MRV: A Primer on Evaluating Energy Savings through Two Models

Introduction

Measuring and verifying specific projects and measures directly influenced by the adoption of a strategic energy management system can be difficult to quantify. There is currently no one standard MRV protocol for quantitatively assessing energy savings from operational and maintenance (O&M) improvements, or the incremental capital energy-efficiency projects resulting from instituting an EnMS standard.

That said, studies emerging from the Pacific Northwest from organizations such as The Northwest Energy Efficiency Alliance (NEEA), Energy Trust of Oregon (ETO) and the Bonneville Power Administration (BPA) suggest that energy intensity can be reduced by two to ten percent with little capital investment and that these savings could persist by applying continuous improvement practices. Energy savings would come directly from behavior changes such as 1) operational and maintenance (O&M) improvements, 2) indirectly, from incremental increases in capital energy-efficiency projects (i.e., more lighting efficiency), 3) from additional capital projects that would not otherwise have been considered (i.e., process changes, consideration of energy efficiency in all capital efforts), and 4) from improved persistence of energy savings associated with capital projects.[1]

Energy savings evaluations typically leverage two broad approaches: top-down and bottom-up. The top-down approach provides a facility-wide analysis of gross savings from all energy-efficiency improvements. It takes into account everything that could affect facility energy usage, creating a more complex energy model, yet producing a comprehensive overview of facility energy savings. Conversely, the bottom-up approach targets specific areas of a facility by evaluating energy savings from individual energy- efficiency projects. For example, a bottom-up analysis observes the increased efficiency of new equipment compared to the old equipment it replaced. This approach only analyzes factors that affect the performance and energy usage of the specified equipment and strives to demonstrate the effectiveness of the equipment installment project.

Despite the different focus and considerations of these two approaches, both seek to derive energy savings, so both must create a baseline model as the foundation of their analysis. A baseline analyzes energy usage before an intervention, then observes energy savings by comparing the post-intervention energy model to the baseline model.

Goal

The goal of this paper is to inform and summarize both the top-down and bottom-up approach, and define what portion of gross energy savings is attributed to capital improvements versus behavioral changes. Theoretically, extracting bottom-up capital improvement savings from the top-down gross savings, delivers “net savings,” –a value attributed to behavior change. The challenge rests in identifying everything that could affect energy usage. Variables including all possible energy drivers, one-time changes as well as periods of intervention create layers of

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[1] ACEEE White Paper #128, “*The Evolution of Continuous Energy Improvement Programs in the Northwest: An Example of Regional Collaboration,”* Ted Jones, Consortium for Energy Efficiency (CEE), Kim Crossman, Energy Trust of Oregon (ETO), Jennifer Eskil, Bonneville Power Administration (BPA), John Wallner, Northwest Energy Efficiency Alliance (NEEA)

complexity. The more thorough and accurate the analysis of bottom-up or top-down models, the more justifiable net savings attributed to behavior change.

This paper is presented in the following steps:

1. **Bottom-up vs. Top-down**: a brief summary and comparison between the two approaches.
2. **Review of Regression Models**: a brief statistical review of regression models.
3. **Bottom-up Analysis**: an exploration of different methods and examples.
4. **Top-down Analysis**: an exploration of different methods and examples.
5. **Derivation of Savings from Behavioral Changes**: an exploration of different methods and examples.

Bottom-up vs. Top-down

The bottom-up model focuses on the analysis of machine/capital specific projects. When using this model, considerations include:

- ✓ Easier to measure energy usage and energy drivers of a machine.
- ✓ Provides more accurate results due to the small number of necessary assumptions.
- ✓ Ability to obtain relevant, detailed facts for the specific machines.

The top-down model focuses on the analysis of facility-wide energy consumption. When using this model, considerations include:

- ✓ Requires accounting for more conditions and establishing more assumptions.
- ✓ Decreases accuracy due to increased scale, including involving multiple energy consumption and production processes.
- ✓ Provides an overview of energy consumption for the whole facility.

Review of Regression Models

A regressional analysis illustrates statistically and graphically the effects of energy drivers on energy consumption as well as predicting future energy consumption trends.

