 means that all generation produced or saved by the project activity would have come from an alternative type of new capacity built in place of the project activity (the BM). A weight between 0 and 1 means that some of the generation would have come from new capacity (BM) and the remainder from existing capacity (the OM). A weight of 0 means that all of the generation would have been provided by existing power plants, and no new capacity would have been built in place of the project activity.

One approach to determining OM and BM can be found in the WRI/WBCSD *Protocol Guidelines for Quantifying GHG Reductions from Grid-Connected Electricity Projects* (see <http://www.wri.org/climate>).

In this approach, there are three options for selecting the BM emission factor:

- **Option #1. Use a project-specific analysis to identify the type of capacity displaced.** Under this option, the BM emission factor is representative of a single type of power plant. This type of power plant will be either (a) the baseline candidate (i.e., baseline power plant) with the lowest barriers or greatest net benefits or (b) the most conservative, lowest-emitting baseline candidate.
- **Option #2. Use a conservative "proxy plant" to estimate BM emissions.** Under this option, the BM emission factor is determined by the least-emitting type of capacity that might reasonably be built. In some cases, this baseline candidate could have an emission rate of zero (e.g., renewables). Another way of determining a proxy is to look at the plants that have recently been built and connected to the grid.
- **Option #3. Develop a performance standard to estimate the BM emission factor.** Under this option, the BM emission factor will reflect a blended emission rate of viable types of new capacity.

If the BM is to be included in the analyses, it must be explicitly specified, including the basis for its calculation. In recent years, estimates for BM emission rates have been based on advanced-technology coal plants or gas-fired, combined-cycle power plants, as most new plants adopt this technology. However, with new technologies being developed and renewable portfolio standards becoming more prevalent, changes in market conditions should be tracked and accounted for if a BM emission factor is to be used.

System Average Emissions Rate

One simple approach for calculating emissions reductions from efficiency programs is to use regional or system average emission rates. Determining a system average rate involves dividing total annual emissions (typically in pounds) from all units in a region or power system (i.e., within the relevant grid boundary) by the total energy output of those units, typically in MWh.

Sources for average emissions rates include the Ozone Transport Commission's "OTC Workbook" (OTC, 2002), the Clean Air and Climate Protection Software (ICLEI, 2003), and EPA's eGRID database (EPA, 2007). Each of these tools contains pre-calculated emissions rates averaged at the utility, state, and regional level. The rates vary by time period, dispatch-order, and region, as discussed further in the medium-effort section below. A shortcoming of this approach is that it does not account for the complexity of regional power systems. While the tools above offer a wide variety of emission factors, it can be difficult to select the most appropriate approach. In many regions, the marginal units displaced by energy efficiency programs can have very different emissions characteristics from the base load units that dominate the average emissions rate.

Another shortcoming of this approach is that energy efficiency savings tend to vary over time, such as savings from an office lighting retrofit that only occurs during the workday. Using an annual average emission factor that lumps daytime, nighttime, weekday, and weekend values together can skew the actual emissions benefits calculation.

A system average emission rate may be purely historical, and thus fail to account for changing emissions regulations and new plant additions. Historical system averages will tend to overestimate emissions impacts if emissions limits become more stringent over time. Alternatively, a system average emissions rate could be estimated for a hypothetical future system, based on assumptions about emissions from new plants and future regulatory effects on existing plants.

In summary, this is an easy approach to apply but the tradeoff can be relatively high uncertainty.

Medium Effort Calculation Approaches

Between system average calculations and dispatch modeling (scenario analysis) lie several "medium effort" approaches to estimating displaced emission rates. These methods have been developed to provide a reasonably accurate estimate of displaced emissions at a lower cost than dispatch modeling. They typically use spreadsheets and require compilation of publicly available data to approximate the marginal generating units supplying power at the time that efficiency resources are reducing consumption. The two major steps in a spreadsheet-based analysis are determining the relevant set of generating units (accounting for the location of the efficiency program's projects, as well as transfers between the geographic region of interest and other power areas) and estimating the displaced emissions from those units. The following approaches indicate how "medium effort" emission factors can be determined.

Existing vs. New Generating Units

The three approaches for calculating an emission factor are all ways to estimate avoided grid electricity emissions, given a defined current or future set of electricity generating units. If energy efficiency is assumed to reduce the need for new generation, a complementary type of computer modeling may be useful: power sector forecasting and planning models. Also, some integrated national energy models such as NEMS and IPM estimate both, calculate future changes in generating units and also providing an overview of how generation would meet load. Such models can represent the competition between different types of generators, adding new generating capacity to meet load growth, within the constraints of current and anticipated future environmental regulations and emission trading programs. This type of model addresses both the environmental regulatory effects and addition of new generating units in an integrated fashion.

- **Estimating grid average emission rates for marginal generators.** This approach assumes that total emissions are reduced at an average emission rate for each additional kWh of energy reduction (a significant simplification for efficiency activities). To more precisely estimate the impact on the marginal generators that are most likely to be displaced, regional or state average rates are adopted that exclude the baseload generators not "backed off" by efficiency programs. (The latest version of EPA's eGRID database includes one such calculation.) The downside of this approach is that it does not capture the precise subset of generators actually following load and thus subject to displacement. These actual load-following units' emission rates could vary significantly from the overall regional average for marginal generators. While the eGRID database is based on historical data, expected new units could also be added in to this type of calculation. This approach was adopted in a 2006 analysis of New Jersey's Clean Energy Program, (see US DOE, 2006).

- **Matching capacity curves to load curves.** As discussed above, generating units are typically dispatched in a predictable order based on cost and other operational characteristics. This means it is possible, in principle, to predict which unit types will be "on the margin" at a given load level, and thereby predict the marginal emission rates. Data on regional power plants may be used to develop supply curves representing different seasons and times of day. These curves are then used to match regional electricity loads to characteristic emission rates. Although this method may be able to use readily available public data, it is based on a simplified view of dispatch process that does not account for transmission congestion.

  Like system average methods, these methods do not provide an approach to determine how large a geographic region should be considered, inter-regional transfer is also estimated. However, both of them improve upon the system average with respect to identifying which generators are marginal. In either case, the analysis must include the effect of changing environmental regulation, as discussed above.

A significant advantage of using time-varying emission rates, either from dispatch models or other approaches, is that they can match up to the time-varying savings from efficiency programs. Even if an hour-by-hour load shape is not used, at least having seasonal weekday and weekend and nighttime and daytime values (i.e., six emission factors) to match up the equivalent time period net efficiency savings will significantly improve estimates over the other emission factor methods described above.

6.3.4 Scenario Approach

At the other end of the complexity spectrum from calculating simple emission factors, computer-based "hourly dispatch" or "production cost" models capture a high level of detail on the specific EGUs displaced by energy efficiency projects or programs.[1] The models are used to generate scenarios of the electric grid's operation, with and without the efficiency program being evaluated. A scenario analysis can estimate avoided emissions much more precisely than the emission factors methods described above. As such, it is a preferred approach where feasible.

An hourly dispatch model simulates hourly power dispatch to explicitly estimate emissions from each unit in a system. That system can represent the current grid and generating units, or can represent an anticipated future system based on detailed assumptions about additions, retirements, and major grid changes. However, dispatch models do not model the competition among different generating technologies to provide new generation. In general, the model produces a deterministic, least-cost system dispatch based on a highly detailed representation of generating units—including some representation of transmission constraints, forced outages, and energy transfers among different regions—in the geographic area of interest.

If the power system is altered through load reduction or the introduction of an efficiency program, the model calculates how this would affect dispatch and then calculates the resulting emissions and prices. This is the basis for the scenario approach: a dispatch model is run with and without the efficiency program and the resulting difference in emissions is calculated. The models can also be used to simply provide hourly, monthly, or annual emission factors.

With a dispatch model, base case data are either (a) inputted from historical dispatch data provided by utilities or a system operator or (b) modeled on a chronological (hourly) basis.[2] The model is then run with the new efficiency resource to obtain the "efficiency case." Commercial models typically are sold with publicly available data already entered, including planned capacity expansions. Dispatch modeling is the most precise means of quantifying avoided emissions, because it can model effects of load reductions that are substantial enough to change dispatch (as well as future changes such as new generating units or new transmission corridors) on an hourly basis, taking into account changes throughout the interconnected grid.

On the downside, dispatch can be labor-intensive and difficult for non-experts to evaluate. These models can also be expensive, although the costs have been reduced over recent years and—particularly if the results can be applied to a large program or several programs—the improved estimate can be well worth the incremental cost. Accordingly, they are probably most appropriate for large programs or groups of programs that seek to achieve significant quantities of electrical energy efficiency or long-term effects. For large statewide programs, the modeling costs may be relatively small compared to the program and evaluation costs; CPUC, for example, is currently using dispatch modeling to determine the avoided greenhouse gases from various efficiency portfolios. (See <http://www.ethree.com/cpuc_ghg_model.html>.)

6.4 Selecting an Approach for Calculating Avoided Emissions

The choice of evaluation approach is tied to the objectives of the program being evaluated, the scale of the program, the evaluation budget and resources, and the specific emissions the program is avoiding. For direct onsite fuel savings and the resulting avoided emissions, standard emission factors can be used. This is a fairly typical practice, except perhaps for very large industrial individual efficiency projects.

For electricity savings programs, system average emission values can be used, but they should be avoided except for the simplest estimates of benefits. There are also medium effort methodologies that can fairly accurately quantify the effects of electricity energy efficiency programs. However, the most precise approaches involve dispatch modeling and the resulting detailed calculation of hourly emissions. While the costs and complexity of these models has limited their use in the past, this is beginning to change. Dispatch models are potentially cost-effective evaluation tools that should be considered for evaluations of large-scale programs.

6.5 Notes

1. These models are also called "production cost models."
2. Historical data could be used to calibrate the chronological model. Using historical data directly for the base year, though, can lead to results that include unusual system performance during the base year as well as changes due to the efficiency program(s).

Wisconsin Focus on Energy Program's Calculation of Avoided Emissions

Evaluators for Wisconsin's Focus on Energy public benefits energy efficiency program have estimated emission factors or rates for the plants serving Wisconsin and used these data to estimate long-term avoided emissions associated with the Focus programs. The evaluation team developed a model to estimate the generation emission rates for NO_X, SO_X, CO_2, and mercury using hourly measured emissions data from EPA for the power plants supplying Wisconsin (using a medium effort calculation approach). Emission factors from reduced use of natural gas at the customer site were also taken from EPA data.

Using the marginal cost emission rates and evaluation-verified gross electricity savings estimates, the Focus programs together potentially avoided 2,494,323 pounds of NO_X; 4,107,200 pounds of SO_X; over 2,369 million pounds of CO_2; and over 15.9 pounds of mercury from inception to December 31, 2006 (See Table 2-11 of the Focus on Energy Public Benefits Evaluation *Semiannual Report—FY07, Mid-year*, May 10, 2007).

Also, Wisconsin's Department of Natural Resources (DNR) has developed an emissions registry to track emissions reductions in Wisconsin. The ongoing reporting of emissions reductions associated with Focus programs' energy impacts has been the basis for entries to DNR's Voluntary Emissions Reduction Registry (<http://www.dnr.state.wi.us/org/aw/air/registry/index.html>).

For this registry, the Focus on Energy evaluator provides independent third-party verification for one of the residential programs. That program, ENERGY STAR Products, promotes the installation of energy-efficient appliances, lighting, and windows. Drawing upon the evaluation activities conducted over the past four years, the emissions savings from the Energy Saver compact fluorescent light bulb portion of the program were verified for the Registry. The calculations, assumptions, and research activity backup that supports the registered reductions in emissions associated with the evaluated energy impacts of the program are cited and available on the state's DNR Web site.

It should be noted that Wisconsin's power plants are included in the federal SO_2 cap and trade program (acid rain provisions). In this cap and trade system, SO_2 emissions may not be considered reduced or avoided unless EPA lowers the SO_2 cap. One can say that the program avoided generation that previously emitted this amount of SO_2, but one cannot claim that future SO_2 emissions will actually be reduced due to the effect of the trading program. Starting in 2009, the plants will also be subject to a cap and trade program for NO_X (the Clean Air Interstate Rule), which will have the same effect.

Provided by David Sumi of PA Consulting Group.

7: Planning an Impact Evaluation

Chapter 7 builds on preceding chapters and presents the steps involved in planning an impact evaluation. These include the development of evaluation approaches, budgets, and a schedule. The first section discusses how evaluation planning and reporting is integrated into the program implementation process, while the second section presents seven key issues and questions that help determine the scope and scale of an impact evaluation. The last section provides guidance on preparing an evaluation plan and includes "model" outlines and checklists for conducting an evaluation plan.

7.1 Integration of Evaluation into the Program Cycle

After reading this chapter, and this Guide, the reader should have the background needed for preparing an evaluation plan to document gross and net energy and demand savings, and avoided air emissions from an energy efficiency program. However, this Guide cannot be a substitute for the experience and expertise of professional efficiency evaluators. While it can be used in preparing an evaluation plan, it may be best used to oversee the evaluation process as implemented by professional evaluators, whether they be internal staff or outside consultants.

Before describing the evaluation planning process, it is important to understand how it is integral to what is typically a cyclic planning-implementation-evaluation process. In most cases the overall cycle timeframe is consistent with program funding and contracting schedules.

These cycles can be one or two years, or even longer. The point at which programs are being designed is when the evaluation planning process should begin. This is primarily so that the program budget, schedule, and resources can properly take into account evaluation requirements.[1] It is also a way to ensure that data collection required to support expected evaluation efforts is accommodated at the time of implementation.

The Program Implementation Cycle

Evaluation results are used to make informed decisions on program improvements and future program designs and offerings. The program implementation cycle is one in which programs are designed, then implemented, and then evaluated. Following the results of the evaluation, programs are re-examined for design changes and then modified so that those design changes result in improved program implementation efforts. This cycle provides for a continuing process of program improvement, so that the programs match available market opportunities and continually improve their cost-effectiveness over time.

Source: CPUC, 2004.

Evaluations should be completed within a program cycle, so that evaluation results can not only document the operations and effects of the program in a timely manner, but also provide feedback for ongoing program improvement, provide information to support energy efficiency portfolio assessments, and help support the planning for future program cycles. For impact evaluations that examine energy savings of certain measures and program mechanisms, the evaluation information can also be used to inform future savings estimates and reduce future evaluation requirements and costs.

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Figure 7-1. Program Implementation Cycle With High-Level Evaluation Activities

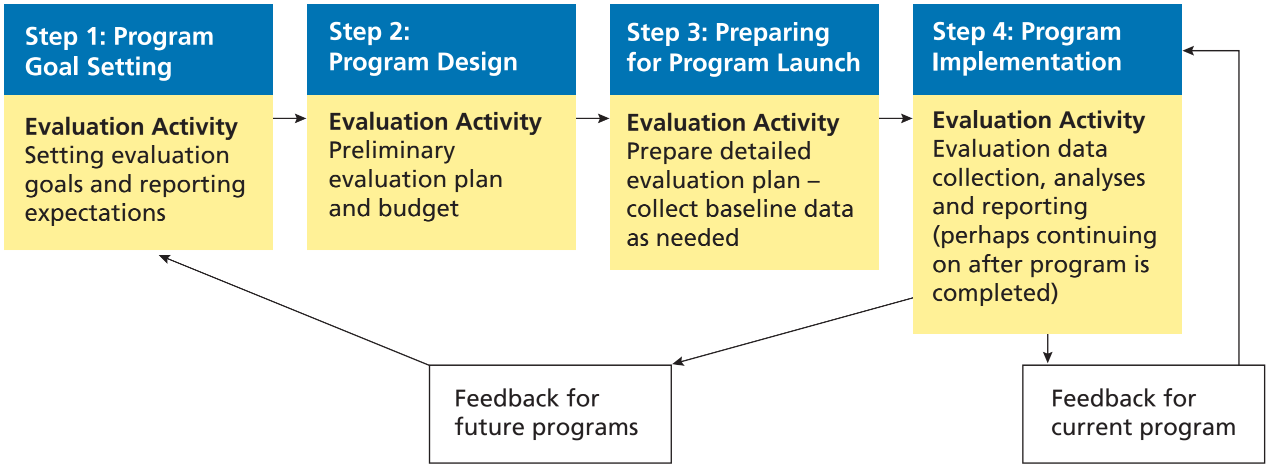

Figure 7-1 shows the energy efficiency program implementation cycle, emphasizing evaluation activities, as well as feedback to the current and future programs.

The steps displayed in Figure 7-1 are further described below:

- **Program goal setting.** When a program is first envisioned, often as part of a portfolio of programs, is when both program goals and evaluation goals should be considered. If the program (or portfolio) goal is to save electricity during peak usage periods, for example, the evaluation goal can be to accurately document how much electricity is saved during the peak (gross impact) and how much of these savings can be attributed to the program (net impact).
- **Program design.** Program design is also when the evaluation design effort should begin. The objective should be a *preliminary evaluation plan and budget*. The seven issues described in Section 7.2 should be raised, although not necessarily fully addressed, at this time. Whereas a *program design* is usually completed at this stage, it is likely that the *evaluation plan* will not be fully defined. This is typically because of the iterative nature of integrating the program design and evaluation process and the timing for when the evaluator is brought into the team. It is not unusual, although not always best practice, to select the evaluator after the program has been designed. In any event, specific evaluation goals and objectives should be set and priorities established based on factors including perceived risks to achieving the savings objectives.
- **Preparing for program launch.** Program launch is when activities, program materials, and timing strategies are finalized and made ready, contracts (if needed) are negotiated, trade allies and key stakeholders are notified, and materials and internal processes are developed to prepare for program introduction and implementation. Before the program is launched—or if not, soon after it is launched—is when the detailed evaluation plan should be prepared. (An outline of such a plan is presented in Section 7.3.) It is in this plan that the seven evaluation issues are fully addressed and resolved, including specifying the data needed to perform the evaluation.

This is also the time when some baseline data collection can take place. *A major reason for starting the evaluation planning process well before a program is launched is if baseline data collection is required*.

