CDM-MP80-A10

Draft Methodological tool

TOOL09: Determining the baseline efficiency of thermal or electric energy generation systems

Version 03.0

United Nations
Framework Convention on
Climate Change

COVER NOTE

1. Procedural background

1. The Executive Board of the CDM (hereinafter referred as the Board) at its ninety-forth meeting (EB 94 report, para. 32) requested the Methodologies Panel (MP) to update default efficiency factors in the methodological tool "TOOL09: Determining the baseline efficiency of thermal or electric energy generation systems" (hereinafter referred as 'tool') on a regular basis (i.e. every two or three years), based on publicly available information.

2. Based on this mandate the MP, at its 79th meeting, started the work. At its 80th meeting, the MP agreed to seek public input on the work related to update the default efficiency factors for thermal energy generation, for grid-connected and off-grid power generation as provided in table 1 to table 3 of the Appendix of the tool.

2. Purpose

3. The present work confirms that the default efficiency factors as provided in the Appendix of the tool are the latest valid values as referred from the publicly available literature sources.

3. Key issues and proposed solutions

4. The secretariat conducted a literature review to compare default efficiency factors from the tool against efficiency factors as reported in the literature. Table 1 to table 6 provide comparison of default efficiency factors between those reported in the literature and the current version of the tool.

5. In case of thermal applications, the MP recommends maintaining the default efficiency factors in the current version of the tool as the values are conservative. Except in the case of coal fired boiler, a change is proposed. Refer to table 1 for further details and the citation of the source for the literature review.

Table 1. Default efficiency factor for thermal application

Technology of the energy generation system	Efficiency (in percentage) as reported in literature[1]	Default efficiency factor (in percentage) as in current version of the tool	Default efficiency factor (in percentage) recommended
Natural gas fired boiler (w/o condenser)	85.7	92	92
Oil fired boilers adapted as Natural gas fired boiler (w/o condenser)	80.6	87	87

[1] IEA ETSAP - Technology Brief I01 <https://iea-etsap.org/index.php/energy-technology-data/energy-supply-technologies-data>.

Technology of the energy generation system	Efficiency (in percentage) as reported in literature[1]	Default efficiency factor (in percentage) as in current version of the tool	Default efficiency factor (in percentage) recommended
Oil fired boiler	89.6	90	90
Biomass fired boiler (on dry biomass basis)	80.0	85	85
Coal fired boiler	90.3	80	90
Other	NA	100	100

6. In case of coal-based power generation, the MP recommends using conservative default efficiency factors among the one reported in the literature and current version of the tool. Refer to table 2 for further details.

Table 2. Default efficiency factor for coal-based power generation

Technology type and region	Efficiency (in percentage) as reported in literature (LHV)[2]			Default efficiency factor (in percentage) as in current version of the tool	Default efficiency factor (in percentage) recommended
	2015	2020	2030		
Steam Coal - SUBCRITICAL					
Europe	39	39	39	39	39
United States	39	39	39		
Japan	39	39	39		
Russia	39	39	39		
China	37	37	37		
India	36	36	36		
Middle East	37	37	37		
Africa	35	35	35		
Brazil	39	39	39		
Steam Coal - SUPERCRITICAL					
Europe	43	43	43	45	45
United States	43	43	43		
Japan	43	43	43		
Russia	43	43	43		
China	41	41	41		
India	40	40	40		
Middle East	41	41	41		
Africa	39	39	39		
Brazil	43	43	43		

[2] Unless otherwise mentioned, the default values are referred from IEA, Energy technology perspective, 2017, IEA, Projected costs of generating electricity, 2015 and IEA, World Energy Outlook, 2018.

Technology type and region	**Efficiency (in percentage) as reported in literature (LHV)[2]**			**Default efficiency factor (in percentage) as in current version of the tool**	**Default efficiency factor (in percentage) recommended**
	2015	**2020**	**2030**		
Steam Coal - ULTRASUPERCRITICAL					
Europe	45	46	47	50	50
United States	45	46	47		
Japan	45	46	47		
Russia	45	46	47		
China	44	45	46		
India	40	41	42		
Middle East	43	44	45		
Africa	41	42	43		
Brazil	45	46	47		
Coal based IGCC					
Europe	44	45	47	50	50
United States	44	45	47		
Japan	44	45	47		
Russia	44	45	47		
China	43	44	46		
India	41	42	44		
Middle East	42	43	45		
Africa	40	41	43		
Brazil	44	45	47		
CFB[3]					
	43.3			40	43
PFB					
	45			45	45

7. In case of combined-cycle gas-based power generation and reciprocal gas engines, the MP noted that the default efficiency factor in the current version of the tool is conservative when compared with the one reported in the literature. The MP recommends retaining the default efficiency factors in the current version of the tool except for open-cycle gas-based power generation. Refer to table 3 for further details.

[3] 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.

