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Greenhouse Gases Emission Inventory of a Coal-Fired Power Plant-Case Study: "A" Company, Indonesia

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Abstract- "A" Company is a power station that uses fossil fuels such as coal and petroleum to produce high-pressure steam to generate electricity. The "A" Power Plant has 800 MW/day capacity for Unit 1 and 2. Pollutants generated from power generation activities consist of conventional pollutants (CO, SO_x, PM, HC) and greenhouse gases (CO_2, CH_4, N_2O, NO_x). However, this study aims to calculate total emission of greenhouse gases (GHG) in CO_{2eq} both from stationary sources and from mobile sources in 2016. The inventory method used in this study was based on Tier 1 and Tier 2 for stationary sources and Tier 2 for mobile sources. The total emission load generated from the stationary source is 4,359 kTon CO_{2eq} and the total emission load generated from the mobile source is 2.905 kTon CO_{2eq}. The biggest pollutant source was Stack Boiler Unit 1 and Unit 2. These power plant has implemented efforts to reduce the amount of greenhouse gas emissions generated such pollutant controller and optimization of Green Space around power plant units.

Keywords- *Power Plant, Fossil Fuel, Greenhouse Gases, CO_{2eq}*

I. INTRODUCTION

"A" Company ("A" Power Plant) is a power station that uses fossil fuels such as coal and petroleum to produce high-pressure steam to generate electricity. The "A" Power Plant is an electricity generation plant where there are 8 sites in the area. The amount of electrical energy that is distributed from the "A" Power Plant to the Java, Madura and Bali through interconnection systems was approximately 5,606.18 GWh annually. The "A" Power Plant is one of the two coal-fired power plants that used coal as its main fuel. The total coal required is about 12,144 million tons per year [1] . The usage of coal as fuel may cause air pollution. The use of coal as a fuel for electricity generation can emit conventional pollutants (CO, SO_x, PM, HC) and greenhouse gases (CO_2, CH_4, N_2O, NO_x).

Indonesia is committed to reducing GHG emissions by 26% by 2020 from the level of business as usual with its own efforts. Indonesia's commitment in reducing greenhouse gas emissions was followed up by enacting Presidential Regulation No. 71 / 2011 on the Implementation of Greenhouse Gas (GHG) Inventory. GHG inventory is the activity of obtaining data on periodic levels, status, and trends of GHG emission change from various sources of emission (Presidential Regulation No.71 of 2011).

According to the Regulation of the Ministry of Environment Number 21/2008 regarding the quality standards for Emission of Stationary Source of Business and/or Thermal Power Generating Activities defines Emission as substances, energy and/or other components resulting from an activity that enters and/or incorporates it into ambient air having and/or no potential as a pollutant element. Therefore, "A" Company is required to meet the quality standards that the government has enacted in order to avoid the negative impacts.

The maximum emission load is the highest exhaust emission load that is still allowed to be discharged into ambient air. The source of the air pollutant consists of a mobile source and a stationary source. A mobile source is a source that can move from one place to another such as a vehicle among the generation unit. An immobile source is static (stationary) source such as emissions from production processes or non-production processes e.g. emissions stack. The criteria used in the calculation of stationary emission load are emission factor, material balance, and stack test. The emission factor used refers to the Regulation of Ministry of Environment No. 12/2012 which refers to international regulations (OGP, US EPA, API Compendium, etc.) with the concept of Tier level. The higher the level, the more accurate the calculation results. Meanwhile the criteria of emission calculation is based on the emission factor, the length of the vehicle mileage and the amount of fuel used. In this study, the objective was to calculate emission of greenhouse gases in CO_{2eq} both from stationary sources and from mobile sources in 2016.

II. METHODS

A. *Emission from Stationary Sources*

GHG emitted by fuel combustion at stationary sources are CO_2, CH_4 and N_2O. In this study, the inventoried pollutants were CO_2 and CH_4. The GHG calculation methodology is based on IPCC Guideline 2006 Volume 2. The amount of GHG emissions from fossil fuel combustion depends on the amount and type of fuel burned. The amount of fuel is represented as activity data while the type of fuel is represented by emission factor. In this study, Tier 1 method was used for calculating CH4 emission when Tier 2 for CO_2. The equation of emission calculation is as follows:

$$\mathrm{Emission}_{\mathrm{GHG,fuel}} = \mathrm{Fuel\ Consumption}_{\mathrm{fuel}} \times \mathrm{Emission\ Factor}_{\mathrm{GHG,fuel}} \quad (1)$$