The overall evaluation plans should be reviewed with program implementers and may need to be reviewed by an appropriate oversight body or bodies to ensure that they will meet the information needs of policy makers, portfolio managers, and regulators, as appropriate. This is also the time when evaluation staff or consultants are

ISO-NE M&V Manual for Wholesale Forward Capacity Market (FCM)

In 2007, the Independent System Operator of New England (ISO-NE) developed an M&V manual that describes the minimum requirements the sponsor of a demand resource (DR) project must satisfy to qualify as a capacity resource in New England's wholesale electricity forward capacity market (FCM). DRs eligible to participate in FCM include demand response, emergency generation, distributed generation, load management, and energy efficiency. DRs are eligible to receive a capacity payment ($/kW per month) based on the measured and verified electrical reductions during ISO-specified performance hours. The manual was developed with input from key stakeholders in the region, including members of the New England Power Pool, ISO-NE, the New England state regulatory staff, electric utility program administrators, Northeast Energy Efficiency Partnerships, and energy service, consulting and technology providers. The Manual specifies the minimum requirements a project sponsor's M&V Plan must address, including:

- **M&V methods.** The sponsor must choose from options based on the IPMVP Options A through D (or equivalent). Other M&V techniques may be used in combination with one or more of these, including engineering estimates supplemented with data collected on the equipment affected by the measures, and/or verifiable measure hourly load shapes (which must be based on actual metering data, load research, or simulation modeling). All DR including distributed generation and emergency generation must be metered at the generator.
- **Confidence and precision.** The project sponsor must describe a method for controlling bias (e.g., calibration of measurement tools, measurement error, engineering model) and achieving a precision of +/- 10 percent, with an 80 percent confidence level around the total demand reduction value(s). This requirement also applies to precision level for statistical sampling.
- **Baseline conditions.** The manual specifies baseline condition requirements for failed equipment (codes/standards or standard practice, whichever is more stringent), early retirement (codes/standards or measured baseline), and new construction (codes/standards or standard practice). Where standard practice is used, baseline conditions must be documented and meet the confidence and precision requirements. For distributed generation and emergency generation, the baseline is zero. The baseline for real time demand response is calculated using a modified rolling average of the host facility load on non-event weekdays during the same hours as the called event.
- **Measurement equipment specifications.** The project sponsor must describe measurement, monitoring, and data recording device type that will be used (and how it will be installed) for each parameter and variable. Any measurement or monitoring equipment that directly measures electrical demand (kW) (or proxy variables such as voltage, current, temp. flow rates, and operating hours) must be a true RMS measurement device with an accuracy of at least ±2 percent.
- **Monitoring parameters and variables.** The project sponsor must describe variables that will be measured, monitored, counted, recorded, collected, and maintained, and meet minimum requirements for data to be collected by end-use and monitoring frequency.

assigned to the program evaluation. Issues for selecting evaluators are discussed in Section 7.2.7.

- **Program implementation.** This is when the evaluation actually occurs. Some baseline and all the reporting period data are collected, the analysis is done, and the reporting is completed. Given the often retrospective nature of evaluation, the evaluation activities can actually carry on after the program implementation is completed.

Closing the Loop—Integration of Implementer and Evaluator

There has been a noticeable paradigm shift in evaluation in recent years. The old model brought in the evaluator on the tail end of the project to assess delivery, cost-effectiveness, and achievement of stated goals. In most cases, the evaluator was faced with the challenge of having to conduct analysis with less than perfect data. Even when data were available, the evaluator may have revealed facts that would have been useful early in making course corrections. Had these corrections been made, better services would have been delivered. A different model brings the evaluator in at the onset of the program, becoming an integral part of the team. Program goals are linked to specific metrics, which are linked to specific data collection methods. The evaluator can provide feedback in real time, essential to instant assessment and determination that the correct course is being followed. This model needs to be balanced with the possible conflicting nature of evaluation goals—the implementer's goal of understanding and improving the program performance and a possible regulating authority's goal of ensuring that the savings reported are "real." This conflict is more likely to occur if the implementer and evaluator are independent entities, as commonly required to meet the regulator's goal.

Although it is preferable to start an evaluation prior to the program launch in order to collect baseline information, in most cases the evaluation and program start simultaneously due to the common interest in initiating a program as soon as possible. Thus, activities to support data collection usually begin after the program is up and running, and hopefully early enough in the program cycle to provide feedback and corrective recommendations to program implementers in time for the program to benefit from those recommendations. In addition, impact evaluation activities can support program progress tracking, such as measure installation tracking and verification.

In terms of reporting, evaluation information can be summarized and provided on any time cycle. The key is to get the information needed to implementers so they can adjust existing programs and design new ones using current and relevant information. The evaluation activities may be conducted with oversight bodies providing review and approval and may therefore have specific reporting requirements.

For future program designs, ex ante savings estimates can be adjusted based on program evaluation results. Assumptions underlying the efficiency potential analysis used at the beginning of the program cycle for planning can then be updated based on the full net impact analysis. These data then feed back into the goal setting and potentials analysis activities, and the cycle repeats to allow for an integrated planning process for future programs.

7.2 Issues and Decisions That Determine the Scope of an Impact Evaluation

Numerous elements and decisions go into the design of an impact evaluation, but there are seven major issues that require some level of resolution before the budget and the evaluation plan are prepared:

1. Define evaluation goals and scale (relative magnitude or comprehensiveness).
2. Set a time frame for evaluation and reporting expectations.
3. Set a spatial boundary for evaluation.
4. Define a program baseline, baseline adjustments, and data collection requirements.
5. Establish a budget in context of information quality goals.
6. Select impact evaluation approaches for gross and net savings calculations and avoided emissions calculations.
7. Select who (or which type of organization) will conduct the evaluation.

These issues are presented in what can be considered a linear sequence, but many are interrelated and the overall planning process is certainly iterative. The end result of addressing the above seven issues is an evaluation plan. Experience has indicated that, if the funding and time requirements for reliable evaluations are not fully understood and balanced with information needs and accuracy expectations, efforts can be under-supported and fail to provide the results desired.

7.2.1 Defining Evaluation, Goals, and Scale

This subsection helps the evaluation planner define evaluation goals, the overall scale of the effort, the specific program benefits to be evaluated, and whether any other evaluations will be concurrently conducted and coordinated.

Evaluations should focus on a program's performance at meeting its key goals and, if desired, provide information for future program planning. To this end, program managers and, as applicable, regulators need to be assured that the evaluations conducted will deliver the type and quality of information needed. Under-designed evaluations can waste valuable resources by not reliably providing the information needed or delay the start of an evaluation. Delays can make it impossible to collect valuable baseline data and delay the results so that they cannot be used for current program improvement or future program design.

Evaluations can also be over-designed, addressing issues that are not priority issues or employing methods that could be replaced by less costly approaches. There is a need to prioritize evaluation activities so that evaluation resources—typically limited—can be focused on the issues of importance. Like many activities, an evaluation that is well-defined and affordable is more likely to be completed successfully than one with undefined or unrealistic objectives and budget requirements.

Setting goals involves defining evaluation objectives and the specific information that will be reported-out from the impact evaluation. The scale of the evaluation is more of a subjective concept, indicating how much effort (e.g., time, funding, human resources) will be expanded on the evaluation.

Program Objectives and Information Reporting

As discussed in the beginning of this Guide, evaluations have two key objectives:

1. Document and measure the effects of a program in order to determine how well it has met its efficiency goals with respect to being a reliable, clean, and cost-effective energy resource.
2. Understand why those effects occurred and identify ways to improve current and future programs.

Additional objectives of evaluation can include determining the cost-effectiveness of a program and, when public or ratepayer funds are involved, documenting compliance with regulatory requirements. One of the other potential objectives of the impact evaluation effort is to provide policy makers and portfolio decision-makers with the information they need to identify programs to run in the future and assess the potential savings from these programs.

Therefore, the first step in planning an evaluation is simply picking which of these objectives are applicable and making them more specific to the evaluated program. Some typical impact evaluation objectives are:

- Measure and document energy and peak savings.
- Measure and document avoided emissions.
- Provide data needed to assess cost-effectiveness.
- Provide ongoing feedback and guidance to the program administrator.
- Inform decisions regarding program administrator compensation and final payments (for regulated programs and performance-based programs).
- Help assess if there is a continuing need for the program.

In practice, the selection of objectives will be shaped by many situational factors. Among the most important are:

- Program goals—it is also important that *program* goals must be quantifiable and able to be measured.

How the goals will be measured (evaluated) must also be taken into account in the program planning process.

- Whether the program is a new effort, an expanding effort, or a contracting effort.
- The policy and/or regulatory framework in which the evaluation results will be reported.
- The relative priority placed upon the evaluation's comprehensiveness and accuracy by the responsible authorities (i.e., the budget and resources available).

In terms of reporting out impact evaluation results, the key parameters are the units and time frame. Some examples are:

- Electricity savings: kWh saved per year and per month.
- Demand savings (example 1): kW saved per month of each year of program, averaged over peak weekday hours.
- Demand savings (example 2): kW savings coincident with annual utility peak demand, reported for each year of the program.
- Avoided emissions (example 1): metric tons of CO_2 and SO_X avoided during each year of the program.
- Avoided emissions (example 2): metric tons of NO_X avoided during ozone season months of each year of the program.
- Lifetime savings (savings that occur during the effective useful life of the efficiency measure): MWh saved during measure lifetime, in years.

In addition, as discussed in Section 3.4 and Appendix D, evaluation results, like any estimate, should be reported as expected values with an associated level of variability.

Evaluation Scale

"Scale" refers to an evaluation effort's relative magnitude or comprehensiveness. Will it be a major effort, a minor effort, or something in between? The following are some attributes that set the scale of an evaluation. The scale can be translated into resource requirement (time, cost, equipment, and people) estimates. Understanding the requirements and comparing them with the objectives, and resources available, should result in a well-balanced evaluation effort.

- How large is the program in terms of budget and goals? Larger programs tend to have larger evaluations.
- Is it a new program with uncertain savings or an established program with well-understood savings? Established programs with a history of well-documented savings may not require the same level of evaluation that a new program, with no history, requires. Related to this consideration is how much confidence exists in pre-program (ex ante) savings estimates. If a fair amount of effort has gone into feasibility studies and perhaps pre-testing, then less of an evaluation effort may be required.
- Is the program likely to be expanded or contracted? A program that may be expanded (i.e. increased in budget) probably deserves more analyses to confirm if it should be expanded than one that is not likely to receive additional funding or may even be cancelled.
- How accurate and precise an estimate of energy and demand savings is required? Less uncertainty generally requires bigger budgets. On one end of the uncertainty scale is simply verifying that the individual projects in a program were installed (and using deemed savings to determine savings). On the other end are rigorous field inspections, data collection, and analyses on all or a large sample of projects in a program.
- Do savings need to be attributed to specific projects within a program? If savings values for each project are desired, then a census evaluation is required. This is more costly than evaluating a sample of projects.
- How long, typically in years, does the evaluation need to be conducted? Obviously, longer evaluation cycles require more funding.

- What is the time interval for reporting savings? For example, reporting annual or monthly savings estimates is usually much simpler than reporting hourly savings. This is particularly important when deciding how accurate an estimate of demand savings needs to be. As discussed in Chapter 3, there are different ways to calculate and report demand savings, with very different levels of effort required.
- What are the reporting requirements and who must review (and approve) evaluation results? While all evaluations should have well-documented results, the frequency that savings need to be reported, and to what audience—for example, a regulatory body—can influence the scale of the effort.
- Are avoided emissions also to be determined, and will the avoided emissions benefits be used in a regulatory program? As discussed in Chapter 6, emissions can be calculated simply or with significant effort and accuracy. If avoided emissions values will be used in a regulated program, the analyses may be subject to specific requirements and third-party verification.
- Are other co-benefits to be evaluated and possibly quantified? If this is more than an anecdotal exercise, then additional resources will be required.

Other Evaluation Efforts and Other Programs

While this Guide is focused on impact evaluations, there are other types of evaluations (as described in Chapter 2 and Appendix B). If other evaluations, such as process or market effects evaluations, are to be conducted, their plans should be integrated with the impact evaluation plan. If cost-effectiveness analyses are to be conducted, it is critical to define which cost-effectiveness test(s) will be used and thus what impact evaluation data are needed. Furthermore, if more than one program is being evaluated and the programs may have some interaction, then coordination of the programs, their evaluations, and the assigning of net benefits to one program versus another need to be coordinated.

Evaluating Co-Benefits

This Guide is focused on documenting three categories of impacts or benefits associated with energy efficiency programs: energy savings, demand savings, and avoided air emissions. However, as discussed in Chapter 3, there are other potential benefits of energy efficiency. As part of the planning process, it must be decided which of these benefits, if any, will be evaluated and how.

7.2.2 Setting the Time Frame for Evaluation and Reporting

This subsection helps the evaluation planner define when the evaluation effort will start, how long it will last, for what time segments and intervals the savings data will be collected and reported (granularity), and the point at which evaluation reports will be available.

The evaluation time frame has two components:

1. **When and over what period of time the evaluation effort will take place.** A standard evaluation would begin before the start of the program implementation (to collect any baseline data) and continue for some time after the program is completed to analyze persistence of savings. However, the actual timing of the evaluation is influenced by several, often competing, considerations. These considerations include:
    a. What will be the time period of analyses, i.e. how many years?
    b. Will persistence of savings be determined, and if so, how?
    c. The timing for policy decisions and evaluation planning.
    d. The desire to have early feedback for program implementers.
    e. Program lifecycle stage (evaluating a first time program or a long-established program)
    f. Evaluation data collection time lags.
    g. Regulatory and/or management oversight requirements.
    h. Contract requirements for reporting savings for “pay for performance” programs.

i. Timing needs for using the evaluation results to update specific measure energy and demand savings, and measure life estimates.

j. Reporting requirements—whether only an end of program report is needed or whether interim or evenly monthly reports are desired.

2. **The time granularity of evaluation analyses.** This relates to whether 15-minute, hourly, monthly, seasonal, and/or annual data collection and savings reporting are required. The granularity decision is based on the uses of the information from the evaluation. Annual savings data are generally only useful for overview indications of the program benefits. More detailed data are usually required for both cost-effectiveness analyses and resource planning purposes. For avoided emissions, annual values are typical; however, for certain programs, such as smog programs, there are specific seasons or time periods of interest.

   If demand savings are to be calculated, the choice of definition (e.g., annual average, peak summer, coincident peak, etc.) is related to time granularity. Chapter 3 includes a discussion of the different definitions and describes how this decision greatly influences the data collection requirements and thus the effort required to complete the evaluation.

7.2.3 Setting the Spatial Boundary for Evaluation

This subsection helps the evaluation planner define the assessment boundary, in at least general terms, for the evaluation.

When evaluating energy and demand savings and avoided emissions, it is important to properly define the project boundaries: what equipment, systems, or facilities will be included in the analyses. Ideally, all primary effects (the intended savings) and secondary effects (unintended positive or negative effects), and all direct (at the project site) and indirect (at other sites) avoided emissions will be taken into account.

From a practical point of view, and with respect to energy and demand savings, the decision concerns whether savings will be evaluated for specific pieces of equipment (the "boundary" may include, for example, motor savings or light bulb savings), the end-use system (e.g., the HVAC system or the lighting system), whole facilities, or even an entire energy supply and distribution system. For avoided emissions calculations, the boundary assessment issues are discussed in Section 3.8.

7.2.4 Defining Program Baseline, Baseline Adjustments, and Data Collection Requirements

This subsection helps the evaluation planner define whether a project- or performance-based baseline will be used and decide on the basis for quantifying the baseline (e.g., existing equipment performance, industry typical practice, minimum equipment standards, etc.), which major independent variables will be considered in the analyses, and what data will need to be collected to analyze benefits.

As mentioned before, a major impact evaluation decision is defining the baseline. The baseline defines the conditions, including energy consumption and related emissions, that would have occurred without the subject program. Baseline definitions consist of site-specific issues and broader, policy-oriented considerations.

Site-specific issues include the characteristics of equipment in place before an efficiency measure is implemented and how and when the affected equipment or systems are operated. For example, for an energy efficient lighting retrofit, the baseline decisions include the type of lighting equipment that was replaced, the power consumption (watts/fixture) of the replaced equipment, and how many hours the lights would have operated. The broader baseline policy issues involve ensuring that the energy and demand savings and avoided emissions are "additional" to any that would otherwise occur due, for example, to federal or state energy standards.

When defining the baseline, it is also important to consider where in the life-cycle of the existing equipment or systems the new equipment was installed.

The options are (a) "*early replacement*" of equipment that had not reached the end of its useful life; (b) new, energy efficient equipment installed for failed *equipment replacement*; or (c) *new construction*. For each of these options, the two generic approaches to defining baselines are the *project-specific* and the *performance standard* procedure.

Project-Specific Baseline

Under the project-specific procedure (used on all or a sample of the projects in a program), the baseline is defined by a specific technology or practice that would have been pursued, at the site of individual projects, if the program had not been implemented. With energy efficiency programs, the common way this is accomplished is an assessment of the existing equipment's consumption rate, based on measurements or historic data, an inventory of pre-retrofit equipment, or a control group's energy equipment (used where no standard exists or often when the project is an "early replacement"—that is, prior to equipment failure).[2] Most organizations, when calculating their own savings, define baseline as what the new equipment actually replaces; that is, the baseline is related to actual historical base year energy consumption or demand. Note that because identifying this type of baseline always involves some uncertainty with respect to free riders, this approach should be used in combination with explicit additionality considerations.

Performance Standard Baseline

The second approach to determining baselines is to avoid project-specific determinations, and thus most free ridership issues, and instead try to ensure the overall additionality of quantified energy and demand savings, and/or avoided emissions. This is done by developing a performance standard, which provides an estimate of baseline energy and demand for all the projects in a program. The assumption is that any project activity will produce *additional* savings and avoided emissions if it has a "lower" baseline than the performance standard baseline. Performance standards are sometimes referred to as "multi-project baselines" because they can be used to estimate baseline emissions for multiple project activities of the same type.

Under the performance standard procedure, baseline energy and demand are estimated by calculating an average (or better-than-average) consumption rate (or efficiency) for a blend of alternative technologies or practices. These standards are used in large-scale retrofit (early replacement) programs when the range of equipment being replaced and how it is operated cannot be individually determined. This would be the case, for example, in a residential compact fluorescent incentive program, where the types of lamps being replaced and how many hours they operate cannot be determined for each home. Instead, studies are used to determine typical conditions.

