Draft approved baseline and monitoring methodology AM00XX

"Energy efficiency improvements of a power plant through retrofitting turbines"

I. SOURCE, DEFINITIONS AND APPLICABILITY

Sources

This baseline and monitoring methodology is based on the following project activity "Energy efficiency improvements of Pucheng Power Plant through retrofitting turbines in China", proposed by China Huadian Corporation, China, whose baseline and monitoring methodology and project design document were prepared by Mitsubishi Research Institute Inc., Japan.

For more information regarding the proposal and its consideration by the Executive Board please refer to case NM0203-rev: "Energy efficiency improvements of a power plant through retrofitting turbines" on http://cdm.unfccc.int/methodologies/PAmethodologies/approved.html

This methodology also refers to the latest approved versions of the following tools:

- Tool to calculate project or leakage CO_2 emissions from fossil fuel combustion;
- Combined tool to identify the baseline scenario and demonstrate additionality; and
- Tool to calculate emission factor for an electricity system.

For more information regarding the proposed new methodologies and the tools as well as their consideration by the Executive Board please refer to http://cdm.unfccc.int/goto/MPappmeth.

Selected approach from paragraph 48 of the CDM modalities and procedures

"Existing actual or historical emissions, as applicable"

Definitions

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

Grid/project electricity system is defined by the spatial extent of the power plants that are physically connected through transmission and distribution lines to the project activity (e.g. the power plant location or the consumers where electricity is being saved) and that can be dispatched without significant transmission constraints, as defined in "Tool to calculate emission factor for an electricity system";

Project activity turbine (PAT). The turbine[1], that is retrofitted under the project activity. There can be more than turbines retrofitted, which can be eligible as CDM project activities under this methodology, subjected to criteria as mentioned in the third applicability condition.

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[1] In case of multi-cylinder steam turbine including high pressure, medium pressure and low-pressure stage cylinders, the PAT covers the entire turbine system, which includes all the cylinders.

Applicability

The methodology is applicable to project activities where steam turbines and gas turbines are retrofitted with component(s) of improved design for energy efficiency improvements in an existing fossil fuel power plant.

The methodology is only applicable if all the following conditions are met:

1. The electricity is generated using fossil fuels;[2] no biomass or waste heat is used;
2. The power plant where the project activity is applied supplies electricity to a grid only;
3. In case of steam turbines, the steam supply and electricity generation should be separately measureable for each turbine retrofitted under the project activity;
4. Activities covered under the following two categories are not eligible as CDM activity under this methodology:

    (a)   All the recommended regular or preventive maintenance activities (including replacements and overhauling) as provided by the manufacturer of turbine;[3]
    (b)   A superior practice of preventive maintenance e.g. sophisticated cleaning systems, resulting into an improved efficiency compared to historical efficiency after maintenance;

5. Project activities are only eligible when:

    (a)   The operational parameters of turbines, that affect the energy efficiency of turbine, remain the same (subject to a variation of +/-5%) in the baseline and the project scenario (e.g. steam pressure and temperature, quality of steam in the case of a saturated steam turbine; condenser vacuum, and combustion temperature for gas turbine)[4];
    (b)   The project activity does not increase the lifetime of the existing turbine during the crediting period (i.e. this methodology is applicable up to the end of the lifetime of the existing turbine, if shorter than crediting period);

6. Where applicability conditions of the latest version of Board approved "Tool to calculate emission factor for an electricity system" apply.

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[2] This methodology is not applicable for turbines used in renewable energy power plants, as a different approach is required for the emission reduction calculations of these turbines as compared to the procedure provided in this methodology.

[3] 'Regular maintenance' of turbines in this methodology mainly refers to preventive maintenance activities conducted intensively during a certain period. Regular maintenance activities include daily inspections and repair of the equipment. Examples of periodic (e.g. every four years) inspections of turbines included in 'regular maintenance' are listed below:
  - Cleaning of turbine rotor blades, removal of scales, cleaning of casing;
  - Inside cleaning of oil tanks;
  - Cleaning and replacement for turbine oil filter;
  - Declination measurement of shaft, measurement for horizontal flange level;
  - Bolt adjustment, gap measurement for bearings and valve shafts;
  - Detailed check for major valves, check for speed governing device;
  - Check for gear and bearings of turning devices;
  - Decomposition of turbine lubrication oil device.

[4] The validating/verifying DOE shall confirm that key operational parameters in project activity are in the same range as in the baseline.

The methodology is not applicable:

- To project activities that involve fuel switch;
- To combined cycle power plants, cogeneration plants, or the power plant that is part of an industry and a portion of the electricity is used to meet the internal demand of the industry.[5]

Finally, this methodology is only applicable if the application of the procedure to identify the baseline scenario provides the results that the continuation of the current practice is the most plausible baseline scenario.

II. BASELINE METHODOLOGY PROCEDURE

Project boundary

The spatial extent of the project boundary, in the power plant where the project activity is implemented, includes:

- For steam turbine(s), the turbine(s) that is/are retrofitted and directly connected to an electric generator (turbo-generator), boiler and condenser;
- For gas turbine(s), the turbine that is retrofitted and directly connected to an electric generator (turbo-generator), that consists of turbine, compressor, combustor and generator.

The project boundary also includes the electricity system to which the CDM project is connected as per the "Tool to calculate emission factor for an electricity system".

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[5] The applicability is restricted because the methodology does not have procedures to account emissions reductions for situations where the ratio of electricity supplied to industry by turbine to the total electricity generated by turbine of electricity generated by industry power plant changes between the baseline and the project activity. Though, if it can be clearly demonstrated that the electricity generated by industrial power generation turbine, where proposed project activity is implemented, is exported only to a grid then the methodology is applicable. In such cases it also needs to be demonstrated that the electricity system associated with such power generation turbine and its connection to grid is historically completely isolated from other turbines and electricity system, which supply part or full electricity to industrial processes. The isolation of the turbine is maintained over the crediting period.

