JCM Proposed Methodology Form

Cover sheet of the Proposed Methodology Form

Form for submitting the proposed methodology

Host Country	Republic of Indonesia
Name of the methodology proponents submitting this form	Yokogawa Electric Corporation
Sectoral scope(s) to which the Proposed Methodology applies	3. Energy demand
Title of the proposed methodology, and version number	GHG emission reductions through optimization of refinery plant operation in Indonesia, version 1.0
List of documents to be attached to this form (please check):	☐The attached draft JCM-PDD: ☒Additional information
Date of completion	08/10/2014

History of the proposed methodology

Version	Date	Contents revised
1.0	08/10/2014	First edition

A. Title of the methodology

GHG emission reductions through optimization of refinery plant operation in Indonesia, version 1.0

B. Terms and definitions

Terms	Definitions
Distributed Control System (DCS)	An IT system used to control the production line in an industry. DCS refers to decentralized elements or subsystems to control distributed processes or complete manufacturing systems, where each section of a process has its own computerized system that controls the operation and is different from a centrally located device controlling all process or systems. The entire system of controllers is connected by network for communication and monitoring.
Advanced Process Control (APC)	An IT system incorporating statistical analysis, decision theory, engineering, signal processing and artificial intelligence. APC is typically used to either refine process control or address a specific issue associated with a process, by connecting to a DCS and providing direction of operation. Key systems referred as APC are: ✓ Dynamic linear process model identifier consisting of combination of following technologies: ・Multi-variable Statistical Analysis ・Finite Impulse Response ・Parametric Model ・Step Response ・Linear Dynamic Model Identifier ✓ Control performance diagnosis equipment ✓ Multi-variable model based predictive controller ✓ Quality estimator Whereas a DCS requires adjustment of the set points manually for each variable by operator, APC automatically controls process for the optimization of production, and/ or energy efficiency when it is activated.

Hydro cracking unit (HCU)	A production unit in an integrated crude oil refinery which produces oil (naphtha, kerosene, diesel) from heavy gas oil and hydrogen.
Hydrogen production unit (HPU)	A production unit in an integrated crude oil refinery which produces hydrogen from natural gas and steam.
Reactor	A production equipment in HCU where heavy gas oil is heated up at pre-heater and heater, then cracked into produced oil by hydrogen and catalyst.
Debutanizer	A production equipment in HCU to remove butane in produced oil by vaporizing the oil at heater (reboiler) and partially condensing the butane at top of the column and flows the remaining butane gas to downstream process by own pressure.
Reformer	A production equipment in HPU to produce hydrogen from natural gas and steam by heating and reacting.

C. Summary of the methodology

Items	Summary
GHG emission reduction measures	Introduction of plant optimization control systems (APC) that reduce energy consumption in the hydrogen production unit (HPU) and hydro cracking unit (HCU) at a refinery plant.
Calculation of reference emissions	Reference emissions are calculated on the basis of historical specific emission per feed (or production volume) and the feed input (or production volume) in the project case. Historical specific emission per feed (or production volume) is determined on the basis of the fuel consumption and feed input (or production volume) to HPU and HCU during a historical period before implementation of project.
Calculation of project emissions	Project emissions are calculated on the basis of monitored fuel consumption at HPU and HCU.
Monitoring parameters	Quantity of feed input (or production volume) to the process unit, fuel consumption, and hydrogen consumption at the process unit.

D. Eligibility criteria

This methodology is applicable to projects that satisfy all of the following criteria.

<table>
<tr><td>Criterion 1</td><td>The project introduces APC to existing single or multiple hydrogen production unit (HPU) or hydro cracking unit (HCU) at a refinery plant. APC serves one or more of the following functions:

