The value of regression models in determining industrial energy savings

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Keywords

energy savings, modelling, energy management system, energy model, ISO 50001

Abstract

Determination of industrial facility energy savings is commonly undertaken to comply with legal requirements, meet sustainability goals, and quantify greenhouse gas emissions, cost savings, and as one way to demonstrate energy performance improvement per the requirements of an energy management system standard, such as ISO 50001. At their most basic level, energy savings are determined through a process of accounting for baseline and reporting period energy consumption followed by a calculation of energy savings as the difference in the levels of energy consumption between the two periods.

The determination of industrial facility-wide energy savings can be undertaken in a wide variety of ways and in relation to energy performance improvement; energy savings can be expressed as any number of energy performance indicators (EnPIs). Energy savings values will vary depending upon if an absolute, intensity, or regression basis of calculation is selected for use. The use of one of the three basis of energy savings calculation will alter the relevance, meaning, and comparability of the resulting energy savings values To increase consistency in the determination of energy savings values, standards such as the International Performance Measurement and Verification Protocol (IPMVP), ISO 17747 – *Determination of Energy Savings in Organization*, and the U.S. Department of Energy (U.S. DOE) Superior Energy Performance (SEP) program Measurement and Verification Protocol (SEP M&V Protocol) have been published.

Industrial facilities in the United States, Mexico, and Canada are certified to the U.S. DOE SEP program after becoming ISO 50001 certified and verification by a third party of calculated energy savings per the SEP M&V Protocol. This paper discusses some of the different meanings energy savings values will have when calculated by using the three different bases. Additionally, data from five SEP certified industrial facilities are used to calculate energy savings values using the three bases and compared as energy performance improvement percentage (EPI %) values. Discussion of why a large degree in variation in EPI % values are seen for any given set of data is provided. Ultimately, while each energy saving calculation basis has merit and can be used appropriately in its own context, the regression basis is shown to best translates energy savings values into contextualized energy performance improvement values by conveying comparable information regarding operational and behavioural improvements not otherwise observable with the absolute or intensity bases.

Introduction

The determination of energy savings is conducted for a wide variety of reasons, including to comply with legal requirements, meet sustainability goals, quantify greenhouse gas emissions and cost savings, and as one way to demonstrate energy performance improvement per the requirements of an energy management system standard, such as *ISO 50001 – Energy management system standard – Requirement with guidance for use*. This wide variety of reasons to determine energy savings is matched with an equally wide variety of methods detailing processes to conduct energy savings determination. Different energy calculation methods will be expressed as different energy performance indicators (EnPIs): quantitative values or measures of energy performance.

At their most basic level, energy savings are determined through a process of calculating the difference between energy consumption accounted for during an established baseline and reporting period. Adjustments to energy consumption values prior to calculation of energy savings are sometimes performed in order to impart additional meaning to calculated energy savings values. These adjustments create different EnPIs that can convey context regarding uses and independent variables that affect energy consumption and thus energy performance levels. Rarely can the entirety of energy performance improvement be understood by a singular EnPI and thus a variety of methods of calculating energy savings may be of use (Goldstein and Almaguer, 2013).

A variety of internationally relevant standards present methods to transparently determine energy savings values. These standards include International Performance Measurement and Verification Protocol (IPMVP), ISO 17747 – *Determination of Energy Savings in Organizations*, and the U.S. Department of Energy (U.S. DOE) Superior Energy Performance (SEP) program Measurement and Verification Protocol (SEP M&V Protocol). The SEP M&V Protocol is used across North America and was drawn from in the formation of ISO 17747. In turn, the recent revised version of the SEP M&V Protocol has benefitted from the international development of ISO 17747.

Methods to determine facility-wide energy savings at industrial facilities are typically based upon either a bottom-up or top-down energy accounting approach. These approaches can be used in isolation or together such that one approach can reconcile the other.

A bottom-up approach to determining facility-wide energy savings conducts accounting of energy consumption before and after the implementation of one or more energy performance improvement actions. The bottom-up approach can be used to determine facility-wide energy savings by aggregating the saving from multiple energy performance improvement actions. The additional expense of sub-metering may be required to be placed on individual equipment, systems, or processes. Bottom-up energy savings are useful for focusing on a specific or a set of energy performance improvement actions. Complications due to interactive effects and difficulty in quantifying savings from operational or behaviour based energy performance improvement actions can cause uncertainty in energy savings values. Bottom-up approaches are widely used throughout industry, they often do not require modelling and rely on pre and post engineering estimates or metered data for determining the energy savings.

A top-down approach to determining facility-wide energy savings conducts accounting on a facility basis, that is, most commonly at the physical boundaries of a facility. Utility meters are typically the source of data and the contribution of individual energy performance actions within the facility boundaries is not determined. This approach provides the overall savings level for the facility, thus avoiding issues related to the implementation of multiple energy performance improvement actions such as interactive effects or double counting. This paper will focus solely on energy savings calculated with the top-down approach.

The calculation of energy savings with a top-down approach can conducted on one of three bases; absolute, intensity, or normalization. The absolute energy savings basis utilizes unadjusted energy consumption values while both the intensity and normalization bases make adjustments to energy consumption values. Adjustments to energy consumption values are done to impart context and additional meaning to calculated energy savings values. Industrial organizations as well as national and regional energy efficiency and performance improvement programs use all three of these calculation bases for various reasons.

Relevant variables are independent variables such as production or weather that directly affect the amount of energy consumed within the facility boundaries. These variables can be used to normalize energy consumption as part of an adjustment model. As part of the energy accounting, relevant variables and energy consumption data are both recorded. Most energy savings standards require relevant variables to be physical quantities, characteristics, or conditions. Financial metrics such as product price or energy costs are not allowed because they lack a physical relationship to energy consumption.