The conceptual diagram of the project boundary for the case of a steam turbine and gas turbine is shown separately in Figure 1.
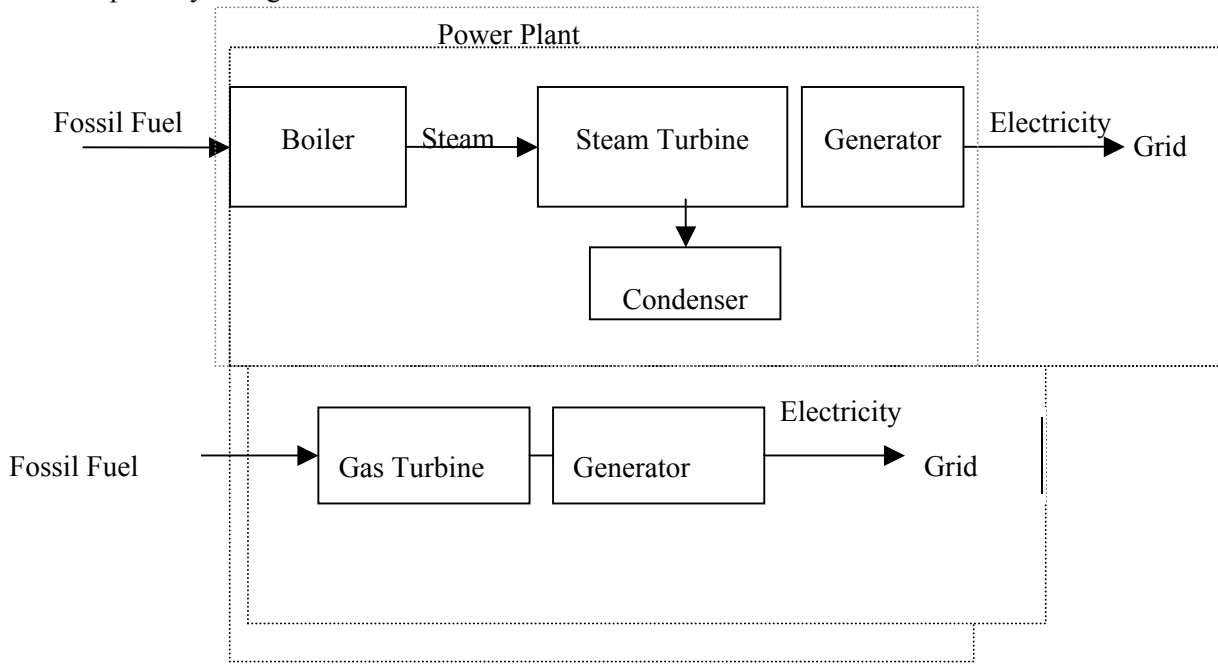

Figure 1: Conceptual diagram of the project boundary for steam turbine and gas turbine

The greenhouse gases included in or excluded from the project boundary are shown in Table 1.

Table 1:   Emissions sources included in or excluded from the project boundary

Source		Gas	Included?	Justification / Explanation
Baseline	Grid electricity generation	CO_2	Yes	Main emission source.
		CH_4	No	Excluded for simplification. This is conservative.
		N_2O	No	Excluded for simplification. This is conservative.
	On-site fossil fuel consumption to operate the power plant.	CO_2	Yes	An important emission source.
		CH_4	No	Excluded for simplification. This emission source is assumed to be very small.
		N_2O	No	Excluded for simplification. This emission source is assumed to be very small.
Project activity	On-site fossil fuel consumption to operate the power plant.	CO_2	Yes	An important emission source.
		CH_4	No	Excluded for simplification. This emission source is assumed to be very small.
		N_2O	No	Excluded for simplification. This emission source is assumed to be very small.

Procedure for estimating lifetime of the turbine(s)

In order to estimate the remaining lifetime or the time when the existing turbine would need to be replaced in the absence of the project activity, project participants shall take the following approaches:

a) The typical average technical lifetime of the type of equipment shall be determined and documented in the CDM-PDD, taking into account common practices in the sector and country, e.g. based on industry surveys, statistics, technical literature, etc.;
b) The practices of the responsible company regarding replacement schedules shall be evaluated and documented in the CDM-PDD, e.g. based on historical replacement records for similar equipment.

Specially for gas turbines, the different lifetimes of the different parts of the turbine should be defferentiated, considering any scheduled part replacement program from the manufacturer.

The point in time when the existing equipment would need replacement in the absence of the project activity should be chosen in a conservative manner, i.e. the earliest point in time should be chosen in cases where only a time frame can be estimated or where some parts of the turbine have a shorter lifetime than the other parts, and should be documented in the CDM-PDD.

The emission reductions can be claimed for the minimum period between the crediting period and the lifetime of the turbine.

Procedure for the identification of the most plausible baseline scenario and the demonstration of additionality

The selection of the most plausible baseline scenario shall be performed in accordance with the latest approved version of the *"Combined tool to identify the baseline scenario and to demonstrate additionality"*. The section below provides additional information to that provided in the tool for using the tool.

Step 1: Further guidance on identification of alternative scenarios

The tool requires identification of all other plausible and credible alternative scenarios to the project activity scenario, including the common practices in the power sector that deliver electricity with comparable quality, properties and application areas. Provide common practices of maintenance, repair and retrofit of turbines in the CDM-PDD, that have been implemented previously or are currently being applied in the relevant geographical areas (defined by the grid as in the Tool to calculate emission factor for an electricity system) taking into account the characteristics (size, technology, age) of power plants by documentation taking into account maintenance and repair records, updated information by turbine manufacturers, literature, and policy direction.

All identified scenarios should be technically feasible alternatives to provide the amount of electricity generated by the project activity throughout the crediting period. For example, if it is not possible to provide sufficient electricity with the continuation of the current practice or if the current practice is too unreliable to be continued, it cannot be considered a credible alternative scenario.

