RENEWABLES

WORKING DOCUMENT

FIVE-YEAR STATUTORY PROTOCOL REVIEW

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1. Introduction: Renewables

1.1. Overview

Renewable energy (RE) technologies make use of energy sources regenerated in nature, and thus maintain sustainable supplies. These projects have been installed all over the world, through numerous efforts funded by governments, private companies, public organizations, and third-party financers. Recognizing the actual benefits of renewable energy technologies requires developing a protocol for measuring energy generation and performance.

Renewable energy technologies utilize highly diverse resources and conversion technologies. Nevertheless, the technologies share several commonalities distinguishing them from energy-efficiency projects. Foremost among these, all renewable energy technologies supply energy rather than reduce energy consumed. Measuring the amount of energy actually supplied can, in some cases, serve as a simplified approach to measuring system performance in contrast to measurement and verification (M&V) for efficiency measures, which must quantify the amount of energy *not* used. If the energy supplied depends on a variable renewable energy source, however, then system performance should take into account the resource conditions during the monitoring and verification period in order to differentiate the effect of the underlying resource from the RE system performance. Measurement of actual system delivery is often evaluated by comparing to a model that predicts what the output should have been under measured conditions.

An M&V objective always includes measuring savings in purchased fuel or electricity. Other objectives may be equally important to a project, including: savings in first costs (solar photovoltaics [PVs] often provide the least-cost option for small remote loads); reductions in atmospheric emissions; reductions in fuel transportation risks (fuel spills); employing a community's industry rather than importing fuel; avoiding fuel supply interruptions or price fluctuations; or other "externalities".

Renewable energy projects may require a longer investment term or performance contract period than energy-efficiency projects. For example, Power Purchase Agreement (PPA) periods typically exceed ten years. Therefore, an M&V program for renewable energy may need to verify sustained benefits over longer time periods. This situation favors M&V approaches initially costing more, but returning benefits over a longer time period. An M&V plan based on periodically, and remotely, analyzing data from an onsite Data Acquisition System (DAS) is one example.

1.2. Scope and Purpose

This document describes special M&V considerations regarding renewable energy systems. Its scope includes M&V options for renewable energy systems within the International Performance Measurement and Verification Protocol (IPMVP) framework as well as examples and recommendations for specific applications. Renewable energy technologies include: solar, wind, biomass (e.g., sustainably harvested food crops, organic wastes, and landfill gas), geothermal, small hydroelectric, ocean thermal, wave and tidal energy.

1.3. Intended Audience

This revised protocol seeks to aid in establishing M&V Plans for the following groups:

- Project developers and financiers
- Energy Service Companies (ESCOs)
- Performance Contractors
- Power Purchase Agreement (PPA) providers and customers
- Facility owner's implementing RE projects on their sites
- State Clean Power Plan (CPP) program administrators
- Renewable energy incentive program managers
- Renewable Energy Credit (REC) tracking and certification organizations
- Renewable energy aggregators and third party meter reader
- Utilities installing renewable energy

To determine the best M&V Option for the above groups to use in developing a project-specific M&V Plan involves understanding the nature of the investment in the RE project and contract as well as the objectives of the project, including how the benefit, or savings, from the RE system will be valued/viewed, quantified or monetized. Different investments require different measures of performance. How will performance, or non-performance, be contractually defined? What are the risk elements and who holds the risk? Are economic and environmental benefits to be quantified? What aspect of performance is to be guaranteed?

These groups may also be looking to the M&V process to determine performance for a single project (project based) or to determine savings for multiple or an entire portfolio of projects as part of an established RE/EE/REC program (program based).

For PPA developers and financiers, by nature of the contract, delivery or generation of the RE system output must be measured in order to determine if the performance of the system has been met and to determine the value of the PPA payment. The quantification of the monetary payments are typically based on an agreed upon contractual price (e.g. $/kWh) in the PPA itself.

For ESCOs developing and implementing performance contracts utilizing RE energy conservation measures (ECMs), typically the delivery of the RE system is measured, but how this delivery is monetized as savings is determined through careful review of a customer's utility rate structures in the context of the existing facility utility purchasing structures. Since these are guaranteed performance financial contracts, and like PPAs, the M&V measured performance is tied to payments, the method and rates to be used to quantify the financial performance must be defined in the contract M&V Plan. For both ESCOs and PPA developers, other factors which are out of their direct control, such as environmental conditions and the facility operational load and O&M practices, must be addressed in the M&V Plan to define who holds the risk and how any impact to measured performance will be taken into account.

For facility owners directly implementing RE projects, the approach or goals may be very similar to an ESCO in a performance contract in that delivery of the RE system is desired to be measured and the determination of savings is then quantified based on the facility's existing utility purchasing procedures. While the owner is very interested in determining the savings from the RE project, there is not a contractual payment to a contractor that must be quantified from the outcome of the M&V effort.

For typical project-based M&V Plans that focus on the measurement of the RE system delivery, as the key performance metric, a corresponding measurement of the baseline system performance is not required or applicable since the output measurement defines the performance of the system. So even though there may not be an M&V defined baseline, there are still baseline activities and analysis which must be undertaken during project development for overall RE system M&V and project application and design. Depending on the project, this could involve the detailed review and analysis of the existing facility energy use profiles (electric interval data; hourly load data (electric and/or thermal)), review and analysis of existing facility utility purchasing rate structures as well as detailed review and analysis of the local environmental attributes which are key to the RE system performance. Therefore, all RE projects will conduct these baseline analyses to one level or another, but what is done with the output of these analyses and how, or if, these factors will be measured post-installation and how they are applied in the M&V Plan are a function of the contract structure and which party is holding the risk for those variables.

For an ESCO in a guaranteed performance contract where RE delivery is the measured performance, the results of the baseline analyses would be used to define the contractual utility rates to be used to calculate the financial value of the savings. The ambient environmental conditions would also typically be monitored in order to determine if there were any unusual weather conditions (different than the historical data used in the baseline project development activities) that could have had an impact on the delivered performance of the RE system. The details of how these measured conditions would be used to adjust any performance output would be detailed in the project-specific M&V Plan.