Whether simple or complex expressions of performance, energy savings values can be misinterpreted or misrepresented as a measure of energy performance improvement (Goldstein and Almaguer 2013, Goldstein et. al., 2011) In most cases, this can be linked to selecting the wrong energy savings calculation method and basis to convey accurate meaning regarding energy performance improvement for the user. In order to be used effectively, EnPIs must be designed and used for the intended and specific purpose. This paper discusses the various reasons why one of the three bases of energy savings calculation may be selected for use over another. Additionally, variation in calculated energy savings values resulting from the different bases is demonstrated by applying each of the three bases to facility-wide industrial energy consumption and relevant variable data from five SEP certified facilities. A discussion of why a variation in the calculated energy savings values occurs is presented.

Absolute, Intensity, and Normalization Bases

A top-down approach to energy savings is applicable when considering energy savings across multiple energy end-uses, such as a process or facility. The top-down approach simultaneously captures the effects of multiple energy performance improvement actions, including those that may be difficult to enumerate, such as behavioural actions. However, these approaches may rely on developing proxies or relationships to adjust energy consumption to reflect energy productivity. While these adjustments are intended to isolate the effect of energy performance improvement actions, they may introduce errors.

Three bases, absolute, intensity, and normalization, used in top-down facility-wide energy savings determination are evaluated in this paper. The selection of a basis will often depend on the desired use of the energy savings estimate. Each basis can be applied to a single energy type or to multiple energy types in aggregate.

ABSOLUTE BASIS

The absolute savings basis involves comparing unadjusted energy consumption data from two time periods, with the difference being the energy savings. Energy savings are reported in units of energy (e.g. kWh, MJ, MMBTU), or as an energy performance improvement percentage. This basis can be beneficial to organizations interested in reporting progress towards absolute goals to reduce greenhouse gas emissions or for those that are unable

to satisfactorily determine appropriate metrics to use to adjust for productivity or operating conditions. They may also be useful to organizations seeking to track energy consumption for reasons other than quantifying the impact of energy efficiency actions. Examples include tracking costs or evaluating business risk associated with energy use and consumption. Changes in production throughput, divestures or acquisitions, weather conditions, changes to raw materials, changes to products produced, actions taken to comply with environmental regulations, or any other factor that drives energy consumption at a facility will affect absolute energy savings. Absolute energy savings values do not provide context to changes in operation or behaviour at the facility, only if energy consumption increased or decreased. The absolute approach is generally the simplest of all energy saving determination approaches, but is the least effective method for tracking energy efficiency improvements.

Parties interested in the absolute savings basis typically view energy consumption at an industrial facility in how it impacts their operations, not the performance of the operations within the facility. These parties include financial officers, air quality regulators, and electric grid operators.

INTENSITY BASIS

The intensity basis involves the process of identifying a metric for correlating to and indexing energy consumption. These metrics should quantify physical output, such as volume, weight, or number of units of produced. Other metrics with less relationship to the operations of the facility may include revenue, facility physical size (e.g. square meter, square foot), or weather. Changes to the metric are tracked and used to determine energy savings. The resulting energy savings will account for changes in the metric adopted. Examples of when this basis may be selected by an organization include those producing multiple products and seeking a single metric to use across all processes/facilities, seeking to track energy productivity, aligning with metrics used by other business units (e.g. financial accounting metrics), and assessing the value added by their operations (i.e. for the purposes of pricing products). A drawback to this basis is it may oversimplify the connection between energy consumption and a single relevant variable. Often in industrial settings, energy consumption is not a function of a single variable, but of multiple variables. The intensity approach is relatively simple and does not address the complexity of the correlation between energy consumption and the variables driving it. The intensity basis provides limited context to energy savings as it accounts for changes in a singular relevant variable, but does not remove the effects of other relevant variables.

Results from the intensity basis can be misinterpreted to be the effect of energy performance improvement actions. As an illustrative example, a facility's production output was significantly reduced due to a global economic slowdown. The intensity basis energy savings value, based upon energy consumption per unit output, indicated a significant drop in energy performance, (increased energy consumption per unit output) regardless of the fact that investments in energy performance improvement actions were made. The drop in energy performance can be seen as a disappointment, as the effect of energy performance improvement efforts was masked.

Parties interested in the intensity savings basis typically view energy consumption at a corporate level where aggregation of energy savings values is needed to provide a simple metric of improvement or those that wish to quickly determine a contextualized energy savings value. These parties include corporate energy managers and facility energy managers and operators who wish to report a simple energy savings metric.

NORMALIZATION BASIS

The normalization basis is the most sophisticated of the three bases and provides the greatest context in the final energy savings value. The energy savings value calculated by the normalization basis can be considered a true energy performance improvement value as it reflects not only changes in energy consumption but energy efficiency and energy use as well. The normalization basis involves identifying the relevant variables that affect energy consumption and developing a model of energy consumption over a period of time as a function of the variables.

Adjustment models are generally required to meet statistical requirements quantifying the strength of the correlations. The model should be reviewed to ensure that it is consistent with engineering knowledge of the processes and operations employed at an industrial facility. Energy savings are determined using the actual energy consumption compared to the modelled energy consumption evaluated at actual operating conditions over the same time period. The normalization basis tracks the impact of energy performance improvement actions with more confidence than the other bases by removing the effect on energy consumption from relevant variables unrelated to the operation of equipment and processes. For this reason, it is the strongest approach for organizations seeking to track energy performance improvement. A potential drawback of this approach is its rigor. Identifying relevant variables and developing models involves the use of statistical techniques, which can be a burden for some facilities.

Outside of calculating energy savings of EPI %, additional benefits of the normalization basis can include an increased understanding of how the relevant variables affect energy consumption which often leads to the identification of opportunities to reduce energy consumption. A further benefit is that these models allow ongoing and routine monitoring of energy performance and the identification of deviations from expected energy consumption.

Parties interested in the normalization savings basis typically view energy consumption at the facility or subsystem level and wish to understand how energy performance improvement actions are resulting in changes to energy performance, rather than just changes in energy consumption. These parties include facility energy managers and operators.