Another very common use of performance standards is to define a baseline as the minimum efficiency standard for a piece of equipment as defined by a law, code, or standard industry practice (often used for new construction or equipment that replaces failed equipment).

New Construction Baselines

It can be difficult to define baselines and additionality for new construction programs. This is somewhat obvious in that there are no existing systems to which the reporting period energy consumption and demand can be compared. However, the concepts of project and performance standard baseline definitions can still be used, and thus the common ways in which new construction baselines are defined are:

- What would have been built or installed without the program at the specific site of each of project? This might be evaluated by standard practice or plans and specifications prepared prior to the program being introduced.
- Building codes and/or equipment standards.
- The performance of equipment, buildings, etc., in a comparison group of similar program nonparticipants.

Defining Adjustment Factors

As discussed in Chapter 4, the "adjustments" distinguish properly determined savings from a simple comparison of energy usage before and after implementation of a program. By accounting for factors (independent variables) that are beyond the control of the program implementer or energy consumer, the adjustments term brings energy use in the two time periods to the same set of conditions. Common examples of adjustment are:

- **Weather corrections**—for example, if the program involves heating or air-conditioning systems in buildings.
- **Occupancy levels and hours**—for example, if the program involves lighting retrofits in hotels or office buildings.
- **Production levels**—for example, if the program involves energy efficiency improvements in factories.

The choice of independent variables can be a major effort, as it involves testing which variables are meaningful. This is typically done during the implementation phase as part of data analysis efforts, but can also occur during the planning phase with significant variables identified on the basis of intuition and experience.

Defining Data Collection Requirements

Assessing baseline and adjustment issues in the planning stage is important for determining data collection and budgeting requirements. The goal is to avoid reaching the analysis stage of an evaluation and discovering that critical pieces of information have either not been collected or have been collected with an unreliable level of quality. These scenarios can be guarded against by providing specific instructions to program administrators and others. This may be necessary because the information needed for calculating benefits is not always useful to program administrators for their tasks of managing and tracking program progress. Planning for data collection is necessary to give administrators notice and justification for collecting items of data they would not ordinarily collect.

7.2.5 Establishing a Budget in the Context of Information Quality Goals

This subsection helps the evaluation planner define the accuracy expected for evaluation results. It also helps establish the overall evaluation budget, given the seven major issues identified in this chapter.

Establishing a budget (i.e., funding level) for an evaluation requires consideration of all aspects of the evaluation process, particularly the six other issues raised in this chapter. This subsection, however, discusses budgeting in the context of determining the appropriate level of certainty for the evaluation results.

California Example of Risk Management Approach to Evaluation Budgeting

California has a $170 million budget for evaluation studies and $70 million for impact studies. However, it still does not have enough money for rigorous evaluations of all but the most important and high-risk programs (i.e., those programs for which accuracy of findings is critical).

To help assign evaluation resources, California used a risk analysis approach that weighed the need for confidence and precision with the risk of the answer being wrong at the program level, the technology level, and the portfolio level. A prioritized list of programs was prepared in which the rigor levels of the evaluations could be structured to match the need for reliable information. The budget was then distributed to match the need. California used the Crystal Ball® analysis program. Using sets of possible error distributions (shapes) at the technology level for kWh, kW, and therms saved, a few hundred thousand risk analysis runs were made based on the probability of the assigned distribution shapes and the expected savings within those shapes.

Provided by Nick Hall of TecMarket Works.

When designing and implementing a program, the primary challenge associated with evaluation is typically balancing (a) the cost, time and effort to plan and complete, and uncertainty of various approaches with (b) the value of the information generated by the efforts. Most of the value of information is tied to the value of energy savings and overall program integrity. The costs for high levels of confidence in the calculations must be compared to the risks (and costs) associated with the value of savings being allocated to projects and programs. In this sense, evaluation processes are about risk management. Low-risk projects require less evaluation confidence and precision; high-risk projects require more confidence and precision. The acceptable level of uncertainty is often a subjective judgment based on the value of the energy and demand savings, the risk to the program associated with over- or underestimated savings, and a balance between encouraging efficiency actions and high levels of certainty. An important aspect of evaluation planning is deciding what level of risk is acceptable and thus the requirements for accuracy and a corresponding budget.

How much risk is acceptable is usually related to:

- The amount of savings expected from the program.
- Whether the program is expected to grow or shrink in the future.
- The uncertainty about expected savings and the risk the program poses in the context of achieving portfolio savings goals.
- The length of time since the last evaluation and the degree to which the program has changed in the interim.
- The requirements of the regulatory commission or oversight authority, and/or the requirements of the program administrator.

On a practical level, the evaluation budget reflects decisions that have been made about the level of quality associated with evaluation results. For example, steps to reduce or evaluate measurement error might require special follow-up studies, additional short-term metering, additional training of staff, or more intensive testing of questionnaires and recording forms to reduce data collection errors. Additional resources might be used to ensure that "hard-to-reach" portions of the population are included in the sampling frame (reducing non-coverage error) or devoted to follow-up aimed at increasing the number of sample members for whom data are obtained (reducing non-response bias).

The determination of the appropriate sample size also affects the evaluation budget. There are procedures, such as a statistical power analysis, that help researchers determine the sample size needed to achieve the desired level of precision and confidence for key outcomes so that those of a substantively important magnitude will be statistically significant. Appendix D discusses the steps that can be taken to increase the accuracy of evaluation results.

While it is difficult to generalize, a rule of thumb is that evaluation costs (including any M&V costs) range from 1 to 10 percent of program costs. In general, on a unit-of-saved-energy basis, costs are inversely proportional to the magnitude of the savings (i.e., larger projects have lower per-unit evaluation costs) and directly proportional to uncertainty of predicted savings (i.e., projects with greater uncertainty in the predicted savings warrant higher EM&V costs).

7.2.6 Selecting Impact Evaluation Approaches for Energy Savings and Avoided Emissions Calculations

This subsection reiterates the reasons for calculating gross or net energy savings and the various approaches for calculating net and gross energy savings and avoided emissions.

Chapters 4, 5, and 6 define approaches and present criteria for selecting approaches for determining gross and net energy and demand savings, as well as avoided emissions estimates. These will not be repeated here, but deciding (a) which of these results will be determined and (b) which of the calculation approaches will be used is a critical part of the planning process. For completeness, the major calculation approaches are listed again below.

- For gross energy and demand savings, one or more of the following calculation approaches are used:
  - One or more M&V methods from the IPMVP are used to determine the savings from a sample of projects, and these savings are then applied to all of the projects in the program.
  - Deemed savings based on historical, verified data are applied to conventional energy efficiency measures implemented in the program.
  - Statistical analyses of large volumes of energy meter data are conducted.
- For net energy and demand savings, the calculation approaches are:
  - Self-reporting surveys.
  - Enhanced self-reporting surveys.
  - Econometric methods.
  - Stipulated NTGR.
- Related to the choice of net energy and demand savings approach are the factors used to convert gross to net savings. Thus, these should be selected concurrently. Factors for consideration are:
  - Free ridership.
  - Spillover.
  - Rebound.
  - T&D losses (electricity efficiency).
  - Economy factors and energy prices (or others).
- Avoided emission factor calculation approaches involve using:
  - System average emission rates.
  - Dispatch models.
  - Medium effort calculation approaches.

The decision to calculate net or gross energy savings depends on the program objectives and available evaluation resources. Gross savings are calculated when all that is needed is an estimate of the savings for each project recorded as having participated in a program. The most common example of this is projects involving a contractor completing energy efficiency measures in facilities for the sole purpose of achieving energy savings (e.g., performance contracts). Net savings are calculated when it is of interest to know the level of savings that occurred as a result of the program's influence on program participants and non-participants. This is usually the case when public or ratepayer monies fund the evaluation program, and when accurate avoided emission estimates are desired.

7.2.7 Selecting An Evaluator

This subsection helps the evaluation planner select the evaluator.

Either the program implementer or a third party typically conducts the evaluation. The third party—valued for a more independent perspective—can be hired either by the implementer, with criteria for independence, or by an overseeing entity such as a utility regulator. A typical approach for utility-sponsored efficiency programs is for the utility's evaluation staff to manage studies that are completed by third-party consultants, whose work is reviewed by the utility regulatory agency. The objective is for all parties to the evaluation to believe that the reported results are based on valid information and are sufficiently reliable to serve as the basis for informed decisions.

Using either implementers or independent third parties to conduct evaluations has advantages and disadvantages; selection of one or the other depends on the goals of the evaluation. Regulated energy programs and programs with a financial outcome hinging on the results of the evaluation tend to require third-party evaluation. Another approach is to have the evaluation completed by the implementer with the requirement for third-party verification. Some emission programs, such as the European Trading System for greenhouse gases, require third-party independent verification of avoided emissions information.

On the other hand, a common objective of evaluation is to inform on the performance of the program and help with program improvement. This latter objective favors a tight relationship between the evaluator and the implementer. Thus, the selection of an evaluator can require balancing evaluation independence (so that the evaluation is objective) with the desire to have the evaluator close enough to the process such that the evaluation provides ongoing and early feedback without the implementer feeling "defensive."

Evaluators can either be in-house staff or consultants. Evaluation consulting firms tend to use either econometricians (professionals who apply statistical and mathematical techniques to problem solving) and engineers. Many are members of industry professional organizations, or are Certified Measurement and Verification Professionals (CMVPs).[3] Two of the professional organizations that energy evaluators participate in are:

- Association of Energy Service Professionals, http://www.aesp.org.
- International Energy Program Evaluation Conference, http://www.iepec.org.

In addition, the California Measurement Advisory Council (CALMAC) now offers a directory of evaluators: http://www.calmac.org/contractorcontact.asp.

7.3 Evaluation and M&V Plan Outlines

The program evaluation plan should be a formal document that clearly presents the evaluation efforts and details the activities to be undertaken during the evaluation. The evaluation plan is a stand-alone decision document, meaning it must contain the information the evaluator and others need to understand what is to be undertaken and how. The plan is also an important "historical" document in that it is not unusual for programs with long life cycles to undergo staff changes.

The following subsections outline the contents of an impact evaluation plan and an M&V plan. The M&V plan is included because it is a very common approach for calculating gross energy savings. Following the M&V plan outline are evaluation planning checklists.

7.3.1 Evaluation Plan and Report Outlines

The following is a template that can be used to produce an impact evaluation plan.

A. Program Background

1. Short description of the program(s) being evaluated (e.g., the market, approach, technologies, budget, objectives, etc.).
2. Presentation of how the program will save energy and demand, and avoid emissions.
3. List of the technologies offered by the program.
4. Program schedule.
5. Numerical savings and avoided emission goals.

B. Evaluation Overview

1. List of evaluation objectives and how they support program goals.
2. List of which indicators will be reported (e.g., annual MWh, monthly peak kW, annual therms, annual CO_2).
3. Gross and net impact evaluation approaches selected and methodology for calculating avoided emissions, as appropriate.
4. List of primary factors will be considered in analysis of gross and net savings (e.g. weather, occupancy, free riders, spillover).
5. Budget and schedule summary.
6. Listing of evaluators (if known) or evaluator selection method.

C. Detailed Evaluation Approach, Scope, Budget, Schedule, and Staffing

(This is the detailed presentation of the evaluation activities to be undertaken including the M&V option to be used, as appropriate.)

1. Gross impact savings analysis description—a description of the analysis activities and approaches. (If an M&V evaluation approach is selected, identify the IPMVP Option to be used.)

2. Net impact savings analysis description—a description of how spillover, free ridership, and other effects will be addressed in the evaluation activities and in the data analysis.

3. Data collection, handling, and sampling:

   - Measurement collection techniques.
   - Sampling approach and sample selection methods for each evaluation activity that includes sampling efforts.
   - How the comparison group, or non-participant, information will be used in the evaluation(s) and in the analysis.
   - Data handling and data analysis approach to be used to address the researchable issues.

4. Uncertainty of results—presentation and discussion of the threats to validity, potential biases, methods used to minimize bias, and level of precision and confidence associated with the sample selection methods and the evaluation approaches. Quality control information should also be included here.

5. An activities timeline with project deliverable dates.

6. Detailed budget.

7. Selected evaluation team information concerning the independence of the evaluator. Evaluator contact information should be included here.

The product of an evaluation is a report. The following is a sample report outline (taken from DOE, 2003):

- Table of Contents
- List of Figures and Tables
- Acronyms
- Abstract
- Acknowledgments

1. Executive Summary
   (Include highlights of key recommended improvements to the program, if relevant.)

2. Introduction

   - Program Overview (*e.g., program description, objectives*.)
   - Evaluation Objectives and Methods
   - Structure of the Report

3. Study Methodology

   - Data Collection Approach(es)
   - Analysis Methods
   - Limitations, Caveats

4. Key Evaluation Results
   (Answers for all of the questions specified for the evaluation. Could include several sections on findings. Findings could be presented for each method used, by program components covered, by market segments covered, and so forth, followed by a section on integrated findings or organized and presented by the different observed effects or type of results.)

5. Recommendations
   (If relevant; depends on the type of evaluation. Should include clear, actionable, and prioritized recommendations that are supported by the analysis.)

6. Summary and Conclusions

7. Appendices *(examples)*:

   - *Recommended improvements to the evaluation process, including any lessons learned for future evaluation studies.*

- *Appendices containing detailed documentation of the research design and assumptions, data collection methods, evaluation analysis methodology, results tables, etc.*
- *Survey or interview instrument, coding scheme, and compiled results tables and data.*
- *Sources and quality (caveats on data) of primary and secondary information.*
- *Details on quantitative data analysis: analytical framework, modeling approach, and statistical results.*
- *Qualifications and extensions.*
- *Possible sources of overestimation and underestimation.*
- *Treatment of issues concerning double counting, use of savings factors, synergistic effects.*
- *How attribution was addressed (for impact evaluation).*
- *Sensitivity of energy savings estimates.*
- *Assumptions and justifications.*

7.3.2 M&V Plan Outline

If the M&V gross impact evaluation approach is selected, an M&V plan needs to be prepared that is *applicable to each project selected for analysis*. This section discusses the M&V planning process for individual projects and then presents an M&V plan outline.

M&V activities fall into five areas:

1. Selecting one of the four IPMVP Options for the project. The Options define general approaches to documenting savings.
2. Preparing a project-specific M&V plan that outlines the details of what will be done to document savings.
3. Defining the pre-installation baseline, including equipment and systems, baseline energy use, or factors that influence baseline energy use.

Evaluability

"Evaluability," a relatively new addition to the evaluation lexicon, is basically an assessment protocol to increase the probability that evaluation information will be available when evaluations are actually undertaken. Some data (for example, the age of a building) can be gathered at any time; some data are best gathered at the time of evaluation (participant spillover, current hours of operation); and some data must be gathered at the time of implementation or they will be lost forever or rendered unreliable due to changes in personnel or fading recollection (free ridership, removed equipment, or non-participant customer contact). The list below is an example of some of the items included in an evaluability assessment template:

- Is there a way to track participants?
- Is there a way to track non-participants?
- Are specific locations of measures being tracked? Can they be found?
- Are program assumptions being tracked on a site-specific level (e.g., hours of operation)?
- Is the delivered energy saving service and/or installed retrofit being recorded?
- Does the device recording savings include the outcome or result of the activities?
- Are savings assumptions documented?
- Is the source of savings assumptions specified?
- Are the pre-retrofit or baseline parameters being recorded?
- Does the database record the "as-found" values for parameters used to estimate ex ante savings?
- Does baseline monitoring need to take place?
- Can one of the impact evaluation methods specified in this Guide be used?
- Are there code compliance or program overlap issues for savings estimation?

4. Defining the reporting period situation, including equipment and systems, post-installation energy use, and factors that influence post-installation

energy use. Site surveys; spot, short-term, or long-term metering; and/or analysis of billing data can also be used for the reporting period assessment.

5. Conducting periodic (typically annual) M&V activities to verify the continued operation of the installed equipment or system, determine current year savings, identify factors that may adversely affect savings in the future, and estimate savings for subsequent years.

A project-specific M&V plan should describe in reasonable detail what will be done to document the savings from a project. It can be a plan for each energy efficiency measure included in the project—for example, when a retrofit isolation approach is used. Or, it can cover the entire project—for example, when the whole-facility analyses approach is used. The M&V plan will consider the type of energy efficiency measures involved and the desired level of accuracy.

The M&V plan should include a project description, facility equipment inventories, descriptions of the proposed measures, energy savings estimates, a budget, and proposed construction and M&V schedules. A project-specific M&V plan should demonstrate that any metering and analysis will be done consistently, logically, and with a level of accuracy acceptable to all parties.

The following is a recommended M&V plan outline:

1. Description of project, measures to be installed, and project objectives.
2. Selected IPMVP Option and measurement boundary.
3. Description of base year conditions, data collection, and analyses.
4. Identification of any changes to base year conditions and how they will be accounted for.
5. Description of reporting period conditions, data collection. and analyses.
6. Basis for adjustments that may be made to any measurements and how this will be done.
7. Specification of exact analysis procedures.
8. Metering schedule and equipment specifications.

Table 7-1. Energy Efficiency Project M&V Plan Content—General Components

Category	M&V Plan Components
Project Description	Project goals and objectives
	Site characteristics and constraints (e.g., absence of utility meter data at site)
	Measure descriptions that include how savings will be achieved
Project Savings and Costs	Estimated savings by measure
	Estimated M&V cost by measure
Scheduling	Equipment installations
	M&V activities
Reporting	Raw data format
	Compiled data format
	Reporting interval
M&V Approach	Confidence and precision requirements
	Options used
	Person(s) responsible for M&V activities

Table 7-2. Energy Efficiency Project-Specific M&V Plan Contents—Measure-Specific Components

Category	M&V Plan Components	Examples
Analysis Method	Data requirements	kW, operating hours, temperature
	Basis of stipulated values	Lighting operating hours equal 4,000/year based on metered XYZ building
	Savings calculation equations	kWh savingst = [(kW/Fixturebaseline × Quantitybaseline) – (kW/Fixturepost × Quantitypost)] × Operating Hours
	Regression expressions	Three parameter change-point cooling model
	Computer simulation models	DOE-2 simulation model
Metering and Monitoring	Metering protocols	ASHRAE Guideline 14 pump multiple point test throughout short-term monitoring
	Equipment	ABC Watt Hour Meter
	Equipment calibration protocols	National Institute of Science and Technology protocols
	Metering points	Flow rate, RMS power
	Sample size	25 lighting circuits out of 350
	Sampling accuracy	90% confidence/10% precision
	Metering duration and interval	2 weeks/15-minute data
Baseline Determination	Performance factors	Boiler efficiency
	Operating factors	Load, operating hours
	Existing service quality	Indoor temperature set points
	Minimum performance standards	State energy code
Savings Adjustments	Party responsible for developing adjustments	Smith Engineers, hired by sponsor
	Savings adjustment approach	Baseline adjusted for reported period weather and building occupancy levels

9. Description of expected accuracy and how it will be determined.
10. Description of quality assurance procedures.
11. Description of budget and schedule.
12. Description of who will conduct M&V.

