Capturing Savings Down the Production Line: Measuring the Impacts of Energy Management Programs

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ABSTRACT

Energy management (EM) programs provide an innovative approach to energy conservation in the industrial sector, serving to train industrial energy end users to develop and execute a holistic long-term energy plan beyond conventional capital measures. Such programs fundamentally seek to integrate EM into facilities' business planning; so they continue with EM after disengaging from the program.

Quantifying energy savings produced by EM programs proves vital in establishing program savings claims, analyzing cost-effectiveness, and substantiating the program's value and achievements for participating facilities and ratepayers. Recognizing the program's value will secure future program funding. However, the program's very nature, where equipment, operations and maintenance (O&M), and behavioral improvements occur on an ongoing basis, poses many challenges for detecting energy savings.

Several studies have estimated energy savings from industrial EM programs. A recent evaluation of the Bonneville Power Administration's (BPA) Energy Management Pilot program used several innovative approaches that provided valuable lessons to program implementers and evaluators. The BPA evaluation:

- Compared site-specific models to a pooled model to determine which more precisely estimated savings.
- Found a relationship between billing and production data frequency (bimonthly, monthly, weekly, or daily) and savings detection.
- Compared the results of statistical models with Fractional Savings Uncertainty values, which allow program operators to predict if statistically significant savings can be detected for a facility.
- Found key differences in program savings assessment and evaluation savings assessment methodologies, such as model functional forms and reporting of negative site savings.

Introduction

BPA's Energy Smart Industrial (ESI) program launched in October 2009. The Energy Management Pilot, a component of ESI, presents an innovative approach to acquiring conservation resources in the industrial sector through improving energy efficiency of O&M practices and capital measures.

The Energy Management Pilot strategy differs from traditional energy-efficiency programs in that it focuses on implementing a holistic energy-management strategy that extends beyond replacing inefficient equipment. The program provides long-term energy-management consulting services to educate and train industrial energy users to: (1) develop and execute a long-term energy-planning strategy; and (2) integrate energy management into their business planning permanently.

The pilot has three core components:

- **Energy Project Manager Co-Funding.** With Energy Project Manager co-funding, participants can devote staff time to EM. This serves as an important component of the pilot, as limited staff time presents the primary market barrier to effective EM practices in industrial facilities

(Cadmus 2012). The pilot uses Energy Project Manager co-funding in conjunction with the Track and Tune and the High-Performance Energy Management components. A facility chooses whether to participate in Track and Tune or High Performance Energy Management, and whether they will take advantage of the Energy Project Manager co-funding.

- **Track and Tune.** Track and Tune projects help industrial facilities improve O&M efficiencies financially and technically, while establishing a system that allows the ESI program and the facility to track energy performance and savings over several years.
- **High-Performance Energy Management.** High Performance Energy Management provides training and technical support, engaging both upper management and process engineers; so they can implement EM in their core business practices. High Performance Energy Management entails the application of the principles and practices of continuous energy improvement and energy management within an industrial facility.

The EM program team developed a methodology called Monitoring, Targeting, and Reporting to estimate the monthly savings (i.e., program savings estimate). This methodology employs regression analysis of monthly consumption to establish a baseline for the pilot period and to estimate the monthly savings that serve as the basis for annual program savings estimates.

The first year of the Energy Management Pilot ran from July 1, 2010, through June 30, 2011. Two facilities participated in Track and Tune, and 15 facilities participated in High Performance Energy Management. Nine of the 17 facilities also participated in Energy Project Manager (eight from High Performance Energy Management and one from Track and Tune). Within the Energy Management Pilot, there was significant diversity in the types of industry represented:

- Two drinking water plants;
- Four food processing facilities;
- Three lumber processers (one site, High Performance Energy Management site 13, had two separate meters; the remainder of the paper refers to these as High Performance Energy Management site 13a and 13b); and
- Two municipal wastewater facilities.

The remaining six sites were: a chemical processor; an open pit mine and mill; and manufacturers of custom machinery, synthetic fabrics, electronics, and newsprint.

Program Evaluation Methodology

Evaluation Goals

BPA, recognizing the lack of experience in savings estimation for EM programs, initiated an early (during the design phase) evaluability assessment of the program (Cadmus 2010). This assessment recommended: some alterations to the initial method for program savings estimation; and an evaluation using a pooled regression model after one year of experience.