The alternative baseline scenarios, which should be considered, include inter alia:

- Continuation of the current practice – the turbine continues to be operated without retrofitting;
- Turbine retrofit project activity is implemented without CDM;
- Part of turbine retrofit project activity is implemented without CDM;
- Turbine retrofit project activity (or part thereof) is implemented without CDM at a later point in time when technology is more common practice or other barriers are removed;
- A new turbine (either steam turbine, open cycle or combined cycle turbine) with a higher efficiency is installed to replace the existing turbine;
- Other retrofit activities that could result in increase in electricity generation.

Step2: Investment analysis

When making an investment analysis, the increase in power generation of the retrofitted system compared to the baseline system has to be taken into account when calculating cash flows.

Step 3: Further guidance on common practice analysis

Analyze power plants with the similar characteristics with respect to size (within 50% of nameplate capacity), technology (steam turbine or gas turbine), age (within similar plant is max. 10 years older or younger) to cover electricity supplied in the relevant geographical area as defined by the grid. If the relevant geographical area does not include at least five similar power plants, it has to be expanded to the whole host country. Other registered CDM project activities are not to be included in this analysis. Provide documented evidence and quantitative information in the CDM-PDD.

The methodology is only applicable, if the baseline selection demonstrates that the baseline scenario is the following:

Electricity would be generated by the operation of the power plant without retrofitting the turbine, by grid-connected power plants.

Baseline emissions

Electricity generation in the project activity power plant will displace in the baseline scenario less efficient electricity generation in the project plant and can, in addition, displace electricity in the grid, if the quantity of electricity generation is increased as result of the project activity. The calculation of baseline emissions is therefore based on different emission factors for different quantities of electricity generated. As represented in Figure 2, the following cases are differentiated:
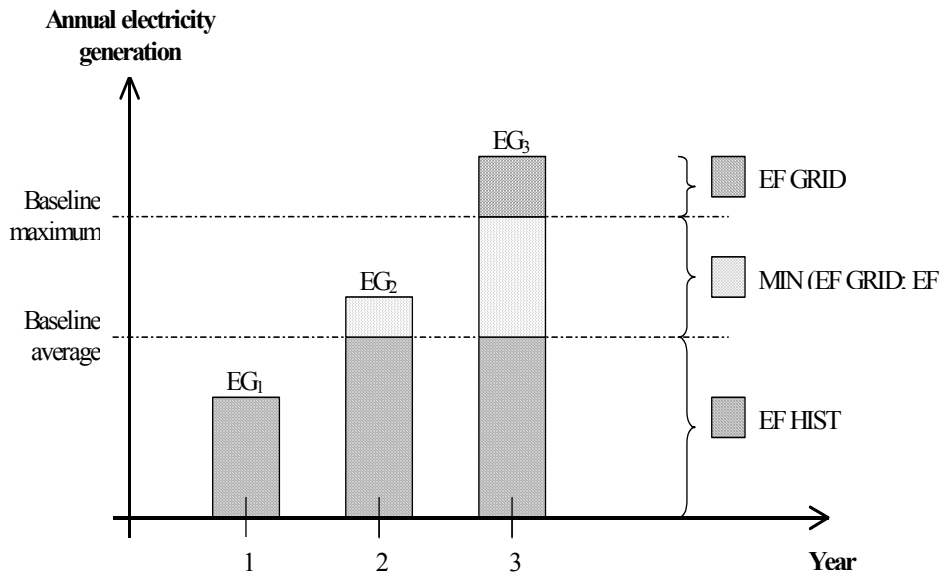
Figure 2: Different emission factors for different quantities of electricity generated.

The baseline emissions for year 'y' (BE_y) are calculated as follows:

Step 1: Determine Baseline Emissions for different scenarios of project electricity generation

Since the project activity turbine provides electricity to the grid, the following cases are differentiated:[6]

Case a)   The quantity of electricity generated in the project activity turbine ($EG_{PJ,y}$) exceeds the maximum annual quantity of electricity that the turbine could have produced prior to the implementation of the project activity (EG_{MAX}). Baseline emissions are calculated as:

$$BE_y = EG_{AVR} \cdot EF_{BL,y} + \left(EG_{MAX} - EG_{AVR}\right) \cdot \min\left(EF_{BL,y}; EF_{grid,y}\right) + \left(EG_{PJ,y} - EG_{MAX}\right) \cdot EF_{grid,y} \tag{1}$$

Case b)   The quantity of electricity generated in the project activity turbine ($EG_{PJ,y}$) exceeds the historic average annual generation level (EG_{AVR}) but is lower than the maximum annual quantity of electricity that the turbine could have produced prior to the implementation of the project activity (EG_{MAX}). Baseline emissions are calculated as:

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[6] If electricity generation in the project activity turbine is increased beyond historical levels after the implementation of the project activity, it is difficult to clearly attribute whether such an increase is the result of the CDM project activity or would have occurred anyhow. If the increase is a result of the project activity, the project activity displaces grid electricity; if it is not a result a of the project activity, the use of fossil fuel in the project activity turbine is displaced. To deal with this uncertainty in this methodology, the lower emission factor between the project activity turbine fired with the baseline fuel and the grid emission factor is used, as a conservative approach.

$$BE_y = EG_{AVR} \cdot EF_{BL,y} + \left(EG_{PJ,y} - EG_{AVR}\right) \cdot \min\left(EF_{BL,y}; EF_{grid,y}\right) \tag{2}$$

Case c) The quantity of electricity generated in the project activity turbine ($EG_{PJ,y}$) is lower or the same as the historic average annual generation level (EG_{AVR}). Baseline emissions are calculated as:

$$BE_y = EG_{PJ,y} \cdot EF_{BL,y} \tag{3}$$

Where:

BE_y = Baseline emissions in year 'y' (tCO_2/yr)

$EG_{PJ,y}$ = Quantity of electricity supplied by the project activity turbine to the grid in year 'y' (MWh/yr), adjusted for changes in efficiency.