<table>
<tr><th></th><th>Location of installation</th><th>Location of emission reduction</th><th>Mechanism of emission reduction</th></tr>
<tr><td>A</td><td>HCU</td><td>HCU</td><td>Reduction in heater fuel consumption due to increased reactor column temperature</td></tr>
<tr><td>B</td><td>HCU</td><td>HCU</td><td>Reduction in reboiler fuel consumption in debutanizers due to reduced variability of column top pressure and lower the pressure</td></tr>
<tr><td>C</td><td>HCU</td><td>HPU</td><td>Reduction in fuel consumption in HPU due to reduced hydrogen demand in HCU</td></tr>
<tr><td>D</td><td>HPU</td><td>HPU</td><td>Improved efficiency of hydrogen production in HPU</td></tr>
</table>
</td></tr>
<tr><td>Criterion 2</td><td>The process unit where APC is introduced has been equipped with DCS in operation before the start of project.</td></tr>
<tr><td>Criterion 3</td><td>Retrofit and replacement of the process units, cleaning of heat exchangers and/or columns which are performed during a turnaround beyond the regular or preventive maintenance activities are not taken place at the process unit where APC is introduced (this criterion is checked upon each instance of verification, and credit will be issued only up to the date of such retrofit). Regular maintenance refers to preventive maintenance activities include daily inspections and lubrication of rotating equipment.</td></tr>
<tr><td>Criterion 4</td><td>Feed (or production volume), fossil fuel consumption, and hydrogen consumption at the process unit are acquired, integrated and recorded electrically according to pre-determined time intervals.</td></tr>
</table>

E. Emission Sources and GHG types

Reference emissions	
Emission sources	**GHG types**
Fossil fuel combustion at HPU and HCU	CO_2
Project emissions	
Emission sources	**GHG types**
Fossil fuel combustion at HPU and HCU	CO_2

F. Establishment and calculation of reference emissions

F.1. Establishment of reference emissions

Reference emissions are calculated on the basis of historical specific emission per feed (or production volume), and feed (or production volume) in the project case. Historical specific emission per input is determined on the basis of energy consumption and input to HPU and HCU during a historical period before implementation of the project. If multiple units exist in the refinery for the same target process (i.e. multiple HPU units or HCU units), calculation will be carried out for each unit.

Depending on the location of installation of APC, emission reduction in HPU and HCU can occur as follows:

APC installation location	Emission reduction in HCU	Emission reduction in HPU
HCU (reactor column)	A. Reduction in heater fuel consumption due to increased column temperature. ($RE_{HCU1,p}$ - $PE_{HCU1,p}$)	C. Emission reduction in HPU as a result of reduction in hydrogen demand in HCU ($RE_{HPU1,p}$ - $PE_{HPU1,p}$)
HCU (debutanizer)	B. Reduction of reboiler fuel consumption in debutanizers due to reduced variability of column top pressure and lowering the pressure to the required level. ($RE_{HCU2,p}$ - $PE_{HCU2,p}$)	None
HPU	None	D. Emission reduction in HPU as a result of improved efficiency of hydrogen production. ($RE_{HPU2,p}$ - $PE_{HPU2,p}$)

Therefore, it should be noted that emission reduction in HPU can occur due either to installation of APC in HCU or in HPU. The former is calculated in terms of reduced hydrogen consumption per feed, and the latter due to improved efficiency of hydrogen production.

Ensuring net emission reduction

The methodology assures net reduction by not taking into account for reduction in consumption of electricity and steam from outside the process (on-site generators and boilers) which occurs as a result of process optimization due to implementation of the project. Furthermore, CO_2 emission from chemical reaction in HPU is also reduced due to reduction in hydrogen demand in HCU, but this is not taken into account, leading to additional conservativeness.

F.2. Calculation of reference emissions

Reference emissions are calculated as per one of the following options.

- Options A1, B1, C1, and D1: reference emissions are calculated using historical three-year data.
- Options A2, B2, C2, and D2: reference emissions are calculated using data of thirty consecutive operating days taken not more than one year after turnaround, for reasons of conservativeness. Such data can be obtained from historical records or from a campaign.

Options A1, B1, C1 and D1 are the preferred approach.

1. Installation of APC in HCU

Emission reduction due to installation of APC in HCU can be divided into a) emission reduction at reactor in HCU from reduction in fuel consumption, b) emission reduction at debutanizer in HCU, and c) emission reduction at reformer in HPU from reduction in hydrogen consumption in HCU. Therefore, reference emission can be divided accordingly, as follows:

A. Reference emissions to calculate emission reduction in HCU as a result of reduction in heater fuel consumption due to increased reactor column temperature ($RE_{HCU1,p}$)

Option A1: Where data on daily feed input and fossil fuel consumption for the historical three-year period is available.