The following tables summarize what could be contained in the M&V plans. Table 7-2 lists general requirements for an overall plan. Table 7-3 lists requirements that could be addressed for each measure (e.g., building lighting retrofit, building air conditioning retrofit, control system upgrade) that is included in the project being evaluated. More information on the contents of an M&V Plan can be found in the IPMVP (EVO, 2007).

7.3.3 Checklists of Planning Decisions for an Impact Evaluation

The following four tables present checklists for preparing an impact evaluation plan. They are organized around the decisions associated with the gross savings calculation, net savings calculation, calculation of avoided emissions, and generic issues.

Table 7-3. Checklist for Gross Impact Evaluation (Chapter 4)

Savings to Be Reported	
Energy savings (annual, seasonal, monthly, hourly, other)	
Demand savings (peak, coincident, average, other)	
Selected Gross Energy Savings Calculation Approach	
Measurement and verification approach	
Deemed savings approach	
Large-scale billing analysis approach	
Quality assurance approach	
Measurement and Verification Approach	
IPMVP Option A, B, C, or D	
Deemed Savings Approach	
Source of deemed savings identified and verified	
Large-Scale Billing Analysis Approach	
Time-series comparison	
Control group comparison	
Control group, time-series comparison	
Sample Size Criteria Selected	

Table 7-4. Checklist for Net Impact Evaluation (Chapter 5)

Net Savings Factors to Be Evaluated	
Free ridership	
Spillover effects	
Rebound effect	
Electricity T&D losses	
Other(s)	
Net Savings Calculation Approach Selected	
Self-reporting surveys	
Enhanced self-reporting surveys	
Econometric methods	
Stipulated net-to-gross ratio	
Sample Size Criteria Selected	

Table 7-5. Checklist for Avoided Emissions Calculations (Chapter 6)

Electricity efficiency savings—grid-connected	
Operating or build margin evaluated, or both	
System average emissions rate	
Hourly dispatch model emissions rate	
Middle ground emissions rate	
Natural Gas, Fuel Oil, and Non-Grid-Connected Electric Generating Units	
Default emission factor	
Source testing	

Table 7-6. Generic Evaluation Considerations

Overall Goals	
Does the evaluation address the key policy, regulatory, and oversight needs for evaluation information?	
Will the program success in meeting energy, demand, and emissions goals be quantifiably evaluated in the same manner as they are defined for the program?	
Does the evaluation plan represent a reasonable approach to addressing the information needs?	
Are there missing opportunities associated with the evaluation approach that should be added or considered? Are any additional co-benefits being evaluated?	
Does the impact evaluation provide the data needed to inform other evaluations that may be performed, particularly cost-effectiveness analyses?	
Has a balance been reached between evaluation costs, uncertainty of results, and value of evaluation results?	
Uncertainty of Evaluation Results	
Can the confidence and precision of the evaluation results be quantified? If so, how?	
Are there key threats to the validity of the conclusions? Are they being minimized given budget constraints and study tradeoffs? Will they be documented and analyzed?	
Is the evaluation capable of providing reliable conclusions on energy and other impacts?	
Budget, Timing, and Resources	
Does the evaluation take advantage of previous evaluations and/or concurrent ones for other programs?	
Does the cost of the study match the methods and approaches planned?	
Do the scheduled start and end times of the evaluation match the need for adequate data gathering, analysis, and reporting?	
Are adequate human resources identified?	
Does the evaluation rely on data and project access that are reasonably available?	
Reporting	
Are the time frames and scopes of evaluation reported defined?	
Do the data collection, analysis, and quality control match the reporting needs?	
Are the persistence of savings and avoided emissions being evaluated?	
Have measurement and impacts (emissions) boundaries been properly set?	
Sampling and Accuracy	
Is the sampling plan representative of the population served?	
Is the sampling plan able to support the evaluation policy objectives?	
Are there threats to the validity of the evaluation results that are incorporated into the evaluation design?	

7.4 Notes

1. A companion National Action Plan document that addresses program planning is the *Guide to Resource Planning with Energy Efficiency*, available at www.epa.gov/eeactionplan.

2. In early replacement projects, a consideration in whether to use existing conditions or code requirements for a baseline is if the replaced equipment or systems had a remaining lifetime shorter that the time period of the evaluation. In this situation, the first year(s) of the evaluation might have an existing condition baseline and the later years a code requirements baseline.

3. The CMVP program is a joint activity of the Efficiency Valuation Organization and the Association of Energy Engineers (AEE). It is accessible through EVO's Web site, <http://www.evo-world.org>.

Appendix A: National Action Plan for Energy Efficiency Leadership Group

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Appendix B: Glossary

This glossary is based primarily on three evaluation-related reference documents:

1. 2007 IPMVP
2. 2004 California Evaluation Framework
3. 2006 DOE EERE Guide for Managing General Program Evaluation Studies

In some cases, the definitions presented here differ slightly from the reference documents. This is due to discrepancies across documents and author interpretations.

Additionality: A criterion that says avoided emissions should only be recognized for project activities or programs that would not have "happened anyway." While there is general agreement that additionality is important, its meaning and application remain open to interpretation.

Adjustments: For M&V analyses, factors that modify baseline energy or demand values to account for independent variable values (conditions) in the reporting period.

Allowances: Allowances represent the amount of a pollutant that a source is permitted to emit during a specified time in the future under a cap and trade program.. Allowances are often confused with credits earned in the context of project-based or offset programs, in which sources trade with other facilities to attain compliance with a conventional regulatory requirement. Cap and trade program basics are discussed at the following EPA Web site: http://www.epa.gov/airmarkets/cap-trade/index.html.

Analysis of covariance (ANCOVA) model. A type of regression model also referred to as a "fixed effects" model.

Assessment boundary: The boundary within which all the primary effects and significant secondary effects associated with a project are evaluated.

Baseline: Conditions, including energy consumption and related emissions, that would have occurred without implementation of the subject project or program. Baseline conditions are sometimes referred to as "business-as-usual" conditions. Baselines are defined as either project-specific baselines or performance standard baselines.

Baseline period: The period of time selected as representative of facility operations before the energy efficiency activity takes place.

Bias: The extent to which a measurement or a sampling or analytic method systematically underestimates or overestimates a value.

California Measurement Advisory Council (CALMAC): An informal committee made up of representatives of the California utilities, state agencies, and other interested parties. CALMAC provides a forum for the development, implementation, presentation, discussion, and review of regional and statewide market assessment and evaluation studies for California energy efficiency programs conducted by member organizations.

Co-benefits: The impacts of an energy efficiency program other than energy and demand savings.

Coincident demand: The metered demand of a device, circuit, or building that occurs at the same time as the peak demand of a utility's system load or at the same time as some other peak of interest, such as building or facility peak demand. This should be expressed so as to indicate the peak of interest (e.g., "demand coincident with the utility system peak") Diversity factor is defined as the ratio of the sum of the demands of a group of users to their coincident maximum demand. Therefore, diversity factors are always equal to one or greater.

Comparison group: A group of consumers who did not participate in the evaluated program during the program year and who share as many characteristics as possible with the participant group.

Conditional Savings Analysis (CSA): A type of analysis in which change in consumption modeled using regression analysis against presence or absence of energy efficiency measures.

Confidence: An indication of how close a value is to the true value of the quantity in question. Confidence is the likelihood that the evaluation has captured the true impacts of the program within a certain range of values (i.e., precision).

Cost-effectiveness: An indicator of the relative performance or economic attractiveness of any energy efficiency investment or practice. In the energy efficiency field, the present value of the estimated benefits produced by an energy efficiency program is compared to the estimated total costs to determine if the proposed investment or measure is desirable from a variety of perspectives (e.g., whether the estimated benefits exceed the estimated costs from a societal perspective).

Database for Energy-Efficient Resources (DEER): A California database designed to provide well-documented estimates of energy and peak demand savings values, measure costs, and effective useful life.

Deemed savings: An estimate of an energy savings or energy-demand savings outcome (gross savings) for a single unit of an installed energy efficiency measure that (a) has been developed from data sources and analytical methods that are widely considered acceptable for the measure and purpose and (b) is applicable to the situation being evaluated.

Demand: The time rate of energy flow. Demand usually refers to electric power measured in kW (equals kWh/h) but can also refer to natural gas, usually as Btu/hr, kBtu/hr, therms/day, etc.

Direct emissions: Direct emissions are changes in emissions at the site (controlled by the project sponsor or owner) where the project takes place. Direct emissions are the source of avoided emissions for thermal energy efficiency measures (e.g., avoided emissions from burning natural gas in a water heater).

Effective useful life: An estimate of the median number of years that the efficiency measures installed under a program are still in place and operable.

Energy efficiency: The use of less energy to provide the same or an improved level of service to the energy consumer in an economically efficient way; or using less energy to perform the same function. "Energy conservation" is a term that has also been used, but it has the connotation of doing without a service in order to save energy rather than using less energy to perform the same function.

Energy efficiency measure: Installation of equipment, subsystems or systems, or modification of equipment, subsystems, systems, or operations on the customer side of the meter, for the purpose of reducing energy and/or demand (and, hence, energy and/or demand costs) at a comparable level of service.

Engineering model: Engineering equations used to calculate energy usage and savings. These models are usually based on a quantitative description of physical processes that transform delivered energy into useful work such as heat, lighting, or motor drive. In practice, these models may be reduced to simple equations in spreadsheets that calculate energy usage or savings as a function of measurable attributes of customers, facilities, or equipment (e.g., lighting use = watts × hours of use).

Error: Deviation of measurements from the true value.

Evaluation: The performance of studies and activities aimed at determining the effects of a program; any of a wide range of assessment activities associated with understanding or documenting program performance, assessing program or program-related markets and market operations; any of a wide range of evaluative efforts including assessing program-induced changes in energy efficiency markets, levels of demand or energy savings, and program cost-effectiveness.

Ex ante savings estimate: Forecasted savings used for program and portfolio planning purposes. (From the Latin for "beforehand.")

Ex post evaluation estimated savings: Savings estimates reported by an evaluator after the energy impact evaluation has been completed. (From the Latin for "from something done afterward.")

Free driver: A non-participant who has adopted a particular efficiency measure or practice as a result of the evaluated program.

Free rider: A program participant who would have implemented the program measure or practice in the absence of the program. Free riders can be total, partial, or deferred.

Gross savings: The change in energy consumption and/or demand that results directly from program-related actions taken by participants in an efficiency program, regardless of why they participated.

Impact evaluation: An evaluation of the program-specific, directly induced changes (e.g., energy and/or demand usage) attributable to an energy efficiency program.

Independent variables: The factors that affect energy use and demand, but cannot be controlled (e.g., weather or occupancy).

Indirect emissions: Changes in emissions that occur at the emissions source (e.g., the power plant). Indirect emissions are the source of avoided emissions for electric energy efficiency measures.

Interactive factors: Applicable to IPMVP Options A and B; changes in energy use or demand occurring beyond the measurement boundary of the M&V analysis.

Leakage: In the context of avoided emissions, emissions changes resulting from a project or program not captured by the primary effect (typically the small, unintended emissions consequences). Sometimes used interchangeably with "secondary effects," although leakage is a more "global" issue whereas secondary, interactive effects tend to be considered within the facility where a project takes place.

Load shapes: Representations such as graphs, tables, and databases that describe energy consumption rates as a function of another variable such as time or outdoor air temperature.

Market effect evaluation: An evaluation of the change in the structure or functioning of a market, or the behavior of participants in a market, that results from one or more program efforts. Typically the resultant market or behavior change leads to an increase in the adoption of energy-efficient products, services, or practices.

Market transformation: A reduction in market barriers resulting from a market intervention, as evidenced by a set of market effects, that lasts after the intervention has been withdrawn, reduced, or changed.

Measurement: A procedure for assigning a number to an observed object or event.

Measurement and verification (M&V): Data collection, monitoring, and analysis associated with the calculation of gross energy and demand savings from individual sites or projects. M&V can be a subset of program impact evaluation.

Measurement boundary: The boundary of the analysis for determining direct energy and/or demand savings.

Metering: The collection of energy consumption data over time through the use of meters. These meters may collect information with respect to an end-use, a circuit, a piece of equipment, or a whole building (or facility). Short-term metering generally refers to data collection for no more than a few weeks. End-use metering refers specifically to separate data collection for one or more end-uses in a facility, such as lighting, air conditioning or refrigeration. Spot metering is an instantaneous measurement (rather than over time) to determine an energy consumption rate.

Monitoring: Gathering of relevant measurement data, including but not limited to energy consumption data, over time to evaluate equipment or system performance, e.g., chiller electric demand, inlet evaporator temperature and flow, outlet evaporator temperature, condenser inlet temperature, and ambient dry-bulb temperature and relative humidity or wet-bulb temperature, for use in developing a chiller performance map (e.g., kW/ton vs. cooling load and vs. condenser inlet temperature).

Net savings: The total change in load that is attributable to an energy efficiency program. This change in load may include, implicitly or explicitly, the effects of free drivers, free riders, energy efficiency standards, changes in the level of energy service, and other causes of changes in energy consumption or demand.

Net-to-gross ratio (NTGR): A factor representing net program savings divided by gross program savings that is applied to gross program impacts to convert them into net program load impacts.

Non-participant: Any consumer who was eligible but did not participate in the subject efficiency program, in a given program year. Each evaluation plan should provide a definition of a non-participant as it applies to a specific evaluation.

Normalized annual consumption (NAC) analysis: A regression-based method that analyzes monthly energy consumption data.

Participant: A consumer that received a service offered through the subject efficiency program, in a given program year. The term "service" is used in this definition to suggest that the service can be a wide variety of services, including financial rebates, technical assistance, product installations, training, energy efficiency information or other services, items, or conditions. Each evaluation plan should define "participant" as it applies to the specific evaluation.

Peak demand: The maximum level of metered demand during a specified period, such as a billing month or a peak demand period.

Persistence study: A study to assess changes in program impacts over time (including retention and degradation).

Portfolio: Either (a) a collection of similar programs addressing the same market (e.g., a portfolio of residential programs), technology (e.g., motor efficiency programs), or mechanisms (e.g., loan programs) or (b) the set of all programs conducted by one organization, such as a utility (and which could include programs that cover multiple markets, technologies, etc.).

Potential studies: Studies conducted to assess market baselines and savings potentials for different technologies and customer markets. Potential is typically defined in terms of technical potential, market potential, and economic potential.

Precision: The indication of the closeness of agreement among repeated measurements of the same physical quantity.

Primary effects: Effects that the project or program are intended to achieve. For efficiency programs, this is primarily a reduction in energy use per unit of output.

Process evaluation: A systematic assessment of an energy efficiency program for the purposes of documenting program operations at the time of the examination, and identifying and recommending improvements to increase the program's efficiency or effectiveness for acquiring energy resources while maintaining high levels of participant satisfaction.

Program: A group of projects, with similar characteristics and installed in similar applications. Examples could include a utility program to install energy-efficient lighting in commercial buildings, a developer's program to build a subdivision of homes that have photovoltaic systems, or a state residential energy efficiency code program.

Project: An activity or course of action involving one or multiple energy efficiency measures, at a single facility or site.

Rebound effect: A change in energy-using behavior that yields an increased level of service and occurs as a result of taking an energy efficiency action.

Regression analysis: Analysis of the relationship between a dependent variable (response variable) to specified independent variables (explanatory variables). The mathematical model of their relationship is the regression equation.

Reliability: Refers to the likelihood that the observations can be replicated.

Reporting period: The time following implementation of an energy efficiency activity during which savings are to be determined.

Resource acquisition program: Programs designed to directly achieve energy and or demand savings, and possibly avoided emissions

Retrofit isolation: The savings measurement approach defined in IPMVP Options A and B, and ASHRAE Guideline 14, that determines energy or demand savings through the use of meters to isolate the energy flows for the system(s) under consideration.

Rigor: The level of expected confidence and precision. The higher the level of rigor, the more confident one is that the results of the evaluation are both accurate and precise.

Secondary effects: Unintended impacts of the project or program such as rebound effect (e.g., increasing energy use as it becomes more efficient and less costly to use), activity shifting (e.g., when generation resources move to another location), and market leakage (e.g., emission changes due to changes in supply or demand of commercial markets). These secondary effects can be positive or negative.

Spillover: Reductions in energy consumption and/or demand caused by the presence of the energy efficiency program, beyond the program-related gross savings of the participants. There can be participant and/or non-participant spillover.

Statistically adjusted engineering (SAE) models: A category of statistical analysis models that incorporate the engineering estimate of savings as a dependent variable.

Stipulated values: See "deemed savings."

Takeback effect: See "rebound effect."

Uncertainty: The range or interval of doubt surrounding a measured or calculated value within which the true value is expected to fall within some degree of confidence.

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Appendix C: Other Evaluation Types

C.1 Process, Market Effects, and Cost-Effectiveness Evaluations

The following subsections briefly introduce two other, non-impact types of evaluations and cost-effectiveness analysis. These types of evaluations can involve interrelated activities and have interrelated results, and are often conducted at the same time. Table C-1 compares these three types plus impact evaluations.

C.1.1 Process Evaluations

The goal of process evaluations is to produce improved and more cost-effective programs. Thus, process evaluations examine the efficiency and effectiveness of program implementation procedures and systems. These evaluations usually consist of asking questions of those involved in the program, analyzing their answers, and comparing results to established best practices.