At the end of the first program year, BPA contracted with Cadmus to evaluate the impacts of the Energy Management Pilot (Cadmus 2013). The evaluation's key objectives were to: (1) review the facility savings estimation methodologies and results; and (2) independently estimate energy savings for each facility.

Documentation Review and Replication of Monitoring, Targeting, and Reporting Models

The evaluation reviewed information provided by the ESI program for each of the 17 pilot sites. This information encompassed the following:

- Background information about the industry, site, and program implementation;
- Savings estimates for capital projects;
- Savings estimates for High Performance Energy Management and Track and Tune projects;
- Monitoring, Targeting, and Reporting process reports and documentation; and
- Raw data from the site (billing, weather, production, and other data used in the Monitoring, Targeting, and Reporting model).

In reviewing the raw data, the authors noted the frequency of energy use and production data varied. Five sites had daily billing and production data; three sites had weekly data; and nine sites had either monthly (8) or bimonthly (1) data.

To understand how the program was implemented at each site and to assess the facility data and assumptions of the Monitoring, Targeting, and Reporting models, the evaluation studied the Monitoring, Targeting, and Reporting savings estimation models, paying particular attention to the following:

- Completeness and quality of the data series;
- Effects of capital projects;
- Definitions of the baseline period; and
- Potential omission of any variables affecting energy use that might correlate with the adoption of program measures.

Modeling

The evaluation used regression analysis of interval meter data to estimate the energy savings at each of the 17 sites, an approach similar to that described in Luneski's publication (2011). The interval meter data and facility production data included at least one year of baseline period data and one year of test period data. Most sites included more than one year of baseline and test period data. When available, data from the second year of participation was included to refine the savings estimate for year one.

For two primary reasons, regression analysis proves appropriate for estimating savings from O&M changes:

- As the Energy Management Pilot may affect a variety of energy end uses, it may be more practical and cost-effective to measure savings at the site level rather than at the end-use or measure levels.
- As the pilot savings derive largely from multiple O&M changes over time, challenges emerge in developing engineering estimates of the savings for each individual O&M measure.

The evaluation estimated a separate consumption model for each site as industries have very different production outputs and energy-use sensitivities with respect to production and weather. Furthermore, the evaluation did not attempt to develop a control group of industrial sites for two reasons: (1) the uniqueness of the pilot sites; and (2) the difficulty of acquiring energy use and production data for nonparticipants.

The EM program team developed engineering savings estimates for most capital measures installed during the pilot baseline and test periods. The evaluation approach for O&M savings controlled for energy savings from capital measures. The team first derived annual savings at the facility-level, then subtracted the energy savings from capital measures, and the remaining savings were attributed to behavioral and

O&M changes. This was an important step as savings from the capital measures were (or will be) claimed by the ESI program separately.

Findings

The ability to detect energy savings at a program site using regression analysis depends on:

- The correlation between program activity and the other independent variables;
- The variance of the dependent variable explained by the independent variables; and
- The number of observations included in the baseline and test periods.

In turn, the number of observations depends on the data frequency and length of the baseline and test periods. Although the number of pilot sites was small, the authors found a relationship between the frequency of energy consumption data and the ability to detect measurable savings. The authors could detect O&M savings at the 20% significance level at seven of the eight sites with daily or weekly data. In contrast, only two of the nine sites with monthly or bimonthly data had detectable savings. Thus, higher-frequency (daily or weekly) data appear to increase the probability of detecting savings.

Facility-Level Energy Savings Estimates

Figure 1 shows the point estimates of the facility O&M electricity savings in the pilot's first year; and Figure 2 shows savings as a percent of consumption. Figure 3 shows the point estimates of the sum of facility O&M and capital measure electricity savings in the pilot's first year; and Figure 4 shows savings as a percent of consumption.

These figures also show 80% confidence intervals. The savings estimates are statistically significant at the 20% significance level, if the confidence interval for savings excludes zero.

Note that all the plots exclude two sites as their savings could not be estimated. At both High Performance Energy Management site 4 and High Performance Energy Management site 13a, the start of High Performance Energy Management coincided with the installation of capital measures, which meant the High Performance Energy Management O&M measure savings could not be separately identified from the capital measure savings. In all the figures, the shadowed diamonds represent sites managed by an Energy Project Manager.