Step A1-1: Obtain data on daily feed input to reactor in HCU (FI_{HCURd}) and fossil fuel consumption in HCU reactor heater ($FC_{HCUR,i,d}$) for the three years preceding introduction of APC or (if APC is not yet introduced) three years up to the period not earlier than 6 months before submission of the draft PDD. Convert $FC_{HCUR,i,d}$ into energy consumption $EC_{HCUR,d}$ by multiplying by net calorific value of fossil fuel type $_i$ (NCV_i), as follows:

$$EC_{HCUR,d} = \sum_i (FC_{HCUR,i,d} \times NCV_i) \quad (1)$$

Where

EC_{HCURd}	=	Energy consumption of fuel *i* on day d during the historical three-year period in HCU reactor heater. [GJ]
$FC_{HCUR,i,d}$	=	Daily consumption of fossil fuel type *i* on day *d* during the historical three-year period in HCU reactor heater. [mass or volume unit]
NCV_i	=	Net calorific value of fossil fuel type *i*. [GJ/mass or volume unit]

Step A1-2: Plot the data with daily feed input in day *d* during the historical period (FI_{HCURd}: mass or volume unit) on the *x*-axis and $EC_{HCUR,d}$ on the *y*-axis. Omit data obtained during periods of startup, shutdown, maintenance (defined as periods where daily consumption of feed input is less than 50% of its daily rated capacity), or malfunction of equipment or measurement device.

Perform a linear regression analysis with non-negative *y*-intercept. If the regression coefficient R^2 of the plotted data is smaller than 0.49 or the *y*-intercept is negative, omit statistical outliers with a plot outside 2 times the standard deviation from the regression line.

Repeat the process until the R^2 of the plotted data is larger than 0.49 and until the *y*-intercept is not negative. Perform a linear regression analysis with the remaining data with a non-negative *y*-intercept to derive a linear regression equation $y = ax + b$ where variable *y* is the energy consumption of the process (in GJ), variable *x* is the daily feed input (tonnes or other appropriate mass or volume unit), and variable *a* is the specific energy consumption of process per feed. If the R^2 of the plotted data remain lower than 0.49 or the *y*-intercept remains below zero, then the methodology is not applicable.

Step A1-3: Obtain reference emissions by the following equation.

$$RE_{HCU1,p} = EF_{HCUR,p} \times (a \times FI_{HCUR,p} + b) \quad (2)$$

and

$$EF_{HCUR,p} = \frac{\sum_i (FC_{HCUR,i,p} \times NCV_i \times EF_i)}{\sum_i (FC_{HCUR,i,p} \times NCV_i)} \quad (3)$$

Where

$RE_{HCU1,p}$	=	Reference emission to calculate emission reduction in HCU as a result of reduction in fuel consumption due to increased column temperature during a given time period *p*. [tCO_2/p]
a	=	Constant (specific emission factor) obtained by the regression analysis as per step A1-2. [GJ/mass or volume unit]
b	=	Constant (*y*-intercept) obtained by the regression analysis as per step A1-2. [GJ]
$FI_{HCUR,p}$	=	Feed input to HCU reactor during the time period *p*. [mass or volume unit]
$EF_{HCUR,p}$	=	Weighted average CO_2 emission factor of fossil fuel consumed in HCU reactor heater during the time period *p*. [tCO_2/GJ]
$FC_{HCUR,i,p}$	=	Daily consumption of fossil fuel type *i* during the time period *p* in HCU reactor heater. [mass or volume unit]
NCV_i	=	Net calorific value of fossil fuel type *i*. [GJ/mass or volume unit]
EF_i	=	CO_2 emission factor of fossil fuel *i*. [tCO_2/GJ]

During the period *p*, only the days where daily consumption of feed input is more than 50% of its daily rated capacity is eligible.

Option A2: Where data for the historical three-year data cannot be obtained, $RE_{HCU1,p}$ is derived by the following procedure.

Step A2-1: Obtain data on hourly feed input in HCU and fossil fuel consumption in HCU heater without installation of APC for a period of thirty consecutive operating days, taken not more than one year after turnaround. Obtain data on hourly feed input and energy consumption. Conduct a campaign if necessary.

Step A2-2: Derive a linear regression equation using the method described in step A1-2 but using the hourly data during the thirty consecutive operating days obtained in step A2-1.

Step A2-3: Calculate $RE_{HCU1,p}$ using the equation described in step A1-3 but using the regression parameters obtained in step A2-2.

B. Reference emissions to calculate emission reduction in HCU as a result of reduction in reboiler fuel consumption in debutanizers due to reduced variability of column top pressure and lower the pressure ($RE_{HCU2,p}$)

Option B1: Where data on daily feed input to debutanizer and fossil fuel consumption for the historical three-year period is available.