The normalization basis of energy savings determination uses regression analysis conducted with the use of adjustment models such that that baseline and reporting periods can be compared as if all relevant variables were the same in the two periods. Normalized baseline period and/or reporting period energy consumption are calculated using one or more adjustment models for each independent energy type consumed at a facility or of all energy types aggregated. Regression analysis is a statistical technique that estimates the dependence of a variable (e.g. energy consumption for energy use and intensity tracking) on one or more independent relevant variables. A properly used regression analysis can provide a reliable es-

timate of energy savings resulting from energy performance improvement actions by accounting for the effects of relevant variables such as production variation and weather. Four types of normalization are commonly used and are described below. Analysis in this paper utilizes only forecast normalisation.

Forecast Normalization

Forecast normalization results in a model of baseline period energy consumption that is applied to the reporting period relevant variable values to calculate adjusted baseline period energy consumption for comparison with observed (actual) reporting period energy consumption. The adjusted baseline period energy consumption is an estimate of the energy consumption that would have been expected at reporting period relevant variable values, if the baseline operating systems and practices were still in place during the reporting period.

Retrospective Normalization

Retrospective normalization results in a model of reporting period energy consumption that is applied to the baseline relevant variable values to calculate adjusted reporting period energy consumption for comparison to observed (actual) baseline period energy consumption. The adjusted reporting period energy consumption is an estimate of the energy consumption that would have been expected at baseline period relevant variable values, if the reporting period operating systems and practices were in place during the baseline period.

Standard Condition Normalization

Standard condition normalization results in two adjustment models, one of baseline period energy consumption and one for reporting period energy consumption. Standard conditions are applied to each of the models to calculate adjusted energy consumption values. The adjusted energy consumption for each period is the estimated energy consumption that would have been expected at a standard set of conditions (relevant variable values).

Chaining Normalization

Chaining normalization is a composite of the forecast and retrospective normalization methods. The chaining method may be used if there is a 12-month (1 year) intermediate period between the baseline period and the reporting period for which a model can be developed In this case, the intermediate period model is used to backcast to the baseline period year and forecast to the reporting period year. Chaining normalization may be useful if the reporting period conditions for energy consumption and relevant variables are outside the range of conditions of the baseline period model, and the baseline period conditions are outside the range of conditions of the reporting period, or a model cannot be developed for either the reporting or baseline periods.

ISO 50001 and the U.S. DOE SEP M&V Protocol

Published in June 2011, ISO 50001 – *Energy management system standard – requirements with guidance for use*, is an international standard that provides a framework for the implementation of an energy management system (EnMS) for the purpose of continuously improving energy performance (ISO 2011). ISO 50001 provides guidance to industrial and commercial facilities for integrating energy efficiency into their daily management practices. For industrial facilities this includes fine-tuning production processes and improving the energy efficiency of industrial systems. The standard gives organizations management strategies that can be used to reduce energy consumption, carbon emissions, and costs, and to improve environmental performance. Organizations implementing ISO 50001 conduct an energy review, develop an energy policy, establish objectives, targets and action plans related to its significant energy uses, and engage top management in decision making. Though quantitatively unspecified, ISO 50001 does require that an organization demonstrate improvement in energy performance. Many organizations seek to demonstrate energy performance improvement through the calculation of energy savings. The basis on which energy savings values are calculated for ISO 50001 will vastly change the contextualization of the demonstrated energy performance improvement.

A large number of countries have nationally adopted ISO 50001. These countries are encouraging uptake of ISO 50001 within their industrial sector in a wide variety of ways. To facilitate clear understanding of energy performance improvement resulting from ISO 50001, countries have developed programs requiring facility-wide top-down energy savings determined using either the absolute, intensity, or normalization basis.

The U.S. DOE developed the Superior Energy Performance (SEP) program in collaboration with industry and other stakeholders. The SEP program requires participating industrial facilities to achieve ANAB third-party verification of its ISO 50001 EnMS and meet pre-established energy performance improvement targets, of at least 5 % over 3 years (US DOE 2016). The SEP certification program provides industrial facilities and companies a transparent, globally accepted system for verifying improvements in energy performance and management practices through the SEP M&V Protocol. As of May 2016, 35 facilities representing a diverse range of sectors, sizes, and locations are certified to SEP, improving their energy performance on average by 12 % over 3 years (US DOE 2016). The success of the program's initial demonstration has led to a growing interest in SEP.

The SEP M&V Protocol sets forth the verifiable methodology for determining and demonstrating achievement of the energy performance improvement level claimed by an organization for a defined facility. The SEP M&V Protocol contains requirements necessary to demonstrate, through the SEP program specific energy performance indicator (EnPI), SEnPI, the achieved energy performance improvement for the SEP program. The SEP M&V Protocol was initially developed and released in 2012 and based upon stakeholder feedback, the SEP program has been updated, requiring modification of the 2012 version of the SEP M&V Protocol. The structure and language of the SEP M&V Protocol was updated to reflect common elements between ISO 50001 and supporting standards such as ISO 50015 – *Measurement and verification of organizational energy performance – General principles and guidance* and ISO 17747 – *Determination of energy savings in organization*.

The EnPI Tool is a regression analysis based Excel Add-in developed by the U.S. Department of Energy. The Tool was created to help plant and corporate managers establish a nor-

malized baseline of energy consumption and track annual progress of intensity improvements, energy savings, and SEP EnPIs, while accounting for variations due to weather, production, and other relevant variables. The EnPI Tool is available as a free download from the U.S. DOE Advanced Manufacturing Office Energy Resources Centre. The EnPI Tool will accept any relevant variables that are input by the user. However, it is up to the user to ensure SEP allows for all relevant variables included in the model. For example, although the EnPI Tool would accept them, SEP does not allow for the inclusion of financial based relevant variables because they do not have a direct effect on energy consumption. The Tool requires monthly or weekly energy consumption data. The energy consumption can be adjusted for multiple variables such as heating degree days (HDD), cooling degree days (CDD), dew point temperature, product output, moisture content of the product, shift schedule adjustments, etc. Regression analysis can be performed for multiple energy types separately, or for aggregated energy consumption. It is also capable of modelling multiple parts of a facility independently, and then aggregating final results.