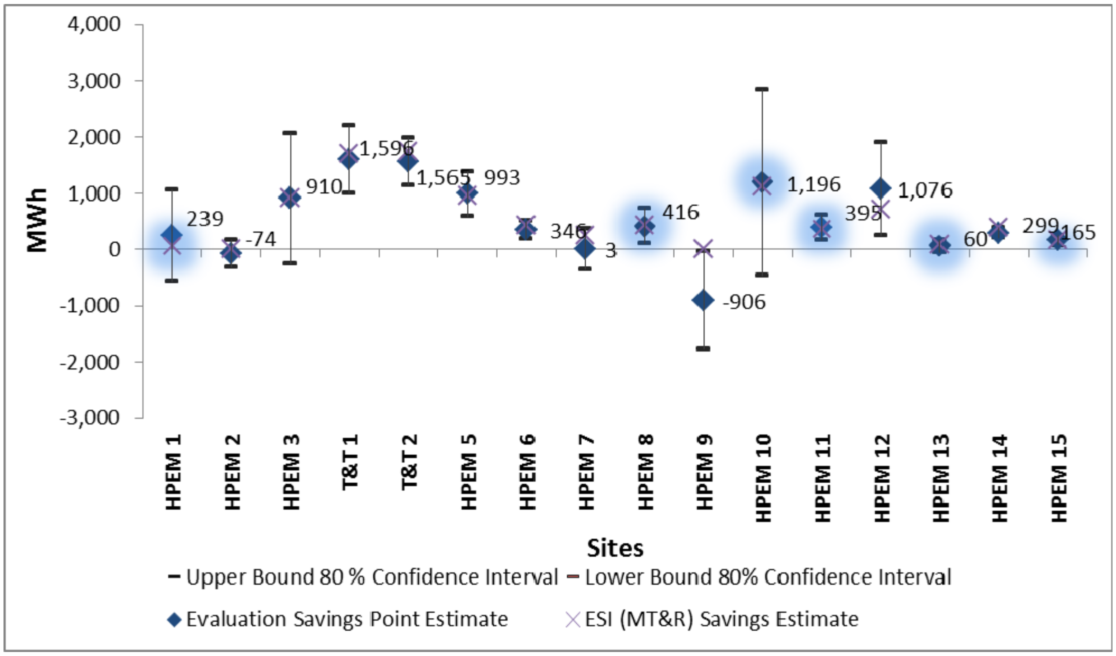

Figure 1. First-Year O&M Electricity Savings with 80% Confidence Intervals

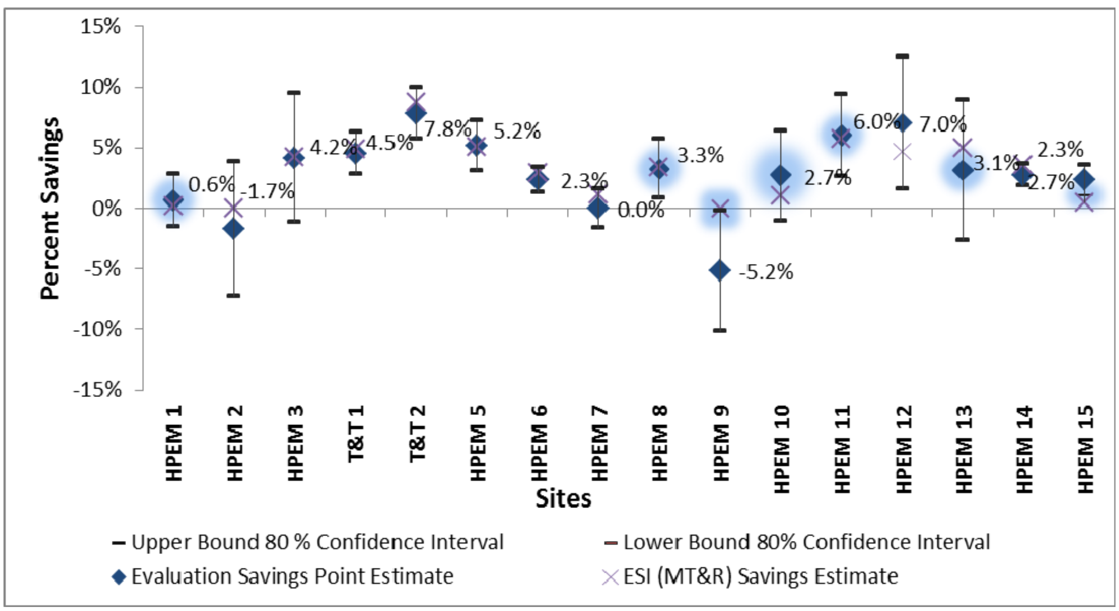

Figure 2. First-Year O&M Electricity