Step B1-1: Obtain data on daily feed input in HCU debutanizer ($FI_{HCUD,d}$) and fossil fuel consumption at debutanizer reboiler in HCU ($FC_{HCUD,i,d}$) for the three years preceding introduction of APC or (if APC is not yet introduced) three years up to the period not earlier than 6 months before submission of the draft PDD. Convert $FC_{HCUD\ i,d}$ into energy consumption $EC_{HCUD,d}$ by multiplying by net calorific value of fossil fuel type $_i$ (NCV_i), as follows:

$$EC_{HCUD,d} = \sum_i (FC_{HCUD,i,d} \times NCV_i) \quad (4)$$

Where

$EC_{HCUD,d}$	=	Energy consumption of fuel *i* on day d during the historical three-year period at HCU debutanizer reboiler. [GJ]
$FC_{HCUD,i,d}$	=	Daily consumption of fossil fuel type *i* on day *d* during the historical three-year period at HCU debutanizer reboiler.[mass or volume unit]
NCV_i	=	Net calorific value of fossil fuel type *i*.[GJ/mass or volume unit]

Step B1-2: Plot the data with daily feed input in day *d* during the historical period ($FI_{HCUD,d}$: mass or volume unit) on the *x*-axis and $EC_{HCUD,d}$ on the *y*-axis. Omit data obtained during periods of startup, shutdown, maintenance (defined as periods where daily consumption of feed input is less than 50% of its daily rated capacity), or malfunction of equipment or measurement device.

Perform a linear regression analysis with non-negative *y*-intercept. If the regression coefficient R^2 of the plotted data is smaller than 0.49 or the *y*-intercept is negative, omit statistical outliers with a plot outside 2 times the standard deviation from the regression line.

Repeat the process until the R^2 of the plotted data is larger than 0.49 and until the *y*-intercept is not negative. Perform a linear regression analysis with the remaining data with a non-negative *y*-intercept to derive a linear regression equation $y = cx + d$ where variable *y* is the energy consumption of the process (in GJ), variable *x* is the daily feed input (tonnes or other appropriate mass or volume unit), and variable *c* is the specific energy consumption of process per feed. If the R^2 of the plotted data remain lower than 0.49 or the *y*-intercept remains below zero, then the methodology is not applicable.

Step B1-3: Obtain reference emissions by the following equation.

$$RE_{HCU2,p} = EF_{HCUD,p} \times (c \times FI_{HCUD,p} + d) \quad (5)$$

and

$$EF_{HCUD,p} = \frac{\sum_i (FC_{HCUD,i,p} \times NCV_i \times EF_i)}{\sum_i (FC_{HCUD,i,p} \times NCV_i)} \quad (6)$$

Where

$RE_{HCU2,p}$	=	Reference emissions to calculate emission reduction in HCU as a result of reduction in reboiler fuel consumption in debutanizers due to reduced variability of column top pressure and lower the pressure during a given time period *p*. [tCO_2/p]
c	=	Constant (specific emission factor) obtained by the regression analysis as per step B1-2. [GJ/mass or volume unit]

d	=	Constant (y-intercept) obtained by the regression analysis as per step B1-2. [GJ]
$FI_{HCUD,p}$	=	Feed input to HCU debutanizer during the time period p. [mass or volume unit]
$EF_{HCUD,p}$	=	Weighted average CO_2 emission factor of fossil fuel consumed in HCU debutanizer reboiler during the time period p. [tCO_2/GJ]
$FC_{HCUDi,p}$	=	Daily consumption of fossil fuel type i during the time period p in HCU debutanizer reboiler. [mass or volume unit]
NCV_i	=	Net calorific value of fossil fuel type i. [GJ/mass or volume unit]
EF_i	=	CO_2 emission factor of fossil fuel i. [tCO_2/GJ]

During the period p, only the days where daily consumption of feed input is more than 50% of its daily rated capacity is eligible.

Option B2: Where data for the historical three-year data cannot be obtained, $RE_{HCU2,p}$ is derived by the following procedure.

Step B2-1: Obtain data on hourly feed input in HCU and fossil fuel consumption in HCU reboiler without installation of APC for a period of thirty consecutive operating days, taken not more than one year after turnaround. Obtain data on hourly feed input and energy consumption. Conduct a campaign if necessary.