Methodology

The three different bases; absolute, intensity and normalization, were used to determine facility-wide top-down energy savings for five industrial facilities using real data collected for the SEP program. While the basis for energy savings calculation was varied, all other components of the determination were held constant, including the energy accounting methodology and statistical tests for normalization regression as defined by the updated SEP M&V Protocol.

For all bases, data were analysed on a monthly basis for both the baseline and the reporting periods. Energy consumption and relevant variable data were recorded by energy type in units of delivered and primary. The Primary Energy Consumption (ECP), the source energy consumption for all energy types summed over a specified time period, was calculated for the baseline period and reporting period for each of the five facilities. The relevant variable quantities were individually summed for the baseline and reporting period for the energy intensity calculation methodology.

ABSOLUTE BASIS

The absolute basis provides a simple, straightforward basis for calculating energy savings. With the absolute basis, ECP_b is compared directly to ECP_r to establish an absolute energy savings value which can be translated to an energy performance improvement percentage value. Energy savings and energy performance improvement percentage for the absolute basis are described as:

$$ES_a = ECP_b - ECP_r$$

$$EPI_a\,(\%) = \left(1 - \frac{ECP_r}{ECP_b}\right) \times 100$$

INTENSITY BASIS

Intensity basis uses a very simple form of energy adjustment model to adjust energy consumption values for a singular relevant variable. The intensity basis provides a basic level of context and meaning to energy savings and energy performance improvement percentage values as at least one factor affecting energy consumption is considered. While the intensity basis accounts for the effects of one relevant variable, in many cases multiple relevant variables typically affect energy consumption. Variations in these other relevant variables will not be reflected in the intensity basis calculation, potentially leading to misinterpretation regarding the impact energy performance improvement actions have had. Intensity based EPI % values were calculated for all relevant variables provided. Energy savings and energy performance improvement percentage for the intensity basis are described as:

$$EI_b = \frac{ECP_b}{RV_b}$$

$$EI_r = \frac{ECP_r}{RV_r}$$

$$EPI_i\,(\%) = \left(1 - \frac{EI_r}{EI_b}\right) 100$$

NORMALIZATION BASIS

Normalization basis uses adjustment models to adjust energy consumption values for multiple relevant variables. Normalization can be conducted in a forecast, backcast (retrospective), or standard (reference) conditions approach. Regression analysis is a statistical technique that estimates the dependence of energy consumption on one or more independent relevant variables. Regression analysis can reveal the affect energy performance improvement actions have on facility-wide energy performance by removing the influence relevant variables such as production variation and weather. The analysis in this paper focuses solely on the forecasting approach to normalization. The U.S. DOE EnPI Tool, a regression analysis based Excel Add-in that follows the SEP M&V Protocol was used to calculate normalized energy savings and EPI % used in this paper.

Forecast normalization requires the formation of a baseline period energy consumption adjustment model. This model is applied to reporting period relevant variable values to calculate adjusted baseline period energy consumption ($ECP^a_{b|r}$) for comparison with observed (actual) reporting period energy consumption (ECP_r). The adjusted baseline period energy consumption is an estimate of the energy consumption that would have been expected given reporting period relevant variable values, if the baseline operating systems and practices were still in place during the reporting period. The adjusted baseline period energy consumption is described as:

$$ECP^a_{b|r} = b_0 + b_1x_1 + b_2x_2 + \ldots + b_kx_k$$

where x_i is the relevant variable quantity during the reporting period, b_0 is the modelled primary energy consumption level assuming all relevant variables have a zero value (sometimes referred to as baseload energy or y-axis intercept of the model), and $b_{i>0}$ is the incremental energy consumption per unit of that relevant variable (coefficient), determined using multiple linear regression analysis on baseline period consumption and relevant variable quantities. Modelled baseline period primary energy consumption can be compared to the actual reporting

period primary energy consumption in order to determine energy performance improvement percentage as described:

$$EPI_n\ (\%) = \left(1 - \frac{ECP_r}{ECP^a_{b|r}}\right) \times 100$$

The concept of forecast normalization is visually explained in Figure 1 where B1 through B12 and R1 through R12 are the 12 months of the baseline and reporting periods.

Per the SEP M&V Protocol, adjustment models were considered statistically valid for the analysis of this paper if they met the following requirements:

- An F-test for the overall model fit has a p-value of 0.10 or less (i.e., the overall fit of the adjustment model is statistically significant with a greater than 10 % significance level).
- All included relevant variables in the model have a p-value of 0.20 or less.
- At least one of the relevant variables in the model has a p-value of 0.10 or less.
- The coefficient of determination (R^2) for the regression is 0.50 or greater.
- The selection of relevant variables in the adjustment model and the subsequently determined relevant variable coefficients are consistent with a logical understanding of the energy use and energy consumption of the facility.

For all five SEP certified facilities included in this study, adjustment models were created for each energy type consumed. For facilities that consumed more than one energy type, multiple energy performance improvement values were calculated by combining all valid combinations of statistically valid models.

Available Data

Energy savings percentages include data from five SEP certified industrial facilities with a 12-month baseline primary energy consumption ranging from 950 to 3,600 TJ. Figure 2 presents the breakdown of energy consumption by energy type for each facility. The five facilities span a wide range of industrial sub-

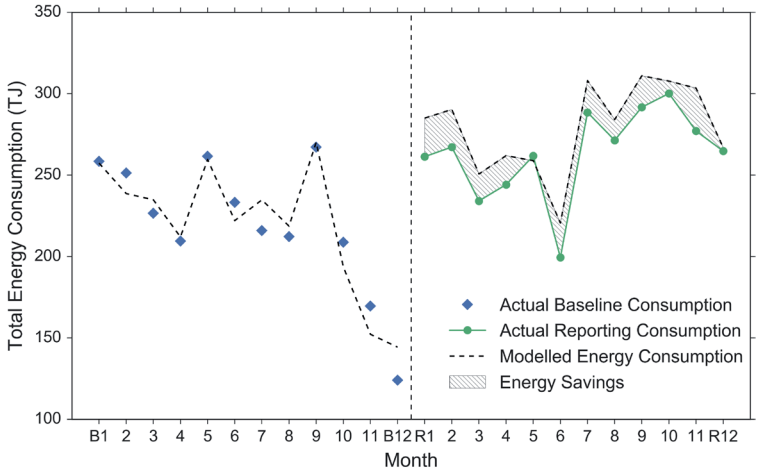


Figure 1. Graphical Representation of Energy Savings Determined by Normalization Basis with Regression Analysis.