While the above groups would typically be employing project-based M&V Plans, the remaining groups may be involved with either project and/or program-based M&V Plans where the RE delivery and/or savings must be determined for a portfolio of projects. The M&V option selected would most likely be dictated by the program requirements for the type of RE system. For example, the 2015 EPA Clean Power Plan will require measurement and verification of the delivery of the generated electric output of an RE system with a revenue-grade meter for that generation to be accounted for in the chosen State compliance method. (States will be submitting their individual Plans for compliance with the CPP choosing either a mass-based or rate-based plan to meet the CPP goals.) Similarly, other RE incentive, REC and/or utility and publicly administered programs may require direct measurement of the RE delivery or, due to the number and scale of the RE projects, may instead need to employ M&V that is focused on the main utility meter. For M&V utilizing the main utility meter, the details of determining the baseline for the purposes of M&V savings determination, must be carefully and practically defined in the M&V Plan. M&V strategies addressing a program with multiple individual systems may take a sampling approach, rather than monitoring every system.

1.4. References to IPMVP Core Document

This Application Guide is written in reference to the International Performance Measurement and Verification Protocol Core Concepts document, released October 2016 under document number EVO 10000-1:2016.

2. General Guidance on Operational and Savings Verification for Renewable Energy Systems

This section discusses M&V of renewable energy systems, within the framework established by the IPMVP. Readers should note Core Concepts and Guides presents an M&V program's basic requirements, including: M&V planning; the four M&V options; statistical sample size; metering and instrumentation; cost vs. accuracy trade-offs; and adherence. The following section addresses application of the four M&V options listed in the Core Concepts to renewable energy projects.

2.1. Operational Verification

Verifying the correct installation and operation of renewable energy systems is very important to accurately assessing the performance of these types of systems and is a first step towards more involved M&V efforts.

Operational verification is intended to answer several questions:

- Do the system specifications match design and expectations?
- Is the system installed according to the relevant manufacturer requirements, codes, and standards?
- Is the system operating as expected, given the relevant resource availability?

The methods for operational verification vary but typically include review of design documents, onsite visual inspection, and spot measurements of key performance indicators. Operational verification lays a foundation for more detailed M&V efforts and should be a minimum requirement for M&V planning. Without operational verification, further planning may be based on inaccurate and/or incomplete information, resulting in wasted effort or results that do not address the intended purpose of the M&V effort.

At a minimum, operational verification should include collection of the following key information:

- Manufacturer, model number, and quantity of equipment installed *(e.g., PV modules, inverters)*
- Location and ratings of key equipment *(e.g., meters, disconnects, fuses)*
- Resource/fuel availability
- Compliance with relevant codes and standards, including:
  - Manufacturer instructions
  - Electrical code
  - Utility interconnection requirements
  - Building code
  - Plumbing code
  - Mechanical code

The exact method for completing the Operational Verification phase depends on several factors, such as the technology being employed and the scale of the project.

Operational Verification Example: Solar PV System Inspections

With growing investment in solar PV systems worldwide, it is important to ensure that the systems are installed correctly to ensure customer safety and long-term performance. One method of ensuring this is to conduct a technical inspection of completed solar PV systems. These inspections typically include:

- Verifying equipment/design decisions
- Investigating compliance with local codes (especially the National Electrical Code)
- Measuring shading/orientation impacts on system productivity
- Confirming that system output is reasonable for configuration and available resource

This type of inspection can be equally applicable to PV systems from residential through utility scale. Typical residential PV system inspections can be completed in 1-2 hours, with the results documented in a detailed written report that identifies installation deficiencies and documents the engineer's observations regarding the system. Such a report can be incredibly useful to financiers, investors, incentive programs, and system installers who are all invested in the long-term performance of these projects, with minimal maintenance costs, to ensure a viable financial return. Examples of common installation issues found during inspection of residential PV systems in the northeastern U.S. are shown in the figure, below.

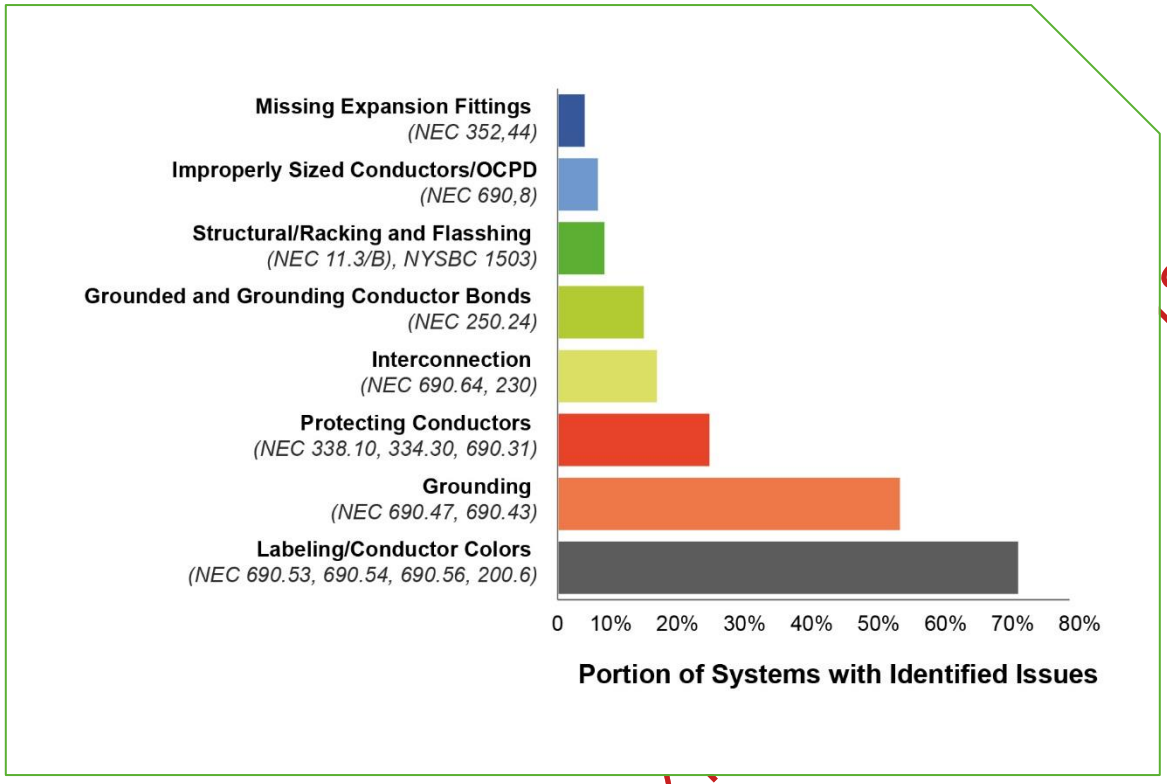


Figure 1. Installation Issues Found During Inspection of Residential PV Systems

REFERENCES:

Data courtesy of The Cadmus Group, Inc. based on 2,209 completed PV inspections using Cadmus' PV Quality Evaluation and Scoring Tool (PVQUEST).