Step B2-2: Derive a linear regression equation using the method described in step B1-2 but using the hourly data during the thirty consecutive operating days obtained in step B2-1.

Step B2-3: Obtain reference emissions using the equation described in step B1-3 but using the regression parameters obtained in step B2-2.

C. Reference emissions to calculate emission reduction in HPU as a result of reduction in hydrogen demand in HCU ($RE_{HPU1,p}$)

Option C1: Where data on daily feed input and hydrogen consumption in HCU, hydrogen production and fuel consumption in HPU for the historical three-year period is available.

Step C1-1: Obtain data on daily hydrogen consumption in HCU ($HC_{HCU,d}$), daily feed input in HCU reactor ($FI_{HCUR,d}$), daily hydrogen production at HPU ($HP_{HPU,d}$), fossil fuel consumption in HPU ($FC_{HPU,i,d}$) for the three years preceding introduction of APC or (if APC is not yet introduced) three years up to the period not earlier than 6 months before submission of the draft PDD. Convert $FC_{HPUi,d}$ into energy consumption $EC_{HPU,d}$ by multiplying by net calorific value of fossil fuel type $_i$ (NCV_i), as follows:

$$EC_{HPU,d} = \sum_i (FC_{HPU,i,d} \times NCV_i) \quad (7)$$

Where

EC_{HPUd}	=	Energy consumption of fuel *i* on day *d* during the historical three-year period in HPU reformer heater. [GJ]
$FC_{HPU,i,d}$	=	Daily consumption of fossil fuel type *i* on day *d* during the historical three-year period in HPU reformer heater. [mass or volume unit]
NCV_i	=	Net calorific value of fossil fuel type *i*. [GJ/mass or volume unit]

Step C1-2: Regression analysis (energy consumption in HPU per hydrogen production)

Plot the data with $HP_{HPU,d}$ (Nm^3) on the *x*-axis and $EC_{HPU,d}$ (GJ) on the *y*-axis. Omit data obtained during periods of startup, shutdown, maintenance (defined as periods where daily consumption of feed input is less than 50% of its daily rated capacity), or malfunction of equipment or measurement device.

Perform a linear regression analysis with non-negative *y*-intercept. If the regression coefficient R^2 of the plotted data is smaller than 0.49 or the *y*-intercept is negative, omit statistical outliers with a plot outside 2 times the standard deviation from the regression line.

Repeat the process until the R^2 of the plotted data is larger than 0.49 and until the *y*-intercept is not negative. Perform a linear regression analysis with the remaining data with a non-negative *y*-intercept to derive a linear regression equation $y = ex + f$ where variable *y* is the $EC_{HPU,d}$ and variable *x* is $HP_{HPU,d}$ (in Nm^3), *e* is the specific energy consumption of process per hydrogen production. If the R^2 of the plotted data remain lower than 0.49 or the *y*-intercept remains below zero, then the methodology is not applicable.

Step C1-3: Regression analysis (hydrogen consumption in HCU per feed input)

Plot the data with $FI_{HCUR,d}$ (mass or volume unit) on the *x*-axis and $H_{HCU,d}$ (Nm^3) on the *y*-axis. Omit data obtained during periods of startup or maintenance (defined as periods where daily consumption of feed input is less than 50% of its daily rated capacity, or malfunction of equipment or measurement device. Perform a linear regression analysis with *y*-intercept. If the regression coefficient R^2 of the plotted data is smaller than 0.49, omit statistical outliers with a plot outside 2 times the standard deviation from the regression line. Repeat the process until the R^2 of the plotted data is larger than 0.49. Perform a linear regression analysis with the remaining data to derive a linear regression equation $y = gx + h$ where variable y is the hydrogen consumption in HCU (in Nm^3), variable x is the daily feed input (tonnes or other appropriate mass or volume unit), g is the specific hydrogen consumption of process per feed. If the R^2 of the plotted data remain lower than 0.49, then the methodology is not applicable.