EG_{AVR} = Average annual quantity of electricity supplied by the project activity turbine to the grid during the three most recent historical years prior to the implementation of the project activity (MWh/yr)

EG_{MAX} = Maximum annual quantity of electricity that could have been supplied to the the electricity grid by the project activity turbine prior to the implementation of the project activity (MWh/yr)

$EF_{BL,y}$ = Baseline emission factor of the project activity turbine in year y, (tCO_2/MWh)

$EF_{grid,y}$ = Emission factor of the electricity grid to which the project activity turbine is connected (tCO_2/MWh), estimated using "Tool to calculate emission factor for an electricity systems".

Note for above equations: When the project efficiency of turbine $\eta_{PJ,y}$ is above maximum efficiency of turbine $\eta_{PJ,\max}$ (as defined in section III), the adjusted generation of electricity ($EG_{PJ,y,adjusted}$) needs to be used in place of electricity generation ($EG_{PJ,y}$). For the procedure to estimate $EG_{PJ,y,adjusted}$ please refer Step-3 in this section.

<u>*Calculation of EL_{MAX}*</u>

The maximum annual amount of electricity that could have been supplied to the electricity grid by the PAT prior to the implementation of the project activity is calculated as:

$$EG_{MAX} = CAP_{max} \cdot T_{max} \tag{4}$$

Where:

EG_{MAX} = Maximum annual quantity of electricity that could have been supplied to the electricity grid by the project activity turbine prior to the implementation of the project activity (MWh/yr)

CAP_{max} = Maximum power generation capacity of the project activity turbine prior to the implementation of the project activity (MW)

T_{max} = Maximum amount of time in which the project activity turbine could have operated at full load prior to the implementation of the project activity (hours)

Calculation of T_{max}

$$T_{max} = 8,760 - \frac{\sum_{x=1}^{5} HMR_x}{3} \tag{5}$$

Where:

T_{max} Maximum amount of time during a year in which the project activity power plant could have operated prior to the implementation of the project activity (hours).

HMR_x Average number of hours in a year during which the plant did not operate due to maintenance or repair, based on data for the three most recent years x prior to the implementation of the project activity (hours).

Calculation of EL_{AVR}

The average annual amount of electricity supplied to the electricity grid by the PAT prior to the implementation of the project activity is calculated as follows:

$$EG_{AVR} = \frac{\sum_{x=1}^{3} EG_{Tur,x}}{3} \tag{6}$$

Where:

EG_{AVR} = Average annual quantity of electricity supplied by the project activity turbine to the grid during the three most recent historical years prior to the implementation of the project activity (MWh/yr)

$EG_{Tur,,x}$ = Quantity of electricity supplied by the project activity turbine (Project Activity Turbine) to the electricity grid in year x prior to implementation of project activity (MWh/yr)

x = Three most recent historical years prior to the implementation of the project activity

Step 2: Determine Baseline Emission Factor

The emissions factor for the baseline generation in tCO$_2$/MWh is calculated as follows:

Case 1: Emission factor for steam turbine, where fuel is fired in a boiler

$$EF_{BL,y} = \frac{3.6}{1000} \times \frac{EF_{FF,BL} \times HI_{PJ,y}}{\eta_{BL,y} \times FC_{PJ,y}} \tag{7}$$

Case 2: Emission factor for a gas turbine, where fuel is combusted in the turbine itself

$$EF_{BL,y} = \frac{3.6}{1000} \times \frac{EF_{FF,BL}}{\eta_{BL,y}} \tag{8}$$

Where:

$EF_{BL,y}$	=	Baseline emission factor of the project activity turbine in year '*y*', (tCO$_2$/MWh)
$EF_{FF,BL}$	=	CO$_2$ emission factor of the fossil fuel used in the project activity turbine prior to the implementation of the project activity (tCO$_2$/TJ)
$\eta_{BL,y}$	=	Energy efficiency of the turbine without retrofitting estimated using options A, B or C, as described below[7]
$\eta_{PJ,y}$	=	Energy efficiency of the turbine in year '*y*'
$EG_{PJ,y}$	=	Actual electricity generated by project in year '*y*' (MWh)
$FC_{PJ,y}$	=	Actual fuel consumption by project in year '*y*' (MWh)
$HI_{PJ,y}$	=	Heat input to the steam turbine in year '*y*' (MWh). In case of multi-cylinder steam turbines, this is the sum of the heat input at the inlet of first stage and the heat inputs in re-heaters[8] of steam between various cylinders (e.g. high-pressure, medium pressure and low-pressure cylinders).

Option A: Use the turbine baseline load-efficiency function[9]

$$\eta_{BL,y} = \sum_t \frac{(EG_{PJ,t}/\eta_{BL,t})}{\sum_t EG_{PJ,t}} \tag{9}$$

Where:

$\eta_{BL,y}$	=	Energy efficiency of the turbine without retrofitting in year '*y*'
$EG_{PJ,t}$	=	Actual electricity generated in discrete time interval t, by project activity turbine in year '*y*' (MWh)
$\eta_{BL,t}$	=	Energy efficiency of the turbine without retrofitting, at discrete time interval 't', (Use following equation)
t	=	Discrete time interval of 1 hour (if the higher interval value is chosen by project proponents, the selection needs to be justified to DoE.)

Option A1: Establish an efficiency-load-function of the turbine, without retrofit, as defined in Annex I.

$$\eta_{BL,t} = f(\mathrm{EG}_{PJ,t}) + 1.96 \times \mathrm{SE}(\mathrm{f}(\mathrm{EG}_{PJ,t})) \tag{10}$$

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[7] The efficiency of turbine in the project and the baseline implicitly takes into account the efficiency of electricity generation and not break horsepower.

