



Methodological tool

“Tool to determine the baseline efficiency of thermal or electric energy generation systems”

(Version 01)

I. SCOPE, APPLICABILITY AND PARAMETERS

Definitions

For the purpose of this tool, the following definitions apply:

Energy generation system or system. The term *system* refers to a facility that generates electricity or thermal energy from combustion of fuels. In case of electricity generation, the term *system* refers to the entire power plant including all necessary equipments, such as boiler, turbine, and generator as well as auxiliary equipment such as fuel processing systems, water conditioning systems, cooling tower, etc. This could include steam turbine generators or gas turbine generators or combined cycle power plants. In case of thermal energy generation, the term system includes all systems that produce thermal energy, such as steam boilers, fluid heaters, etc. The term energy generation system should include all auxiliary equipment, such as the fuel processing system, the water conditioning system etc.

Load. *Load* refers to the output of the energy generation system at which the system is operated during efficiency determination tests. It is expressed in kW or MW.

Efficiency. *Efficiency* is defined as the net quantity of useful energy generated¹ by the energy generation system per quantity of energy contained in the fuel fired. In case of boilers that are used only for thermal energy generation (and not for power generation), the efficiency is defined as the net quantity of useful heat generated per quantity of energy contained in the fuel fired in the boiler. In case of power plants producing only electric power (not cogeneration plants), the efficiency is defined as the net electricity generated by the power plant as a whole divided by the quantity of energy contained in the fuel fired.

Load – Efficiency function. A mathematical function representing the efficiency of the energy generation system as a function of the load.

Regression analysis. *Regression analysis* is a statistical method used to establish cause-effect for the investigation of relationships between the variables.

Performance curves. *Performance curves* are a graphical representation of the efficiency of the energy generation system at different loads and different operating conditions. For example, performance curves of a boiler illustrate the efficiency against load at different operating conditions, such as the steam pressure and temperature.

¹ Useful energy generated refers to useful energy supplied by the energy generating system. In the case of boilers that are used only for thermal energy generation (and not for power generation), the net quantity of useful energy corresponds to the enthalpy of the steam supplied by the boiler minus the enthalpy of the feed water, the enthalpy of any condensate return and the enthalpy of any boiler blow-down that is recovered. In case of power plants, the useful energy generated corresponds to the total quantity of electricity generated by the power plant minus the auxiliary electricity consumption of the power plant (e.g., for pumps, fans, controlling, etc).

Scope and Applicability

The tool describes various procedures to determine the baseline efficiency of an energy generation system, for the purpose of estimating baseline emissions. The tool may be used in case of project activities that improve the energy efficiency of an existing system through retrofits or replacement of the existing system by a new system.

This tool provides different procedures to determine the baseline efficiency of the energy generation system: either a) a load-efficiency function is determined which establishes the efficiency as a function of the operating load of the system or b) the efficiency is determined conservatively as a constant value.

This tool is applicable to energy generation systems that:

- (a) Generate only electricity (and no heat); or
- (b) Produce only thermal energy (and no electricity).

Also, the following conditions apply:

- The tool is not applicable to cogeneration systems and waste heat recovery systems;
- The tool can be applied only if load is the main operating parameter² that influences the efficiency of the energy generation system.

Methodologies referring to this tool should specify for which energy generation systems the tool is used and whether a load-efficiency function and/or a constant efficiency should be determined.

Parameters

This tool provides procedures to determine the following parameters:

Parameter	SI Unit	Description
η	Dimensionless	Efficiency of the energy generation system as a constant value
$\eta=f(L)$	Dimensionless	Load-efficiency function expressing the efficiency of the energy generation system as a function of the load at which the system is operated

II. BASELINE METHODOLOGY PROCEDURE

Project participants may use one of the following options to estimate the efficiency of the energy generation system:

- (a) Use the manufacturer's load-efficiency function;
- (b) Establish a load-efficiency function based on measurements and a regression analysis;
- (c) Establish the efficiency based on historical data and a regression analysis;
- (d) Use the manufacturer's efficiency values;
- (e) Determine the efficiency based on measurements and use a conservative value;
- (f) Use a default value.