Table 3. Default efficiency factor for gas-based power generation

Technology type and region	Efficiency (in percentage) as reported in literature (LHV)[4]			Default efficiency factor (in percentage) as in current version of the tool	Default efficiency factor (in percentage) recommended
	2015	2020	2030		
Combined Cycle Gas Turbine (CCGT)					
Europe	59	59	60	62	62
United States	59	59	60		
Japan	59	59	60		
Russia	57	57	58		
China	57	57	58		
India	56	56	57		
Middle East	57	57	58		
Africa	58	58	59		
Brazil	58	58	59		
Open Cycle Gas Turbine (OCGT)					
Europe	40	40	41	42	44
United States	40	40	41		
Japan	40	40	41		
Russia	38	38	39		
China	38	38	39		
India	38	38	39		
Middle East	38	38	39		
Africa	38	38	39		
Brazil	38	38	39		
Belgium	44				
Germany	40				
New Zealand	30				
United Kingdom	39				
Reciprocal gas engine[5]					
	27 – 42			48.5	48

[4] Refer to footnote 2.

[5] Catalog of CHP technologies, section 2 – Technology Characterization – Reciprocating Internal Combustion Engines, US EPA, Combined heat and power partnership, March 2015.

8. The MP, in case of oil-based reciprocal engines recommends retaining default efficiency factor, while in case of oil-based steam turbines, recommends using the default efficiency factor as mentioned in the current version of the tool as it is conservative over the one reported in literature. Refer to table 4 for further details.

Table 4. Default efficiency factor for oil-based power generation

Technology type and region	Efficiency (in percentage) as reported in literature[6]	Default efficiency factor (in percentage) as in current version of the tool	Default efficiency factor (in percentage) recommended
Steam turbine			
	42	44	44
Reciprocal engine			
	48	48.5	48

9. In case of biomass-based integrated gasification combined cycle power generation, MP recommends using the default efficiency factors as reported in the literature and, in case of biomass-based steam turbine recommends retaining the current value. Refer to table 5 for further details.

Table 5. Default efficiency factor for biomass-based power generation

Technology type and region	Efficiency (in percentage) as reported in literature (LHV)[7]			Default efficiency factor (in percentage) as in current version of the tool	Default efficiency factor (in percentage) recommended
	2015	**2020**	**2030**		
Biomass based IGCC					
	35	38	42	40	42
Biomass based steam turbine					
	30	33	35	35	35

10. In case of co-generation, MP recommends retaining default efficiency factor value as in the tool, except in case of combined cycle-based cogeneration, it recommends the default efficiency factor value as reported in the literature. Refer to table 6 for further details.

[6] Based on US EPA data, converted to LHV of fuel.

[7] Refer to footnote 2.

Table 6. Default efficiency factor for co-generation

Technology type and region	Efficiency (in percentage) as reported in literature (gross, LHV)[8]			Default efficiency factor (in percentage) as in current version of the tool	Default efficiency factor (in percentage) recommended
	2015	2020	2030		
Steam turbine					
Europe	70	70	70	83.5	83
United States	70	70	70		
Japan	70	70	70		
Russia	70	70	70		
China	70	70	70		
India	70	70	70		
Middle East	70	70	70		
Africa	70	70	70		
Brazil	70	70	70		
CCGT – CHP					
Europe	82	82	83	78.8	83
United States	82	82	83		
Japan	82	82	83		
Russia	80	80	81		
China	80	80	81		
India	79	79	80		
Middle East	80	80	81		
Africa	81	81	82		
Brazil	81	81	82		
Reciprocal engine[9]					
	77 - 83			88.8	89
Microturbine (up to 500 kW)[10]					
	63 - 71			77.7	78

11. Further, the MP also reviewed the default efficiency factors for off-grid power plants and recommends maintaining the current values as provided in the tool. Refer table 7 for further details.

[8] Refer to footnote 3.

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

[10] Refer footnote 3.

Table 7. Default efficiency factor for power plants with 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) [11]	28%	33%	35%	37%	39%	42%
Gas turbine systems[12]	28%	32%	34%	35%	37%	40%
Small boiler/steam/turbine system[13]	7%	7%	7%	7%	7%	7%

12. The MP noted that the tool is not applicable in case of use of fuel mix. However, it recommends that the tool should be made applicable for equipment that uses fuel mix and, in such cases, the efficiency of the energy generating equipment is based on the highest efficiency of the fuel used, that constitute more than 10% of the fuel used.

13. Further, the MP recommends differentiation of categorisation of the power generating equipment based on the capacity of the equipment rather than whether it is grid-connected or off-grid. Simplification is also suggested by rounding-off the default efficiency factor values to the nearest integer, for example, 83.7 will be round-off to 84 and 90.3 will be round-off to 90.

4. Impacts

14. The proposed draft revised tool, if approved, will have updated default efficiency factors for technology used, for thermal energy generation, and for grid-connected and off-grid power generation purpose.

5. Subsequent work and timelines

15. The MP, at its 80th meeting, agreed on the draft version of the tool. After receiving public inputs on the document, the MP will continue working on the revision of the tool, at its next meeting, for recommendation to the Board at a future meeting of the Board.