2.2. Savings Verification

- Metered electrical generation systems
- Thermal/non metered applications
- Comparing Energy and Cost Savings

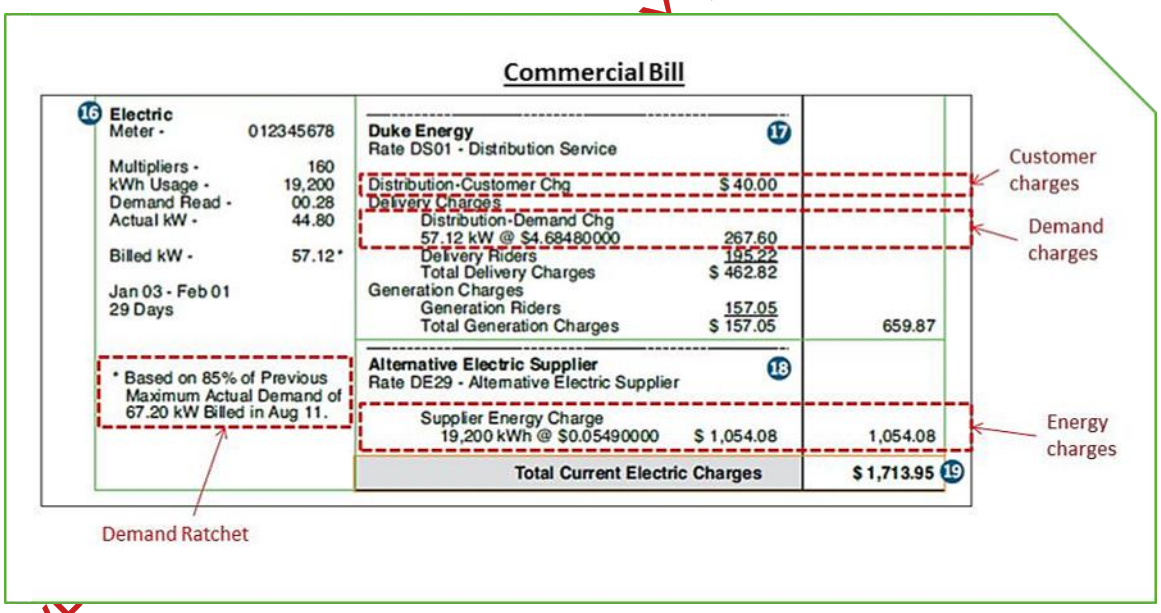
Once the new measure has undergone operational verification, as described above, the next step is to measure and verify the energy savings. The approach for savings verification is covered, with reference to the IPMVP options, in Section 3 of this Application Guide. In general, renewable energy savings can be measured either directly or indirectly. Directly measured energy savings typically involve isolated electricity or thermal generation systems-such as solar PV, wind, or solar hot water heating systems. In these systems, there is a clear point of connection between the renewable energy system and the rest of the associated infrastructure (e.g., the electrical system in a building or a hot water heating system) at which the contribution made by the renewable energy system can be measured directly. Indirectly measured renewable energy systems, on the other hand, provide energy benefits that can only be reasonably measured by measuring a reduction or change in the behavior of other associated systems. For example, the

contribution of a sunspace or passive solar building addition might be best measured as a reduction in heating load/costs.

2.2.1. Savings Verification: Energy Savings or Cost Savings?

Renewable energy systems are often installed in conjunction with conventional utility service. It is easy to meter the actual energy delivery of a renewable energy system, and while it is tempting to multiply this measured RE delivery (kWh) by the blended utility rate ($/kWh), and such a calculation is a useful approximation, to accurately estimate the utility cost savings of an on-site RE project requires that the details of the utility rate structure be calculated both with and without the RE system, and the savings is the difference between these two calculations.

There are many different types of utility rate structures: energy ($/kWh); demand ($/kW/month); time of day; seasonal; block rates; various tiers and thresholds, charges for ancillary services such as power factor; charges for assessed charges and riders such as contributing to demand side management programs; and to further complicate matters many rate schedules combine several of these features. The figure below shows one example of a relatively simple utility bill based on energy and demand, with some fixed customer costs. This example includes a demand ratchet that bases demand charges on 85% of the maximum actual demand in the previous year (57.12 kW), rather than just the demand for the month billed (44.80 kW).



Source: Duke Energy, "Understanding your utility bill: a guide for businesses in Ohio"

Figure 3. Example of a Commercial Utility Bill Including Charges for Fixed Costs, Energy Costs ($/kWh), Demand Cost ($/kW/Month) and a Demand Ratchet Which Bases Demand Charges on 85% of the Largest Demand in the Previous Year

So intermittent RE generators such as solar and wind do not save all components of the utility bill in proportion to the delivered energy. Rate schedules that charge more for demand and fixed customer charges reduce the value of RE energy, whereas time of use rates and season rates may increase the value of the RE energy delivered. A discussion of how each feature of a rate schedule is affected by on-site RE generation follows:

Energy *(cents/kWh)*	The output of an RE generator varies with conditions, but monthly or annual energy delivery is more predictable and reliable. This is the feature of the rate schedule in which most of the benefits of the RE energy delivery will accrue. Every kWh of RE delivery will reduce this part of the utility bill according to the energy rate (c/kWh).
Demand *($/kW/month)*	Solar and wind energy systems may be expected to reduce demand on a sunny or windy day, but there is always a 15-minute period during the month when the solar or wind systems are not generating and demand charges are assessed. This does not mean that intermittent renewable energy generators do not save any demand- they do- but the peak by which the demand charge is assessed moves to another period of the month and a new value. Many commercial buildings have their peak load in the afternoon due to cooling loads, and many of these cooling loads are exacerbated by solar heat gain, so there is a coincidence of peak demand and solar output for many types of buildings in many climates. But odds are that there will be some period when the solar is not contributing and the new demand charge is determined, though the increasing popularity of energy storage measures can play a substantial role in increasing demand savings by mitigating short term variability in renewable resource. A rule of thumb is that solar can save demand equivalent to about 10% of its rated capacity- so a 1 MW PV system might be expected to save an average of 100 kW in demand, though it can be higher in many cases, depending on the characteristics of the facility peak load profile.
Demand Ratchet	This 10% rule of thumb would not apply if there is a demand ratchet, which bases demand charges on a historic (usually annual) demand peak (kW) rather than the measured peak in a month. Now it becomes much more likely that there will be some 15-minute demand period in the year when the solar is not contributing. So a demand ratchet generally results in little or no demand savings for an RE system driven by intermittent resources such as solar or wind.
Time of Use Rates	Time of use rates are meant to discourage energy use during the day with higher rates when system loads are highest, and incentivize energy use at night with lower rates when loads are lower. Types of RE generators that are driven by solar energy (PV, concentrating solar power, solar water heating, solar ventilation air preheating, daylighting) are generally favored by this type of rate structure because they offset the most expensive power during the afternoon.
Seasonal Rates	Many utilities have rates that are higher in the summer months than in the winter months. Types of RE generators that are driven by solar energy produce good utility cost savings because the solar resource is maximum in the summer months when the rates are the highest.
Block Rates	Block rates establish costs based on consumption, for example $0.07/kWh for the first 100 kWh per kW; $0.06/kWh for the next 100 kWh/kW; and then $0.05/kWh for all consumption in excess of 200 kWh/kW. Delivery from an on-site generator is subtracted from the highest block of