Savings as Percent of Consumption with 80% Confidence Intervals

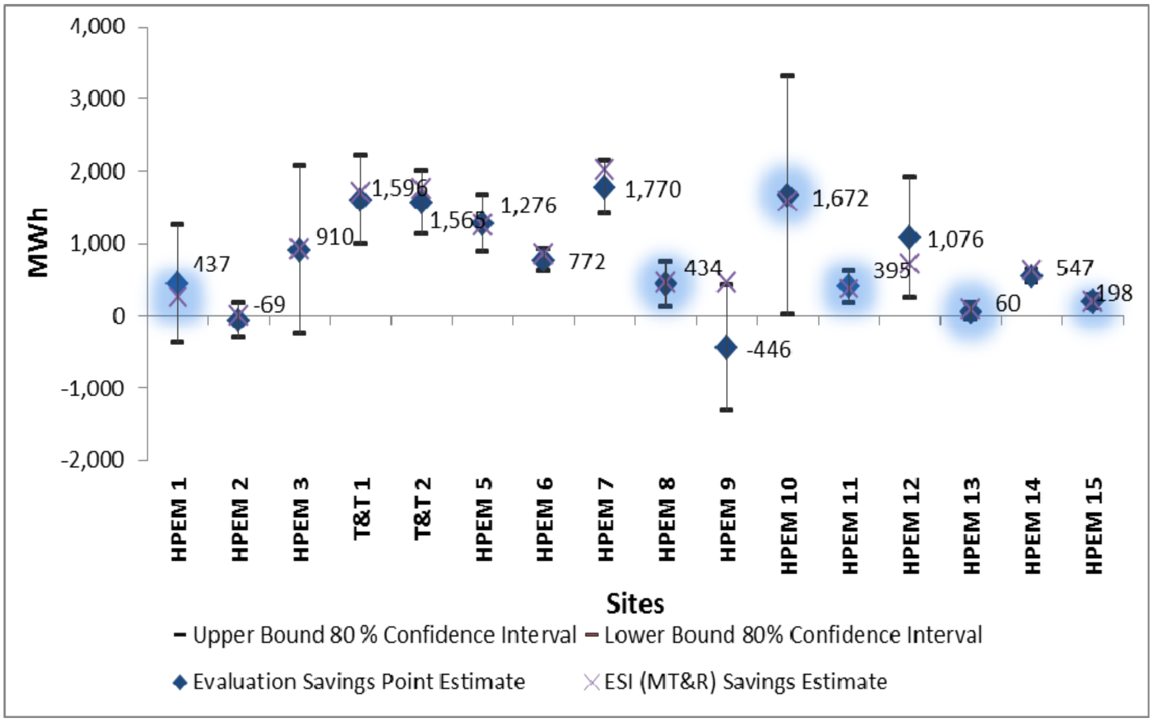

Figure 3. First-Year O&M and Capital Measure Electricity Savings with 80% Confidence Intervals