6. Recommendations to the Board

16. Not applicable (call for public inputs).

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

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

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

7. References

(a) IEA, Energy technology perspective, 2017

(b) IEA, Projected costs of generating electricity, 2015

(c) IEA, World Energy Outlook, 2018

(d) IEA ETSAP - Technology Brief I01, May 2010

(e) Catalog of CHP technologies, section 2 – Technology Characterization – Reciprocating Internal Combustion Engines, US EPA, Combined heat and power partnership, March 2015.

(f) Implementing EPA's Clean Power Plan: A Menu of Options, 2015 <http://www.4cleanair.org/NACAA_Menu_of_Options>

(g) Factsheet from the US DoE: available at <https://www.energy.gov/sites/prod/files/2016/09/f33/CHP-Steam%20Turbine.pdf>

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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. 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.

2.2. Applicability

4. 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); or

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

5. Also, the following conditions apply:

   (a) The tool is not applicable to waste heat recovery systems;

   (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.

2.3. Entry into force

7. The date of entry into force is the date of the publication of the EB ### meeting report on DD month YYYY.

[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.

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 apply, and overall efficiency is defined of the sum of both efficiencies;

(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

[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.).

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. Net heat of combustion at constant pressure is expressed as Qp (net).

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. In case of fuel mix, the efficiency of the energy generating equipment is based on the highest efficiency of the fuel used, that constitute more than 10% of the fuel used. [3]

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[4]; 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;[5] 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

[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] The highest value in 30 continuous operation days during the monitoring period shall be considered as representative value.

[5] 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.

mathematical function or the table should closely represent the manufacturer's performance curves.

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[6] and applying a regression analysis on the test results. The efficiency tests shall be conducted following the guidance provided in relevant national/international standards[7], 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.[8] 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.

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

[7] 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.

[8] 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.

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 participants should choose the most suitable regression[9] 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-colinearity 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 ANOVA9[10] (Analysis of Variance) table showing the regression and residual sum of squares and the significance;

(ii) The coefficients table showing the SIG, 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.

[9] 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.

[10] 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[11] (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[12] 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.

[11] 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.

[12] 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.[13]

[13] 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
~~New~~ ~~n~~ Natural gas fired boiler (w/o condenser)	92%
~~Old n~~ Oil fired boilers adapted as Natural gas fired boiler (w/o condenser)	87%
~~New~~ ~~o~~ Oil fired boiler	90%
~~New~~ ~~b~~ Biomass fired boiler (on dry biomass basis)	85%
~~Old oil fired boiler~~	~~85%~~
~~Old biomass fired boiler (on dry biomass basis)~~	~~80%~~
~~Old~~ ~~c~~ Coal fired boiler	~~80~~ 90%
Other	100%

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

~~Grid power plant~~			
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~~S~~	35.5%	-	-
CFB~~S~~[2]	36.5%	40%	~~40~~ 43%
PFB~~S~~	-	41.5%	45%
~~Oil/n~~ Natural gas			
~~Steam turbine~~	~~37.5%~~	~~39%~~	~~44 %~~
Reciprocal gas engine	33%	40%	~~48.5~~ 48%
Open cycle gas turbine	30%	~~39.5~~ 39%	~~42~~ 44%
Combined cycle gas turbine	46%	60%	62%
Oil			

[1] ~~Values partially taken from the "Tool to calculate the emission factor for an electricity system".~~ 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: ~~IEA energy technology perspectives from 2012: <http://www.iea.org/publications/freepublications/publication/energy-technology-perspectives-2012.html>.~~

[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.

~~**Grid power plant**~~			
Steam turbine	37.5%	39%	~~42~~ 44%
Reciprocal engine	33%	40%	~~48.5~~ 48%
Biomass[3]			
IGCC	~~40~~ 42%		
Other	35%		
Cogeneration[4]			
Steam turbine	~~83.5~~ 83%		
Gas turbine	~~78.8~~ 83%		
Reciprocal engine	~~88.8~~ 89%		
Mircoturbine (up to 500kW)	~~77.7~~ 78%		

Table 3. Default efficiency for ~~off-grid~~ power plants with installed capacity up to 1000 kW

	~~**Off-grid power plants**~~						
	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	~~CAP>1000~~
Reciprocal engine system (e.g. diesel-, fuel oil-, gas-engines) [5]	28%	33%	35%	37%	39%	42%	~~45%~~
Gas turbine systems[6]	28%	32%	34%	35%	37%	40%	~~42%~~
Small boiler/steam/turbine system[7]	7%	7%	7%	7%	7%	7%	~~N/A%~~

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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.~~Main source for biomass values: IEA Energy Technology Essentials ETE03 <http://www.leonardo-energy.org/sites/leonardo-energy/files/root/pdf/2008/essentials3%20-%20Biomass%20Power%20Gen.pdf>~~.

[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

Version	*Date*	*Description*
03.0	9 October 2019	MP 80, Annex 10 A call for input will be issued for this draft document. Revision to update the default efficiency factor values for thermal energy and electrical energy generating equipment.
02.0	27 November 2015	EB 87, Annex 11 Revision to: • Expand the tool to include cogeneration; • Include default values for cogeneration and biomass technologies.
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