Where, $Emission_{GHG,fuel}$: GHG emission of a type based on a fuel type (kg GHG); $Fuel\ Consumption_{fuel}$: amount of burned fuel according to a fuel type (in TJ); $Emission\ Factor_{GHG,fuel}$: a type of GHG emission factor based on a fuel type (kg/TJ)

The emission factors of some fuel types can be seen in Table I. Based on the Regulation of the Ministry of Environment No. 21/2008 regarding the Quality Standard of Stationary Sources of Emissions for Enterprises and / or Thermal Electricity Power Generation Activities, the calculation of CO_2 emission load can be calculated as the following equation:

$$E_{CO2} = \sum F \text{ x Ac.CC x OF x } MWco_2/ANc \quad (2)$$

Where, E_{CO2} : CO_2 emission; $\sum F$: total number of fuel consumption (kton); Ac.CC: actual carbon content (ton C/kton); OF: oxidation factor; $MWCO_2$: molecular weight of CO_2 (44); ANc : atom weight of C (12)

TABLE I. EMISSION FACTORS OF STATIONARY SOURCES IN ENERGY INDUSTRY (KG GRK PER TJ NET CALORIFIC VALUE)

Fuel	CH_4		
	Default F.E	*Lower*	*Upper*
Gas/diesel oil	3	1	10
Anthracite coal	1	0,3	3
Subbituminous coal	1	0,3	3
Fuel	N_2O		
	Default F.E	*Lower*	*Upper*
Gas/diesel oil	0,6	0,2	2
Anthracite coal	1,5	0,5	5
Subbituminous coal	1,5	0,5	5

Source: IPCC Guideline 2006 Volume 2 [2]

B. Emission of Mobile Sources

According to the Government Ordinance No. 55/2012, the mobile sources include motor vehicles that are driven by mechanical equipment in the form of machines other than vehicles running on the railroad. The calculation of mobile emission load was done by VKT (Vehicle Kilometer Travelled) approach. The transport sector contributes to the increase in greenhouse gas emissions, especially CO_2 emission. The types of vehicles that contributed most of CO_2 emission in the “A” Power Plant are passenger vehicles, pick-up trucks, and buses.

The calculation of emission from mobil sources depends on some parameters, i.e. emission factor, machine characteristics, vehicle technology, fuel characteristics, age, operation and maintenance of vehicles. The emission factors can be seen in Table II.

TABLE II. EMISSION FACTORS FOR MOBILE SOURCES

Category	CO_2
Motorcycle	3180
Passenger vehicle (gasoline)	3180
Passenger vehicle (diesel fuel)	3172
Passenger vehicle	3178
Bus	3172
Truck	3172
Pick-up truck	3178

Source: Regulation of Ministry of Environment No.12/2010

This calculation used Tier 2 concept that uses emission factor based on *vehicle kilometer travelled* (VKT) or average length of travelled annually. For the main road network, emission was assumed as line source. In VKT calculation, each vehicle category on a certain road was assumed that the traffic characteristic was static so that the equatin can be written as follows:

$$\mathrm{VKT}_{\mathrm{j,line}} = \sum_{i=1}^{n} Q_{ji} I_i \quad (3)$$

$$E_{cji} = \mathrm{VKT}_{ji}.\mathrm{EF}_{cj}(100 - C)/100 \quad (4)$$

Where, $\mathrm{VKT}_{\mathrm{j,line}}$: VKT category vehicle *j* on road *i* as a line source (km/year); Q_{ji}: volume of vehicle in category *j* on road *i* (vehicles/year); I_i : length of road *i*; E_{cji} : emission *c* for category vehicle *j* on road *i*; EF_{cj}: emission factor of *c* for category vehicle *j*. C: efficiency of emission control (%), if none, C = 0.

The first step taken in estimating the emission load by the vehicle mileage approach was done by collecting the length of the road passed-by daily. Then, the average vehicle volume was calculated per day by multiplying the number of times the vehicle enters the road. In this case, the calculation was done by multiplying the number of working shift in a day and the number of working day each year. VKT was obtained by multiplying the vehicle volume each year and the length of road passed-by.