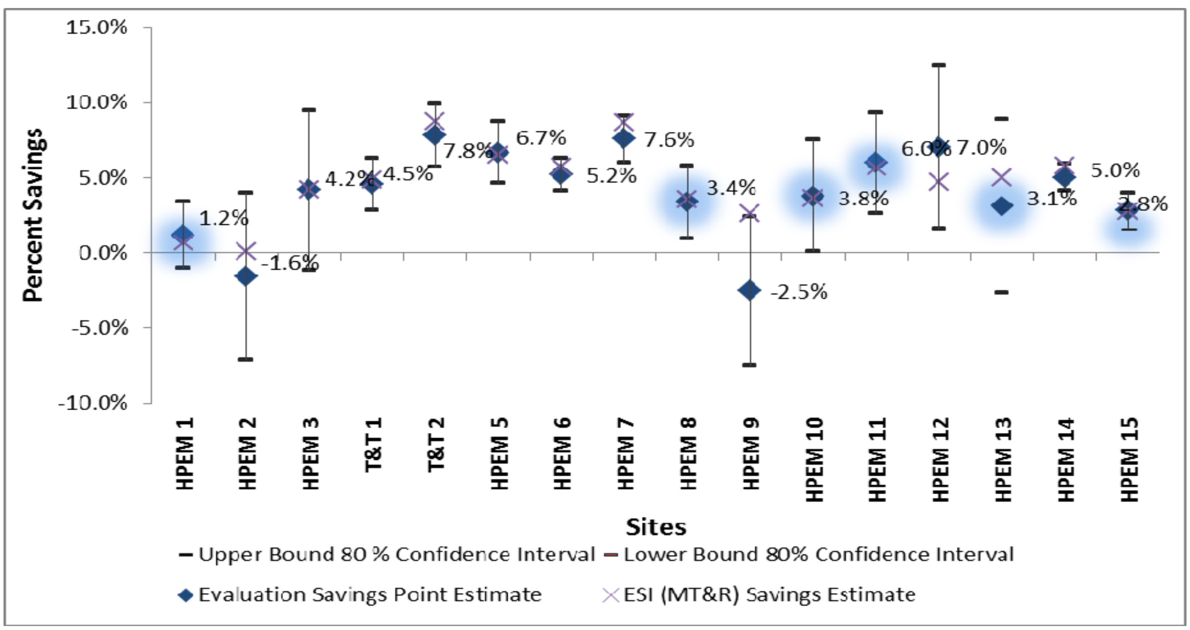

Figure 4. First-Year O&M and Capital Measure Electricity Savings as Percent of Consumption with 80% Confidence Intervals

The evaluation estimated positive O&M electricity savings at 14 sites (including High Performance Energy Management site 13b). Negative O&M electricity savings estimates resulted at two sites, and savings could not be estimated at two sites (including High Performance Energy Management site 13a). Negative O&M electricity savings at two sites indicated an increase in electricity use. Negative savings were statistically significant at one of the two sites, but these negative savings do not necessarily mean the program increased electricity use.

Negative savings mean one or more of the following:

- The program caused the facility to use more energy because either: (1) the O&M changes were ineffective and had an effect opposite of what was intended; or (2) the O&M changes increased the efficiency of the facility's energy use so much that the facility increased its overall use of energy (take-back).
- The engineering estimate of savings from capital measures in the test period is an overestimate. Since O&M savings are estimated as the residual between total savings and capital measure savings, an overestimate of the engineering savings will bias the O&M savings downward. If the estimate of capital measure savings is sufficiently high, the estimate of O&M savings will be negative.
- The data may not allow for an unbiased savings estimate. For example, there may have been unobserved changes at the facility that caused consumption to increase in the test period. It is also possible that O&M changes and the installation of capital measures may coincide, making it difficult to separately identify the O&M savings.

Although most sites had positive O&M savings, some savings were not precisely estimated; thus, they were not statistically significant at the 20% level (80% confidence level). Only nine of 16 sites had electricity savings that were positive and statistically significant at the 20% level.

Program Savings Estimates

Table 1 shows the ESI and evaluation estimates of the total electricity savings in the pilot's first year (July 1, 2010, to June 30, 2011). The ESI Energy Management Pilot, via the Monitoring, Targeting, and Reporting models, reported savings of 9,860 MWh for O&M measures at 17 sites. Because the evaluation could estimate O&M savings at only 16 sites, Table 1 presents the Monitoring, Targeting, and Reporting O&M savings for the same 16 sites for comparison purposes.

Table 1. Pilot O&M Electricity Savings Estimates

	Sites (N)	Energy Management O&M Savings (kWh)	Lower Bound 80% Confidence Interval	Upper Bound 80% Confidence Interval	Energy Management O&M as Percent of Consumption	Reali-zation Rate
Monitoring, Targeting, and Reporting: All Sites	16	9,366,362	-	-	3.1%	n/a
Evaluation Results: All sites	16	8,277,665	5,765,508	10,789,822	2.7%	88%

Notes:
(1) The Monitoring, Targeting, and Reporting estimates did not include standard errors or confidence intervals.
(2) O&M savings for High Performance Energy Management sites 4 and 13a are not reported because it was not possible to estimate the O&M savings.