[8] Re-heaters between turbines cylinders are provided for steam conditioning (heating) as per the requirements of next turbine cylinder stage. The heat inputs to re-heaters may be in form of steam, condensate or direct fossil fuel firing. If steam or condensate is used as heat input in the steam re-heater, and the outlet condensate of the re-heater is returned to a boiler for heat recovery, the difference of enthalpy of input steam/ condensate and output condensate should be estimated as input heat.

[9] While determining the efficiency of baseline turbine in accordance with options A1 and A2, the following guidance can be considered for the loads, that are beyond the grid demand and/or its capacity, and the turbine in project scenario is operated on these loads. For the loads beyond the grid demand and/or capacity of baseline turbine, consider the efficiency to be equal to maximum efficiency achieved over the range of loads.

Where:

$EG_{PJ,t}$ = Load of the turbine in discrete time interval '*t*' in year '*y*'

$f(\mathrm{EG}_{PJ,t})$ = Efficiency load function of the turbine, determined through the regression analysis, as described in Annex 1.

$\mathrm{SE}(\mathrm{f}(\mathrm{EG}_{PJ,t}))$ = Standard error of the result of the efficiency-load-function f ($\mathrm{Ld}_{PJ,y}$)

t = Discrete time interval of duration *T hrs* for which the test is conducted

Option A2: Use manufacturer's load-efficiency function for the turbine without retrofit
The load-efficiency function (curve) should clearly show the efficiency of the turbine at various electrical loads. In case, the turbine is retrofitted (before the project activity occurs) in order to enhance the efficiency, the curve supplied by the turbine manufacturer may not match. Therefore a validation of the curve of the previously retrofitted turbine is necessary to show that the actual efficiency of the curve at few selected load points is either equal to or lower than the manufacturer's efficiency. Otherwise, for such retrofitted turbines, step-A1 should be followed.

Option B: Assume a constant efficiency for the baseline turbine and determine the efficiency, as a conservative approach, for optimal operation conditions. Efficiencies shall be determined through measurements based on performance tests as prescribed by international standards, norms and guidelines (ASME PTC 6-1996 or IEC 60953-3 (2001)) or an equivalent international and national standard).

Option C: Use manufacturer's specification of efficiency at optimum load.

Treatment of different fuels being used in the baseline scenario

Note that the most plausible baseline scenario may be that several fuel types would be used in the baseline power plant. As a conservative approach for estimating baseline emission factor where the use of several fuel types is the most plausible baseline scenario, project participants should, select the emission factor of the fuel type with the lowest CO_2 emission factor from the fuels used in the power plant during the most recent three years prior to the implementation of the project activity.

Step 3: Determine the EG_{adjusted}

$$\mathrm{EG}_{PJ,y,adjusted} = \mathrm{EG}_{PJ,y} \times \eta_{PJ,min} / \eta_{PJ,y} \quad \text{If } \eta_{PJ,y} \rangle \eta_{PJ,max} \qquad \textbf{(11)}$$

Where:

$$\eta_{PJ,min} = \min(\eta_{PJ,y-1},.......\eta_{PJ,1}) \qquad \textbf{(12)}$$

$EG_{PJ,y}$ = Quantity of electricity supplied by the project activity turbine to the grid in year '*y*' (MWh)

$EG_{PJ,adjusted,\,y}$ = Adjusted electricity generation in project year for estimation of baseline emissions, if the efficiency of turbine in project year y is above the maximum efficiency,

$\eta_{PJ,max}$ = Maximum project energy efficiency of the turbine at the average load of year y based on load v/s efficiency curve drawn for the project turbine immediately after retrofit, as per the test immediately after the implementation of the project activity.

$\eta_{PJ,min}$ = Minimum project energy efficiency of the turbine observed as per measurement

        =   requirements during the previous years (1 to 'y-1') after the implementation of the project activity

$\eta_{PJ,y-1}$ =   Project energy efficiency of the turbine during the year 'y-1'

Determination of efficiency of project activity turbine $\eta_{PJ,y}$

The efficiency of project activity turbine can be estimated either by using the following equations or in accordance with the recognized standards for the measurement of the turbine efficiency, such as ASME PTC 6 (1996) or IEC 60953-3 (2001). Please refer to the note on efficiency of the project activity turbine in section III.

Case: $\eta_{PJ,y}$ for steam turbines

$$\eta_{PJ,y} = \frac{EG_{PJ,y}}{HI_{PJ,y}} \qquad\qquad\qquad \textbf{(13)}$$

Case: $\eta_{PJ,y}$ for gas turbines

$$\eta_{PJ,y} = \frac{EG_{PJ,y}}{FC_{PJ,y}} \qquad\qquad\qquad \textbf{(14)}$$

Where:

$\eta_{PJ,y}$	=	Energy efficiency of the turbine in year '*y*'
$EG_{PJ,y}$	=	Actual electricity generated by project in year '*y*' (MWh)
$HI_{PJ,y}$	=	Heat input to the steam turbine in year '*y*' (MWh). In case of multi-cylinder steam turbines, this is the sum of the heat input at the inlet of first stage and the heat inputs in re-heaters of steam between various cylinders (e.g. high-pressure, medium pressure and low-pressure cylinders).
$FC_{PJ,y}$	=	Actual fuel consumption by project in year '*y*' (MWh)

Note: In case of a steam turbine where steam generated by boiler(s) is distributed to various users (e.g. turbines) in the plant, follow the guidance provided in section of project emissions.

Step 4: Determine EF_{GRID,y}

The Baseline emission factor for the electricity displaced due to the project activity should be calculated as a combined margin (CM), following the guidance in the approved "*Tool to calculate emission factor for an electricity system*".

Project emissions

The CO_2 emissions from fossil fuel consumption in the project activity (PE_y) should be calculated using the latest approved version of the *"Tool to calculate project or leakage CO_2 emissions from fossil fuel combustion"*, where the process *j* in the tool corresponds to the combustion of fossil fuels in the project activity for electricity generation in the project power plants.