	consumption, so generally saves less than the average $/kWh blended rate. So block rates do not favor on-site RE generation in the calculation of utility cost savings.
Fixed Customer Charges & Other Riders	Fixed charges such as customer charges, metering and billing charges, or other fixed charges are not reduced by delivery of energy from the RE system, so they tend to reduce the average value (c/kWh) of the RE energy delivered in terms of utility cost savings.

In a reaction to the threat of lost revenue to on-site RE projects, some utilities are seeking changes to their rate schedule which will reduce the savings of an on-site RE project. In November 2014, Wisconsin voted to significantly increase fixed charges on customers' bills from the state's largest utility to $3.8/kW per month for new solar energy systems (Arizona instituted $0.7/kW) AND increased all customer charges from $9/month to $16/month while decreasing $/kWh fees (effectively making solar less competitive). In December of 2014 Salt River Project proposed adding fees for solar customers and capacity charges of $12.50/month service fee; peak demand charge of ~$8/kW; and to decrease energy costs (kWh charges) from about $0.10/kWh to $0.04/kWh. In December 2014 rating filing, New Mexico's largest utility (PNM) proposed a distributed solar generation fee of $6/kW/month that would apply to new systems starting in 2016, and PNM also wants to increase residential customer charges from $5/month to $12.80/month.

So to accurately estimate the utility cost savings, we must use time-series data (15-minute interval or hourly data) and the details of the rate schedule, and calculate the bill with and without the RE generation. This is a complicated calculation that is generally accomplished using software. For example, the System Advisor Model (SAM)[1] software has the ability to do this for PV, wind, concentrating solar power, and biomass energy projects using a database of utility rate schedules. This database is the Utility Rate Database[2] (URDB) which contains 38,276 utility rate schedules contributed for 3,747 utility companies. Several software products offered by private companies also offer this capability.

For example, in a 2012 calculation for a building in Washington DC the average utility rate was $0.127/kWh but the solar delivery resulted in a $0.115/kWh savings on the utility bill. Demand savings were only about 10% of the PV system rated capacity in kW, but this was offset by a higher time-of-use rate in the summer afternoon, when the solar is at a maximum.

2.2.2. Metering and Data Collection Guidelines

For M&V options involving retrofit isolation or whole building analysis, establishing clear standards for metering of renewable energy systems and collecting reported data provide an important component of a consistent and transparent M&V plan. Ideally, a standard for metering equipment (such as American National Standards Institute (ANSI) C-12) should be adopted. Program requirements, such as those established for the Go Solar California program, may offer effective models to follow.

Reporting intervals can also contribute to the accuracy of the M&V effort. Frequent reporting results in higher-resolution data, which can be more effectively quality assured and used for M&V purposes. The cost, however, may be prohibitive for some renewable energy systems, especially small-capacity systems, to report more often than monthly. Additionally, energy production's seasonal variability should be considered

[1] https://sam.nrel.gov/
[2] http://en.openei.org/wiki/Utility_Rate_Database

in establishing reporting intervals. Limiting reporting to quarterly periods may provide misleading results, and performing quality assurance on systems reporting annually may prove difficult. Provisions also should be included for reporting data via data acquisition systems (DAS) and manual meter reads.

Most projects with electrical outputs include some form of dedicated meter to record electricity generation. Most M&V efforts, particularly for larger projects, primarily install an automated DAS to collect generation data, which can be electronically submitted to the developer, evaluator and/or system owner through a wired or wireless Internet connection, a telephone modem, a cellular modem, or a satellite uplink.

Using an automated DAS can facilitate high-resolution monitoring of numerous parameters, but such systems tend to be costly, and can be prone to data transmission errors. An alternative approach, particularly useful in evaluating a fleet of projects, collects manual meter readings using on-site personnel, such as system owners or installers. This is a very cost-effective approach that has been shown to be comparable to automated DAS, regarding quality assurance requirements. The cost per system monitored this way can be quite low, requiring deployment and administration of remote reporting mechanisms and/or tracking systems, but data generally will only be available in monthly intervals. To complete a typical reporting action, an owner might read a dedicated cumulative electrical generation meter, and, for example, upload the reading to an online database, or e-mail the reading to the developer or evaluator for recording and analysis.

The accuracy of reported results can be further improved through identification of outliers. Using basic statistical methods, such outliers generally can be flagged and corrected, or be removed from the data set. This can be particularly valuable for performing M&V on DG programs, as anomalous readings generally can be addressed through on-site audits, which may identify clerical reporting errors, equipment malfunctions, or resource shortages.

M&V and connected communications systems may fail and require maintenance. In order to ensure that data collection is continuous into a very long performance period (25 years in some cases), the “availability” of the M&V system should be specified so that the contractor is required to service the M&V system. For example, an availability of 95% would require that the contractor allow missing or incorrect data only 5% of the time.

2.2.3. Accounting for Resource Variability

Renewable energy technologies generally rely on variable resources, such as sunlight or wind, to generate useful energy. Consequently, M&V activities must account for these resources’ variability, particularly when comparing predicted or modeled performance, which generally relies on TMY (typical meteorological year) or similar data. For example, if using Option B to measure a wind energy system’s output over a 12-month reporting period, it is important to know whether the 12-month monitoring period corresponds to a high, low, or average wind year. Extrapolating long-term savings using data from an atypical weather year could lead to significant calculation errors. Thus, monitoring of a RE system performance also includes monitoring not only of the system output but also of the underlying resource that the RE system depends on.