Process evaluations are particularly valuable when:

- The program is new or has many changes.
- Benefits are being achieved more slowly than expected.
- There is limited program participation or stakeholders are slow to begin participating.
- The program has a slow startup.
- Participants are reporting problems.
- The program appears not to be cost-effective.

Typical process evaluation results involve recommendations for changing a program's structure, implementation approaches, or program design, delivery, and goals.

The primary mechanism of process evaluations is data collection (e.g., surveys, questionnaires, and interviews) from administrators, designers, participants (such as facility operators), implementation staff (including contractors, subcontractors, and field staff), and key policy makers. Other elements of a process evaluation can include workflow and productivity measurements; reviews, assessments, and testing of records, databases, program-related materials, and tools; and possibly

Table C-1. Program Evaluation Types

Evaluation Type	Description	Uses
Impact Evaluation	Quantifies direct and indirect benefits of the program.	Determines the amount of energy and demand saved, the quantity of emissions reductions, and possibly the co-benefits.
Process Evaluations	Indicates how the program implementation procedures are performing from both administration and participant perspectives.	Identifies how program processes can be improved.
Market Effects Evaluation	Indicates how the overall supply chain and market have been affected by the program.	Determines changes that have occurred in markets and whether they are sustainable with or without the program.
Cost-Effectiveness Evaluation	Quantifies the cost of program implementation and compares with program benefits.	Determines whether the energy efficiency program is a cost-effective investment as compared to other programs and energy supply resources.

Table C-2. Elements of a Typical Process Evaluation

• Program Design – The program mission – Assessment of program logic – Use of new practices or best practices	• Program Administration – Program oversight – Program staffing – Management and staff training – Program information and reporting
• Program Implementation – Quality control – Operational practice—how program is implemented – Program targeting, marketing, and outreach efforts – Program timing	• Participant Response – Participant interaction and satisfaction – Market and government allies interaction and satisfaction

collection and analysis of relevant data from third-party sources (e.g., equipment vendors, trade allies).

Table C-2 lists examples of the issues that are typically assessed during a process evaluation.

C.1.2 Market Effects Evaluations

Program-induced changes that affect non-participants or the way a market operates are addressed in market effects evaluations. One way to think of these is that they estimate the effect a program has on future energy efficiency activities.

Market effects evaluations often involve a significant undertaking, since they are designed to determine whether the market is changing. For example, a market effects study could evaluate increases in the adoption of the products or services being promoted by the program (or more likely, a portfolio of programs). It might answer the question: Are vendors stocking and promoting more energy efficiency technologies as a result of the program? Market effects are sometimes called the ultimate test of a program's success, answering the question—will efficiency best practices continue in the marketplace, even after the current program ends?

Potential Studies

Another form of market study is called a potential study. Potential studies are conducted before a program is implemented in order to assess market baselines and savings potentials for different technologies and customer markets. These studies can also assess customer needs and barriers to adoption of energy efficiency, as well as how best to address these barriers through program design. Potential studies indicate what can be expected in terms of savings from a program. Potential is often defined in terms of *technical potential* (what is technically feasible given commercially available products and services), *economic potential* (which is the level of savings that can be achieved assuming a certain level of participant and/or societal cost-effectiveness is required), and *market potential* (what the market can provide, which is almost always less than market potential). Findings also help managers identify the program's key markets and clients and how to best serve the intended customers.

Market effects evaluations usually consist of surveys, reviews of market data, and analysis of the survey results and collected data. Some possible results from a market assessment include:

- Total market effects.
- An estimate of how much of the market effect is due to the program being evaluated.
- An estimate of whether the market effect is sustainable.

A market effects evaluation analyzes:

- Are the entities that undertook efficiency projects undertaking additional projects or incorporating additional technologies in their facilities that were not directly induced by the program? This might indicate that the facility operators have become convinced of the value of, for example, high-efficiency motors, and are installing them on their own.
- Are entities that did not undertake projects now adopting concepts and technologies that were encouraged by the program? This might indicate that the program convinced other facility operators of the advantages of the efficiency concepts.
- Are manufacturers, distributors, vendors, and others involved in the supply chain of efficiency products (and services) changing their product offerings, how they are marketing them, how they are pricing them, stocking them, etc.? The answers can indicate how the supply chain is adapting to changes in supply of and demand for efficiency products.

As can be deduced, the market effects evaluation can easily overlap with the spillover analyses conducted as part of an impact evaluation. Market effects studies, however, are interested in long-term, sustained effects, versus a more short-term spillover perspective. According to a study by the New England Efficiency Partnership (NEEP, 2006), most programs use direct participation and spillover as the basis for estimating market transformation program benefits, rather than projections of baselines and market penetration. Anecdotal evidence suggests that measurement of participant spillover is relatively common, while measurement of non-participant spillover is inconsistent across program administrators. About one fourth of the states in the 2006 study estimated ultimate effects by projecting change in market penetration relative to a projected baseline for at least some of their market transformation programs.

C.1.3 Cost-Effectiveness Analyses

Cost-effectiveness (sometime called cost-benefit) evaluations compare program benefits and costs, showing the relationship between the value of a program's outcomes and the costs incurred to achieve those benefits. The findings help program managers judge whether to retain, revise, or eliminate program elements and provide feedback on whether efficiency is a wise investment as compared to energy generation and/or procurement options. It also often a key component of the evaluation process for programs using public or utility ratepayer funds.

A variety of frameworks have historically been used to assess cost-effectiveness of energy efficiency initiatives. In the late 1970s, CPUC implemented a least-cost planning strategy in which demand-side reductions in energy use were compared to supply additions. One result of this strategy was *The Standard Practice Manual* (SPM). This document provided several methodologies for conducting cost-benefit analyses of utility-administered efficiency programs. The first version of the SPM was published in 1983. The document has been updated from time to time, with the most reason version dated 2001 (California State Governor's Office, 2001). The SPM is perhaps the definitive resource for information on cost-effectiveness tests for efficiency programs.

The SPM established several tests that can be used to evaluate the cost-effectiveness of publicly funded energy efficiency initiatives. These include the ratepayer impact measure test, the utility cost test, the participant test, the total resource cost test, and the societal test. These metrics vary in terms of (a) their applicability to different program types, (b) the cost and benefit elements included in the calculation, (c) the methods by which the cost and benefit elements are computed, and (d) the uses of the results. Most regulated utility efficiency programs use one or more versions of these tests, sometimes with variations unique to the requirements of a particular regulatory commission. Definitions of these tests (paraphrased from the SPM) are provided below.

- **Total resource cost (TRC) test.** The TRC test measures the net costs of a demand-side management program as a resource option based on the total costs of the program, including both the participants' and the utility's costs. The TRC ratio equals the benefits of the program, in terms of value of energy and demand saved, divided by the net costs. The ratio is usually calculated on a life-cycle basis considering savings and costs that accrue over the lifetime of installed energy efficiency equipment, systems, etc. When the TRC test is used, if the ratio is greater than 1.0, then the program is considered cost-effective, with of course proper consideration of uncertainties in the TRC ratio calculation. This is probably the most commonly applied cost-effectiveness test.
- **Utility cost (UC) test.** The UC test measures the net costs of a demand-side management program as a resource option based on the costs incurred by the administrator of the program (assumed to be a utility, though it can be any organization), excluding any net costs incurred by the participant. The benefits are the same as the TRC benefits (energy and demand savings value), but the costs are defined more narrowly and do not include consumer costs.
- **Participant test.** The participant test assesses cost-effectiveness from the participating consumer's perspective by calculating the quantifiable benefits and costs to the consumer of participating in a program. Since many consumers do not base their decision to participate entirely on quantifiable variables, this test is not necessarily a complete measure of all the benefits and costs a participant perceives.
- **Societal test.** The societal test, a modified version of the TRC, adopts a societal rather than a utility service area perspective. The primary difference between the societal and TRC tests is that, to calculate life cycle costs and benefits, the societal test accounts for externalities (e.g., environmental benefits), excludes tax credit benefits, and uses a societal discount rate.
- **Ratepayer impact measure (RIM) test.** The RIM test only applies to utility programs. It measures what happens to consumer bills or rates due to changes in utility revenues and operating costs caused by the program. This test indicates the direction and magnitude of the expected change in customer bills or rate levels.

C.2 Evaluating Other Program Types

This Guide focuses on the evaluation of programs whose primary goal is to directly achieve energy and demand savings and perhaps avoided emissions—resource acquisition programs. While all efficiency programs hope to achieve savings, some are designed to achieve these savings more indirectly. Evaluation of three other common program types (market transformation, codes and standards, and education and training) is briefly discussed below.

C.2.1 Market Transformation Programs

Market transformation (MT) denotes a permanent, or at least long-term, change in the operation of the market for energy efficiency products and services. MT programs attempt to reduce market barriers through market interventions that result in documented market effects that lasts after the program (intervention) has been withdrawn reduced or changed. During the 1990s, the focus of many energy efficiency efforts shifted from resource acquisition to market transformation. Subsequently there has been a shift back; resource acquisition, MT, and other program types are now implemented, often in a complementary manner. To a large extent, all programs can be considered MT in that they involve changing how energy efficiency activities take place in the marketplace.

MT evaluation tends to be a combination of impact, process, and market effect evaluation and can also include cost-effectiveness evaluations. However, given that the ultimate aim of MT programs is to increase the adoption of energy efficient technologies and practices, MT evaluation usually focuses first on energy efficiency adoption rates by market actors and second on the directly associated energy and demand savings. Also, MT programs are dynamic, and thus the nature of market effects can be expected to vary over time. Market actors that influence end-use consumer choices include installation and repair contractors, retailer staffs, architects, design engineers, equipment distributors, manufacturers, and of course the consumers themselves.

Evaluation plays an important role in providing the kind of feedback that can be used to refine the design of market interventions. This role is equally important for resource acquisition and MT interventions, but arguably more complex for MT programs since the interest is long-term changes in the market versus more immediate and direct energy savings for resource acquisition programs. Most importantly, evaluation for MT entails the collection of information that can be used to refine the underlying program theory (see side bar).

Evaluation of MT interventions also needs to focus on the mechanism through which changes in adoptions and energy usage are ultimately induced. This means that considerable attention must be focused on indicators of market effects through market tracking. Thus, a MT evaluation might first report changes in sales patterns and volumes for particular efficiency products as an indication of program progress in meeting program goals. (For more information on MT evaluation, see DOE, 2007).

C.2.2 Codes and Standards Programs

Most codes and standards programs involve (a) new or changed building codes or appliance and equipment standards and/or (b) increasing the level of compliance with code requirements or appliance standards. These programs are intended to save energy and demand and achieve co-benefits, primarily in new construction or major retrofits (for building codes) or when new equipment is purchased (appliance and equipment standards).

The primary approach to establishing energy and demand savings (and avoided emissions) values for the codes and standards programs is to assess the energy and demand impacts of the market adoption and decision changes caused by the new, modified, or better-enforced codes or standards and then adjust those savings to account for what would have occurred if the code or standard change or enforcement did not occur. The evaluation must identify the net energy impacts that

Theory-Based Evaluation: a Guiding Principle for MT Evaluation

Theory-based evaluation (TBE), an evaluation approach that has been widely used in the evaluation of social programs in other fields, has gained some foothold in the energy efficiency industry over the past few years. It involves a relatively detailed and articulated *program theory*, established up front, that specifies the sequence of events a program is intended to cause, along with the precise causal mechanisms leading to these events. Evaluation then focuses on testing the consistency of observed events with the overall program theory.

A TBE can be considered a process of determining whether a program theory is correct or not (i.e., testing a hypothesis). For example, with an incentive program, the theory is that paying a certain level of incentives will result in a certain level of energy and demand savings.

Having well-defined program theories helps focus an evaluation objective on assessing the validity of those theories, primarily to see whether a program concept is successful and should be expanded and/or repeated.

In the energy efficiency field to date, TBE is particularly well adapted to evaluating the effectiveness of market transformation initiatives. This is largely because market transformation tends to take a relatively long time to occur, involve a relatively large number of causal steps and mechanisms, and encompass changing the behavior of multiple categories of market actors, all of which makes it particularly fruitful to focus on specifying and testing a detailed and articulated program theory.

Provided by Ralph Prahl.

can be directly attributed to the program's actions that would not have occurred over the course of the normal, non-program-influenced operations of the market. For example, analysis of a new appliance standard would involve (a) estimating the life-cycle savings associated with each new appliance placed into service as compared to a standard practice or old-standard appliances, (b) multiplying those savings by the rate over time that the new appliances are placed into service, and (c) adjusting the resulting savings estimate by the number of high-efficiency appliances that consumers would have purchased even if the standard were not in place.

C.2.3 Education and Training Programs

Education and training programs only indirectly result in energy and demand savings. They can include advertising, public service announcements, education efforts, training activities, outreach efforts, demonstration projects, and other information- or communication-based efforts. These programs may be targeted to either end-use customers or other market actors whose activities influence the energy-related choices of end-use customers.

Typically, information and education programs have one or more of the following general goals:

- Educate energy consumers regarding ways to increase the energy efficiency of their facilities and activities, and thus convince them to take actions that help them manage their consumption or adopt more energy-efficient practices.
- Inform energy consumers and/or other market actors about program participation opportunities in order to increase enrollment in these programs.
- Inform energy consumers and/or other market actors about energy issues, behaviors, or products in an effort to transform the normal operations of the market.

Almost every energy efficiency program provides some level of educational and/or informational content. However, education-specific programs are typically designed to achieve energy or demand savings indirectly through changes in behavior, over time (market transformation) or via increased enrollments in other resource acquisition programs.

Understanding and Affecting Behavior

Some recent energy efficiency program efforts have focused on understanding the behavior and decision-making of individuals and organizations with respect to the design, adoption, and use of energy efficiency actions and on using that knowledge to help accelerate the implementation of energy efficiency activities. The proceedings of the 2007 Behavior, Energy and Climate Change Conference provide information on these approaches. See <http://ciee.ucop.edu/>.

For education and training programs, evaluations focus on documenting the degree to which the programs are achieving their desired effects within the markets targeted by the program, which is educating and training people on energy efficiency. The primary mechanisms for this type of evaluation are surveys and focus groups. The following are examples of information topics that may be collected as part of surveys and focus groups (paraphrased from the *California Protocols*):

- Information and education program evaluation topics:
  - Number and percent of customers reached or made aware.
  - Number and percent of customers reached who take recommended actions.
  - Number and type of actions taken as a result of the program.
  - Changes in awareness or knowledge by topic or subject area, by type of customer targeted.
  - Customer perception of the value of the information and/or education received.
  - Elapsed time between information exposure and action(s) taken by type of customer targeted.
  - Attribution of cause for actions taken when multiple causes may be associated with the actions taken.
  - Influence of the program on dealers, contractors, and trade allies.

- Effects of the program on manufacturers and distributors.

- Training program evaluation topics:
  - Pre-program level of knowledge to compare with post-program levels.
  - The specific knowledge gained through the program.
  - The relevance and usefulness of the training as it relates to the participants' to specific needs and opportunities to use the information.
  - Future opportunities and plans for incorporating the knowledge gained into actions or behaviors that provide energy impacts.
  - Whether participants would recommend the training to a friend or colleague.
  - Participant recommendations for improving the program.

Note that programs with large training efforts, or programs designed solely for training, should have evaluation designs that are mindful of the rich literature and methods on evaluating training programs that are available from the larger evaluation community.

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Appendix D: Uncertainty[1]

This appendix provides an introduction on how uncertainty is defined, as well as an overview of the range of factors that contribute to uncertainty and the impact of each of these. This discussion's target audience is evaluators who need an introduction to uncertainty and managers responsible for overseeing evaluations, such as government, regulatory agency staff, and utility staff responsible for energy efficiency evaluations. This appendix assumes readers are *not* trained statisticians and does not aim to provide the reader with all of the tools, formulas, and programs to calculate measures of uncertainty. Rather, we seek to provide the reader with a solid foundation for understanding key concepts and determining evaluation strategies for identifying and mitigating uncertainty. Finally, we wish to provide readers with the ability to review, as needed, more technical and detailed discussions of each source of uncertainty and its mitigation.

D.1 Sources of Uncertainty

Uncertainty is a measure of the "goodness" of an estimate. Without some measurement of uncertainty, it is impossible to judge an estimate's value as a basis for decision-making: uncertainty is the amount or range of doubt surrounding a measured or calculated value. Any report of gross or net program savings, for instance, has a halo of uncertainty surrounding the reported value relative to the true gross or net savings (which are not known). Defined this way, uncertainty is an overall indicator of how well a calculated or measured value represents a true value.

Program evaluation seeks to reliably determine energy and demand *savings* (and, potentially, non-energy benefits) with some reasonable accuracy. This objective can be affected by:

- **Systematic sources of error,** such as measurement error, non-coverage error, and non-response error.
- **Random error**—error occurring by chance, attributable to using a population sample rather than a census to develop the calculated or measured value.

The distinction between systematic and random error is important because different procedures are required to identify and mitigate each. The amount of random error can be estimated using statistical tools, but other means are needed for systematic error. While additional investment in the estimation process reduce both types of error, tradeoffs between evaluation costs and reductions in uncertainty are inevitably required.

D.1.1. Sources of Systematic Error

Systematic errors potentially occur from the way data are:

- **Measured.** At times, equipment used to measure consumption may not be completely accurate. Human errors (e.g., errors in recording data) can also cause this type of error. Measurement error is reduced by investing in more accurate measurement technology and more accurately recording and checking data. The magnitude of such errors is often not large enough to warrant concern in a program evaluation and is largely provided by manufacturer's specifications. In most applications, this error source is ignored, particularly when data sources are utility-grade electricity or natural gas meters. However, other types of measurements, such as flow rates in water or air distribution systems, can have significant errors.
- **Collected.** If some parts of a population are not included in the sample, non-coverage errors result, and the value calculated from the sample might not accurately represent the entire population of interest. Non-coverage error is reduced by investing in a sampling plan that addresses known coverage issues.