A basic equation is used to represent this approach:

$\text{Energy}_t = \text{Intercept} + B_1\text{*Production}_t + B_2\text{*Temperature}_t + B_3\text{*Other Energy Driver} + \ldots + \text{Error Term}_{t.}$

Below describes the equation in detail.

- ✓ **Equation** demonstrates Energy at time t, and is depended upon a set of explanatory variables: Production, Temperature, Other Energy Driver (s), and the Error Term.
- ✓ **The underscore t** is a measure of time. EXAMPLE: 15-minute intervals, hours, days, months, etc.
- ✓ **The Intercept** is a constant that shows how much Energy is consumed without the existence of any energy drivers.
- ✓ **B_1 is the effect** of a 1-unit increase in Production on Energy. It is called the coefficient on Production.
- ✓ **B_2 is the effect** of a 1-unit increase in Temperature on Energy. It is called the coefficient on Temperature.
- ✓ **The Error Term** is the difference between predicted Energy through the regression trend line (given a set of data values for all the explanatory variables) and the actual Energy value for the same set of data values for all the explanatory variables.

Measuring Savings: A Step-by-Step Process

Bottom-Up Analysis
Bottom-up modeling focuses on the analysis of machine/capital specific projects. Examples of a bottom-up scenario include replacing an existing heater with a new, more energy-efficient model, then analyzing the amount of savings resulting from the equipment replacement.

Below is a step-by-step process on how to measure savings from capital improvements (lighting upgrade, more efficient machines, etc):

1. **Begin data collection process to determine the baseline model.**

   ✓ Clearly identify as many energy drivers as possible:
   - What determines the performance and the energy consumption of a machine?

   EXAMPLE: wet-bulb/dry-bulb temperature, operating hours, units of production, the power of the machine, any machine-specific inputs and outputs, etc.

   ✓ Meter/monitor the baseline machine (before any intervention)
   - Baseline period should be a minimum of 2 weeks, 15-minute intervals if possible.
   - Observe and measure all identified variables.
   - Manual install of metering equipment for machines might be required.

2. **Build a baseline model**

   ✓ Run a simple regression with the baseline data to establish the baseline for energy usage
   - $\text{Energy}_t = \text{Intercept} + B_1{*}\text{Operating Hours}_t + B_2{*}\text{Temperature}_t + B_3{*}\text{Other Energy Driver} + \text{Error Term}_t$

   ✓ Check for anomalies: outliers, missing data, statistically insignificant explanatory variables, overall insignificance of the model, etc.
   - Outliers are data values that are abnormally different from the other data.

   EXAMPLE: Guest count for a restaurant is generally around 400 to 600 per day, but the guest count for a certain day is only 10.
   - Consider missing data as values missing from the data set.

   EXAMPLE: Highest and lowest temperatures are obtained daily to calculate the average temperature, but the highest temperature of a certain day is not captured.
   - Explanatory variables are statistically insignificant when their coefficients (their estimated *B* values) obtain a P-value that is more than 0.05 or 0.1, depending on the confidence level the regression model employs. If variables are insignificant, there is no evident causal relationship between that energy driver and the energy usage.
   - The overall significance of the model is determined by a statistical test called the F-test. The P-value obtained from the F-test should also be less than 0.05 or 0.1 for the overall model to be statistically significant.

   ✓ Account for anomalies
   - Manually fix simple data errors.
   - Add/replace with new data, maybe for a longer period or shorter intervals to gain accuracy.
   - Add new energy drivers (explanatory variables).

- Install better metering equipment.
- Probe facility staff for any unusual/one-time changes that might affect the energy consumption/production of the machines. Incorporate those changes in the regression model by methods such as including dummy variables for those changes.

✓ Rerun the baseline regression model

3. **Derivation of Savings**

(IPMVP Option B)[2]

✓ Continue measuring all variables used in baseline regression model for the “intervention” period.
- “Intervention” period typically means the period after a machine is replaced with a more energy efficient machine.
- “Intervention” period can be as long as possible; it does not have to be the same as the baseline period

✓ Calculate predicted energy usage during the “intervention” period using the baseline trend (the regression equation) and the “intervention” data (a set of data values for all the explanatory variables during the “intervention” period)

✓ Calculate energy savings by subtracting predicted energy usage by actual energy usage.