In case of steam turbine, where steam generated by boiler(s) is distributed to various users (e.g. turbines) in the plant, following guidance should be used to determine the proportion of fuel combusted in the boiler for the purpose of supplying steam to the project activity turbine.

The proportion of fuel combusted in the boiler(s) for the purpose of supplying steam to the project activity turbine should be estimated on the basis of the ratio of enthalpy of steam supplied to the project activity turbine to the enthalpy of total steam generated in the boiler(s). Both the steam quantities should be measurable to arrive at a clear estimate of the ratio.

$$FC_{PJ,y} = FC_{Tot,y} \times f_{tur} \tag{15}$$

$$f_{tur} = \frac{HI_{PJ,y}}{HI_{Tot,y}} \tag{16}$$

Where:

$FC_{PJ,y}$ = Actual fuel consumption in boiler(s) towards steam generation for project activity turbine in year '*y*' (MWh),

$HI_{PJ,y}$ = Heat input to the project activity steam turbine in year '*y*' (MWh). In case of multi-cylinder steam turbines, this includes the heat input at the inlet of first stage and the heat inputs in re-heaters of steam between various cylinders (e.g. high-pressure, medium pressure and low-pressure cylinders).

$FC_{Tot,y}$ = Total fuel consumption in boiler(s) in year '*y*' (MWh)

$HI_{Tot,y}$ = Enthalpy of total steam generated by boiler(s) in year '*y*' (MWh)

f_{tur} = Proportion of enthalpy input steam to turbine to the enthalpy of total steam generated by boiler in year '*y*'.

The above guidance requires that:

- Where multiple boilers supply steam into common steam headers, all the boilers have to provide the same quality of steam.
- The calculation should be based on the energy supplied to the steam turbine. The enthalpy and the steam flow rate must be monitored for each boiler to determine the energy content of the steam. The calculation implicitly assumes that the properties of steam (temperature and pressure) generated from different sources are the same. The enthalpy of steam will be determined at measured temperature and pressure and the enthalpy difference will be multiplied with quantity measured by a steamflow meter.

Leakage

No leakage is identified under this methodology.

Emission reductions

Emission reductions are calculated as follows:

$$ER_y = BE_y - PE_y - LE_y \qquad \qquad \textbf{(17)}$$

Where:
ER$_y$ = Emission reductions in year y (t CO_2e/yr)
BE$_y$ = Baseline emissions in year y (t CO_2e/yr)
PE$_y$ = Project emissions in year y (t CO_2/yr)
LE$_y$ = Leakage emissions in year y (t CO_2/yr)

Changes required for methodology implementation in 2nd and 3rd crediting periods

At the start of the second and third crediting period for a project activity, the continued validity of the baseline scenario shall be assessed by applying the procedure to identify the baseline scenario, as outlined above.

Data and parameters not monitored

In addition to the parameters listed in the tables below, the provisions on data and parameters not monitored in the tools referred to in this methodology apply.

Data / parameter:	$EF_{FF,BL}$
Data unit:	tCO$_2$/TJ
Description:	CO$_2$ emission factor of the fossil fuel used in the project activity turbine prior to the implementation of the project activity
Source of data:	Choose the CO$_2$ emission factor corresponding to the applicable fuel type. Use preferably well-documented and reliable regional or national average values. If such data is not available, IPCC default values may be used.
Measurement procedures (if any):	-
Any comment:	Check the note on "Treatment of different fuels, being used in the baseline scenario" in the *baseline emissions* section.

Data / parameter:	CAP$_{max}$
Data unit:	MW
Description:	Maximum power generation capacity of the project activity turbine prior to the implementation of the project activity
Source of data:	Use one of the following options: 1. Installed/rated generation capacity indicated by generation licenses or documented manufacturer's specification, or 2. Maximum generation capacity determined by performance tests under optimal operation conditions (optimal load, after maintenance, etc)
Measurement	1. Generation licenses or manufacturer's specification.

procedures (if any):	2. Using recognized standards for the measurement of the turbine efficiency, such as the ASME PTC 6 (1996) or IEC 60953-3 (2001)
Any comment:	All results of tests have to be documented in the CDM-PDD (including outliers).

Data / parameter	HMR_x
Data Unit	hours
Description	Average hours in which the plant cannot operate due to maintenance or repair in the five most recent years x prior to the implementation of the project activity.
Source of Data	Project activity site.
Measurement procedures (if any)	Use historical records for such maintenance and repair intervals.
Any comment	-

Data / parameter:	$EG_{Tur,x}$
Data unit:	MWh/yr
Description:	Quantity of electricity generated by the project activity turbine (Project Activity Turbine) to the electricity grid in year x prior to implementation of project activity
Source of data:	Generation records, power delivery invoices
Measurement procedures (if any):	
Any comment:	Under the baseline emissions section procedure an average is estimated for the of historical electricity supplied by the project to the grid in three most recent calendar years prior to the implementation of the project activity.

Data / parameter:	$\eta_{PJ,max}$
Data unit:	-
Description:	Load v/s Energy efficiency curve of the turbine immediately after retrofitting
Source of data:	Performance tests for range of loads at commissioning.
Measurement procedures (if any):	Use recognized standards for the measurement of the turbine efficiency, such as the ASME PTC 6 (1996) or IEC 60953-3 (2001). Best practices for operation of turbines should be followed. The measurement should be supervised by a competent independent third party (e.g. the DOE). The measurement should be conducted immediately after turbine retrofit project has been implemented and under good operation conditions. Document the measurement procedures and results (i.e. efficiency at different load levels, application of the regression analysis) transparently in the CDM-PDD.
Any comment:	All results of measurements have to be documented in the CDM-PDD (including outliers). The load v/s efficiency curve too should be provided in the CDM-PDD.