As for the freight transport, GHG emission was estimated by the following equation based on Cefic and ECTA [3]:

$$CO_2 \text{ emission} = \text{tonnes x km x g } CO_2 \text{ per ton-km}/1000000 \quad (5)$$

Meanwhile, GHG for heavy equipment was based on emission factor of EEA. According to EEA Emission Inventory Guidebook 2003, heavy equipment was included in Non-road mobile sources and machinery category, such as excavator, crane, bulldozer, conveyor, etc. The calculation was done by the following equation:

$$E_{pollutant} = \sum_{fueltype} FC_{fueltype} \times EF_{pollutant,fueltype} \quad (6)$$

Where, $E_{pollutant}$: specific pollutant emission; $FC_{fueltype}$: fuel consumption (diesel, LPG, four-stroke gasoline and two-stroke gasoline) for each source category; $EF_{pollutant,fueltype}$: emission factor for each fuel type.

III. Results and Discussion

A. *Stationary Sources*

The coal used by "A" Power Plant is generally from Kalimantan that has a relatively low content of sulfur and ash. The type of coal used is sub-bituminous coal. However, in the operation of power plants, various activities can produce emissions. At PT. PJB UP Paiton, one of the emissions was generated from energy sector derived from the use of coal, then from the activity of land and sea transportation and from the use of Diesel fuel. According to the data from "A" Company Unit 1 & 2, total coal used in 2016 was 2,420,033 tonnes/year, (Unit 1: 1,163,450 tonnes/year and Unit 2: 1,256,583 tonnes/year). Meanwhile, fuel oil used for Unit 1 534.07 kL/year and for Unit 2 1,075.488 kL/year. The calculation of total emission was calculated based on Tier 2.

Figure1 shows the estimation of CO_2 emissions generated from the production process. Total CO_2 emissions generated from the production process of units 1 & 2 was 4338,151 kTonnes/year with total combustion emissions in Unit 1 of 2074,868 kTons/year and total combustion emissions in Unit 2 of 2263,282 kTons/year. Small addition from fuel oil usage in these unit can be seen in Figure 2. In addition to generating CO_2 emissions, from stationary sources the production process also generates CH_4 emissions. Default emission factor from IPCC and Tier 1 method were used to calculate CH_4 emission load. The detailed result of CH_4 emission each month can be seen in Figure 3 while the fuel usage emitted CH4 as can be seen in Figure 4. N_2O is also part of GHG emission that has highest GWP (Global Warming Potential), namely 298, while CH_4 has 25 GWP. N_2O emission is shown in Figure 5 for coal usage and Figure 6 for fuel oil usage.