EXAMPLE: Using the heater scenario, the baseline model is regressed based on daily data would estimate the Intercept, a coefficient on Operating Hours (B_1), and a coefficient on Temperature (B_2). This is assuming there are only two energy drivers for the heater. The predicted energy usage of the heater on a typical day (say, 1/1/2011) during the intervention period (after the installation of the new heater) is calculated by the following equations:
- Predicted Energy$_{1/1/2011}$ = Intercept + B_1*Actual Operating Hours$_{1/1/2011}$ + B_2*Actual Temperature$_{1/1/2011}$
- Savings$_{1/1/2011}$ = Predicted Energy$_{1/1/2011}$ - Actual Energy$_{1/1/2011}$

4. **Alternative Derivation of Savings: Without a Regression**

(IPMVP Option A)[3]

✓ Methods without regression are more general, less accurate

✓ Calculate energy use during the baseline period and calculate energy use during the intervention period.

✓ Savings = Baseline – Intervention
- This method should only be used when the machine does not have any significant energy drivers that might vary throughout the period of estimation.
- The length of the baseline period has to be the same as the length of the intervention period.

EXAMPLE: Imagine a 58-watt light bulb turning on and off automatically at regular hours throughout the baseline period. Its energy usage can be easily calculated by converting its power to energy (turning kW to kWh by a conversion ratio). Then, the total energy used can be calculated by multiplying its kWh by the operating hours of the light bulb. The same method can be used to calculate total energy usage for a 28-watt light bulb, -a light bulb

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[2] International Performance measurement and Verification Protocol

[3] International Performance Measurement and Verification Protocol

used to replace the less efficient 58-watt light bulb. As a result, taking the difference between the two total energy usage values derives the savings.

✓ Differences-in-differences Method: Including a control group
   - Modeling the distinction between pre-intervention and post-intervention as well as distinction between control and intervention group.

   EXAMPLE: Replacing 58-watt light bulbs with more energy efficient light bulbs in one room for the intervention group, but continuing using the 58-watt light bulbs in another room for the control group

   - The result is net savings: savings from the intervention ONLY.

Following are the energy usage values:

$\text{Intervention}_{\text{post}}$: energy usage of light bulbs in the intervention group, post intervention.
$\text{Intervention}_{\text{pre}}$: energy usage of light bulbs in the intervention group, pre intervention.
$\text{Control}_{\text{post}}$: energy usage of light bulbs in the control group, post intervention
$\text{Control}_{\text{pre}}$: energy usage of light bulbs in the control group, pre intervention
Net Savings: $(\text{Intervention}_{\text{post}} – \text{Intervention}_{\text{pre}}) – (\text{Control}_{\text{post}} – \text{Control}_{\text{pre}})$

Note: *The baseline period should be the same length of time as the intervention period. Moreover, the number of new machines installed (the intervention group) should equal the number of machines not being replaced (the control group).*

5. **Determine effectiveness of capital installments**: showing a quantified effect of the intervention on energy usage rather than just calculating the amount of energy savings resulted from the intervention.

✓ Multiple Regression method:
   - $\text{Energy}_t = \text{Intercept} + B_1{*}\text{Production}_t + B_2{*}\text{Temperature}_t + B_3{*}\text{Other Energy Driver}_t + B_4{*}\text{Intervention}_t + \text{Error Term}_{t.}$
   - Intervention is a dummy variable that equals 0 throughout the baseline period, and changes to 1 for the intervention period (e.g. regression runs with a combination of data from the baseline period and the intervention period).
   - The coefficient on Intervention (B_4) is the effect of the intervention program on energy usage. This conveys how much energy is saved per unit of time while the intervention is in place.

EXAMPLE. Using the heater scenario again, B_4 would be the estimated amount of energy saved per day during the intervention period. It can be thought of as an average amount of savings for a typical day during the intervention period. Now, the total energy saved during the intervention period can be calculated by multiplying this B_4 coefficient by the number of days of the intervention period.