The second row of Table 1 shows the evaluation's estimate of the pilot's overall electricity O&M savings. The estimate includes savings from 16 sites, regardless of the statistical significance and sign of the site savings. Although the savings estimates for some sites may be imprecise, the point estimates still represent the evaluation's best estimate of savings. Also, to the extent that savings for some sites were imprecisely estimated, the confidence interval for the pilot savings reflects this uncertainty.

The evaluation estimated pilot O&M savings of approximately 8,278 MWh or 2.7% of consumption. The pilot's electricity savings are statistically significant at the 20% level of precision, although the confidence interval is fairly wide, partially due to the inclusion of facilities with savings that were not statistically significant. An 80% chance exists that the true electricity savings estimate lies within the interval [5,765 MWh, 10,790 MWh].

As the ESI Energy Management Pilot savings estimate lies within this confidence interval, it is impossible to reject the program-reported savings statistically. The evaluation point estimate implies an electricity savings realization rate of 88% for the pilot's O&M measures, with an 80% chance the realization rate lies within the interval [62%, 115%].

Panel Regression Model

The evaluation could not detect statistically significant electricity savings that differ from zero at most sites with monthly electric consumption data. To increase the probability of detecting savings, the authors pooled data from the eight sites with monthly data, and estimated a panel regression model.

To minimize the impact of differences between sites in the variance of consumption, the evaluation specified a log-linear model, with the dependent variable as the natural logarithm of a site's monthly consumption. Including site fixed effects captured differences between sites in average consumption. The evaluation estimated the model by Ordinary Least Squares (OLS), and corrected the standard errors for serial correlation (clustered at the sites). The model also contained separate variables for each site's production (that is, the impact of output on consumption was allowed to vary by site), heating degree days, cooling degree days, dummy variables for any capital projects that did not have engineering savings estimates, and indicator variables for the Year 1 and Year 2 pilot test periods. The coefficients on the pilot test indicator variables can be interpreted as the approximate percent of savings from pilot O&M projects and capital projects with engineering savings estimates.

The panel regression model imprecisely estimated savings impacts in Year 1. The results indicate average site savings of 0.3%, with an 80% confidence interval of [-0.8% 1.4%]. In a variation of the panel regression model described, the output and weather independent variables enter the regression in natural logarithmic form. The savings estimate slightly increases but remains imprecise. The results indicate average site savings of 0.5%, with an 80% confidence interval of [-0.9% 1.8%]. The evaluation attempted other specifications and obtained similar results.

Overall, the panel regression model approach did not improve the ability to detect savings for the eight sites with monthly data. This approach might be more successful with a longer panel or with a panel of sites from the same industry. For example, food processing sites could be organized into a panel, and an average savings rate for food processing sites could be estimated.

Fractional Savings Uncertainty

At the request of BPA's engineering group, the evaluation also performed a fractional savings uncertainty analysis, which indicates whether the time series data—in particular, the frequency and series length—prove sufficient to detect the expected (*ex ante*) savings at a particular significance level.

Fractional savings uncertainty analysis does not provide an alternative savings estimation method, but is useful because it can predict if data available for a site will be sufficient to detect the savings.

A site's fractional savings uncertainty is defined as the ratio of the uncertainty about the savings to the total savings. It depends positively on the coefficient of variation of the regression root mean square error (RMSE) and the expected savings as a percentage of total consumption; further, it depends negatively on the number of observations in the baseline and test periods. A lower fractional savings uncertainty indicates the savings are more likely to be detected; a higher fractional savings uncertainty indicates the savings are less likely to be detected.

According to BPA's Measurement and Verification Protocols, fractional savings uncertainty will be highest when measuring savings at the whole building level (instead of for a system or end use) and with longer-interval (less frequent) data (BPA 2012, 42). ASHRAE Guideline 14-2002 indicates a fractional savings uncertainty of 50% or lower at a confidence level of 68% presents a tolerable uncertainty level (2002).