For instance, a survey implemented through several modes, such as phone and Internet, can sometimes address known coverage issues. Non-response errors occur when some portion or portions of the population, with different attitudes or behaviors, are less likely to provide data than are other portions. For a load research or metering study, if certain types of households are more likely to refuse to participate or if researchers are less likely to be able to obtain required data from them, the values calculated from the sample will understate the contribution of this portion of the population and over-represent the contribution of sample portions more likely to respond. In situations where the under-represented portion of the population has different consumption patterns, non-response error is introduced into the value calculated from the sample. Non-response error is addressed through investments that increase the response rate, such as incentives and multiple contact attempts.

- **Described (modeled).** Estimates are created through statistical models. Some are fairly simple and straightforward (e.g., estimating the mean), and others are fairly complicated (e.g., estimating response to temperature through regression models). Regardless, errors can occur due to the use of the wrong model, assuming inappropriate functional forms, inclusion of irrelevant information, or exclusion of relevant information. For example, in determining energy savings, a researcher may be required to adjust measured energy use data to make comparisons with a baseline. This process can introduce systematic errors.

D.1.2 Sources of Random Error

Whenever a *sample* of a population is selected to represent the population itself—whether the sample is of appliances, meters, accounts, individuals, households, premises, or organizations—there will be some amount of *random sampling error*. The sample selected is only one of a large number of possible samples of the same size and design that could have been selected from that population. For each sample, values calculated will differ from the other potential samples simply because of the element of chance in choosing particular elements. This variability is termed random sampling error. Random sampling error, unlike the systematic errors discussed above, can be estimated using statistical tools (assuming the sample was drawn randomly).

When the time savings actually take place is also essential—another layer of sampling error. Typically, what (or who) is sampled and when they are sampled (e.g., metering energy consumption over one week, metering 5 percent of impacted equipment) introduces uncertainty.

Altering sample design can reduce uncertainty from random sampling error (for instance, increasing the number of elements sampled or changing the way elements are grouped together prior to sampling). As expected, random error and sampling costs are inversely proportional in most instances.

In addition to random sampling error, random measurement error may be introduced by other factors, such as respondents' incorrectly recalling dates or expenses, or other differences in a respondent's mood or circumstances that affect how they answer a question. These other types of random measurement error are generally assumed to "even out," so that they do not affect the mean or point estimate, but only increase the variability. For this reason, researchers generally do not attempt to quantify the potential for random measurement error in the data.

D.2 Energy Efficiency Evaluation Uncertainty

The biggest challenge in evaluating energy efficiency programs is a lack of direct measurement. Energy savings are what *did not happen*, but energy consumption is actually what is measured. The difference between energy consumption and what energy consumption *would have been* had energy efficiency measures not been installed provides a measure of energy savings. Savings computation therefore involves comparing measured energy data and a calculation of "adjustments" to convert both measurements to the same set of operating conditions (i.e., a baseline). Both measurement and adjustment processes introduce uncertainty.

These processes produce statistical "estimates" with reported or expected values and some level of variability. In other words, true values cannot be known; only estimates can be made, with some level of uncertainty. Physical measurements and statistical analyses are based on estimation of central tendencies (mean, median, mode) and associated quantification of variations (standard deviation, standard error, variance).

Because uncertainty arises from many different sources, it is usually difficult to identify and quantify the effect of all potential sources. Research reports often identify only uncertainty arising from random sampling error, because this source of error is usually the easiest component to quantify. Convenient measures, such as confidence intervals and statistical significance tests, are available to provide quantitative estimates of the uncertainty. Uncertainty attributable to forms of systematic error does not have a single comparable measure to provide a parsimonious estimate of uncertainty. Rather, these sources are specific to individual studies, depending on equipment used, research staff, or research and data collection procedures employed. To assess uncertainty from systematic sources, evaluators must address the rigor of evaluation procedures.

Evaluating uncertainty is an ongoing process that can consume time and resources. It may also require the services of specialists familiar with data analysis techniques, further data collection, or additional equipment. Reducing errors usually increases evaluation costs. Thus, improved accuracy should be justified by the value of the improved information.

D.3 Statistical Terms

While studying a phenomenon at the population level (a census) produces greater accuracy, the cost is almost always prohibitive. If properly designed, samples can provide accurate estimates at a greatly reduced cost. Statistics are mathematical methods that, applied to sample data, can help make inferences about whole populations and aid decisions in the face of uncertainty.

For any value calculated from a sample, a set of descriptive statistics, such as the mean, standard deviation, standard error, and a confidence interval, can be calculated. Standard deviation is a measure of variability showing the extent of dispersion around the mean. In normally distributed data, about 68 percent of observations are within one standard deviation of the mean; so a large standard deviation indicates greater dispersion of an individual observation from each sample member, while a smaller standard deviation indicates less dispersion. Based on the amount of variability and standard deviation, a confidence interval can be calculated.

To communicate evaluation results credibly, outcomes need to be expressed with their associated variability. *Confidence* refers to the probability the estimated outcome will fall within some level of *precision*. Statement of precision without a statement of *confidence* proves misleading, as evaluation may yield extremely high precision with low confidence or vice versa. For example, after metering a sample of impacted equipment, one may estimate average savings as 1,000 kWh. This is an *estimate* of the *true average* savings. Further, one may able to state the true average is within ±1 percent of the estimate (precision), but only be 30 percent confident that is the case. Alternatively, one may be 99 percent confident the true average savings are within ±50 percent of the estimate of 1,000 kWh.

If the estimated outcomes are large relative to the variation, they tend to be statistically significant. On the other hand, if the amount of variability is large relative to the estimated outcome, one is unable to discern if observed values are real or simply random. In other words, when variability is large, it may lead to precision levels that are too large (e.g., more than ±100 percent) for observed estimates (e.g., estimated savings) to be meaningful. In an extreme example, if the observed average is 1,000 kWh and the associated precision is ±150 percent, true average savings are somewhere between negative 500 kWh (which means the measure actually caused consumption to increase) and 1,500 kWh.

To formalize these relationships, evaluators use a test called the *t* statistic. The *t* statistic is a measure of a statistical estimate's reliability. When the parameter estimate, such as the mean kWh savings, is small relative to its associated variability, the t statistic value is low. In energy efficiency evaluations it is common to use a 95 percent level of confidence, for which the critical value of t is 1.96. If the t statistic is less than 1.96, the evaluator concludes that the estimated value (e.g., mean kWh savings) is not reliable.

Confidence intervals are a convenient way of expressing the potential random sampling error for an estimate. Confidence intervals are calculated by multiplying the estimated standard error by a value based on the t statistic and adding or subtracting this number from the estimate. For example, once average savings are estimated, true average savings are bracketed in the following confidence interval:

estimated average savings–t(SE $_{savings}$)≤true average savings≤estimated average savings +t(SE $_{savings}$)

The rule of thumb is to use a value of 2 times the standard error for calculating a 95 percent confidence. Table D.1 summarizes the statistical terms useful for in assessing uncertainty. (The table provides an easy reference, not a guide for computations.)

For example, assume that 12 monthly energy bills total 48,000 kWh. Estimated average annual consumption is:

$$\bar{Y} = \frac{\sum Y_i}{n} = \frac{48{,}000}{12} = 4{,}000$$

The *variance* is:

$$S^2 = \frac{\sum (Y_i - \bar{Y})^2}{n-1} = 4{,}488{,}417 \text{ kWh}^2$$

The *standard deviation* is:

$$s = \sqrt{S^2} = \sqrt{4{,}488{,}417} = 2{,}118 \ kHw.$$

The *standard error* is:

$$SE = \frac{s}{\sqrt{n}} = \frac{2{,}118}{\sqrt{12}} = 611 \ kHw$$

Thus, at a 95 percent confidence level, the *absolute precision* is approximately:

$$t \times SE = 2 \times 611 = 1{,}222 \ kWh$$

At a 95 percent confidence level, the *relative precision* is:

$$\frac{t \times SE}{estimate} = \frac{1{,}222}{4{,}000} = 30\%$$

Table D-1. Summary of Statistical Terms

Mean ($\bar{Y}$)	The mean is determined by adding up individual data points and dividing by the total number of these data points.	$\bar{Y} = \frac{\sum Y_i}{n}$
Variance (S^2)	The extent to which observed values differ from each other. Variance is found by averaging the squares of individual deviations from the mean. Deviations from the mean are squared simply to eliminate negative values.	$S^2 = \frac{\sum Y_i \ (Y_i - \bar{Y})^2}{n-1}$
Standard Deviation (s)	This is simply the square root of the variance. It brings the variability measure back to the units of the data (e.g., while variance units are in kWh2, the standard deviation units are kWh).	$s = \sqrt{S^2}$
Standard Error (SE)	The standard deviation divided by the square root of the total number of observations. SE is the measure of variability used in assessing precision and confidence for the true value of the estimate.	$SE = \frac{s}{\sqrt{n}}$
Coefficient of Variance (cv)	Defined as the standard deviation of the readings divided by the mean, this is used in estimating sample sizes.	$cv = \frac{s}{\bar{Y}}$
Absolute Precision	Computed from standard error using a t value.	$t * SE$
Relative Precision	The absolute precision divided by the estimate.	$\frac{t * SE}{Estimate}$

That is, based on observing a sample of 12 months, we estimate average monthly consumption to be 4,000 kWh. There is a 95 percent confidence that the *true* mean monthly consumption lies between 2,778 and 5,222 kWh. It can be said with 95 percent confidence that the *true* mean value is 4,000 ±30 percent.

D.4 Mitigating Random/Sampling Error

In most evaluations, we do not have access to an entire population of interest (e.g., all small commercial customers participating in a program), either because the population is too large or the measurement process is too expensive or time-consuming to allow more than a small segment of the population to be observed. As a result, we make decisions about a population on the basis of a small amount of sample data.

For example, suppose an evaluator is interested in the proportion of program participants installing a particular measure. The fairly large program has a population of about 15,000 participants. The parameter of interest is the proportion of participants actually installing the measure (called π).

The evaluator conducts a survey using a random sample of participants. Each participant is asked whether or not they installed the measure. The number (call it *n*) of participants surveyed will be quite small relative to the population's size. Once these participants have been surveyed, the proportion installing the measure will be computed. This proportion is called a statistic (in this case, it is called *p*). We can reasonably assume *p* will not equal π (an exact match would be extremely unlikely). At a minimum, our statistic *p* involves random sampling error or "the luck of the draw." The difference between the observed *p* and unobserved π is the sampling error. As long as sampling is used, there will be sampling error.

The most direct way to reduce sampling error is to increase the sample's size. Most research consumers are familiar with this underlying principle. For any given population and confidence level, the larger the sample, the more precise estimates will be.

Evaluation research adopts conventions about sample sizes for particular types of projects. Prior research (or in some cases, requirements set by a regulatory authority) should be the first place to turn for appropriate sample sizes. The next question is whether relationships in prior studies seem likely to exist but have not been borne out by research. This might point toward the need to invest in a larger-than-conventional sample size.

The other way to reduce sampling error is to improve the sampling design. In general, the design with the smallest random error is a simple random sample in which each population element has an equal probability of being selected. There are important reasons why a deviation from this design represents an overall improvement in results. For example, using a stratified sampling design (rather than treating all lighting areas as if they were all part of the same "population") divides populations into homogenous strata prior to sampling, greatly reducing overall sampling error. Researchers should justify stratification or clustering of the sample and address the impact on sampling error.

As noted, sampling error can be minimized by increasing the fraction of the population sampled, obviously at an increased cost. Several issues are critical in optimizing sample sizes. The following steps should be followed in setting the sample size.

1. **Select a homogeneous population.** For sampling to be cost-effective, measured "units" should be expected to be the same for the entire population. If there are two different types of units in the population, they should be grouped and sampled separately. For example, when designing a sampling program to measure the operating periods of room lighting controlled by occupancy sensors, rooms occupied more or less continuously (e.g., multiple-person offices) should be sampled separately from those that are only occasionally occupied (e.g., meeting rooms). The size of the sample needed to achieve a certain level of precision and confidence is sensitive to the amount of variability. Figure D.1 presents a hypothetical case. The horizontal axis shows an estimate of variability (in this case, the cv). The vertical axis shows the sample size needed to achieve different levels of

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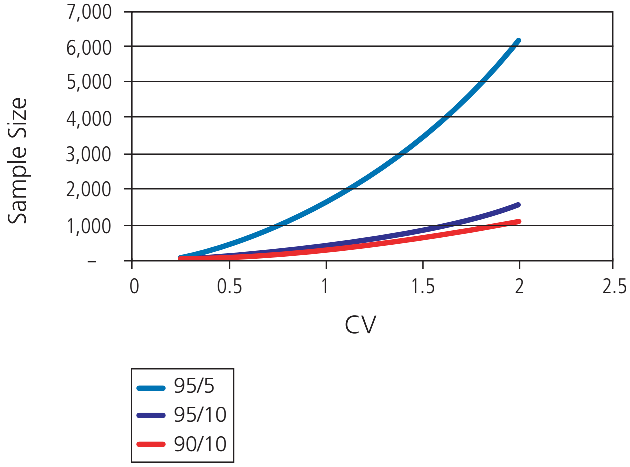
confidence and precision. Each of the lines shows the relationship between variability and sample size. The higher the confidence and precision requirement, the steeper the line, indicating higher sensitivity to the measure of variability. This clearly displays the need for homogeneous groups. A homogeneous group is defined as a group with low variability in whatever is being measured (e.g., hours of use).

Figure D-1. Sample size selection for different levels of confidence and precision.



In addition to placing the population in homogenous groups, the evaluator needs to set the acceptable levels of precision and confidence. A conventional approach (for example, as defined for certain California energy efficiency evaluations) is to design sampling to achieve a 90 percent *confidence* level and ±10 percent *precision*. Figure D.1 illustrates the impact of selecting confidence and precision levels. For example, in the hypothetical situation illustrated, the sample size needed for a cv of 1.0 varies from 270 for 90/10 to over 1,500 for 95/5. This may translate to a difference of thousands of dollars in sampling costs: improving *precision* from ±20 to ±10 percent would require a fourfold increase in sample size, while improving it to ±2 percent would require a hundredfold increase in sample size. This is due to a sample error inversely proportional to $\sqrt{n}$. Thus, selecting the appropriate sampling criteria requires balancing accuracy requirements and the risk of higher uncertainty with costs associated with less uncertainty.

2. **Decide on the level of disaggregation.** It is necessary to establish whether the *confidence* and *precision* level criteria should be applied to the measurement of all components or to various subgroups of components. If a project includes several measures installed in different building types, the evaluator must decide whether the confidence and precision apply at the project level, measures level, end-use level, and so on. Going from measure-level criteria to overall project-level criteria requires larger samples. However, one large sample covering an entire project may still be smaller than several smaller samples at the measure level. As there are no hard and fast rules, different sampling designs need to be examined, and those optimally balancing the precision and cost should be selected. Whatever that final selection, it should be clearly defined in an evaluation plan along with the rationale behind the selection.

3. **Calculate initial sample size.** Based on the information above, an initial estimate of the overall sample size required to meet the research goals can be determined using the following equation:

$$n_o = \frac{n_o N}{n_o + N}$$

where:

n_o is the initial estimate of the required sample size before sampling begins.

cv is the *coefficient of variance*, defined as the *standard deviation* of the readings divided by the *mean*. Until the actual *mean* and *standard deviation* of the population can be estimated from actual samples, 0.5 is often accepted as an initial estimate for cv. The more homogenous the population, the smaller the cv.

e is the desired level of *precision*.

z is the standard normal distribution value for the desired *confidence* level. For example, z is 1.96 for a 95 percent *confidence* level (1.64 for 90 percent, 1.28 for 80 percent, and 0.67 for 50 percent *confidence*).

For 90 percent *confidence* with 10 percent *precision* and a cv of 0.5, the initial estimate of required sample size (n_o) is

$$n_o = \frac{1.64^2 \times 0.5^2}{0.1^2} = 67$$

Values from previous cv studies may be used if available. It may also be desirable to conduct a study with a small sample for the sole purpose of estimating cv.

4. **Adjust initial sample size estimate for small populations.** The necessary sample size can be reduced if the entire population being sampled is no more than 20 times the size of the sample. For the initial sample size example above (no = 67), if the population (N) from which it is sampled is only 200, the population is only 3 times the size of the sample. Therefore the "finite population adjustment" can be applied. This adjustment reduces the sample size *(n)* as follows:

$$n_o = \frac{n_o N}{n_o + N}$$

Applying this finite population adjustment to the above example reduces the sample size (n) required to meet the 90 percent/±10 percent criterion to 50.

D.5 Mitigating Systematic Error

Many evaluation studies do not report any uncertainty measures besides a sampling error–based confidence interval for estimated energy or demand savings values. This is misleading because it suggests the confidence interval describes the total of all uncertainty sources (which is incorrect) or that these other sources of uncertainty are not important relative to sampling error. Sometimes uncertainty due to measurement and other systematic sources of error can be significant.

Measurement error can result from inaccurate mechanical devices, such as meters or recorders, as well as from inaccurate recording of observations by researchers or inaccurate responses to questions by study participants. Of course, basic human error occurs in taking physical measurements or conducting analyses, surveys, or documentation activities. For mechanical devices such as meters or recorders, it is theoretically possible to perform tests with multiple meters or recorders of the same make and model to indicate the variability in measuring the same value. However, for meters and most devices regularly used in energy efficiency evaluations, it is more practical to either use manufacturer and industry study information on the likely amount of error for any single piece of equipment or use calibration data.

Assessing the level of measurement error for data obtained from researchers' observations or respondents' reports is usually a subjective exercise, based on a qualitative analysis. The design of recording forms or questionnaires, the training and assessment of observers and interviewers, and the process of collecting data from study participants are all difficult to quantify. It is possible, however, to conduct special studies of a participant subsample to validate each of these processes. For example, it is possible to have more than one researcher rate the same set of objects, or to conduct short-term metering of specific appliances for a subsample to verify information about appliance use. Participants can also be reinterviewed to test the answer to the same question at two different times, and pretests or debriefing interviews can be conducted with participants to determine how they interpreted specific questions and constructed their responses. Such special studies can be used to provide an assessment of the uncertainty potential in evaluation study results.