Top-Down Analysis

Top-down focuses on facility-wide energy consumption. Examples may include a restaurant tracking monthly gas and electric utility meters. The restaurant obtains monthly guest count, daily Heating Degree Days and Cooling Degree Days, etc. to generate a facility-wide regression model. The restaurant establishes an energy management team at the beginning of this year, and a top-down analysis demonstrates the effect of the effort to improve energy efficiency on the facility-wide energy usage.

Below is a step-by-step process to measure gross savings from all efforts to improve energy efficiency at a facility:

1. **Collect energy data, production data, and data of as many identifiable energy drivers as possible to determine baseline model.**

<u>IPMVP Option C</u>

- ✓ Energy drivers should include all possible factors in the facility impacting energy consumption.
- ✓ Explanatory variables might come from different production processes and different systems, but they should all be included as long as they are from the same facility.
- ✓ The process in data collection and manipulation from the Bottom-Up Analysis section should be employed here as well.

2. **Run a baseline regression model with baseline**
   - ✓ $\text{Energy}_t = \text{Intercept} + B_1{*}\text{Production}_t + B_2{*}\text{Temperature}_t + B_3{*}\text{Other Energy Driver}_t + \text{Error Term}_t$.
   - ✓ Note this regression model does NOT include a dummy variable for the intervention period. This is simply a regression model for the baseline period.

3. **Obtain the same sets of data from the "intervention" period.**
   - ✓ In a top-down analysis, the intervention period is usually the period when the facility begins its efforts to improve energy efficiency.
   - ✓ This intervention period can be the period in which an energy management program is established.

4. **Plug in the "intervention" data of all the explanatory variables**
   - ✓ Apply all data except energy usage to the estimated regression equation to obtain the predicted energy usage for the intervention period.

5. **Subtract predicted energy usage by actual energy usage to get facility-wide savings.**

6. **Conduct further analysis of attributed savings.**
   - ✓ Assign a portion of savings to the sum of all capital installment savings from the bottom-up analysis, adjusting for any known unusual/scenario-based changes or new energy drivers in the intervention period. This generates an energy saving value attributable to behavior changes
     - o Immediate advantage of this method is that the whole analysis only includes one regression: the baseline regression. There is no need to re-evaluate the regression model after the intervention periods.

EXAMPLE: Using the restaurant scenario, the baseline regression model for gas usage based on monthly data of gas use, guest count, HDD, and CDD would estimate the Intercept, a coefficient on guest count (B_1), a coefficient on HDD (B_2), and a coefficient on CDD (B_3). This is assuming there are only three energy drivers for the whole restaurant. The predicted gas usage for the restaurant on a typical month (ex. 1/2011) during the intervention period (after the establishment of an energy management team) is calculated by the following equations:

- <u>Predicted</u> Gas $Use_{1/2011}$ = Intercept + B_1*<u>Actual</u> Guest $Count_{1/2011}$ + B_2*<u>Actual</u> $HDD_{1/2011}$ + B_3*<u>Actual</u> $CDD_{1/2011}$
- $Savings_{1/2011}$ = <u>Predicted</u> Gas $Use_{1/2011}$ - <u>Actual</u> Gas $Use_{1/2011}$

<u>Intervention Step Model</u>:

1. **Same data collection methods** and strategies as mentioned above in IVMVP Option C. However, data collection should cover both the baseline and the intervention periods. The baseline model is not built after the data collection for the baseline period. The baseline model is built together with the intervention period. See below.

2. **The regression model** combines data from the baseline period and the intervention period.
   - ✓ $Energy_t$ = Intercept + B_1*$Production_t$ + B_2*$Temperature_t$ + B_3*Other Energy $Driver_t$ + B_4*$Intervention_t$ + Error $Term_{t.}$
   - ✓ The variable Intervention is a dummy variable that equals 1 for the intervention data and 0 for the baseline period.
   - ✓ The effect of the intervention per 1 unit of time on the facility-wide energy usage is captured in $B_{4.}$

3. **Total energy savings is calculated** by multiplying the length of the intervention period by $B_{4.}$

EXAMPLE: Using the restaurant scenario again, B_4 is the estimated amount of energy saved per month during the intervention period. It can be thought of as an average amount of savings for a typical month during the intervention period. The total energy saved during the intervention period can be calculated by multiplying this B_4 coefficient by the number of months of the intervention period.