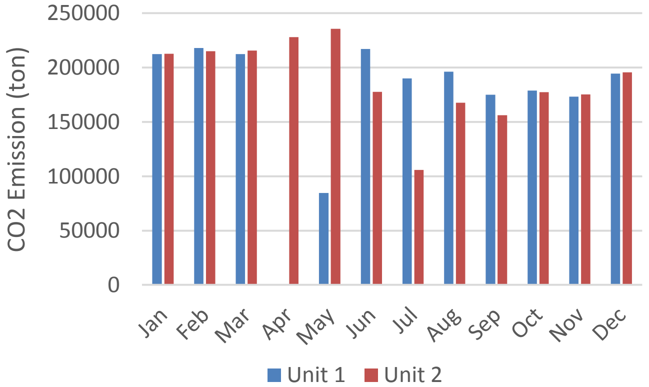

Figure 1. CO_2 Emission from Coal Usage at Stationary Sources

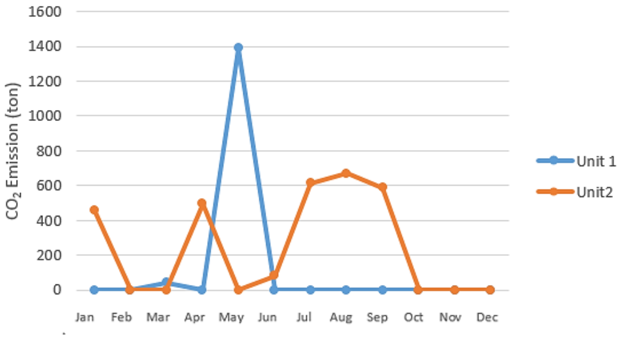

Figure 2. CO_2 Emission from Fuel Oil Usage at Stationary Sources

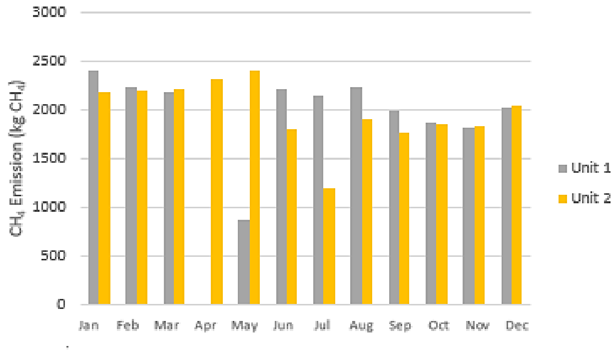

Figure 3. CH_4 Emission from Coal Usage at Stationary Sources

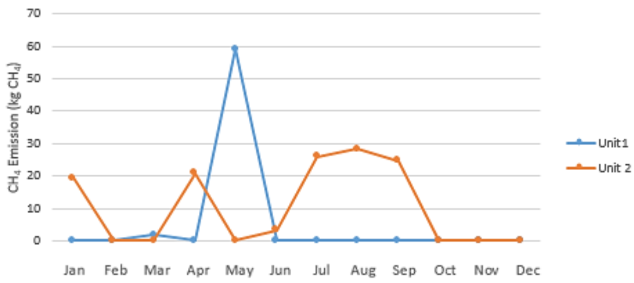

Figure 4. CH_4 Emission from Fuel Oil Usage at Stationary Sources

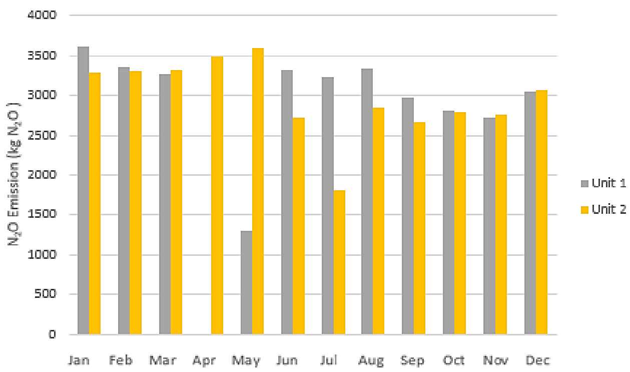

Figure 5. N_2O Emission from Coal Usage at Stationary Sources

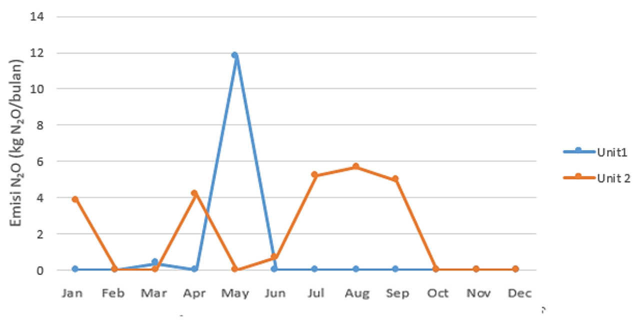

Figure 6. N_2O Emission from Fuel Oil at Stationary Sources

Those emissions (CH_4 and N_2O) were then converted to CO_{2eq}, the GHG emissions from coal usage and fuel oil in Unit 1 were 10.379 kTon CO_{2eq} and 0.00515 kTon CO_{2eq}, respectively. The GHG emissions from Unit 2 were slightly higher, namely 11.210 kTon CO2eq and 0.0104 kTon CO_{2eq}, respectively. Therefore, total emission from stationary sources was 4359.754 kTon CO_{2eq} where Unit 2 contributed the higher number, i.e. 2274.502 kTon CO_{2eq}.

B. *Mobile Sources*

The availability of adequate transportation is one of the basic capitals to facilitate operational activities within "A" Power Plant, both economic activities and shuttle activities of workers and good road facilities. The length of the road in UP Paiton is 3.93 km. It was assumed that the land transportation only consisted of one way within the Unit 1 and Unit 2 plant area. To meet operational activities within UP Paiton, there are four types of vehicles that operated, namely passenger cars (gasoline fuel), passenger cars (diesel fuel), pick-up truck, and bus (diesel fuel). The land transportation activities can be seen in Table III.

"A" Company also generates emissions from heavy equipment activities. In this case, the heavy equipment fuel consumption data every period were needed. The fuel used for operation is diesel. Heavy equipment used in the operation of "A" Power Plant is bulldozer, car crane, dump truck, excavator, fork lift, hauling dump truck, fly ash transporter, fire engine, sky master, vacuum truck, wheel loader, and water tanker. Fuel consumption in 2016 was 715.725 liters.