Another challenge lies in estimating the effect of excluding a portion of the population from a sample (sample non-coverage) or of the failure to obtain data from a certain portion of the sample (non-response). Data needed to assess these error sources are typically the same as those needed to resolve errors in the first place—but these data are usually unavailable. However, for both non-coverage and non-response, it is possible to design special studies to estimate the uncertainty level introduced. For studies whose sample design did not include a particular portion of the population (such as a geographical area or respondents living in a certain type of housing), it is possible to conduct a small-scale study on a sample of the excluded group to determine the magnitude and direction of differences in calculated values for this portion of the population. In some situations, such as a survey, it is also possible to conduct a follow-up study of a sample of members for whom data were not obtained. This follow-up would also provide data to determine if non-respondents were different from respondents, as well as an estimate of the magnitude and direction of the difference.

Determining steps needed to mitigate systematic error is a more complex problem than mitigating random error as various sources of systematic error are often specific to individual studies and procedures. To mitigate systematic error, evaluators typically need to invest in additional procedures (such as meter calibration, a pretest of measurement or survey protocols, a validation study, or a follow-up study) to collect additional data to assess differences between participants who provided data and those who did not.

To determine how rigorously and effectively an evaluator has attempted to mitigate sources of systematic error, the following should be examined:

1. Were measurement procedures, such as the use of observational forms or surveys, pretested to determine if sources of measurement error could be corrected before the full-scale study was fielded?

2. Were validation measures, such as repeated measurements, inter-rater reliability, or additional subsample metering, used to validate measurements?

3. Was the sample frame carefully evaluated to determine what portions of the population, if any, were excluded in the sample and, if so, what steps were taken to estimate the impact of excluding this portion of the population from the final results?

4. Were steps taken to minimize the effect of non-response in surveys or other data collection efforts? If non-response appears to be an issue, were steps taken to evaluate the magnitude and direction of potential non-response bias?

5. Has the selection of formulas, models, and adjustments been conceptually justified? Has the evaluator tested the sensitivity of estimates to key assumptions required by the models?

6. Did trained and experienced professionals conduct the work, and was it checked and verified by a professional other than the one conducting the initial work?

D.6 Addressing More Complex Uncertainty

Our discussion has assumed that uncertainty arises from variation in one variable (e.g., hours of use or level of consumption). Often, uncertainty is caused by variability in several components in a savings estimation equation. For example, total savings may be the sum of savings from different components:

$$savings = savings_1 + savings_2 + \ldots + savings_p$$

Where total savings are the result of lighting, cooling, and so on. Each savings component is likely to have some variability of its own. Combining savings into the total requires the evaluator to also combine the variability associated with the different estimates. Components must be *independent* to use the suggested methods for combining uncertainties. Independence means whatever random errors affect one component are unrelated to the affecting other components. The standard error of reported savings can be estimated by:

$$SE(savings) = \sqrt{SE(savings_1)^2 + SE(savings_2)^2 + \ldots\ldots + SE(savings_p)^2}$$

Savings can also be estimated as the difference between baseline and post-installation energy use. The *standard error* of the difference (*savings*) is computed as:

$$SE(savings) = \sqrt{SE(adjusted\ baseline)^2 + SE(reporting\ period\ energy)^2}$$

At times, the savings estimate is a *product* of several independently determined components (i.e., $savings = C_1 x C_2 x \ldots x C_p$); in that case, the *relative* standard error of the *savings* is given approximately by:

$$\frac{SE(savings)}{savings} \approx \sqrt{\left(\frac{SE(C_1)}{C_1}\right)^2 + \left(\frac{SE(C_2)}{C_2}\right)^2 + \ldots\ldots + \left(\frac{SE(C_p)}{C_p}\right)^2}$$

A good example of this is the determination of lighting savings as:

$$savings = \Delta \text{ Watts} \times \text{Hours}$$

The relative standard error of savings will be computed using the above formula as follows:

$$\frac{SE(savings)}{savings} = \sqrt{\left(\frac{SE(\Delta\ watts)}{\Delta\ watts}\right)^2 + \left(\frac{SE(hours)}{hours}\right)^2}$$

If savings at a particular hour are what is needed, the affected end-use must be metered hourly. The estimated average is energy use in that particular hour. The variability measure is the usage observed at that hour, and the sampling unit is the number of hours to be metered. Metering periods must account for weather and other seasonal variations, and metered hours must include a sample of different use patterns. In other words, sampling becomes more complex as an evaluator needs to estimate a sample size in number of hours per usage pattern as well as the number of impacted end-uses to be metered.

In many cases, the estimate of uncertainty attributable to systematic errors will have to be stated in qualitative terms. However, it is important to recognize these error sources may be significant. As a result, relying only on confidence intervals and standard errors to express uncertainty may be very misleading.

D.7 Monte Carlo Methods

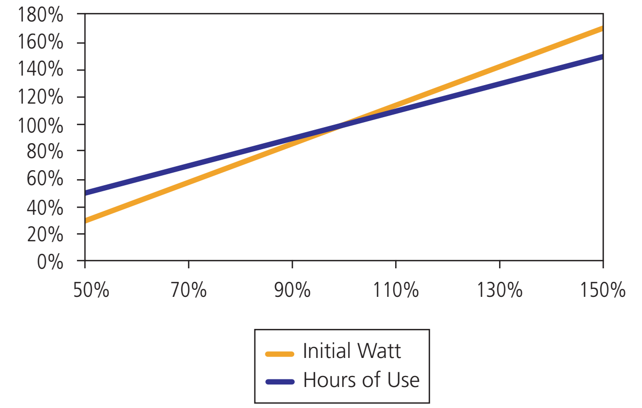
We have discussed uncertainty as a range of values surrounding a point value that has been arrived at directly through a measurement process. Monte Carlo methods arrive at uncertainty in a different way: by simulating reality using chance (hence the gambling reference) and a model of factors contributing uncertainty to the outcome we are examining.

A "Monte Carlo" method can refer to any technique using random numbers and probability to develop a simulation to solve a problem. Monte Carlo methods are used in many fields, such as chemistry and physics, as well as in studying how to best regulate the flow of traffic on highways or in risk management for businesses and organizations. They are used when a large number of uncertainty sources exist in the inputs, and direct measurements of outcomes are not possible. In this case, we refer to Monte Carlo simulation to estimate a population distribution.

Monte Carlo techniques are perfectly viable alternatives when problems are too complex (i.e., too many factors are involved in computing savings). Assessing the importance of individual components is often the best first step in assessing uncertainty.

For example, the Monte Carlo method could be applied for a simple lighting retrofit. Simply stated, such analysis begins by allowing these factors (e.g., hours of use) to vary from plausible lows to plausible highs. The impact on final savings values are observed, then the impact of initial wattage is investigated by allowing its value to vary between plausible lows and highs. The factor that has a higher impact on final savings may be the one worthy of further research. Figure D.2 shows a hypothetical case in which the initial wattage level and hours of use are allowed to vary independently from 50 percent of assumed or most likely values to 150 percent. Savings are estimated for all these variations. The vertical axis shows the change in savings as percentage terms. In this example, the initial wattage has a steeper curve, indicating higher sensitivity of final savings estimates.

Figure D-2. Hypothetical analysis lighting project.



Some commercially available software (e.g., Crystal Ball™) uses a Monte Carlo simulation to perform this type of analysis. These models are usually built using spreadsheets and are organized so ranges can be entered by the evaluator for each input variable needed to perform the sensitivity analysis shown above. Monte Carlo simulation is a very flexible technique, widely used for assessment of risk analysis in various fields.

In the example, hours of use and initial wattage levels were allowed to vary independently one at a time. Using Monte Carlo tools, the evaluator can allow factors to vary concurrently. Thus, Monte Carlo simulation can be as simple or complex as the user requires.

An extended example provides the best explanation of how this approach might be used in evaluating an energy efficiency program. Suppose energy savings from a residential air conditioning upgrade program are assumed to be a function of the net number of participants (subtracting free riders), multiplied by the average savings from each installed air conditioner. The savings from each installed air conditioner is a function of the average difference in SEER, relative to the old unit and a behavioral component related to thermostat settings also incorporated in the program.

Given these assumptions:

- There is uncertainty about the number of free riders. We estimate a 25 percent probability that 10 percent of participants are free riders, a 50 percent probability that 20 percent of participants are free riders, and a 25 percent probability that 30 percent of participants are free riders.
- There is also uncertainty regarding the average difference in SEER. We have not directly measured this through surveys, but we know the distribution of SEER values for qualifying air conditioners and the average SEER of currently installed air conditioners. We do not know whether program participants are different than the general population. We estimate a 25 percent probability that the average difference in SEER values is SEER 1.5, a 50 percent probability that the average difference is SEER 2.0, and a 25 percent probability that the average difference is SEER 2.5.
- Finally, uncertainty exists regarding the behavioral component. We believe there is a 50 percent probability that the average effect of the campaign has no change in thermostat settings, a 40 percent probability that the average effect reduces settings by 0.5 degrees, and a 10 percent probability that the average effect reduces settings by 1.0 degree.

We are modeling 27 possible scenarios (all possible combinations of the three factors, i.e., 33) and can calculate a savings for each state. Using the probability of each state, we can estimate a probability distribution for program savings, including a mean, standard deviation, and confidence intervals. For instance, the probability that actual savings are at the peak estimate (where free ridership is low, SEER difference is high, and thermostat setting is reduced by 1.0 degree) is 0.25 × 0.25 × 0.10 = 0.00625, or 0.625 percent.

So far this does not involve chance because the example has only 27 possible scenarios. As the number of factors or states increases, it becomes impossible to calculate savings for every possible combination. If there are 10 uncertainty factors, with each having 10 possible states, there are 1010 or 10 billion possible combinations. To estimate uncertainty, we can simulate the population of scenarios using random number generators and draw multiple samples of a reasonable size; for instance, we could draw 1,000 samples of 1,000 scenarios. For each sample, we could calculate a mean program savings. Using the laws of probability, we know the average of the 1,000 samples (i.e., the average of the averages) is a good point estimate of energy savings, and the distribution around that estimate is normally distributed and provides a good estimate of uncertainty surrounding the estimate.

The key caution about Monte Carlo analysis is that, as with all simulations, poor assumptions built into the model can yield inaccurate estimates of the true uncertainty surrounding an estimate. Nevertheless, in fields where interrelations are very complex or direct measurements impossible, Monte Carlo analysis can yield useful uncertainty estimates.

D.8 Notes

1. This appendix was prepared by Dr. M. Sami Khawaja, President, Quantec, LLC, and Dr. Bob Baumgartner, Principal, PA Consulting.

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Appendix E: Resources

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The information in this document is a summary of definitions, approaches, and issues that have developed over the last 30 years of energy efficiency program implementation and evaluation. This experience and expertise is documented in numerous guides, protocols, papers, and reports. From a historical perspective, many of the basic references on energy and energy efficiency impact evaluations were written in the 1980s and 1990s. There are two reference documents in the public domain that provide a historical perspective and solid fundamentals:

- Violette, D.M. (1995). *Evaluation, Verification, and Performance Measurement of Energy Efficiency Programmes*. Prepared for International Energy Agency.
- Hirst, E., and J. Reed, eds. (1991). *Handbook of Evaluation of Utility DSM Programs.* Prepared for Oak Ridge National Laboratory ORNL/CON-336.

However, most of the early reference documents are not easily available to the general public (i.e., they are not posted on the Web).

E.1 Primary Impact Evaluation Resources

The key documents used in the development of this Guide are available via the Web and are presented in this section; they can be considered the current primary resources for efficiency program evaluation and project M&V. These documents are well-established *project* M&V guides and *program* evaluation protocols. They constitute the core M&V guidance documents used for energy efficiency projects in the United States and many other countries.

- **2007 International Performance Measurement and Verification Protocol (IPMVP).** The IPMVP provides an overview of current best practices for verifying results of energy efficiency, water, and renewable energy projects in commercial and industrial facilities. Internationally, it is the most recognized M&V protocol for demand-side energy activities. The IPMVP was developed with DOE sponsorship and is currently managed by a nonprofit organization[1] that continually maintains and updates it.

  The IPMVP provides a framework and definitions that can help practitioners develop M&V plans for their projects. It includes guidance on best practices for determining savings from efficiency projects. It is not a "cookbook" of how to perform specific project evaluations; rather, it provides guidance and key concepts that are used in the United States and internationally. The IPMVP is probably best known for defining four M&V Options for energy efficiency projects. These Options (A, B, C and D) differentiate the most common approaches for M&V and are presented in Chapter 5.

  Reference: Efficiency Valuation Organization (2007). *International Performance Measurement and Verification Protocol*. <http://www.evo-world.org>

- **2000 FEMP M&V Guidelines.**[2] The purpose of this document is to provide guidelines and methods for measuring and verifying the savings associated with federal agency performance contracts. It contains procedures and guidelines for quantifying the savings resulting from energy efficiency equipment, water conservation, improved operation and maintenance, renewable energy, and cogeneration projects.

  References: U.S. Department of Energy (2000). *M&V Guidelines: Measurement and Verification for Federal Energy Projects*. Version 2.2. <http://ateam.lbl.gov/mv/docs/26265.pdf>

U.S. Department of Energy (2002). *Detailed Guidelines for FEMP M&V Option A*. <http://ateam.lbl.gov/mv/docs/OptionADetailedGuidelines.pdf>

- **2002 ASHRAE Guideline 14 Measurement of Energy and Demand Savings.**[3] ASHRAE is the professional engineering society that has been the most involved in writing guidelines and standards associated with energy efficiency. Compared to the FEMP M&V Guidelines and the IPMVP, Guideline 14 is a more detailed technical document that addresses the analyses, statistics, and physical measurement of energy use for determining energy savings.

  Reference: American Society of Heating, Refrigerating, and Air-Conditioning Engineers (2002). *Guideline 14 on Measurement of Demand and Energy Savings*.

In addition, in terms of energy efficiency *program* protocols, two documents are often cited as standards in the United States for energy efficiency evaluation:

- California Public Utilities Commission (2006). *California Energy Efficiency Evaluation Protocols: Technical, Methodological, and Reporting Requirements for Evaluation Professionals*. <http://www.calmac.org/publications/EvaluatorsProtocols_Final_AdoptedviaRuling_06-19-2006.pdf>
- California Public Utilities Commission (2004). The California Evaluation Framework. <http://www.calmac.org/publications/California_Evaluation_Framework_June_2004.pdf>

These documents provide a great deal of information on evaluation options and principles for impact, process, and market evaluations of a wide variety of energy efficiency program types. In many respects, they are a more detailed version of this Guide. Along with many other evaluation reports and guidance documents, they can be found at two Web-accessible databases:

- CALifornia Measurement Advisory Council (CALMAC): http://www.calmac.org.
- The Consortium for Energy Efficiency's Market Assessment and Program Evaluation (MAPE) Clearinghouse: http://www.cee1.org/eval/clearinghouse.php3.

Readers can also look at the Proceedings of the IEPEC Conference (http://www.iepec.org) and ACEEE Summer Studies (http://www.aceee.org), where there are shorter (10- to 12-page) examples of evaluations (versus the 100+ pages for a typical evaluation study).

Three other important program guides are:

- International Energy Agency (2006). *Evaluating Energy Efficiency Policy Measures & DSM Programmes*. <http://dsm.iea.org>
- U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy (2003). EERE Program Analysis and Evaluation. In *Program Management Guide: A Reference Manual for Program Management*. <http://www1.eere.energy.gov/ba/pdfs/pm_guide_chapter_7.pdf>
- U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy (2007). *Impact Evaluation Framework for Technology Deployment Programs*. Prepared by J. Reed, G. Jordan, and E. Vine. <http://www.eere.energy.gov/ba/pba/km_portal/docs/pdf/2007/impact_framework_tech_deploy_2007_main.pdf>

Another important resource is the Database for Energy Efficient Resources (DEER). Sponsored by the California Energy Commission and CPUC, DEER provides estimates of energy and peak demand savings values, measure costs, and effective useful life. CPUC has designated DEER its source for deemed and impact costs for program planning. The current version (October 2005) has more than 130,000 unique records representing over 360 unique measures within the DEER dataset. The data are presented as a Web-based searchable data set: http://www.energy.ca.gov/deer/index.html.

For calculating avoided emissions, several publications prepared as part of the Greenhouse Gas Protocol Initiative were consulted. The Initiative is a multi-stakeholder partnership of businesses, non-government organizations (NGOs), governments, and others convened by the WRI and the WBCSD. The Initiative's mission is to develop internationally accepted accounting and reporting protocols for corporate emissions inventories and greenhouse gas mitigation projects and to promote their use by businesses, policy makers, NGOs, and other organizations. It consists of three GHG accounting modules, as well as outreach activities. The accounting modules are:

- **Corporate Accounting and Reporting Standard.** Standards, guidance, and Web-based calculation tools to help companies, regulators and others develop an organization-wide greenhouse gas emissions inventory.
- **GHG Project Accounting and Reporting Protocol.** Requirements and guidance for quantifying reductions from greenhouse gas mitigation projects, such as those used to offset emissions or to generate credits in trading programs.
- **Guidelines for Quantifying GHG Reductions from Grid-Connected Electricity Projects.**

These documents are available at http://www.wri.org/climate/.

Another series of greenhouse gas guides is the International Organization for Standardization (ISO) 14064 series. There are three parts to the ISO 14064 standards:

- **ISO 14064-1,** which specifies principles and requirements at the organization level for the design, development, management, maintenance, and verification of an organization's GHG inventory.
- **ISO 14064-2,** which specifies principles and requirements and provides guidance at the project level for quantifying and reporting activities intended to cause GHG emission reductions or removal enhancements.
- **ISO 14064-3,** which specifies principles and requirements and provides guidance for those conducting or managing the validation and/or verification of GHG assertions, such as the validation or verification of an organization's GHG inventory emissions claim or a project's GHG emission reduction claim.

These can be downloaded for a fee at http://www.iso.org/.

An additional source of general reporting requirements for greenhouse gases is the California Climate Action Registry (CCAR). CCAR has published several widely used general reporting and project reporting protocols. These can be found at http://www.climateregistry.org.