<u>Intervention Trend Model:</u>

Note: Intervention model should only be considered and explored when the data clearly shows a shift in the trend line (a change in the slope of the trend line) from the baseline period to the intervention period. This can be shown by running a regression for both the baseline period and the intervention period based on the equation presented in IPMVP Option C.

1. Same data collection methods and strategies as mentioned above in the Intervention Step Model.
2. This model is a more complex model compared to the Intervention Step Model.
   - ✓ $Energy_t$ = Intercept + B_1*$Production_t$ + B_2*$Temperature_t$ + B_3*Other Energy $Driver_t$ + B_4*$TrendBaseline_t$ + B_5*$TrendIntervention_t$ + Error $Term_t$
   - ✓ Another reason to consider this method is if the energy usage in the intervention period increases but at a rate less then the baseline trend.

<u>Multi-step Intervention Step Model</u>

Note: This is very similar to the Intervention Step Model. The only difference is this method allows the effect of the intervention on each intervention month to vary while the Intervention Step Model estimates the effect of intervention on each intervention month to be the same.

<u>Case 1:</u>

1. **Same data collection methods** and strategies as mentioned in the Intervention Step Model.
2. **The regression model is run** with a combination of data from the baseline period and data from the intervention period.
   - ✓ $Energy_t$ = Intercept + B_1*$Production_t$ + B_2*$Temperature_t$ + B_3*Other Energy $Driver_t$ + B_4*$Intervention_{month1}$ + B_5*$Intervention_{month2}$ + … + Error $Term_t$
   - ✓ The regression model needs to be rerun after each new intervention interval (maybe after each month or every 6 months, etc)
   - ✓ There are two ways of defining the values for the Intervention variables. The two different cases have different purposes and results. See below
   - ✓ Case 1: $Intervention_{month1}$ = 1 for month 1 and 0 for all other months, $Intervention_{month2}$ = 1 for month 2 and 0 for all other months, so on
     - Equation for month 1 of the intervention period:
     - $Energy_1$ = Intercept + B_1*$Production_1$ + B_2*$Temperature_1$ + B_3*Other Energy $Driver_1$ + $\boldsymbol{B_4}$ + Error $Term_1$
     - Equation for month 2 of the intervention period:
     - $Energy_2$ = Intercept + B_1*$Production_2$ + B_2*$Temperature_2$ + B_2*Other Energy $Driver_2$ + $\boldsymbol{B_5}$ + Error $Term_2$
     - The effect of the intervention during month 1 is captured B_4 while the effect of the intervention during month 2 is captured in B_5

EXAMPLE: Using the restaurant scenario, B_4 is the estimated amount of energy saved per month during the first month of the intervention period. B_5 is the estimated amount of energy saved per month during the second month of the intervention period. If the total length of the intervention period is just two months, then the total energy saved during the intervention period can be calculated by adding B_4 and B_5 together.

<u>*Case 2:*</u>

This case differs from Case 1 in the sense that it seeks to identify whether there exists a significant difference between the effects of the intervention in different periods.

1. $Intervention_{month1}$ = 1 for month 1 and 0 for all other months, $Intervention_{month2}$ = 1 for months 1 & 2, and 0 for all other months, so on
   - ✓ Equation for month 1 of the intervention period
     - $Energy_1$ = Intercept + B_1*$Production_1$ + B_2*$Temperature_1$ + B_3*Other Energy $Driver_1$ + $\boldsymbol{B_4}$ + Error $Term_1$
   - ✓ Equation for month 2 of the intervention period
     - $Energy_1$ = Intercept + B_1*$Production_2$ + B_2*$Temperature_2$ + B_3*Other Energy $Driver_2$ + $\boldsymbol{B_4}$ + $\mathbf{B_5}$ + Error $Term_2$
   - ✓ The B_5 term in the equation for month 2 is NOT the total effect of intervention in month 2, it is merely the difference between the effect of intervention in month 2 and the effect of intervention in month 1.
   - ✓ The total effect of intervention in month 1 = B_4.
   - ✓ The total effect of intervention in month 2 = B_4 + B_5.