² In some of the project activities that implement energy efficiency improvements, the efficiency at a particular load point shall be compared between the baseline and project scenarios. In such situations load on the equipment is the main operating parameter that determines the efficiency and associated emissions. Other parameters such as steam pressure and temperature may also influence the efficiency, but for the purpose of this tool, the efficiency is assumed to be constant within the permitted variations specified by the manufacturer e.g. within $\pm 5\%$ or $\pm 10^\circ\text{C}$.



Options A to E are applicable only to energy generation systems that use a single fuel type.³

Project participants should document which option is used to establish the efficiency of the relevant system, including, in the case of options (b), (c) or (e), the type of measuring equipment used, details of how the measurements were carried out and the measurement results.

Option A: Use the manufacturer's load-efficiency function

This option cannot be applied to determine a constant efficiency. The option can be used if:

- The manufacturer of the energy generation system provided load-efficiency functions or performance curves for the system at the time of installation; and
- If these functions or curves clearly show the efficiency of the system at all applicable loads and for the relevant range of operational conditions;⁴ and
- The functions or curves are consistent with the equipment/system characteristics; and
- If no retrofitting was done on the system prior to the implementation of the project activity that could have increased its efficiency.

The load-efficiency function of the energy generation system is derived from the manufacturer's function or curves, whereby each load point should have a corresponding efficiency for the relevant operating conditions (e.g., pressure and temperature of the steam).

In the case of performance curves, project participants may either derive a mathematical function from the curve or develop a table with efficiency vs. load values. The mathematical function or the table should closely represent the manufacturer's performance curves.

If the manufacturer supplies a mathematical relationship, this relationship can be used directly to derive the baseline efficiency of the energy generation system for the relevant operating conditions (e.g., pressure and temperature of the steam).

This option is conservative because the actual efficiency of the energy generation system is generally lower than the efficiency at the time of installation, due to ageing and deterioration of system, unless the system is retrofitted during its service.

Option B: Establish a load-efficiency function based on measurements and a regression analysis

Establish the load-efficiency function by conducting efficiency tests on the energy generation system⁵ and applying a regression analysis on the test results. The efficiency tests shall be conducted following the guidance provided in relevant national/international standards,⁶ such as ASME PTC-6 or IEC 60953-3, ASME PTC-4 or BS 845 or EN 12952-15 etc., preferably using direct methods (i.e., dividing the net output by the sum of all inputs). All measurements shall be conducted immediately after scheduled

³ Options A to E are not applicable to systems that use multiple fuels or different qualities of fuel within the same fuel type. For example if the system uses coal of different grades (e.g., Grade A, B or I, II etc.) with significantly varying calorific values, these options cannot be used to determine the baseline efficiency, as different grades of coal may result in different efficiencies. However, a small quantity of auxiliary fuels may be used for start-ups, not exceeding 3% of the main fuel used in the equipment.

⁴ This option cannot be used if the manufacturer provided efficiency values only at discrete load points. Project participants may consider Option D in this case.

⁵ Tests shall be conducted before implementation of retrofits that are part of the project activity.

⁶ National/International Standards provides detailed procedures, methods, guidance and/or recommendations for system operation conditions, test conditions, recording of measurements, permissible variations in measurements, instrumentation, uncertainty management, etc. during performance/acceptance tests. The same guidance shall be applied as appropriate for conducting the measurements for efficiency determination under this tool.



preventive maintenance has been undertaken and under favorable operation conditions.⁷ During the measurement campaign, the load should be varied over the whole operational range or the rated capacity of the energy generation system. The efficiency of the system should then be determined at different steady-state conditions. Document the monitoring procedures and results transparently. The tests shall be conducted by an independent entity such as the equipment supplier, sectoral experts/consultants etc. and the results of the efficiency tests shall be validated by the DOE.

Efficiency determination tests shall be conducted for the entire system as a whole including auxiliary equipment, such as the fuel conditioning system, preheating systems, etc. All energy inputs and outputs, such as the feed water supply or energy losses through blow down losses, shall be taken into consideration. Measurements shall be done for the complete system using calibrated equipments as required by the relevant national/international standards.