In evaluating weather dependent performance, it is important to identify the appropriate source of weather data. Weather data usually are available from sources such as the National Oceanic and Atmospheric Administration. In the case of larger projects, the source of data may already be identified as part of the pre-development process. In that case, the evaluator may use that data after conducting an independent review to ensure its accuracy and completeness. Options include:

- ***On-site measurement:*** Measurement and data-logging of the solar or wind resource is accomplished by installing instruments and communications as part of the RE system installation.
- ***Measurements from nearby sources:*** If it is close by, measurements from a weather station, university, or another RE system are often used instead of new measurement.
- ***Satellite data:*** Measurements of the incident solar resource made by satellites are processed and made available to the public through commercial subscription services. For example, one company charges $8.50 per site per month to report the solar resource. On-site measurements are thought to be better than satellite measurements, which may involve error on the order of 5%, but satellite data are preferred to on-site measurements if the instruments are not well maintained- dirt on a pyranometer could skew the result by more than 5%.

If a direct, linear relationship exists between weather measurements and energy generation, a simple ratio of long-term and monitoring period weather values can be used to modify the renewable energy system's monitored performance. The exact method for applying this modified resource varies by technology. For some applications, a linear adjustment proves sufficient. Other technologies, such as wind turbines, require more sophisticated statistical treatment. Often, the computer models used for system design and performance prediction are used to generate and estimate how much energy the system should have delivered by inputting the weather data measured during the performance reporting period into the model.

Example: Use of PV Capacity Tests to Validate Performance Modeling

Some of the most common software tools available for calculating the electricity generation of solar PV systems begin with the nameplate capacity of the PV system as an input. Beginning with this DC rating, the modeling software uses a variety of factors to adjust the DC capacity into an effective AC output value. By measuring, over a short period of time, the AC power output, irradiance, and module temperature a commissioning engineer can validate that a PV system is generating AC electricity consistent with the expected DC to AC derate factors used in the performance model. If this method were employed and the result was within an acceptable range of the predicted power output, then the evaluator could apply Option A to validate the performance model with stipulated inputs for other variables, such as solar irradiance.

A "Short-term Performance Test" is a comparison of actual photovoltaic system efficiency to efficiency predicted by the characteristics of the system, based on observing actual power output comparing to predicted output.

$$T_{cell} = T_{ambient} + \frac{(NOCT - 20C)}{\left(800W/m^2\right)} I_c$$

Where:

- P_{solar} is the actual power delivery in kW instantaneous or averaged over the duration of the test.
- I_c is the solar insolation in plane of array
- T_{cell} is the PV cell temperature (C), averaged over the duration of the test; if it is not possible to measure cell temperature directly, it can be estimated from ambient temperature according to the equation

- NOCT is the nominal operating cell temperature, which is a number found in the manufacturer's literature and is often 47C.
- η_{bos} is the balance of system efficiency, estimated by dividing the actual amount of power measured by the power of the PV system as calculated as a function of environmental conditions with the following equation:

$$\eta_{bos} = \left(\frac{P_{solar}}{P_{STC}\left\{ \frac{(\deg r)}{(1000W/m^2} Ic(1-\delta(T_{cell}-25C)) \right\}} \right) \quad \textbf{(Eq. 2)}$$

The parameters that describe the size and type of system are:

- P_{STC} is the rated size in kW, nameplate capacity; STC refers to Standard Test Conditions
- Deg *r* is an age degradation factor that is 1.0 initially but degrades at 0.5 % per year
- δ is the temperature coefficient of power (1/C)

The balance of system efficiency is typically = 0.77 to 0.84 (NREL, 2011) but stipulated based on published inverter efficiency and other system details. This is a "spot check" on instantaneous power performance and may be used to determine if your system is operating as expected (i.e., efficiency lower than stipulated value) or if it may be experiencing problems and in need of inspection/maintenance. In a recent test at a 67 kW PV system in Colorado, the measured balance of system efficiency was 0.789, which was greater than the 0.77 stipulated value, indicating acceptable system performance.

3. Renewable Energy Application of IPMVP Options

3.1. Option A: Retrofit-Isolation, Key Parameter Measurement

In this option, a system's capacity to perform (for example, to deliver renewable energy) is measured in the field, with operating conditions stipulated. Field measurement may be made continuously or periodically throughout the reporting measurement period. The reporting period can last as long as required to satisfy contractual or legal requirements. Periodic inspections also must be conducted throughout the reporting period to ensure systems remain as specified and operate as expected.

Option A is generally the simplest and least expensive of the IPMVP options, though it provides a less accurate measure of actual system performance. Under Option A, the evaluator, developer, or ESCO uses short-term measurements and observations to determine the operating characteristics of the system and then applies those results to long-term generic data to calculate energy savings. While Option A may require some measurement of system generation (key parameter), it is typically done over a short period of time for purposes of correlating with other variables. Option A can often be exercised using data gathered during a commissioning or start up process. However, the key parameter measurement should be re-measured periodically during the reporting period.

3.2. Option B: Retrofit-isolation, All Parameter Measurement

As renewable energy systems deliver rather than conserve energy, a distinguishing feature over efficiency measures is that energy can often be measured directly with a meter. However, to assess whether the system is performing at an expected level, the renewable resource, if variable, should also be measured. Measuring the resource, in addition to the energy output, provides information to determine whether unexpected generation values are due to performance issues, or just variability in the resource.

Using Option B, the supplier takes responsibility for metered energy delivery, but the renewable resource available is taken into account when establishing whether the system is meeting performance expectations. For example, typically in a performance contract, the ESCO would perform an Option B approach utilizing the resource data to make adjustments, as appropriate, to the verified savings per the methodology defined in the M&V Plan.

Long Term Energy Test for Tracking PV System

Figure 2. 2-Axis Tracking Solar PV System

In order to measure the performance of a tracking PV system, the evaluator measured AC electricity generation, solar irradiance (plane of array), ambient temperature, humidity, and other key parameters. By measuring electricity generation and normalizing to irradiance, the evaluators were able to normalize actual generation to baseline weather conditions used in the pre-installation performance modeling and determine that the PV system was generating approximately 19% more electricity than predicted in the performance model, after normalizing to typical meteorological year (TMY) irradiance levels.