Data / parameter:	$\eta_{BL,y}$
Data unit:	-
Description:	Energy efficiency of the turbine without retrofitting in year 'y'
Source of data:	Performance tests, regression analysis
Measurement procedures (if any):	Establish an efficiency-load-function for the turbine ($\eta_{BL,t} = f(EG_{PJ,t})$) without retrofitting turbines through on-site measurements. *t* represents the discrete time intervals in which measurements are recorded. Use recognized standards for the measurement of the turbine efficiency, such as the ASME PTC 6 (1996) or IEC 60953-3 (2001). Following points should be taken into consideration while carrying out the performance test. 1. For a steam turbine, the test should be carried out under ambient conditions when the cooling tower supplying water to condenser provides the coolest water. This is because; the vacuum generated under such conditions will be highest and therefore will provide optimal baseline efficiency. These conditions will pertain to best combination of ambient dry bulb and wet bulb temperatures. Generally the best conditions for operation of a cooling tower are achieved on the coldest days of the winter season. 2. For a gas turbine, the inlet air temperature should be representative of optimal efficiency of turbine. For example, the most optimal conditions for the efficiency of a turbine are in the hottest days of summer. 3. Best practices for operation of turbines should be followed. 4. The measurement should be supervised by a competent independent third party (e.g. the DOE). 5. The measurement should be conducted immediately after scheduled preventive maintenance has been undertaken and under good operation conditions. During the measurement campaign, the load is varied over the whole operation range and the efficiency of the turbine is measured for different steady-state load factors. The efficiency should be measured for different load factors at a suitable interval covering the operation range. Apply a regression analysis to the measured efficiency for different load factors. Calculate the standard deviation of the regression as given in Annex-1. Document the measurement procedures and all results (i.e. efficiency at different load levels, application of the regression analysis) transparently in the CDM-PDD or, if undertaken during the crediting period, in the monitoring report.
Any comment:	Measurements should be undertaken; ・ Before the start of the project activity; ・ At the renewal of a crediting period. All results of measurements have to be documented in the CDM-PDD (including outliers).

III.   MONITORING METHODOLOGY

All data collected as part of monitoring should be archived electronically and be kept at least for 2 years after the end of the last crediting period. 100% of the data should be monitored if not indicated otherwise in the tables below. All measurements should be conducted with calibrated measurement equipment according to relevant industry standards.

In addition, the monitoring provisions in the tools referred to in this methodology apply.

Determining the efficiency of the project activity turbine

The efficiency ($\eta_{PJ,y}$) of turbine in crediting period should be calculated once in a year as per equation nos. 10 or 11, provided in baseline emissions section. If efficiency gains due to further retrofits or replacement or superior preventive maintenance activities exceed maximum efficiency ($\eta_{PJ,max}$) for a particular year, the emission reductions for that year can be claimed only based on the minimum project efficiency of the turbine after implementation of project activity, as per the procedure described in formulae 10 and 11.

Data and parameters monitored

Data / parameter:	$EG_{PJ,y}$
Data unit:	MWh
Description:	Quantity of electricity supplied by the project activity turbine to the grid in year '*y*'
Source of data:	Measurements by project participants
Measurement procedures (if any):	Electricity meters
Monitoring frequency:	Continuously
QA/QC procedures:	The metered net electricity generation should be cross-checked with receipts from sales. The electricity meter should be calibrated at appropriate intervals.
Any comment:	Ensure that $EG_{PJ,y}$ is the net electricity generation (the gross generation by the project plant minus all auxiliary electricity consumption of the plant)

Data / parameter:	$EF_{grid,y}$
Data unit:	
Description:	Emission factor of the electricity grid to which the project activity turbine is connected (tCO_2/MWh)
Source of data:	Power suppliers, government monitoring agency, technical audit data
Measurement procedures (if any):	$EF_{grid,y}$ is estimated as combined margin emission factor using the latest approved version of the "Tool to calculate the emission factor for an electricity system".
Monitoring frequency:	Yearly
QA/QC procedures:	Data from authentic sources should only be collected.
Any comment:	

Data / Parameter:	$FC_{PJ,y}$
Data unit:	MWh
Description:	Actual fuel consumption towards electricity generation in project activity turbine in year '*y*' (MWh), Following point should be noted in this regard; - For a gas turbine, fuel is directly consumed in turbine - For a steam turbine, fuel is consumed in boiler(s)
Source of data:	Fuel measurement device (fuel meter, etc.)
Measurement procedures (if any):	Direct measurements
Monitoring frequency:	Continuously
QA/QC procedures:	The consistency of monitored fuel consumption quantities should be crosschecked by applying an annual energy balance that is based on purchased quantities and stock changes. Where the purchased fuel invoices can be identified specifically for the CDM project, the metered fuel consumption quantities should also be crosschecked with available purchase invoices from the financial records.
Any comment:	The quantity of fossil fuel combusted should be collected separately for all types of fossil fuels used in the project power plant.

Data / Parameter:	$HI_{PJ,y}$
Data unit:	MWh
Description:	Heat input to the steam turbine in year '*y*'. In case of multi-cylinder steam turbines, this includes the heat input at the inlet of first stage and the heat inputs in re-heaters of steam between various cylinders (e.g. high-pressure, medium pressure and low-pressure cylinders).
Source of data:	Plant records for flow and properties of steam, steam tables for enthalpy of steam.
Measurement procedures (if any):	The steamflow at the turbine inlet should be measured. If a by-pass is provided and steamflow is measured before the by-pass, the by-pass steam should be measured separately and deducted from the metered quantity of steam supplied to turbine in year y. In case of multi-cylinder turbines, the heat input will also include the heat supplied to the re-heaters. The heat inputs to re-heaters may be in form of steam, condensate or direct fossil fuel firing. If steam or condensate is used as heat input in the steam re-heater, and the outlet condensate of the re-heater is sent back to the boiler for heat recovery, the difference of enthalpy of input steam/ condensate and output condensate should also be estimated as input heat. The enthalpy of steam should be determined using steam tables.
Monitoring frequency:	Measured continuously, aggregated yearly
QA/QC procedures:	Steam meter should have required pressure temperature calibration. The calibration should be performed at suitable time intervals.
Any comment:	