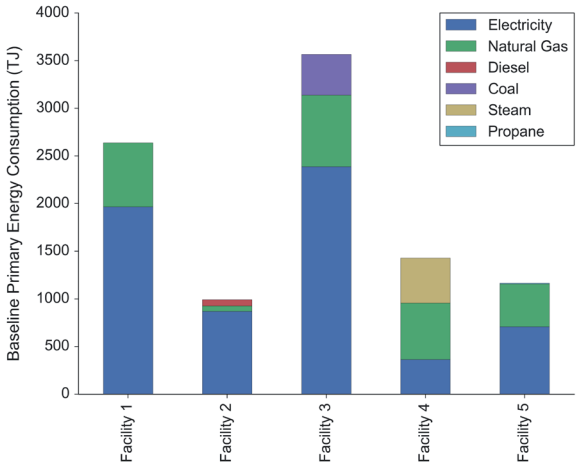


Figure 2. Baseline Energy Consumption (Primary) by Energy Type for the Five Facilities Included in this Study.

sectors including chemical, power generation equipment manufacturing, automotive assembly, and food processing.

Additionally, facilities supplied relevant variable data. The type and number of relevant variables differed for each facility. As such, multiple statistically valid regression models for each facility were created.

Results

For each of the five facilities analysed, absolute, intensity, and normalization basis EPI % values are shown in Figure 3. For each basis and facility, a box-and-whisker plot is shown. The upper and lower whiskers bound the maximum and minimum EPI % value while the box provides the first and third quartiles of the dataset. The median value is indicated with a horizontal line across the box. For each facility there is only one absolute basis EPI % value while the number of intensity and normalization (regression) EPI % values varies depending upon the number of relevant variables provided by the facility and statistically valid adjustment models available. Facility 1 relevant variables are called out in Figure 2 as they are analysed later in greater detail. For each facility, an x marker indicates the regression basis energy performance improvement level for which the facility was certified to the SEP program.

For each facility, there is a high degree of variability of the calculated EPI % values between the three calculation methodologies. While vastly different, none of the resulting energy performance improvement percentage values should be considered as incorrect. While the absolute basis energy savings value clearly conveys information regarding the change in energy consumption, the intensity and regression bases energy savings values should be understood to be estimations, or rather, representations of energy savings that provide more detail related to energy performance improvement than absolute energy savings values alone. Results generated from the application of each basis relay different contextualized information regarding energy performance at the facility. Depending upon their need, different end users may find more value in results from one basis over another.

The absolute basis calculates actual energy savings by comparing unadjusted energy consumption data from two time periods, the baseline period and the reporting period. This basis can be beneficial to organizations interested in reporting progress towards absolute goals to reduce greenhouse gas emissions or for those that are interested in energy cost savings. However, the absolute basis does not provide any context for the savings numbers or any basis for comparing facilities of varying size and sector, nor does it account for the seasonal and operational variability that may have a large effect on a facility's energy consumption.

Facility 1 provides an example of extremely high variability of EPI % in the use of the absolute, intensity and normalization bases.

On an absolute basis, Facility 1 has a calculated EPI % value of -19.8 %, reflective of the fact that the facility consumed more energy in the reporting period than during the baseline period (top most graph in Figure 4). This result is of value to users seeking information related to information related to the absolute cost of energy consumed or total CO_2 emissions from the facility. However, the result does not provide context for changes in relevant variables, such as production which increased from the baseline period to the reporting period (middle graph in Figure 4).

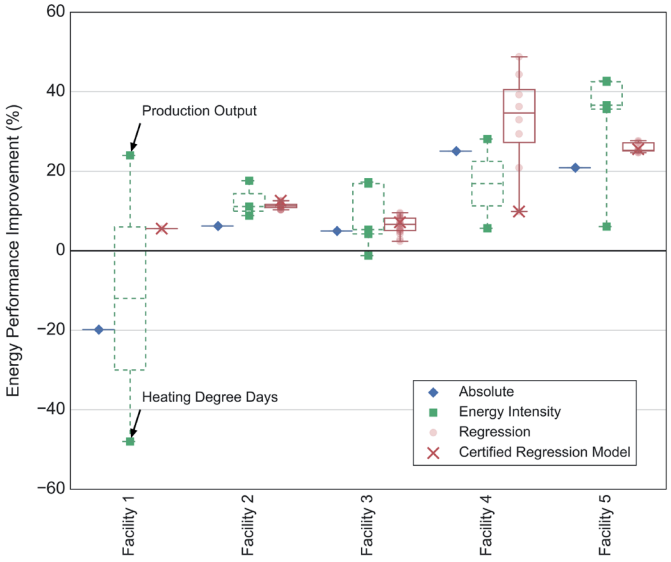


Figure 3. Comparison of Energy Savings Calculation Methodologies.

The intensity basis provides a specific contextual relationship between energy performance improvement percentage and the changes in one relevant variable. However, as shown in Figure 3, intensity basis calculated EPI % can be highly variable and is greatly dependent on the relevant variable that is selected for use. For Facility 1, using production output as the normalization metric leads to a calculated EPI % of 24.0 %. Using heating degree days (HDD) as the normalization metric, the calculated EPI % is -48.0 %. As seen in the middle and bottom graphs of Figure 4, reporting period production is greater than during the baseline period while reporting period HDD is lower than during the reporting period. The divergent direction of these relevant variables is the cause of the dramatically different intensity basis calculated EPI % values. It should be noted that when using the intensity basis, the selection of the relevant variable used in the calculation is typically chosen based upon engineering knowledge of the most energy intensive operation in the facility.