EXAMPLE: Using the restaurant scenario, B_4 is the estimated amount of energy saved per month during the first month of the intervention period. B_4 + B_5 is the estimated amount of energy saved per month during the second month of the intervention period. If the total length of the intervention period is just two months, then the total energy saved during the intervention period can be calculated by adding B_4 and B_4 + B_5 together. B_5 illustrates the difference between the intervention effect (amount of energy saved per month) in month 1 and month 2.

Derivation of Savings from Behavioral Changes
Generally, this method takes the difference between savings from the top-down analysis and total savings from all of the individual bottom-up analyses.

1. Critical assumptions associated with this method:
    - ✓ The facility-wide top-down analysis is as accurate as possible.
    - ✓ The machine-specific bottom-up analysis is as accurate as possible.
    - ✓ The combination of all the bottom-up analyses includes ALL capital installments and projects.
    - ✓ The combination of savings derived from the top-down and the bottom-up analyses accounts for all savings except for savings from the behavioral changes. (e.g. no neglection of any other significant explanatory variables of energy consumption).

2. Savings from Behavioral Changes = Top-Down Savings – Sum of Bottom-Up Savings

EXAMPLE: The restaurant demonstrates behavioral changes by using both top-down and bottom-up analysis of the heater and the light bulbs. Imagine calculating the amount of energy saved due to behavioral changes during a hypothetical intervention period of two months. The restaurant obtains the total energy saved during the two months by one of the top-down analysis methods.

The restaurant returns to the bottom-up analysis of the heater and light bulb installments and calculates the total energy saved during the two months for each installment. Keep in mind that the bottom-up energy savings might need to be converted from daily to monthly to match the top-down, or vice versa. The total energy savings from ALL capital installments for the restaurant is therefore the sum of the energy savings from the heater and the light bulb installments.

Again, this is assuming these installments are the ONLY capital improvement projects in the restaurant during the two months of intervention. Now, the total energy savings from behavioral changes is the difference between the total energy savings from the top-down analysis and the sum of total energy savings from the bottom-up analyses of the two capital improvement projects. Note that this result is always going to be an approximation since there is never absolute certainty that all the critical assumptions stated above are completely true.

Conclusion
This paper presents the foundations and step-by-step examples of both top-down and bottom-up analysis. Whether a facility is capturing energy savings from capital improvement projects, looking at embedding energy management practices across the enterprise or implementing both, these models seek to capture an estimation of energy savings from various interventions. Inherent to these modeling approaches is a level of complexity, underscoring how a 'one-size-fits-all' approach can produce varying results based on the intentions and energy management maturation of the facility.

Appendix

Terms
Often language can be specific, but confusing. Some statistical vocabulary to take into consideration includes:

IPMVP: International Performance Measurement and Verification Protocol allows building owners, energy service companies, and financiers of energy efficiency projects to quantify the energy savings performance of energy conservation measures (ECMs). It provides an overview of current best practice techniques available for verifying savings from both traditionally funded and third-party-financed energy and water efficiency projects.

Dummy variable: a variable that takes the value of either 0 or 1. It is usually used to indicate a change or intervention that cannot be quantified.

> *EXAMPLE: A one-day holiday when there is no production but some machines are still turned on. This would result in abnormal data. A* ***dummy variable*** *can be used to explain this abnormality by taking the value 1 on this day, but remains 0 for the rest of the data collection period.*

Confidence Level: a percentage chosen when regression models are built. It is usually 90% or 95%.

> *CONTEXT: Choosing a 95% confidence level means that if the 95% confidence intervals (ranges of a regression coefficient) are calculated across many repeated samples, the real values of the regression coefficient fall within the estimated confidence interval 95% of the time.*

P-values: values corresponding to the confidence levels. A 95% confidence level is the same as a 0.05 P-value

> *CONTEXT: P-values are used to determine whether an estimated coefficient is statistically significant. For a 95% confidence interval, the desired P-value of any coefficient is some value less than 0.05*

Slope (of a regression trend line): describes how steep the trend line is. The higher the slope, the steeper the trend line.