E.2 Additional Resources

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E.3 Program and Organization Web Sites

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California's Appliance Efficiency Program (including California Title 20 Appliance Standards): http://www.energy.ca.gov/appliances/index.html

California Climate Action Registry: http://www.climateregistry.org

California Demand Response Programs: http://www.energy.ca.gov/demandresponse/index.html

California Energy Commission Efficiency Programs: http://www.energy.ca.gov/efficiency/

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The Climate Trust: http://www.climatetrust.org

Efficiency Vermont: http://www.efficiencyvermont.com/pages/

Efficiency Valuation Organization: http://www.evo-world.org

European Union Energy Efficiency Directive, measurement, monitoring, and evaluation Web site: http://www.evaluate-energy-savings.eu/emeees/en/home/index.php

International Energy Program Evaluation Conference: http://www.iepec.org/

Maine State Energy Program: http://www.state.me.us/msep/

Northeast Energy Efficiency Council: http://www.neec.org

Northeast Energy Efficiency Partnerships: http://www.neep.org

Northwest Energy Efficiency Alliance: http://www.nwalliance.org/

New York State Energy Research and Development Authority: http://www.nyserda.org

Texas Energy Efficiency Programs: http://www.texasefficiency.com/

Western Renewable Energy Generation Information System: http://www.wregis.org/

United Nations Framework Convention for Climate Change, Clean Development Mechanism: http://cdm.unfccc.int/index.html

U.S. Department of Energy:

- Efficiency and renewable energy: http://www.eere.energy.gov
- 1605b Program: http://www.eia.doe.gov/environment.html

U.S. Environmental Protection Agency:

- Clean Energy Programs: http://www.epa.gov/solar/epaclean.htm
- ENERGY STAR: http://www.energystar.gov/

World Business Council for Sustainable Development: http://www.wbcsd.org

World Resources Institute: http://www.wri.org

E.4 Notes

1. The Efficiency Valuation Organization (EVO). The IPMVP and related M&V resources can be found at http://www.evo-world.org.
2. Along with the FEMP M&V Guidelines, a number of other M&V resource documents, including some on the use of stipulations for determining savings, M&V checklists, and M&V resource lists, can be found at the Lawrence Berkeley National Laboratory Web site: http://ateam.lbl.gov/mv/.
3. The Guideline can be purchased at http://www.ashrae.org. As of the publication of this document, a new version of Guideline 14 is under development.

Appendix F: Renewables and Combined Heat and Power Project Measurement and Verification

This Guide addresses energy efficiency programs. However, other clean energy program types are related to efficiency. This appendix provides a brief overview of some of the approaches to the M&V of savings from renewable electrical energy projects and combined heat and power (CHP) projects.

F.1 Renewables Project Electricity Savings

This section introduces methods for determining savings from on-grid electric renewable energy projects and discusses some related issues. There are a variety of diverse technologies that convert renewable energy into electricity. Despite individual differences, these renewable energy technologies supply electricity and reduce the use of other grid-connected sources. In contrast, energy efficiency projects reduce electricity consumption. The implication is that renewable energy project M&V for electricity savings is simpler than energy efficiency M&V. This is because, in most instances, M&V simply involves measuring the electrical output of the subject system to determine the quantity of other grid-based electricity "saved." For renewable generation that produces emissions, however, a net emissions rate for each pollutant will be needed, adding a complication to the emissions estimation step. Life cycle emissions may also be important to compare in cases where major differences between renewables and baseline systems occur upstream.

The renewable energy projects covered in this chapter are the installation of devices or systems that displace grid electricity production through the use of renewable energy resources. Examples of renewable technologies include solar photovoltaics, biomass conversion systems (e.g., landfill gas methane recovery projects), and wind generators.

F.1.1 M&V Approaches and Options

There are two general approaches for calculating electricity savings:

1. **Direct measurement.** This approach assumes that the electricity produced by the renewable system displaces energy that would have been provided by an electric generating unit (EGU). With this one-for-one replacement approach, one only needs to directly measure the net amount of energy produced by the renewable system. This approach is most common with photovoltaic, wind, and biomass electricity production projects (assuming there is no supplementary firing with fossil fuels at the biomass facility).

2. **Net-energy use calculation.** With this approach, purchased electrical energy used at the project site during the reporting period is compared with a baseline to determine the savings in electricity purchases. When a baseline is adopted, there are four methods for calculating savings as defined in the 2003 IPMVP renewables protocol (IPMVP, 2003).

   - **Comparison with a control group.** Electricity consumption of the renewable energy system is compared with the electricity consumption of a control group, with similar characteristics under similar conditions. The control group is used as the baseline.

   - **Before and after comparison.** Electricity consumption of the renewable energy system is compared with the electricity consumption measured before the renewable system was installed for the same loads. The pre-installation situation is the baseline.

   - **On and off comparison.** Electricity consumption with the renewable energy system "on" is compared to consumption with the system "off." The baseline equals the situation with the system "off."

- **Calculated reference method.** The baseline is determined with engineering calculations, and estimated electricity consumption is compared to metered energy use when the renewable energy system is in place. This approach has the weakness of using two different analyses methods (engineering estimates and metered data) to determine a difference, i.e. the savings.

These four methods usually require measurement of electricity consumption or supply over an extended period in order to capture the variation due to changing climatic conditions.

The four IPMVP Options (A, B, C and D) can also be used for renewable energy projects. Options A and B involve measurements of system performance and are the most common. Option A involves stipulation of some parameters, while Option B requires maximum use of measurements in the energy savings analyses. Option C measures the change in whole-facility electricity use, usually with utility metering data, associated with the installation of the renewable system. Option D involves the use of computer simulations, calibrated with actual data, to determine savings from a renewable system installation.

F.1.2 Net Metering of Electrical Output and Fuel Use

In some situations, the electrical output of the renewable system is not directly indicative of electricity savings (and the avoided savings). These are when:

The system consumes electricity in order to produce electricity. The consumption is associated with what is known as *parasitic loads*. For example, a solar thermal electric system consumes electricity to power pumps that circulate fluid through the system. In these situations, either the parasitic loads have to be directly measured and subtracted from the measured output of the system, or a "net output" meter that accounts for parasitic loads is used.

The system consumes a fuel. An example is a landfill gas generation system that uses natural gas as a supplemental fuel. In these situations, incremental fuel usage must be accounted for when calculating energy savings.

F.2 Efficiency Metrics for CHP Systems: Total System and Effective Electric Efficiencies[1]

CHP is an efficient and clean approach to generating power and useful thermal energy from a single fuel source. CHP is used either to replace or supplement conventional separate heat and power (SHP) (e.g., central station electricity available via the grid and an onsite boiler or heater). Every CHP application involves the recovery of otherwise wasted thermal energy to produce additional power or useful thermal energy; as such, CHP offers energy efficiency and environmental advantages over SHP. CHP can be applied to a broad range of applications and the higher efficiencies result in lower emissions than SHP. The advantages of CHP broadly include the following:

- The simultaneous production of useful thermal energy and power in CHP systems leads to increased fuel efficiency.
- CHP units can be strategically located at the point of energy use. Such onsite generation prevents the transmission and distribution losses associated with electricity purchased via the grid from central station plants.
- CHP is versatile and can be designed for many different applications in the industrial, commercial and institutional sectors.

Figure F.1 shows how CHP can save energy compared to SHP.2 CHP typically requires only two thirds to three quarters of the primary energy to produce the same thermal and electric service compared to separate heat and power. This reduced primary fuel consumption is key to the environmental benefits of CHP since burning the same fuel but using more of its energy means fewer emissions for the same level of output.

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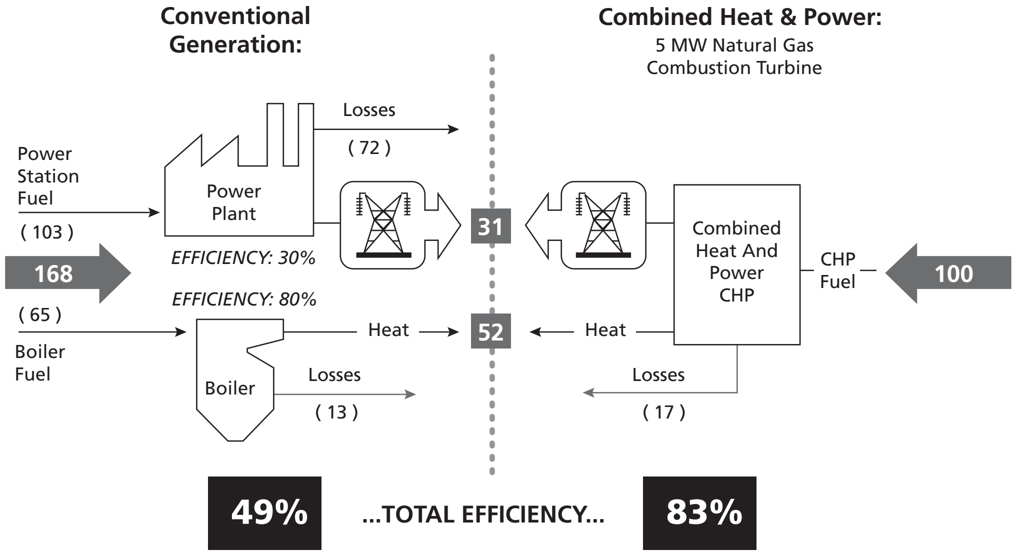
Figure F-1. CHP and SHP Energy Savings



Efficiency is a prominent metric used to evaluate CHP performance and compare it to SHP. Two methodologies are most commonly used to determine the efficiency of a CHP system: total system efficiency and effective electric efficiency.

F.2.1 Key Terms Used in Calculating CHP Efficiency

Calculating a CHP system's efficiency requires an understanding of several key terms, described below.

- **CHP system.** The CHP system includes the unit in which fuel is consumed (e.g. turbine, boiler, engine), the electric generator, and the heat recovery unit that transforms otherwise wasted heat to useable thermal energy.
- **Total fuel energy input (QFUEL).** The energy associated with the total fuel input. Total fuel input is the sum of all the fuel used by the CHP system. The total fuel energy input is often determined by multiplying the quantity of fuel consumed by the heating value of the fuel.[3]

  Commonly accepted heating values for natural gas, coal, and diesel fuel are:

  - 1020 Btu per cubic foot of natural gas
  - 10,157 Btu per pound of coal
  - 138,000 Btu per gallon of diesel fuel

- **Net useful power output (W_E).** Net useful power output is the gross power produced by the electric generator minus any parasitic electric losses. An example of a parasitic electric loss is the electricity that may be used to compress the natural gas before the gas can be fired in a turbine.
- **Net useful thermal output (ΣQ_{TH}).** Net useful thermal output is equal to the gross useful thermal output of the CHP system minus the thermal input. An example of thermal input is the energy of the condensate return and makeup water fed to a heat recovery steam generator. Net useful thermal output represents the otherwise wasted thermal energy that was recovered by the CHP system and used by the facility.

Gross useful thermal output is the thermal output of a CHP system utilized by the host facility. The term *utilized* is important here. Any thermal output that is not used should not be considered. Consider, for example, a CHP system that produces 10,000 pounds of steam per hour, with 90 percent of the steam used for space heating and the remaining 10 percent exhausted in a cooling tower. The energy content of 9,000 pounds of steam per hour is the gross useful thermal output.

F.2.2 Which CHP Efficiency Metric Should You Select?

The selection of an efficiency metric depends on the purpose of calculating CHP efficiency.

- If the objective is to compare CHP system energy efficiency to the efficiency of a site's SHP options, then the *total system efficiency metric* may be the right choice. Calculation of SHP efficiency is a weighted average (based on a CHP system's net useful power output and net useful thermal output) of the efficiencies of the SHP production components. The separate power production component is typically 33 percent efficient grid power. The separate heat production component is typically a 75- to 85-percent-efficient boiler.
- If CHP electrical efficiency is needed for a comparison of CHP to conventional electricity production (i.e., the grid), then the *effective electric efficiency metric* may be the right choice. Effective electric efficiency accounts for the multiple outputs of CHP and allows for a direct comparison of CHP and conventional electricity production by crediting that portion of the CHP system's fuel input allocated to thermal output.

Both the total system and effective electric efficiencies are valid metrics for evaluating CHP system efficiency. They both consider all the outputs of CHP systems and, when used properly, reflect the inherent advantages of CHP. However, since each metric measures a different performance characteristic, use of the two different metrics for a given CHP system produces different values.

For example, consider a gas turbine CHP system that produces steam for space heating with the following characteristics:

Fuel input (MMBtu/hr)	57
Electric output (MW)	5.0
Thermal output (MMBtu/hr)	25.6

According to the total system efficiency metric, the CHP system efficiency is 75 percent: (5.0 × 3.413 + 25.6) ÷ 57).

Using the effective electric efficiency metric, the CHP system efficiency is 68 percent: (5.0 × 3.413) ÷ (57 – (25.6/0.8)).

Calculating Total System Efficiency

The most common way to determine a CHP system's efficiency is to calculate *total system efficiency*. Also known as *thermal efficiency*, the total system efficiency (η_o) of a CHP system is the sum of the net useful power output (W_E) and net useful thermal outputs (SQ_{TH}) divided by the total fuel input (Q_{FUEL}):

$$\eta_o = \frac{W_E + \Sigma\, Q_{TH}}{Q_{FUEL}}$$

The calculation of total system efficiency is a simple and useful method that compares what is produced (i.e., power and thermal output) to what is consumed (i.e., fuel). CHP systems with a relatively high net useful thermal output typically correspond to total system efficiencies in the range of 60 to 85 percent.

Note that this metric does not differentiate between the value of the power output and the thermal output; instead, it treats power output and thermal output as additive properties with the same relative value. In reality and in practice, thermal output and power output are not interchangeable because they cannot be converted easily from one to another. However, typical CHP applications usually have coincident power and thermal demands that must be met. It is reasonable, therefore, to consider the values of power and thermal output from a CHP system to be equal in many situations.

Calculating Effective Electric Efficiency

Effective electric efficiency calculations allow for a direct comparison of CHP to conventional power generation system performance (e.g., electricity produced from central stations, which is how the majority of electricity is produced in the United States). Effective electric efficiency accounts for the multiple outputs of CHP and allows for a direct comparison of CHP and conventional electricity production by crediting that portion of the CHP system's fuel input allocated to thermal output. The calculation of effective electric efficiency is analogous to the method many states use to apply a CHP thermal credit to output-based emissions estimates.

Effective electric efficiency (e_{EE}) can be calculated using the equation below, where (W_E) is the net useful power output, (SQ_{TH}) is the sum of the net useful thermal outputs, (Q_{FUEL}) is the total fuel input, and α equals the efficiency of the conventional technology that otherwise would be used to produce the useful thermal energy output if the CHP system did not exist:

$$\varepsilon_{EE} = \frac{W_E}{Q_{FUEL} - \Sigma\,(Q_{TH} / \alpha)}$$

For example, if a CHP system is natural gas–fired and produces steam, then α represents the efficiency of a conventional natural gas–fired boiler. Typical α values for boilers are 0.8 for a natural gas–fired boiler, 0.75 for a biomass-fired boiler, and 0.83 for a coal-fired boiler.

The effective electric efficiency is essentially the CHP net electric output divided by the fuel the CHP system consumes over and above what would have been used by conventional systems to produce the thermal output for the site. In other words, this metric measures how effectively the CHP system generates power once the thermal demand of a site has been met.

Typical effective electrical efficiencies for combustion turbine–based CHP systems are in the range of 50 to 75 percent. Typical effective electrical efficiencies for reciprocating engine–based CHP systems are in the range of 65 to 80 percent.

Obtaining the Required Data to Calculate CHP System Performance

Typically, CHP systems are sized so that their full electric and thermal output can be used during most of the year. Thermal output is always available from the CHP system when it is running; however, it is only useful when it can be applied to meet specific thermal loads at the site. The useful thermal output from the CHP system displaces load from a boiler, furnace, chiller, or other system. Many thermal loads, such as space heating, only occur for part of the year. As such, the utilization of the thermal output of a CHP system can vary with time of day, month, or season. The annual impact of these variations must be considered to accurately account for the efficiency benefits of CHP systems.

A reasonable M&V program for CHP systems must be able to credibly estimate the net power output and useful thermal output on an annual basis, yet impose only minimal additional burden on the end-user. An effective M&V plan must define the CHP system boundaries, identify applicable thermal loads and how they are served by the CHP system, include simple measurement and calculations approaches, and specify reporting requirements. The plan can be based on key performance assumptions and design estimates contained in initial permit applications. These assumptions can be verified with steady-state measurements at commissioning. However, the primary approach to verifying net power and useful thermal output of a system is long-term cumulative measurement or readings of power and thermal output from the system. These readings can be obtained through the installation of specific metering equipment (as an example, power metering is likely to be installed on most CHP systems; often, electric meters are required by an area's local utility as part of the interconnection requirements), or in many cases through the CHP system's automated control system, programmed to accumulate and log power and thermal data. Cumulative readings of system output can be collected either monthly or annually. The M&V plan should contain procedures to confirm the completeness of the information and the validity of any calculations that estimate thermal energy actually used based on measured system output.

The plan should also recognize that the CHP system may not operate for brief periods during the year due to planned maintenance or unscheduled outages. The availability[4] of CHP systems is an important component of overall system performance, and affects the reliability of power and thermal supply to the user. In general, the availability of CHP systems is high and the use of CHP systems operating in parallel to the grid often improves the reliability of energy supply to the site. The most recent comprehensive review of DG/CHP availability was conducted for Oak Ridge National Laboratory in 2003 (Energy and Environmental Analysis, 2004). Of the systems studied, the availability factor for reciprocating engines averaged 96 to 98 percent. Gas turbines had availability factors ranging from 93 to 97 percent.

F.3 Notes

1. This section was provided by the U.S. EPA.

2. Conventional power plant efficiency based on average U.S. fossil heat rate of 12,215 Btu/kWh (2004 eGRID) and average T&D losses of 7 percent; comparison assumes that thermal energy produced by the CHP system is used on site.

3. Fuel heating values are denoted as either lower heating value (LHV) or higher heating value (HHV). HHV includes the heat of condensation of the water vapor in the products of combustion. Unless otherwise noted, all heating value and efficiency measures in this section are reported on an HHV basis.

4. The availability factor is the proportion of hours per year that a unit “could run” (based on planned and unplanned maintenance) divided by the total hours in the year.

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