If there is a clear understanding that one relevant variable represents the dominant energy use at the facility, then use of that intensity basis EPI % may prove to be of value. Typically for an industrial facility this is a metric of production output though in some assembly facilities HVAC or other non-production metric may be known to be the largest energy use. The intensity EPI % values shown in Figure 3 reflect all potential intensity values based upon the provided relevant variables. As shown in Figure 5, electricity consumption is highly correlated (high R^2 value) with production output while natural gas consumption is highly correlated with heating degree days. Total energy consumption shows a stronger correlation with production output than HDD; however, the correlation is lower than when the energy types were disaggregated. As seen in Figure 2, electricity makes up approximately 75 % of Facility 1 total energy consumption, production would intuitively provide a

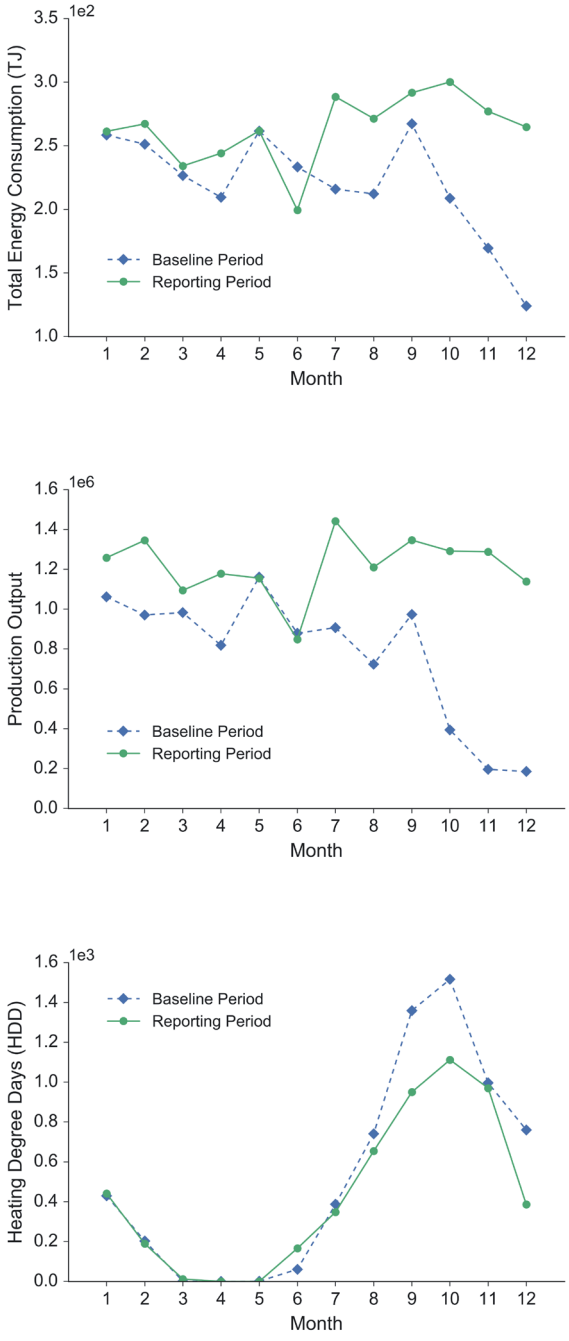


Figure 4. Changes in Baseline and Reporting Period Relevant Variables and Energy Consumption for Facility 1.

stronger correlation to total energy consumption than HDD. However, by using only production output, any contextual information associated with HDD is lost.

The U.S. DOE EnPI Tool was used to conduct normalization basis regression analysis of Facility 1 energy consumption and relevant variable data. For each energy type consumed by Facility 1, only one regression model was statistically valid per the requirements of the SEP M&V Protocol. Electricity consumption was modelled using production as the independent relevant variable, and natural gas consumption was modelled using HDD as the independent relevant variable. The modelled consumption for each energy type was then aggregated to establish the total modelled energy consumption. Using this model combination, the calculated EPI % was 5.6 %.

The benefit of using the forecasting basis is twofold. First, it is capable of modelling the effect of multiple variables, for each energy type. Second, the model selection process relies on both statistics and intuition together, rather than just one of the two, to choose normalization metrics. In the case of Facility 1, the application of statistical tests and engineering logic resulted in an EPI % value that meaningfully reflects the energy performance improvement actions as well as changes in production.

It is important to note that forecasting adjustment models are only as good as the data used to generate them, as well as the stringency of the statistical criteria that are required of them. Engineering logic should be applied to determine if the model is representative of the operations within the facility boundaries and when deciding which statistically valid model combination to use to calculate a final EPI % value. The critical nature of this logical evaluation is demonstrated by the normalization basis results obtained for Facility 4.

Generically for the five facilities, there tends to be a larger degree of variability in the intensity basis results than the forecasting basis results when multiple relevant variables were provided. The primary reason for the decreased range in variability is that the normalization basis determines and applies a weighting coefficient for each relevant variable. This reduces the relative impact of relevant variables that do no affect energy consumption as much as other relevant variables. In the case of Facility 1 this is clearly seen by the vastly different results when either production or HDD are used. HDD probably would not have been used as an intensity basis EPI value for Facility 1 as applying engineering logic shows the largest energy using systems at the facility are directly related to production, not climate control. However, without the use of regression modelling analysis, this cannot be quantitatively proven.

Additionally, this may be due to the fact that the forecasting basis per the SPE M&V Protocol checks for the statistical strength of the correlation between the relevant variables and energy consumption. Model combinations with weak correlation are rejected prior to being considered by the user, while regression models that pass the statistical tests give rise to similar calculated EPI % values. For the intensity basis, there are no checks or tests in place to determine the strength or validity of the normalization metrics.