Step C1-4: Obtain reference emissions by the following equation.

$$RE_{HPU1,p} = EF_{HPU,p} \times \{e \times (g \times FI_{HCUR,p} + h) + f\} \quad (8)$$

and

$$EF_{HPU,p} = \frac{\sum_i (FC_{HPU,i,p} \times NCV_i \times EF_i)}{\sum_i (FC_{HPU,i,p} \times NCV_i)} \quad (9)$$

Where

$RE_{HPU1,p}$	=	Reference emissions to calculate emission reduction in HPU as a result of reduction in hydrogen demand in HCU during a given time period *p*. [tCO_2/p]
e	=	Constant (specific energy consumption per hydrogen production) obtained by the regression analysis as per step C1-2. [GJ/ Nm^3]
f	=	Constant (*y*-intercept) obtained by the regression analysis as per step C1-2. [GJ]
g	=	Constant (specific hydrogen consumption per feed input) obtained by the regression analysis as per step C1-3. [Nm^3/mass or volume unit]
h	=	Constant (*y*-intercept) obtained by the regression analysis as per step C1-3. [Nm^3]
FI_{HCURp}	=	Feed input to HCU reactor during the time period *p*. [mass or volume unit]
$EF_{HPU,p}$	=	Weighted average CO_2 emission factor of fossil fuel consumed in HPU during the time period *p*. [tCO_2/GJ]
$FC_{HPU,I,d}$	=	Daily consumption of fossil fuel type *i* on day *d* during the historical three-year period in HPU. [mass or volume unit]
NCV_i	=	Net calorific value of fossil fuel type *i*. [GJ/mass or volume unit]
EF_i	=	CO_2 emission factor of fossil fuel *i* [tCO_2/GJ]

During the period *p*, only the days where daily consumption of feed input to reactor is more than 50% of its daily rated capacity is eligible.

Option C2: Where data for the historical three-year data cannot be obtained, $RE_{HPU1,p}$ is derived by the following procedure.

Step C2-1: Obtain data on hourly hydrogen consumption in HCU, hourly feed input in HCU reactor, hourly hydrogen production at HPU, fossil fuel consumption in HPU without the introduction of APC for a period of thirty consecutive operating days, taken not more than one year after turnaround. Obtain data on hourly feed input and energy consumption. Conduct a campaign if necessary.

Step C2-2: Regression analysis (energy consumption in HPU per hydrogen production)
Derive a linear regression equation to obtain the parameters e and *f* using the method described in step C1-2, based on the data obtained in step C2-1.

Step C2-3: Regression analysis (hydrogen consumption in HCU per feed input)
Derive a linear regression equation to obtain the parameters *g* and *h* using the method described in step C1-3, based on the data obtained in step C2-1.

Step C2-4: Obtain reference emissions using the equation described in step C1-4 but using the regression parameters obtained in steps C2-2 and C2-3.

2. Installation of APC in HPU

D. Reference emissions to calculate emission reduction in HPU as a result of improved efficiency of hydrogen production ($RE_{HPU2,p}$)

Option D1: Where data on daily hydrogen production and fuel consumption in HPU for the historical three-year period is available.

Step D1-1 : Calculation of specific energy consumption of hydrogen production.
See steps C1-1 and C1-2.

Step D1-2: Calculation of reference emissions to calculate emission reductions in HPU as a result of improved efficiency of hydrogen production.

$$RE_{HPU2,p} = EF_{HPU,p} \times (e \times HP_{HPU,p} + f) \quad (10)$$

And

$$EF_{HPU,p} = \frac{\sum_i (FC_{HPU,i,p} \times NCV_i \times EF_i)}{\sum_i (FC_{HPU,i,p} \times NCV_i)} \quad (11)$$

Where

$RE_{HPU2,p}$	=	Reference emissions to calculate emission reductions in HPU as a result of improved efficiency of hydrogen production. [t-CO_2]
e	=	Constant (specific energy consumption per hydrogen production) obtained by the regression analysis as per step C1-2. [GJ/ Nm^3]
f	=	Constant (y-intercept) obtained by the regression analysis as per step C1-2. [GJ]
$HP_{HPU,p}$	=	Hydrogen production during a given time period p in HPU. [Nm^3]
$EF_{HPU,p}$	=	Weighted average CO_2 emission factor of fossil fuel consumed in HPU during the time period p. [tCO_2/GJ]

During the period p, only the days where daily consumption of feed input to reactor is more than 50% of its daily rated capacity is eligible.

Option D2: Where data for the historical three-year data cannot be obtained, $RE_{HPU2,p}$ is derived by the following procedure.

Step D2-1 : Calculation of specific energy consumption of hydrogen production.

Derive a linear regression equation to obtain the parameters e and f using the method described in step C1-2, based on the data obtained in step C2-1.