For the tests, two successive load points in the load range shall have an increment of at least 5% of the system's rated capacity. All efficiency tests shall be conducted for a predetermined discrete time interval as specified in standards. All tests shall be conducted for the same duration.

Each efficiency test provides a pair of data, i.e., (1) the load of the system and (2) the efficiency of system at that particular load. Based on the data collected at all load points, the load-efficiency function shall be established using a regression analysis. Project participants should choose the most suitable regression⁸ model such as linear, polynomial etc. following the general guidance given below:

- (i) Measure efficiency of the energy generation system at different load points as described above;
- (ii) Run a scatter plot, to determine the degree of the model. Identify the potential outliers to be filtered or re-run the test at that level to confirm the outlier. The fitting of higher-order polynomials of an independent variable with a mean not equal to zero can create complex multi-collinearity problems. Specifically, the polynomials will be highly correlated due to the mean of the primary independent variable. The correct sample size is critical to ensure a good representative curve is established. Take into account that polynomial models cannot be used for extrapolation;
- (iii) Determine the coefficient of the equation using any methodology but taking into account the recommendations in (ii) above;
- (iv) The model should display:
 - An ANOVA⁹ (Analysis of Variance) table showing the regression and residual sum of squares and the significance;
 - The coefficients table showing the SIG, these must be lower than 0.05.

⁷ Favorable operation conditions are optimal operation conditions, representative or favorable ambient conditions for the best efficiency of the energy generation system, including temperature and humidity, etc.

⁸ For using regression analysis, necessary safeguards in order to ensure conservativeness and rigor of the fitted regression model should be used. In the process of fitting the regression, assumptions and requirements for regression models should be considered e.g. testing for multi-collinearity. It is recommended that project participants use the standard software for regression analysis and to determine the standard error.

⁹ In statistics, a result is called statistically significant if it is unlikely to have occurred by chance. "A statistically significant difference" simply means there is statistical evidence that there is a difference; it does not mean the difference is necessarily large, important, or significant in the common meaning of the word. The significance level of a test is a traditional statistical hypothesis testing concept. In simple cases, it is defined as the probability of making a decision to reject the null hypothesis when the null hypothesis is actually true (a decision known as a Type I error, or "false positive determination"). The decision is often made using the p-value: if the p-value is less than the significance level, then the null hypothesis is rejected. The smaller the p-value, the more significant the result is said to be.



- (v) Run a confirmatory data analysis, using the null hypothesis test to cover the entire population and allow forecasting for only the range of sample data.
- Use α = probability (Reject H_0/H_0 TRUE), a 0.05 value is recommended to assure the statistical significance.
- (vi) The resultant load-efficiency function derived using regression model shall be adjusted for uncertainty in a conservative manner, by considering the upper bound values of the range at 95% confidence level at the load point where efficiency is to be derived.

Option C: Establish the efficiency function based on historical data and a regression analysis

This option can be used to determine a load-efficiency function or a constant efficiency.

The following conditions apply:

- In the case where the tool is used to establish a load-efficiency function, this option can only be used if measured data on the load and other parameters that are required to establish the efficiency of the system are available on an hourly basis (or a shorter time period) for the most recent year prior to the implementation of the project activity;
- In the case that the tool is used to establish a constant efficiency, this option can only be used if annual data on the efficiency of the energy generation system is available for the most recent three years prior to the implementation of the project activity;
- No retrofitting was done during the period for which historical data is used that could have increased the efficiency of the energy generation system. The historical data shall be the actual measured data such as flow, pressure, temperature, fuel consumption, energy outputs, etc. as applicable (e.g. from plant operational log books).

If the tool is used to establish a constant efficiency, the highest annual efficiency from the most recent three years should be chosen.

If the tool is used to establish a load-efficiency function, a regression analysis should be applied, following the guidance given under option b) above, using the historical data from the most recent year instead of conducting measurements on the system. The data pairs for load and efficiency should be used for the time interval at which they are available (one hour or, if available, for a shorter time interval). Project participants shall document the complete data set used to establish the efficiency function.