However, this trend does not hold for Facility 4, which has a larger degree of variability in the EPI % values calculated using the forecasting basis than with the intensity basis. Facility 4 is unique in that there is extreme seasonal variability in its operation. There are two relevant variables that are assumed to affect energy consumption: monthly production level and average monthly ambient temperature. Therefore, for a given energy type, there are three possible models. Energy consumption as a function of:

- Production output,
- Ambient temperature, or
- Production output and ambient temperature.

Facility 4 consumes electricity, natural gas and steam, which means there are 9 possible independent models (3 for each energy type). The need to aggregate the modelled consumption

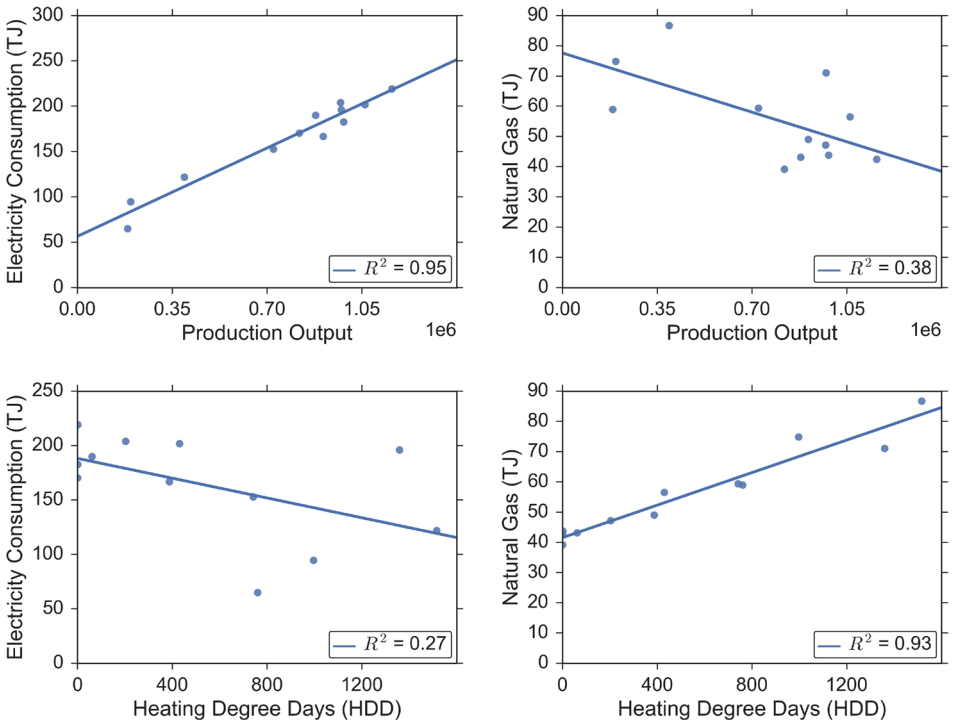


Figure 5. Correlations Between Facility 1 Energy Types and Relevant Variables.

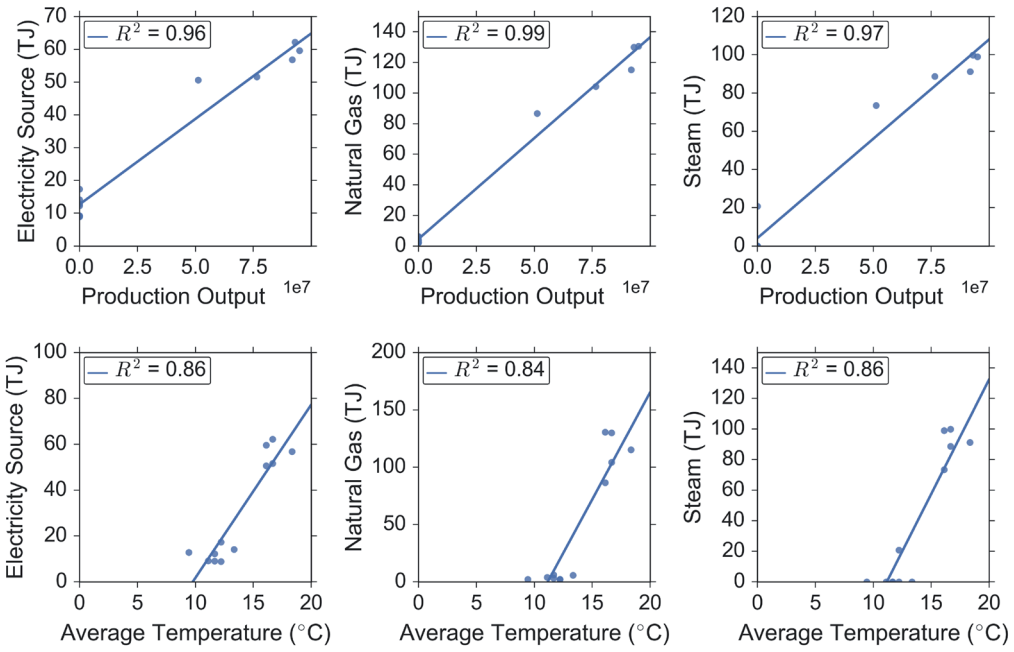


Figure 6. Correlations Between Facility 4 Energy Types and Relevant Variables.

per energy type into one total modelled consumption means there are 27 possible combinations of models. Through use of the U.S. DOE EnPI Tool, it was found that the multi-variate model of production output and ambient temperature was not statistically valid for any of the energy types. Therefore, the possibilities were narrowed to 8 valid combinations of models (hence the 8 values of Regression basis EPI % in Figure 3).