Step D2-2: Calculation of reference emissions to calculate emission reductions in HPU as a result of improved efficiency of hydrogen production.

Obtain reference emissions using the equation described in step C1-2 but using the regression parameters obtained in steps D2-1.

G. Calculation of project emissions

Project emissions are calculated as follows:

1. Installation of APC in HCU

A. Project emissions to calculate emission reduction in HCU as a result of reduction in heater fuel consumption due to increased reactor column temperature ($PE_{HCU1,p}$)

$PE_{HCU1,p}$ is calculated as follows:

$$PE_{HCU1,p} = \sum_i (FC_{HCUR,i,p} \times NCV_i \times EF_i) \quad (12)$$

Where

$PE_{HCU1,p}$	=	Project emissions to calculate emission reduction in HCU as a result of reduction in fuel consumption due to increased column temperature during a given time period *p*. [tCO_2/p]
$FC_{HCUR,i,p}$	=	Consumption of fossil fuel *i* in HCU reactor heater during the period *p*. [mass or volume unit]
NCV_i	=	Net calorific value of fossil fuel type *i*.[GJ/mass or volume unit]
EF_i	=	CO_2 emission factor of fossil fuel *i* [tCO_2/GJ]

During the period *p*, only the days where daily consumption of feed input to reactor is more than 50% of its daily rated capacity is eligible.

B. Project emissions to calculate emission reduction in HCU as a result of reduction in reboiler fuel consumption in debutanizers due to reduced variability of column top pressure and lower the pressure ($PE_{HCU2,p}$)

$PE_{HCU2,p}$ is calculated as follows:

$$PE_{HCU2,p} = \sum_i (FC_{HCUD,i,p} \times NCV_i \times EF_i) \quad (13)$$

Where

$PE_{HCU2,p}$	=	Project emissions to calculate emission reduction in HCU as a result of reduction in reboiler fuel consumption in debutanizers due to reduced variability of column top pressure and lower the pressure during a given time period *p*. [tCO_2/p]
$FC_{HCUDi,p}$	=	Daily consumption of fossil fuel type *i* during the time period *p* in HCU debutanizer reboiler. [mass or volume unit]
NCV_i	=	Net calorific value of fossil fuel type *i*. [GJ/mass or volume unit]
EF_i	=	CO_2 emission factor of fossil fuel *i*. [tCO_2/GJ]

During the period *p*, only the days where daily consumption of feed input to debutanizer is more than 50% of its daily rated capacity is eligible.

C. Project emissions to calculate emission reduction in HPU as a result of reduction in hydrogen demand in HCU ($PE_{HPU1,p}$)

$PE_{HPU1,p}$ is calculated as follows:

$$PE_{HPU1,p} = EF_{HPU,p} \times (e \times HC_{HCU,p} + f) \quad (14)$$

Where

$PE_{HPU1,p}$	=	Project emissions to calculate emission reduction in HPU as a result of reduction in hydrogen demand in HCU during a given time period *p*. [tCO_2/p]
e	=	Constant (specific energy consumption per hydrogen production) obtained by the regression analysis as per step C1-2. [GJ/ Nm^3]
f	=	Constant (*y*-intercept) obtained by the regression analysis as per step C1-2. [GJ]
$HC_{HCU,p}$	=	Hydrogen consumption in HCU during a given time period *p*. [Nm^3]
$EF_{HPU,p}$	=	Weighted average CO_2 emission factor of fossil fuel consumed in HPU during the historical three-year period, obtained by the equation in step C1-2. [tCO_2/GJ]

During the period *p*, only the days where daily consumption of feed input to reactor is more than 50% of its daily rated capacity is eligible.

2. Installation of APC in HPU

D. Project emissions to calculate emission reductions in HPU as a result of improved efficiency of hydrogen production ($PE_{HPU2,p}$)

$PE_{HPU2,p}$ is calculated as follows:

$$PE_{HPU2,p} = \sum_i (FC_{HPUi,p} \times NCV_i \times EF_i) \quad (15)$$

Where

$PE_{HPU2,p}$	=	Project emissions to calculate emission reductions in HPU as a result of improved efficiency of hydrogen production during the time period *p*. [tCO_2]
$FC_{HPU,i,p}$	=	Consumption of fossil fuel *i* in HPU during the period *p*. [mass or volume unit]
NCV_i	=	Net calorific value of fossil fuel type *i*. [GJ/mass or volume unit]
EF_i	=	CO_2 emission factor of fossil fuel *i*. [tCO_2/GJ]

During the period *p*, only the days where daily consumption of feed input to reactor is more than 50% of its daily rated capacity is eligible.

