CLEAN DEVELOPMENT MECHANISM

TOOL09

Methodological tool

Determining the baseline efficiency of thermal or electric energy generation systems

Version 03.0

United Nations
Framework Convention on
Climate Change

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1. Introduction

1. The tool provides methodological guidance to estimate efficiency of both thermal energy and power generation units.

2. Scope, applicability, and entry into force

2.1. Scope

2. 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.

3. The 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.

2.2. Applicability

4. This tool is applicable to energy generation systems that:

   (a) Generate only electricity (and no thermal energy); or

   (b) Produce only thermal energy (and no electricity); or

   (c) Produce both electricity and thermal energy (cogeneration).

5. Also, the following conditions apply:

   (a) The tool is applicable to waste heat recovery systems to calculate efficiency values using options (A) to (E) as provided under paragraph 12 below;

   (b) The tool can be applied only if load is the main operating parameter[1] that influences the efficiency of the energy generation system. For cogeneration systems, the heat to power ratio may also be considered a main operating parameter.

6. 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.

[1] 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 ±5% or ±10ºC.

2.3. Entry into force

7. The date of entry into force is the date of the publication of the EB 106 meeting report on 12 June 2020.

3. Normative references

8. This tool refers to the following documents:

   (a) ASME PTC-4: Fired Steam Generators;

   (b) ASME PTC-6: Steam Turbines;

   (c) BS 845: Methods for assessing thermal performance of boilers for steam, hot water and high temperature heat transfer fluids;

   (d) EN 12952-15: Water tube boilers and auxiliary installations - Part 15: Acceptance tests;

   (e) IEC 60953-3: Rules for steam turbine thermal acceptance tests - Part 3: Thermal performance verification tests of retrofitted steam turbines.

4. Definitions

9. The definitions contained in the Glossary of CDM terms shall apply.

10. For the purpose of this tool, the following definitions also apply:

   (a) **Cogeneration plant** - a power-and-heat plant in which at least one heat engine simultaneously generates both heat and power;

   (b) **Efficiency** - is defined as the net quantity of useful energy generated[2] by the energy generation system per quantity of energy contained in the fuel fired, while considering its lower heating value:

      (i) 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;

      (ii) 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;

      (iii) In case of cogeneration plants, both definitions of efficiency as above applies, and overall efficiency is defined as the sum of both efficiencies;

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[2] 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.).

(c) **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 equipment, 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.;

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

(e) **Load - Efficiency function** - a mathematical function representing the efficiency of the energy generation system as a function of the load;

(f) **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;

(g) **Regression analysis** - a statistical method used to establish cause-effect for the investigation of relationships between the variables;

(h) **Lower heating value (LHV)** - The heat produced by combustion of unit quantity of a solid or liquid fuel when burned, at a constant pressure of 1 atm (0.1 MPa), under conditions such that all the water in the products remains in the form of vapor.

5. Parameters

11. This tool provides procedures to determine the following parameters:

Table 1. 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

6. Baseline methodology procedure

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

(a) Option A: Use the manufacturer’s load-efficiency function;

(b) Option B: Establish a load-efficiency function based on measurements and a regression analysis;

(c) Option C: Establish the efficiency based on historical data and a regression analysis;

(d) Option D: Use the manufacturer’s efficiency values;

(e) Option E: Determine the efficiency based on measurements and use a conservative value;

(f) Option F: Use a default value.

13. Options (A) to (E) are applicable only to energy generation systems that use a single fuel type and fuel mix including waste energy. In case of fuel mix, the efficiency of the energy generating equipment is calculated based on the fuel with highest percentage of share in a monitoring year in terms of calorific value.

14. 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.

15. For cogeneration projects, project participants shall also document and justify the choice of heat to power ratio used in the measurements.

6.1. Option A: Use the manufacturer’s load-efficiency function

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

(a) The manufacturer of the energy generation system provided load-efficiency functions or performance curves for the system at the time of installation; and

(b) If these functions or curves clearly show the efficiency of the system at all applicable loads and for the relevant range of operational conditions;[3] and

(c) The functions or curves are consistent with the equipment/system characteristics; and

(d) If no retrofitting was done on the system prior to the implementation of the project activity that could have increased its efficiency.

17. 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).

18. 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.

[3] 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.

19. 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).

20. 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.

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

21. Establish the load-efficiency function by conducting efficiency tests on the energy generation system[4] and applying a regression analysis on the test results. The efficiency tests shall be conducted following the guidance provided in relevant national/international standards[5], such as ASME PTC-6, IEC 60953-3, ASME PTC-4 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 preventive maintenance has been undertaken and under favourable operation conditions.[6] 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.

22. 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 equipment as required by the relevant national/international standards.

23. 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.

24. 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

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[4] Tests shall be conducted before implementation of retrofits that are part of the project activity.

[5] 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.