In Figure 6, production output shows the strongest correlation with all energy types, and thus the EnPI tool selects the production output model for each of the 3 energy types, which leads to a calculated EPI % of 9.9 %. However, there are 7 other valid model combinations, which include a temperature data model for one or more of the energy types. The model combination that uses temperature data for all three energy types

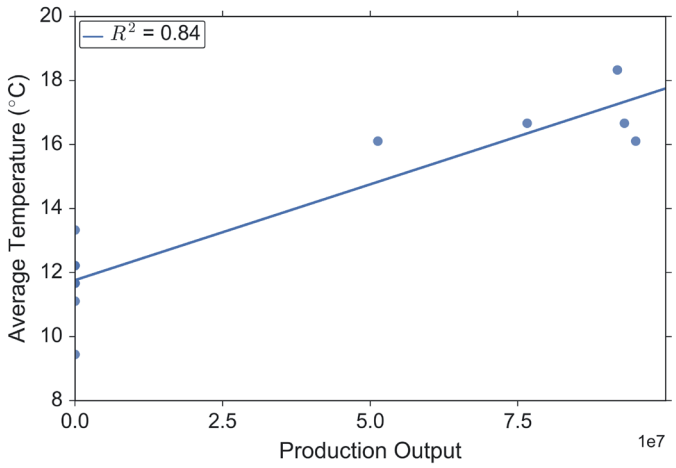


Figure 7. Relationship between the two Facility 4 Relevant Variables.

leads to an EPI % of 48.8 %. A closer examination into the extreme variability in EPI % focuses on the use of ambient temperature as a relevant variable.

Plotting the two relevant variables against each other in Figure 7 shows that ambient temperature is highly correlated with production output, suggesting that the correlation between energy consumption and ambient temperature may be coincidental. Production at the facility requires large quantities of natural gas to operate heated process equipment during summer months when ambient temperatures are independently elevated. Therefore, as production output is the result of the primary operation at the facility and that it has a stronger statistical correlation to energy consumption, it should be selected as the relevant variable for use.

Additional considerations for Facility 4 could include altering the average temperature relevant variable to one that is more traditional of year-to-year weather variability, such as CDD. Though still weaker than production output, the use of CDD as the relevant variable shows stronger statistical performance than average ambient temperature for Facility 4. CDD is also strongly correlated with production output, once again indicating that the strong correlation with energy consumption may be coincidental, due to the seasonal dependence of production.

Despite the statistical validity and greater EPI % of the other models, the adjustment model with the strongest statistical performance and agreement with engineering logic was selected for use in seeking SEP certification for Facility 4. While regression basis EPI % values inherently pose greater context than those calculated via the absolute or intensity bases, it is the statistical and logical tests that give confidence that the EPI % value is representative and meaningful.

Conclusion

Energy savings and EPI % values can be calculated on an absolute, intensity, and normalization basis. Each of these bases has merit in their own right though all three are contextually different and convey different meaning. An appropriate scope of each basis has been presented and discussion relative to their use presented.

Absolute energy savings values represent the actual change in energy consumption at a facility, intensity and normalization basis savings values are adjusted and are thus estimations of actual savings. Absolute savings values however do not provide insights to the actual impact energy performance improvement action have had on energy performance as changes in other factors such as production and weather may have changed.

Intensity basis savings values provide additional meaning relative to changes in a singular variable as compared to absolute savings. However, the limitations imposed by the use of a singular variable, and with no statistical method of determining if that variable has a large effect on energy consumption, results from the intensity basis can be misleading. Intensity basis should be used only if all external influences can be held constant over the period being analysed.

Regression analysis adjusts energy consumption values in order to remove the influences of relevant variables such as production and weather so the effect of energy performance improvement actions can be clearly quantified. Unlike the intensity basis, he regressions basis can account for a large number of variables and statistical tests can be applied, providing confidence in the relationship between energy consumption and the variables being controlled for. Engineering logic, in addition to statistical tests, must be applied to ensure that the relationship between relevant variables and energy consumption being used is reflective of operations in the facility.

EPI % values based on each of the three bases were calculated from energy consumption and relevant variable data from five SEP certified industrial facilities. Results show that even with the same input data from a given facility, EPI % values can vary greatly depending upon the basis utilized. Additionally, when more than one outcome is valid for a given basis, variation in the results can occur. A deep examination into the variations in intensity and normalization bases was performed. Variations in EPI % values from these bases are due to the relationship and the relative statistical strength, or lack thereof, between individual relevant variables and energy consumption data.

Additionally, normalization basis also allows for the direct comparison of EPI % across a set of facilities as well as meaningful comparison across different regions and types of facilities (e.g., comparing EPI % from an iron and steel facility in China to an automotive assembly facility in Germany). The other measures by their very nature are specific to the location and operation of the facility. By providing an analysis that normalizes local impacts like weather and facility specific variables like production, the normalized regression analysis provides a meaningful comparison of energy performance improvement regardless of location and facility type. Lastly, the accelerated pace of change in the global climate and economy necessitate the need for energy managers and facility managers to effectively understand their energy performance improvement in light of abnormal weather conditions is a key argument for the case of normalized basis regression analysis of EPI %. Normalized regression is the best tool for evaluating energy performance given the changing nature of what is considered normal weather.

A logical conclusion of this analysis is that along with reasonable statistical tests and engineering logic, the normalization

basis of calculating energy savings and EPI % values though adjustment model regression analysis provides the most contextually meaningful energy savings value results that can be used to demonstrate energy performance improvement. However, consideration of why an energy savings value is needed should be taken into account, realizing that the energy performance improvement of an organization may be best represented by a combination of EnPIs generated by calculating energy savings value from a number of the bases detailed.

Nomenclature

EPI_a Energy performance improvement (%), baseline to reporting period on an absolute basis
EPI_i Energy performance improvement (%), baseline to reporting period on an intensity basis
EPI_n Energy performance improvement (%), baseline to reporting period on a normalization basis
ECP_b Primary energy consumption of all energy types summed over baseline period
ECP_r Primary energy consumption of all energy types summed over reporting period
RV_b Relevant variable for the baseline period
RV_r Relevant variable for the reporting period
EI_b Energy intensity for baseline period
EI_r Energy intensity for reporting period
$ECP^a_{b|r}$ Modelled baseline period primary energy consumption adjusted to reporting period conditions
ES_a Energy savings calculated on an absolute basis
ES_i Energy savings calculated on an intensity basis
ES_n Energy savings calculated on a normalization basis

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