The evaluation estimated the *ex ante* fractional electricity savings uncertainty for each site using the estimated regression model RMSE and assuming expected electricity savings of 5% and a confidence level of 80%. Figure 5 plots a site's evaluation-estimated first-year pilot percentage savings against its fractional savings uncertainty. Diamonds indicate sites with statistically significant savings, and squares indicate sites without detectable savings. Shadowed diamonds or squares indicate sites with monthly or bimonthly billing data.

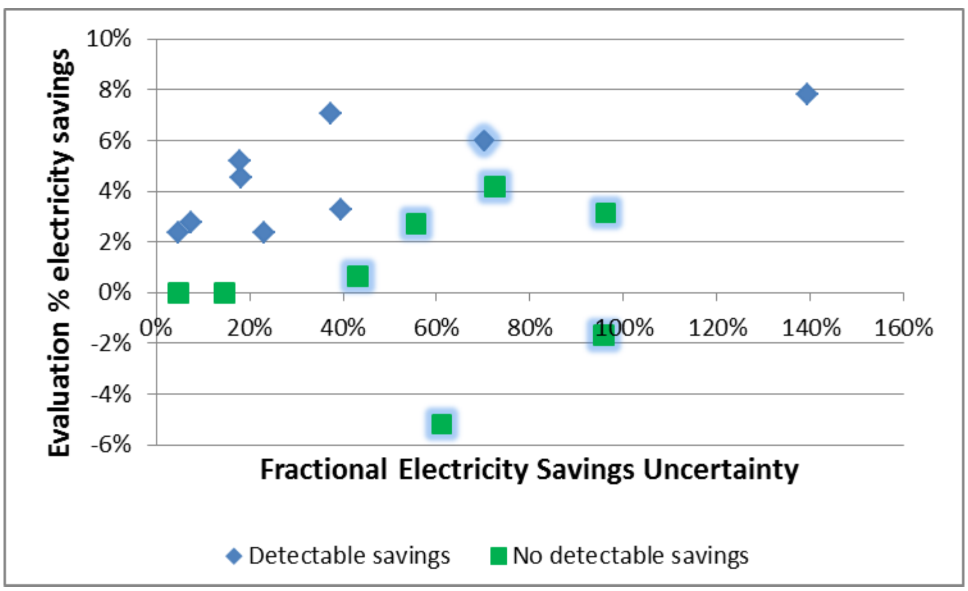

Figure 5. Estimated Percent Electricity Savings vs. Site Fractional Savings Uncertainty

Several patterns become evident in Figure 5:

- Sites with low frequency (monthly or bimonthly) billing data tended to have high fractional savings uncertainty. The median fractional savings uncertainty for sites with monthly or bimonthly data was 71%. The median fractional savings uncertainty for sites with higher frequency data was 18%.
- Sites with positive and significant savings tended to have a smaller fractional savings uncertainty, as expected. The median fractional savings uncertainty coefficient for these sites was 39%, versus 61% for sites with insignificant or negative savings. As noted, sites with

significant savings tended to have high frequency (weekly or daily) data.

- Sites with significant savings tended to have higher estimated electricity savings. A lower fractional savings uncertainty and higher percentage of savings would both increase the probability of detecting significant savings.

The evaluation detected savings at two sites with high fractional uncertainty (>60%). This can happen when true electricity savings are higher than the expected savings value used in the fractional savings uncertainty analysis (this analysis expected 5% savings at each site). The evaluation estimated the percentage of savings as greater than 5% at the two sites with high fractional savings uncertainty. Even low fractional savings uncertainty does not guarantee savings can be detected: actual savings must be sufficiently large, and there must be sufficient variation (a low correlation over time) between capital measure and O&M measure savings. This condition could not always be satisfied, precluding precise estimation of O&M measure savings.

Conclusions

The ESI program's Energy Management Pilot achieved electricity savings that accounted for 4.4% of participants' baseline electricity consumption. Table 2 lists the evaluation's estimate of total pilot electricity savings from both capital and O&M measures. This table includes the evaluation estimates of O&M savings from the second row of Table 1.

Capital measure savings are included for all 17 facilities. The electricity savings from capital projects in the pilot's first year equaled approximately 4,806 MWh (1.6% of electricity consumption). The combined capital and O&M savings equaled 13,084 MWh (4.4% of electricity consumption).