H. Calculation of emissions reductions

Emission reductions are calculated as follows:

$$ER_p = (RE_{HCU1,p} - PE_{HCU1p}) + (RE_{HCU2,p} - PE_{HCU2p}) + (RE_{HPU1,p} - PE_{HPU1p}) + (RE_{HPU2,p} - PE_{HPU2p}) \quad (16)$$

Where

ER_p	=	Emission reductions during a given time period *p*. [tCO_2/p]
$RE_{HCU1,p}$	=	Reference emissions to calculate emission reduction in HCU as a result of reduction in fuel consumption due to increased reactor column temperature during a given time period *p*. [tCO_2/p]
$PE_{HCU1,p}$	=	Project emissions to calculate emission reduction in HCU as a result of reduction in fuel consumption due to increased reactor column temperature during a given time period *p*. [tCO_2/p]
$RE_{HCU2,p}$	=	Reference emissions to calculate emission reduction in HCU as a result of reduction in reboiler fuel consumption in debutanizers due to reduced variability of column top pressure and lower the pressure during a given time period *p*. [tCO_2/p]
$PE_{HCU2,p}$	=	Project emissions to calculate emission reduction in HCU as a result of reduction in reboiler fuel consumption in debutanizers due to reduced variability of column top pressure and lower the pressure during a given time period *p*. [tCO_2/p]
$RE_{HPU1,p}$	=	Reference emissions to calculate emission reduction in HPU as a result of reduction in hydrogen demand in HCU during a given time period *p*. [tCO_2/p]
$PE_{HPU1,p}$	=	Project emissions to calculate emission reduction in HPU as a result of reduction in hydrogen demand in HCU during a given time period *p*. [tCO_2/p]
$RE_{HPU2,p}$	=	Reference emissions to calculate emission reductions in HPU as a result of improved efficiency of hydrogen production during a given time period *p*. [tCO_2/p]
$PE_{HPU2,p}$	=	Project emissions to calculate emission reductions in HPU as a result of improved efficiency of hydrogen production during a given time period *p*. [tCO_2/p]

I. Data and parameters fixed *ex ante*

The source of each data and parameter fixed *ex ante* is listed as below.

Parameter	Description of data	Source
$FC_{HCUR,i,d}$	Daily consumption of fossil fuel type *i* on day *d* during the historical three-year period at reactor heater in HCU. [mass or volume unit]	Plant-specific record.
NCV_i	Net calorific value of fossil fuel type *i*. [GJ/mass or volume unit]	In the order of preference: a) values provided by the fuel supplier; b) measurement by the project participants; c) regional or national default values; d) IPCC default values provided in table 1.2 of Ch.1 Vol.2 of 2006 IPCC Guidelines on National GHG Inventories.
$FI_{HCUR,d}$	Daily feed input in day *d* during the historical period in HCU reactor. [mass or volume unit]	Plant-specific record.
EF_i	CO_2 emission factor of fossil fuel *i*. [tCO_2/GJ]	In the order of preference: a) values provided by the fuel supplier; b) measurement by the project participants; c) regional or national default values; d) IPCC default values provided in table 1.4 of Ch.1 Vol.2 of 2006 IPCC Guidelines on National GHG Inventories.
$FI_{HCUD,d}$	Daily feed input in day *d* during the historical period at debutanizer in HCU. [mass or volume unit]	Plant-specific record.
$FC_{HCUD,i,d}$	Daily consumption of fossil fuel type *i* on day *d* during the historical three-year period in HCU debutanizer reboiler. [mass or volume unit]	Plant-specific record.

$HC_{HCU,d}$	Daily hydrogen consumption at HCU on day *d* during the historical three-year period. [Nm^3]	Plant-specific record.
$HP_{HPU,d}$	Daily hydrogen production at HPU on day *d* during the historical three-year period. [Nm^3]	Plant-specific record.
$FC_{HPU,i,d}$	Daily consumption of fossil fuel type *i* on day *d* during the historical three-year period in HPU. [mass or volume unit]	Plant-specific record.
a, b, c, d, e, f, g, h	Parameters derived as a result of linear regression analyses.	Calculated according to the procedure described in section F2.