TABLE III. VEHICLES VOLUME AND EMISSION IN 2016

Vehicle Category	Volume of vehicles each year	GHG Emission (kg CO_{2eq}/year)
Bus	240	848.94
Truck	2352	7792.54
Passenger car gasoline)	10176	21591.02
Passenger car (diesel)	1776	4225.29
Pick up	1152	2567.02
Mini bus	912	2497.36
Box truck	240	534.8
Motorcycle	80256	36952.22
Total land transport emission	-	77009.17

Fuel used to operate heavy equipment that was diesel. Density of diesel fuel was 0.84 kg/L. The emission factor used in this calculation was 3160 kg/ton fuel. The CO_2 emission generated from the heavy equipment in 2016 was 1.90 kTon, whereas CH4 emission was 0.00083 kTon CO_{2eq}. According to personal communication, the most of fuel oil usage in heavy equipment was the use of bulldozer, namely about 90% of total fuel oil every month.. The bulldozers were mainly operated to transport coal.

The calculation of the emission load resulting from the marine transportation activity was derived from equation (5) The required data parameters were ship type, number of vessel, type of fuel used, vessel capacity, and track length. The heavy duty barge data of DWT (Dead Weight Tonnage) data on ship arrival and LWT (Light Weight Tonnage) data on ship return were needed. The total CO_2 emissions resulting from marine transportation activities in 2016 amounted to 0.095 kTon CO_2. The emissions are total emissions due to roundtrip of barges.

C. *Recapitulation of the emission invetory*

From the estimated amount of emission load at PT. PJB UP Paiton, it is concluded that "A" Power Plant efficiency has Emission Expenses per unit of 0.870 kTon/GWh in Unit 1 and 0.874 kTon/GWh in Unit 2. According to Figure 7, it is clear that stationary sources, such as stacks of Unit 1 and Unit 2 Power Plant was the highest sources of CO_2 emission. Because coal has higher CO_2 emission factor than oil, the switch of energy source from oil to coal, of course, will give higher CO_2 emission [4]. Although coal-fired power plant contributes high CO_2 emission rate, coal-fired power plants provided over 41% of the electricity generated worldwide in 2013 [5].Compared to China, the emission of this power plant unit is lower because in 2011 using national practice technology, the GHG emission was 0.913 kTon/GWh [6]. It should be noted that the GHG emissions from "A" Power Plant were only include stationary sources.

In order to reduce GHG emission from coal-fired power plant, Carbon Capture and Storage (CCS) technology could be used. In the addition of amine-based CCS for 90% CO_2 capture would increase the plant cost of electricity generation significantly by 58%–108% in comparison with the plant without CCS at 95-percent confidence and result in a CO_2 avoidance cost within the 95-percent confidence interval from $35/ton to $67/ton [7].

The more favorable and long-term solution for generating energy is using renewable energy. Renewable energy is often praised for its ability to mitigate environmental emissions, improve public health, increase economic activity through job creation, and provide a more reliable and affordable energy system [8]. Renewable energy generally consists of self-replenishing energy sources such as wind, waves, sunlight, tides, biomass, biofuel, geothermal heat, and hydroelectric power [8]. The coal-fired power plants have to be replaced eventually [9].

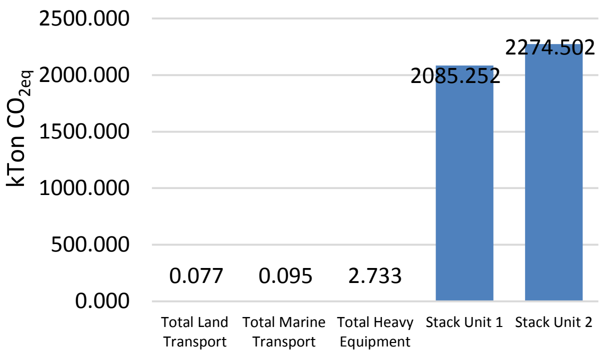

Figure 7. Recapitulation of Total CO_2 Emissions

IV. CONCLUSIONS

It is concluded that "A" Power Plant efficiency has Emission Expenses per unit of 0.870 kTon/GWh in Unit 1 and 0.874 kTon/GWh in Unit 2. The total emission load generated from the stationary source is 4,359 kTon CO_{2eq} and the total emission load generated from the mobile source is 2.905 kTon CO_{2eq}. The biggest pollutant source was Stack Boiler Unit 1 and Unit 2. Some recommendations for reducing GHG emission are implementation of Carbon Capture and Storage (CCS) technology and as for long-term solution, phasing-out the coal-fired power plant.

As for the method of GHG emission inventory, Indonesia could develop emission factor to create more reliable figures of GHG emission than just applying IPCC emission factor. The method could be adopted from the study of GHG emission factor for coal-fired power plant in Korea [10].

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