Data / Parameter:	$HI_{Tot,y}$
Data unit:	MWh
Description:	Enthalpy of total steam generated by boiler(s) in year '*y*' (MWh)
Source of data:	Plant records for flow and properties of steam, steam tables for enthalpy of steam.
Measurement procedures (if any):	The flow of steam generated by boiler should be measured. The enthalpy of steam should be determined using steam tables.
Monitoring frequency:	Measured continuously, aggregated yearly.
QA/QC procedures:	Steam meter should have required pressure temperature calibration. The calibration should be performed at suitable time intervals.
Any comment:	

IV. REFERENCES AND ANY OTHER INFORMATION

Annex 1: Procedure for estimating efficiency (baseline efficiency-load function)

Efficiencies shall be determined through measurements based on performance tests as prescribed by international standards, norms and guidelines (ASME PTC 6-1996 or an equivalent international and national standard). The performance tests shall be conducted for a range of loads that is representative of the situation during the project activity. Based on the data collected from the efficiency determination tests at different loads, the following equation is estimated through regression analysis:

$$\eta_{BL,t} = f(\text{EG}_{\text{PJ,t}}) + 1.96 \times \text{SE}(f(\text{EG}_{\text{PJ,t}})) \tag{1}$$

Where:

$EG_{Pj,,t}$	=	Load of the turbine in discrete time interval t in year y
$f(\text{EG}_{\text{PJ,t}})$	=	Efficiency load function of the turbine, determined through the regression analysis, as described in Annex 1.
$\text{SE}(f(\text{EG}_{\text{PJ,t}}))$	=	Standard error of the result of the efficiency-load-function f(Ld$_{\text{PJ,y}}$)
t	=	Discrete time interval of duration T *hrs* for which the test is conducted

Each time interval t should have the same duration T. In choosing the duration T, the typical load variation of the turbine should be taken into account.

The load is estimated as per above equation for each time period t. The efficiency-load-function should be derived by applying a regression analysis to all measurements t within a range of load factor (or operation mode) that is representative of the situation during the project activity. Where a representative load factor (or operation mode) cannot be determined, measurements should be conducted for different load factors (or operation modes) and be weighted by the time these load factors (or operation modes) are typically operated. Measurements should be carried out following national or international standards. It is recommended that project participants apply standard software to apply the regression analysis. More details on the procedure to measure the efficiency at different loads are provided in the monitoring methodology. Each measurement t delivers a data pair of electricity generation (EG$_t$) and efficiency of the turbine (η_t). Project participants should choose an appropriate regression equation to apply to the measurement results. For example, in case of a polynomial function, the following regression equation would be applied:

$$n_t = f(EG_{PJ,t}) = a + b_1 EG_t + b_2(EG_{PJ,t})^2 + \ldots\ldots + b_n(EG_{PJ,t})^n \tag{2}$$

Where:

$(\eta_t, \text{EG}_{\text{PJ,t}})$	=	Pair of data recorded from measurement t at a defined load factor
η_t	=	Efficiency of the turbine at measurement x
$\text{EG}_{\text{PJ,t}}$	=	Load of the power plant during the time length T at the measurement t (fraction)
t	=	Measurements undertaken at defined load factors
a, b$_1$, b$_2$,…, b$_n$	=	Parameters of the regression equation estimated using the regression analysis

In order to ensure that the results of the regression analysis are conservative, the baseline efficiency is adjusted for the upper bound of uncertainty of the result of efficiency-load-function at a 95% confidence level by introducing the standard error $\text{SE}(f(\text{EG}_{\text{PJ,t}}))$ in equation (1) above. The standard error

$SE(f(EG_{PJ,t}))$ has to be determined for each time interval t. It is recommended that project participants use the standard software to determine the standard error $SE(f(EG_{PJ,t}))$.

In case of a linear regression equation, i.e. if n=1 in equation (7) above, the standard error can be determined as follows:

$$SE\left(f\left(EG_{PJ,t}\right)\right) = \sigma * \sqrt{\left(1 + \frac{1}{N_x} + \frac{\left(EG_{PJ,t} - EG\right)^2}{\sum\limits_{x=1}^{N_x}\left(EG_x - EG\right)^2}\right)} \tag{3}$$

with

$$\sigma = \frac{1}{N_x - 2} * \sqrt{\left(1 - R^2\right) * \left[\sum\limits_{x=1}^{N_x}\left(\eta_x - \eta\right)^2\right]} \quad \text{and} \tag{4}$$

and

$$EG = \frac{\sum\limits_{x=1}^{N_x} EG_x}{N_x} \quad \text{and} \tag{5}$$

$$R = \frac{b_1^2 * \sum\limits_{x=1}^{N_x}\left(EG_x - EG\right)}{\sum\limits_{x=1}^{N_x}\left(\eta_x - \eta\right)} \tag{6}$$

Where:

$SE(f(EG_{PJ,t}))$	=	Standard error of the result of the efficiency-load-function $f(EG_{PJ,t})$ for time interval t
$f(EG_{PJ,t})$	=	Efficiency load function of the turbine, determined through the regression analysis
σ	=	Standard error of the regression equation
$EG_{PJ,t}$	=	Electricity generated by the power plant during the time interval t (MWh)
EG_x	=	Quantity of electricity generated by the power plant during the time length T at the measurement x (MWh)
EG	=	Mean electricity generation by the power plant during the time length T of all measurements x (MWh)
(η_x, EG_x)	=	Pair of data recorded from measurement x at a defined load factor
η_x	=	Efficiency of the turbine at measurement x
η	=	Mean efficiency of the turbine of all measurements x
R	=	Adjusted R square
x	=	Measurements undertaken at defined load factors
N_x	=	Number of measurements x undertaken to establish the efficiency-load function
t	=	Discrete time interval of duration T during the year y
T	=	Duration of the discrete time intervals t (h)

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