Option D: Use the manufacturer's efficiency values

This option can be used to determine a constant efficiency.

The following conditions apply:

- If the manufacturer does not provide full load-efficiency functions or performance curves (if these functions are provided, Option A applies) but only the maximum efficiency at the optimal operating conditions;
- No retrofitting was done prior to implementation of the project that could have increased the efficiency of the energy system.

If these conditions are met, the efficiency provided by the manufacturer can be used as a conservative approach.

**Option E: Determine the efficiency based on measurements and use a conservative value**

This option can be used to determine a constant efficiency. Under this option, the efficiency of the energy generation system shall be measured based on performance tests before the implementing the project activity following national/international standards (e.g., ASME PTC-6 or IEC 60953-3, ASME PTC-4 or BS 845 or EN 12952-15 or other equivalent international and national standards), at discrete loads within the operation range or over the entire rated capacity, preferably using direct methods (i.e. dividing the net output by the sum of all inputs).

For tests, two successive load points in the load range shall have an increment of at least 5% of the system's rated capacity. At each load point one set of measurements shall be conducted. All efficiency tests shall be conducted for a same predetermined discrete time interval as specified in standards in the presence of an independent party (e.g. system manufacturer, technical consultant etc.).

All measurements shall be conducted immediately after scheduled preventive maintenance has been undertaken and under favorable operation conditions¹⁰ (optimal operating conditions, representative or favorable ambient conditions for the best efficiency of the energy generation system, including temperature and humidity, etc.). During the measurement campaign, the load is varied over the whole operation range and the efficiency of the energy generation system is determined for different steady-state load levels. Document the measurement procedures and results transparently. A minimum of 10 measurements shall be taken at different loads in the full operation range or rated capacity and among the measurements, the highest efficiency shall be considered as a conservative approach.

Tests shall be conducted for the entire system including auxiliary equipment, such as the fuel conditioning system, preheating systems, etc. All energy inputs and outputs, such as the feed water supply or energy losses through blow down losses, shall be taken into consideration. Measurements shall be done using calibrated equipments as required by the relevant national/international standards.

Alternatively, if the efficiency test was conducted as part of concluding a previous retrofit activity¹¹ or energy audits or performance evaluation of the equipment, within 3 years prior to the implementation of the project activity and if the measurements and efficiency determination has already been verified and certified by an independent party, project participants may use the same data without conducting a new measurement campaign. This alternative is not applicable where a retrofit to increase the energy efficiency was done later.

Project participants shall justify and document the chosen optimal operating conditions.

Option F: Use a default value

This option can be used to determine a constant efficiency. Project participants may use the default values for the applicable technology from Table 1 as constant efficiency.¹²

¹⁰ Favorable operation conditions are optimal operation conditions, representative or favorable ambient conditions for the best efficiency of the energy generation system, including temperature and humidity, etc.

¹¹ Not part of the project activity.

¹² Project participants are encouraged to request for an amendment of this tool and may propose default values for technologies not covered in the table.

**Table 1: Default baseline efficiency for different technologies**

Technology of the energy generation system	Default efficiency
New natural gas fired boiler (w/o condenser)	92%
New oil fired boiler	90%
Old natural gas fired boiler (w/o condenser)	87%
New coal fired boiler	85%
Old oil fired boiler	85%
Old coal fired boiler	80%

The above default values are applicable for thermal energy generating equipment. For electricity generation technologies, default values as provided in the Annex I of the “Tool to calculate the emission factor for an electricity system” may be used. In the table, for the purposes of this tool, “old” refers to equipment with an individual age of at least 10 years. “New” refers to equipment with an individual age of less than 10 years. In situations where a specific technology is not included in the table, project participants may also choose to use a maximum default efficiency of 100%, as simple and very conservative approach.

History of the document

Version	Date	Nature of revision(s)
01	EB 48, Annex 12 17 July 2009	Initial adoption.
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