Table 2. Total Pilot Verified O&M and Capital Electricity Savings

	Electricity Savings (kWh)	**Savings as Percent of Consumption**	**Realization Rate**
Capital Measure Savings	4,806,470	1.6%	100%
O&M Savings	8,277,665	2.7%	88%
Total Savings	**13,084,135**	**4.4%**	**92%**

The program claimed savings of 14,172 MWh for capital measures and O&M installed during the participants' first year in the program. The evaluation verified a total savings of 13,084 MWh for capital and O&M measures combined. The electricity savings realization rate for capital and O&M measures was 92%. The evaluation verified O&M savings of 8,278 MWh. The realization rate for the O&M measures was 88%.

The first-year pilot electricity and gas savings estimates statistically differ from zero. For the electricity savings, an 80% chance exists that the realization rate lies within the interval [62%, 115%]. The 80% confidence intervals for electricity and gas savings include the claimed program savings, indicating the evaluation and program estimates are statistically indistinguishable.

Challenges in Detecting Energy Savings

In conducting the analysis, the following challenges arose in estimating energy savings significantly different from zero:

- **Data Frequency.** A relationship was identified between the frequency of the energy consumption and production data and the ability to detect savings. Specifically, higher frequency data increased the probability of detecting savings.
- **Capital Measures Confounding the Analysis.** At some sites, installation of capital measures just before or after the start of a facility's participation in High Performance Energy Management or Track and Tune made it difficult or impossible to isolate O&M savings.
- **Implementation Timing of Measures.** The energy savings for O&M measures installed near the end of a program year may not be fully estimated, as there may not be enough months of post-implementation data to identify these savings.

Recommendations for EM Programs to Improve Energy Savings Estimates

Based on the challenges encountered in estimating energy savings, the following five recommendations seek to improve energy savings estimations for this and other EM programs:

1. **Perform a fractional savings uncertainty analysis.** When beginning an engagement with a site, perform fractional savings uncertainty analysis to estimate the probability of detecting *ex ante* savings. The fractional savings uncertainty could be used to assess the sufficiency of the planned baseline and test periods (i.e., the number of days, weeks, or months) to detect savings.
2. **Increase the frequency of data collected.** When possible, collect higher frequency billing and production data to provide more certainty in energy savings and to decrease the confidence interval range.
3. **Re-estimate first-year savings for sites with insignificant savings.** With data for additional periods (i.e., months, weeks, days) in the pilot's second year, it may be possible to detect savings in the first year. If savings can be detected for these sites, the confidence interval range around the program savings will decrease.
4. **Be aware of analysis impacts when implementing simultaneous capital and O&M measures.** Application of regression analysis to measure savings from O&M requires the savings from O&M and any capital measures be sufficiently independent (uncorrelated). Simultaneous or near-simultaneous implementation of capital and O&M measures increases the savings correlation, and makes it difficult to estimate their savings impacts separately.
5. **Use a panel approach, when applicable.** If a program's participants can be grouped into similar industries, a panel approach could be used with more success, and would provide a more efficient method than estimating savings separately for each site. For example, all food processors could be grouped together, and the model would estimate their average savings rate. It should be noted, however, that a panel approach will not provide feedback for individual sites, and if a program is interested in assessing individual site performance then site-specific models should be used.

References

ASHRAE Guideline 14-2002. 2002. *Measurement of Energy and Demand Savings.*

Bonneville Power Administration. 2012. *Verification by Energy Modeling Protocol.* May. Portland, Ore.

Cadmus. 2010. *BPA Energy Smart Industrial Program: Early Evaluation Report.* June 18. http://www.bpa.gov/energy/n/reports/evaluation/pdf/ESI_Early_Evaluation_Report_20090618_FINAL.pdf. Portland, Ore.: Bonneville Power Administration.

Cadmus. 2012. *Process Evaluation of California's Continuous Energy Improvement Pilot Program.* October. Portland, Ore.

Cadmus. 2013. BPA Energy Management Pilot Impact Evaluation. February 1. http://www.bpa.gov/energy/n/reports/evaluation/pdf/BPA_Energy_Management_Impact_Evaluation_Final_Report_with_Cover.pdf. Portland, Ore.: Bonneville Power Administration.

Luneski, R.D. 2011. "A Generalized Method for Estimation of Industrial Energy Savings from Capital and Behavior Programs." *Industrial Energy Analysis.*