[6] 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.

participants should choose the most suitable regression[7] model such as linear, polynomial etc. following the general guidance given below:

(a) Measure efficiency of the energy generation system at different load points as described above;

(b) 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;

(c) Determine the coefficient of the equation using any methodology but taking into account the recommendations in (b) above;

(d) The model should display:

  (i) An ANOVA[8] (Analysis of Variance) table showing the regression and residual sum of squares and the significance;

  (ii) The coefficients table showing the significance, these must be lower than 0.05.

  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 Ho/Ho TRUE), a 0.05 value is recommended to assure the statistical significance.

(e) 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.

[7] 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-colinearity. It is recommended that project participants use the standard software for regression analysis and to determine the standard error.

[8] 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.

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

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

26. The following conditions apply:

    (a) 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;

    (b) 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;

    (c) 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).

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

28. 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).

29. Project participants shall document the complete data set used to establish the efficiency function.

6.4. Option D: Use the manufacturer's efficiency values

30. This option can be used to determine a constant efficiency.

31. The following conditions apply:

    (a) 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;

    (b) No retrofitting was done prior to implementation of the project that could have increased the efficiency of the energy system.

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

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

33. 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, IEC 60953-3, ASME PTC-4, 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).

34. 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.).

35. All measurements shall be conducted immediately after scheduled preventive maintenance has been undertaken and under favorable operation conditions[9] (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.

36. 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 equipment as required by the relevant national/international standards.

37. Alternatively, if the efficiency test was conducted as part of concluding a previous retrofit activity[10] 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.

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

[9] 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.

[10] Not part of the project activity.

6.6. Option F: Use a default value

39. This option can be used to determine a constant efficiency. Project participants may use the default values for the applicable technology from the appendix as constant efficiency.[11]

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

Appendix. Default efficiency factors

Table 1. Default efficiency factor for thermal applications

Technology of the energy generation system	Default efficiency
Natural gas fired boiler (w/o condenser)	92%
Oil fired boilers adapted as Natural gas fired boiler (w/o condenser)	87%
Oil fired boiler	90%
Biomass fired boiler (on dry biomass basis)	85%
oal fired boiler	90%
Other	100%

Table 2. Default efficiency factor for power plants with installed capacity more than 1MW[1]

Generation technology	**Commissioning year**		
	y≤2000	**2000<y≥2012**	**y>2012**
Coal			
Subcritical	37%	39%	39%
Supercritical	-	45%	45%
Ultra-supercritical	-	50%	50%
IGCC	-	50%	50%
FB	35.5%	-	-
CFB[2]	36.5%	40%	43%
PFB	-	41.5%	45%
Natural gas			
Reciprocal gas engine	33%	40%	48%
Open cycle gas turbine	30%	39%	44%
Combined cycle gas turbine	46%	60%	62%
Oil			
Steam turbine	37.5%	39%	44%
Reciprocal engine	33%	40%	48%

1 Main sources for values are IEA Energy technology perspective publication 2010 to 2017, IEA, Projected costs of generating electricity, 2015 and IEA, World Energy Outlook, 2018.

2 IFSA 2014, Industrial Fluidization South Africa, Glenburn Lodge, Cradle of Humankind, 19–20 November 2014, 'The value proposition of circulating fluidized-bed technology for the utility power sector', by R. Giglio and N. J. Castilla.

Biomass[3]	
IGCC	42%
Other	35%
Cogeneration[4]	
Steam turbine	83%
Gas turbine	83%
Reciprocal engine	89%
Mircoturbine (up to 500kW)	78%

Table 3. Default efficiency for power plants with installed capacity up to 1000 kW

	Nominal capacity of power plants (CAP, in kW)						
Generation Technology	**CAP≤10**	**10<CAP ≤50**	**50<CAP ≤100**	**100<CAP ≤200**	**200<CAP ≤400**	**400<CAP ≤1000**	
Reciprocal engine system (e.g. diesel-, fuel oil-, gas-engines)[5]	28%	33%	35%	37%	39%	42%	
Gas turbine systems[6]	28%	32%	34%	35%	37%	40%	
Small boiler/steam/turbine system[7]	7%	7%	7%	7%	7%	7%	

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[3] Biomass calorific value is measured on dry basis. Maximum of 1% on energy basis fossil fuel co-firing is allowed, including start-up fuel. Main sources of values are IEA, Energy technology perspective, 2017, IEA, Projected costs of generating electricity, 2015 and IEA, World Energy Outlook, 2018.

[4] The values are the overall efficiency, for electric efficiency, use the power-only default values. Main source for cogeneration values: Implementing EPA's Clean Power Plan: A Menu of Options <http://www.4cleanair.org/NACAA_Menu_of_Options> and IEA, Energy technology perspective, 2017, IEA, Projected costs of generating electricity, 2015 and IEA, World Energy Outlook, 2018.

[5] Based on diesel consumption data available at https://www.dieselserviceandsupply.com/Diesel_Fuel_Consumption.aspx.

[6] Refer footnote 6 and Implementing EPA's Clean Power Plan: A Menu of Options http://www.4cleanair.org/NACAA_Menu_of_Options.

[7] Factsheet from the US DoE and available at: https://www.energy.gov/sites/prod/files/2016/09/f33/CHP-Steam%20Turbine.pdf.

Document information

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