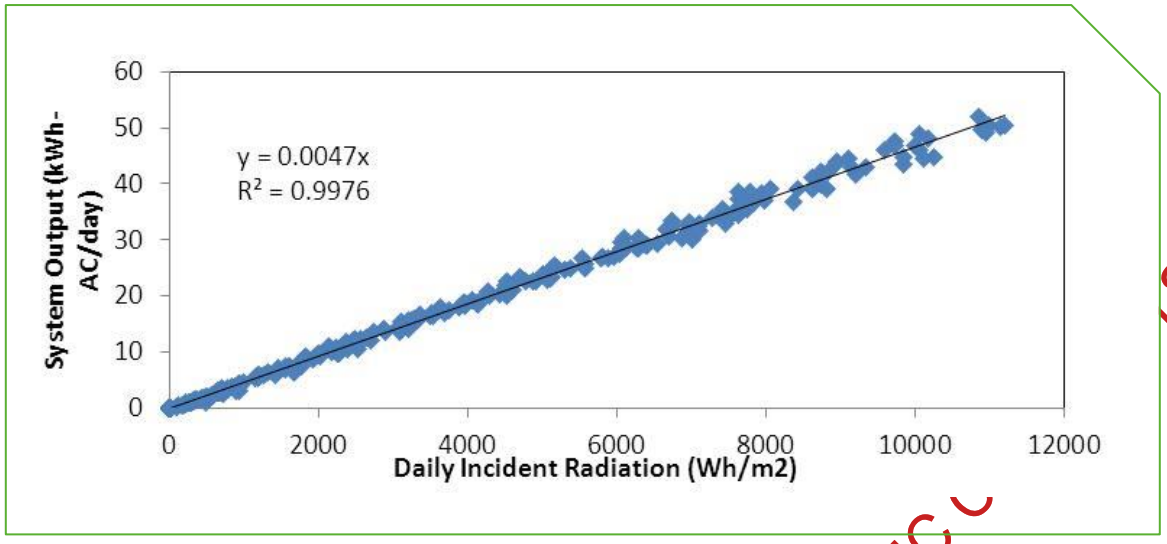


Figure 3. Performance Measurement Data for 2-Axis Tracking Solar PV System

REFERENCES:

Cadmus et al., *NYSERDA American Reinvestment and Recovery Act 2012 Impact Evaluation Report: Energy Efficiency and Conservation Block Grant*, September 30, 2012.

Example of Solar Hot Water Metering Application of Option B

Figure 4. Parabolic Trough Solar Water Heating at Phoenix Federal Correctional Institution, Phoenix AZ (photo by Ed Hancock, Mountain Energy Partners).

The Federal Correctional Institution in Phoenix, Arizona houses more than 1,200 inmates. The Department of Justice installed a central solar water heating system to provide domestic hot water for the inmates. This system is owned by Industrial Solar Technology Corporation (IST, now Abengoa) and operated under an Energy Savings Performance Contract (ESPC). At the end of the contract in 2016, the prison will take over ownership and operation of the solar field.

The system consists of 120 parabolic trough collectors totaling 17,040 ft^2 (1,584 m^2) of collector aperture area; propylene glycol solution circulating fluid; a master start-up and field controller and 4 local sun-tracking controllers. Storage is provided by 2 stainless steel water tanks, totaling 23,000 gallons (87,055 liters). The load served by the system is around 4,000 kWh/day to heat 50,000 gallons of water for laundry, kitchen, and other domestic applications. The 650,000 dollar initial cost of the system was financed through an ESPC, with the prison paying the company 90 percent of whatever the utility company would have charged for the same amount of power.

Delivered energy is measured by a BTU meter manufactured by Hersey and consisting of a water flow meter, a temperature sensor on the incoming cold water pipe, a temperature sensor on the pipe delivering solar preheated water to the prison, and integrating electronics. The system delivered over a million kilowatt-hours of heat in 1999, and the prison saved 77,000 dollars. 70,000 dollars of this went to the ESPC payment and the prison saved the remaining 10 percent, or 7,000 dollars. The cost savings to the prison each month are based on the average, blended utility rate (about $0.07/kWh in 1999), which neglects the details of the utility rate schedule but was chosen based on simple implementation. In order to ensure that actual cost savings are not significantly less than this, the system is controlled in such a way to save up solar heat in the storage tank and reduce facility peak demand on a daily basis rather than deliver maximum energy.

REFERENCES:

May, K., Barker, G., Hancock, E., Walker, A., Westby, B., and Dominick, J., *Performance of a Large Parabolic Trough Solar Water Heating System at Phoenix Federal Correctional Institution*, Journal of Solar Energy Engineering, Vol. 122, No. 4 pp. 165-169. November 2000.

3.3. Option C: Whole Facility

Option C analyses information available through utility bills or whole-facility metering to determine energy savings or production. After renewable energy system installation, the utility bill (which constitutes the measurement) or utility meter reading is subtracted from a baseline, with adjustments for changes in use or facility operations, to determine energy savings. The baseline can be determined using one of three comparison techniques: Control Group Comparison; Before-and-After Comparison; or On-and-Off Comparison (RE system temporarily disabled to gauge impact).

If the baseline has been established by a control group, participants may debate and determine by consensus factors constituting sufficient similarity between buildings. However, the intent is to select a control group essentially identical to the sample (e.g., identical military housing units, with the same use and in the same location).

As driving forces, such as weather and occupancy, frequently change, Option C involves routine baseline adjustments. ASHRAE Guideline 14 describes baseline methods appropriate to Option C, and PRISM and ASHRAE RP1050 are referenced for software used to calculate monthly baseline utility bills, based on weather (PRISM 2002).

The method's accuracy can be limited by numerous variables affecting building energy use. These limitations make Option C unsuitable for evaluating the performance of systems with small energy outputs, compared to a building's overall electrical load. Option C's usefulness for evaluating renewable energy projects also is partially driven by the resolution of available consumption data. Recent advances in Advanced Metering Infrastructure (AMI) technologies have made application of smart metering solutions more common, even in some residential markets. With hourly consumption profiles for both baseline and retrofit groups, identification of energy production trends associated with renewable energy systems improves (e.g., a marked reduction in early afternoon can be attributed to a new solar PV system).

While Option C, even with AMI hourly data profiles, does not present the most accurate method for determining savings attributable to any single renewable energy project, the method bears merit when considering a fleet of systems. Using Options A, B, or D in program evaluations generally requires use of a statistical sample, due to budgetary constraints. Obtaining and analyzing hourly data through an AMI, however, has a significantly lower incremental cost, which suggests a larger sample size could be employed. Theoretically, the larger sample size could offset Option C's reduced accuracy, offering a more cost-effective method for evaluating energy savings.

Example of Solar Hot Water Metering Application of Option C

Figure 5. Solar Hot Water Panels

The Cadmus Group, Inc. (Cadmus) conducted an evaluation of National Grid's Solar Hot Water (SHW) Pilot Program in 2012. In order to measure the performance of the systems Cadmus obtained data through billing analyses, customer surveys, site visits, and engineering reviews of solar hot water systems installed through this program.

Cadmus compared pre- and post-installation period summer gas consumption data to calculate gas savings resulting from the installation of the SHW system. The difference in gas usage pre-SHW system versus post-SHW system yields the reduction in gas usage due to the installation of the SHW system. Cadmus used the months of June, July, August, and September to minimize any impacts from heating system operation, and adjusted the savings by the amount of insolation that occurred during the billing assessment period in relation to the entire year, since SHW systems generally collect more energy during the longer hours of sun in summer than they do in winter.

Cadmus used a regression model to calculate solar water heater gas savings for each site. The regression model estimates the gas savings, normalized for weather differences in the fall and early spring months between the pre- and post-measure installation periods. The regression equation is shown in Equation 1. Cadmus applied this equation twice for each site, for both the pre- and post-measure installation periods.

$$ADC_{t,pre/post} = \alpha + \beta_1 AVGHDD_t + \beta_2 POST_t + \varepsilon_t$$

Where, for billing month '*t*':

- $ADC_{t,pre/post}$ is the average daily consumption (therms) during the pre- and post-periods, obtained from provided gas bills.
- α is the base therm usage of the water heater.
- β_1 is the average daily therm consumption per heating degree day.
- $AVGHDD_t$ is the average daily base 65 heating degree days based on site location.
- β_2 is the average site level daily savings from the solar water heaters.
- $POST_t$ is a dummy variable that is '1' in the post-period and '0' otherwise.
- ε_t is the regression model error term.

Cadmus then applied seasonal and annual adjustment factors applied to the post period average daily gas consumption and the gas savings to account for variability in the solar resource. Since it was necessary to calculate post-period gas consumption based on spring and summer periods when gas bills were unlikely to reflect space-heating loads, simply annualizing the results would over-estimate energy savings. To account for this, Cadmus applied a seasonal adjustment factor based on TMY3 solar radiation data, as shown in Equation 2.

3.4. Option D: Calibrated Simulation

Option D, relying on comprehensive whole-building or systems models to determine performance and estimate project savings, is commonly used in new construction projects with extensive efficiency and/or renewable energy components, where isolated metering and baseline characterizations prove difficult. Though isolated component metering may be conducted to support simulation calibration as part of Option D, this does not constitute the main focus of M&V activities.

This method produces an estimation of annual energy performance using the results of a short-term test. First, a computer simulation model allows determination of performance, based on independent variables and specified operating parameters. To calibrate the model, independent variables (e.g., load, solar radiation, wind speed, and ambient temperature) are measured and recorded simultaneously with system energy performance (e.g., energy delivery) over a specific time period, which includes all operating modes. Next, simulation model parameters are adjusted to provide the correlation between simulated and measured performance. To provide estimated annual project savings, the calibrated simulation employs independent variables, representing load and environmental conditions through the course of a year (e.g., agreed upon operating schedules, TMY weather file for the site).

Challenges in performing calibrated simulations include:

- Providing proper inputs, such as occupancy and operation patterns, correct weather variables, and system parameters.
- Understanding the model's limitations.
- Selecting parameters to vary for calibrating the model and running parametric.

Whole-building simulation models often used as part of Option D include EnergyPlus. These comprehensive computer programs account for interactions between different building systems and energy resources (for example, daylighting affecting lighting and cooling energy). Often a whole-building model is required to

determine thermal or electric loads on a renewable energy system serving a building. If the load can be known or agreed upon, TRNSYS can be used (Univ. of Wisconsin, Madison). In applications where renewable energy delivery is not limited by the load (such as PV system outputs never exceeding the building load, or a wind turbine connected to the utility grid), whole-building analysis is not required, and only the renewable energy system need be simulated.

Example of Calibrated Simulation Used for Solar Thermal Project

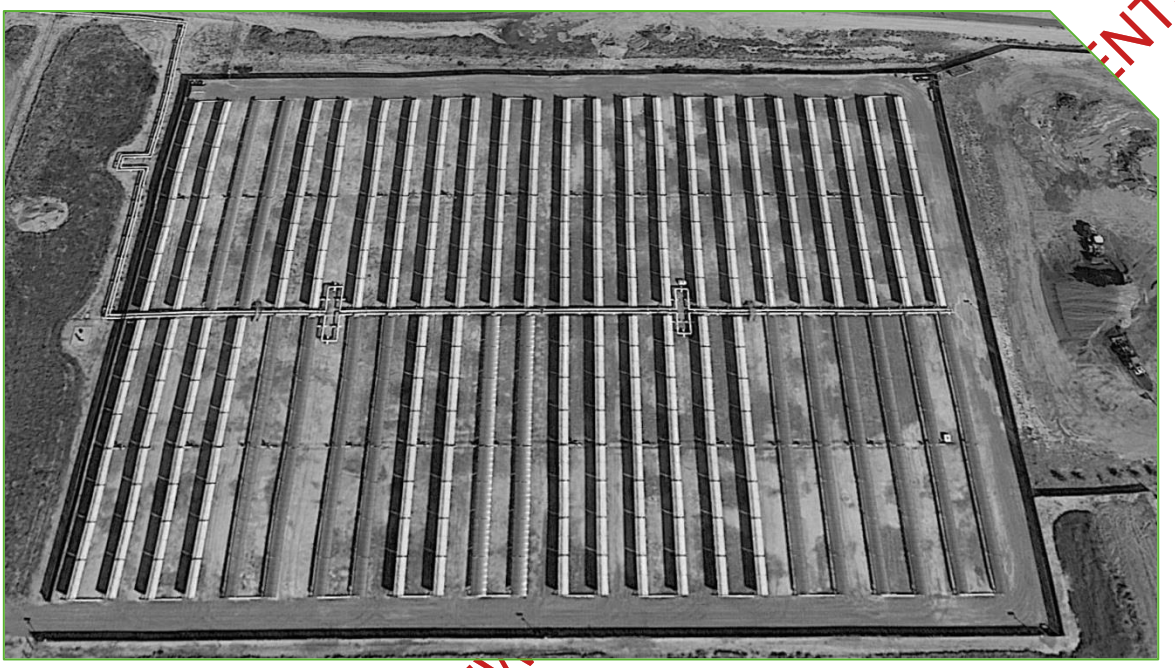


Figure 6. Parabolic Trough Solar Thermal Energy System

During the summer of 2008 a 5,068 m^2 (54,528 ft^2) parabolic trough solar thermal energy system was constructed at the Frito-Lay plant in Modesto, California. The system heats pressurized water to about 243°C (470°F) (which is used to generate 300 psig (216°C, 422°F saturated) steam at the plant. A team conducted a short term test to renormalize the coefficients of a computer model. The performance guarantee provided by Abengoa Solar in the contract with AEA was that the system should deliver 2.3 MW (8.0 MBtu/hr) of heat under standard conditions. Standard conditions are more favorable conditions than are typical at the Modesto site, so calibration of a computer model is needed to evaluate compliance under actual measured conditions.

Standard conditions are the most favorable conditions typical at the Modesto site (*872 W/m^2 direct normal sun, inlet temperature 13°C and outlet temperature 200°C*). Since these conditions did not occur during the test period, calibration of a computer model is needed to evaluate compliance under measured conditions. Under the more favorable standard reference conditions, the calibrated computer model predicts a peak output of 2370 kW (8.1 MBtu/hr), which is greater than the guarantee of 2300 kW (8.0 MBtu/hr).

In this case, the use of a short-term testing program to calibrate the simulation model provided the necessary data to demonstrate that the solar thermal system provided the contractually required level of performance, even though the actual weather conditions present during the reporting period did not match those used in

the initial performance model. Note that use of Option D, as in this case, frequently coincides with measurement under Option B in order to provide the necessary model calibration data. Therefore, Option D is sometimes an extension of Option B, with added emphasis on the software/modeling aspects beyond direct reporting of energy savings as measured.

4. Guidelines for M&V Applications

4.1. Programmatic Applications

In addition to providing a means for establishing savings and evaluating individual renewable energy projects, this Application Guide is also applicable to fleets of renewable energy systems. A common example of this application is the process of evaluating a large volume of residential solar PV systems supported by a statewide incentive program. Such incentive programs exist in many states and territories and evaluating the benefits of these programs can pose a challenge, as there are rarely sufficient resources available to collect performance data on a full census of completed projects. This suggests that the methods for conducting M&V on a single project need to be expanded upon to cover large fleets of systems and, notably, programmatic energy benefits may need to be expressed based on a statistical sampling approach.

4.1.1. Statistical Sampling for Renewable Energy Fleets

As with energy conservation measures, a statistical sampling approach can provide a cost-effective method for evaluating the energy savings/generation for fleets of renewable energy projects. Statistical sampling and uncertainty is covered in detail in the Statistics and Uncertainty Application Guide but the following key points refer to evaluation of renewable energy fleets:

1 **Select a Target Confidence and Precision**	Before beginning the sampling process, the evaluator must select a target confidence and precision level. Many Utility program evaluations require a 90/10 confidence and precision but this selection drives the sampling process and, in general, an increased confidence and/or precision level will require a larger sample and be more costly to evaluate.
2 **Define Population**	In evaluating a fleet of renewable energy projects, it is important to properly define the population to be analyzed. The most basic question, which must be answered, is whether sampling will be conducted based on expected energy, quantity of projects, or some other metric. In cases where there are many projects with similar levels of expected energy savings, drawing a sample based on project count may be sufficient. If, however, the sample could contain projects with varying energy savings potential a sample based on expected energy savings may provide a more accurate approach.
3 **Stratify Sample**	How the overall sample is stratified will substantially impact the scope of evaluation and the type of information that can be gleaned. This is a particularly important consideration for fleets of mixed project types and scales, as a sample could be dominated by a single large project that contributes the majority of savings, while neglecting a large number of smaller projects. For example, placing a large commercial PV system in the same strata as a fleet of residential PV systems might lead to improperly emphasizing one group over the other and combining results for two sets of very different measure types. Typically, strata are defined based on system capacity/size, expected energy output, technology, resource availability, location, or market sector.

The accuracy of any measured value can be properly expressed as the range within which the true value can be expected to fall, with some level of confidence. For renewable energy systems, this confidence level could be established around the fleet's mean capacity factor, expressed as:

$$\bar{Y} = \frac{\sum \frac{kWh}{kW \times Hours}}{n}$$

Using the mean capacity factor and the standard deviation of the observed or estimated population, a model for the population's distribution should be developed. Most populations distribute normally, or log-normally; it is, however, feasible that other distributions could be observed if the population includes significantly higher or lower efficiencies (i.e., a concentrated solar power system included in a fleet of PV systems). Appendix B-1 of Volume 1 details the procedure for establishing confidence and precision to express uncertainty in the accuracy of energy savings; a similar approach should be developed and used to verify generation data.

Metered systems, with capacity factors falling outside confidence levels, should be closely evaluated for the accuracy of production readings. Generation from systems that cannot be verified should be removed from the fleet, or be estimated using established methods (e.g., historical estimates or statistical models).

5. Costs & Benefits

M&V programs inherently provide the quality assurance required for renewable energy projects. M&V costs, however, can vary greatly, according to a particular project's requirements.

An M&V program's total cost includes: the cost of purchasing, installing, and maintaining the instrumentation (including periodic calibration); the cost of labor involved in designing the program; and the cost of periodically collecting, reducing, and presenting the program results. Overly detailed or poorly designed M&V programs can be very expensive; so money budgeted should be determined by the value of benefits resulting from the M&V program.

The value of these benefits can be determined through negotiations between customers and project developers for each project, with an objective of all parties working together to minimize total M&V program costs, while achieving acceptable uncertainty levels regarding savings.

To lower project costs, the customer may assume some performance risk by agreeing to periodic and limited (rather than continuous) measurements, or by increasing allowable error in the measurements. Other requirements of a particular M&V program might include verification for emissions credits, or other regulating bodies' certifications, as noted in Chapter 1. Total costs will include costs of measuring and verifying such requirements.

Typically average annual M&V costs are less than 10% of the average annual savings being assessed. The quantity of savings at stake therefore places a limit on the M&V budget, which in turn determines how much uncertainty is acceptable. In the DOE ESPC program, annual M&V costs range from 2-5% of annual projected costs savings with 3% being the overall average. Please note this includes all project types including but not limited to renewable energy projects.

For photovoltaic systems, PV Magazine reported in 2016 that monitoring capital costs are relatively small, with investment allocated to monitoring and data logging averaging 2% of a total plant's capital cost, with that figure somewhat higher in the residential segment, and lower in larger installations. On-going costs to process and report data can add up over time. Companies offer sophisticated analysis that can predict what the system should have produced under measured conditions based on models. For a 10 MW plant, monthly monitoring services may cost $10,000, one U.S. source estimates. Cost to maintain instruments in calibration, periodically check for proper function, and log and report data costs at least $1,000 per month even for small systems, so most approaches involve a high level of automation once the M&V hardware is installed in order to reduce monthly costs[3].

[3] For more information, access to PV Magazine, Monitoring and data logging services multiply, (Online) November 2016.