Impact Assessment of Coal Power Plant Using Life Cycle Assessment (LCA)

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Abstract. The electricity production using coal starts with the process of transforming heat energy into mechanical energy which drives turbines and generators to produce electricity. These activities produce emissions that can cause environmental impacts. Air pollutants causing impacts generated by coal power plants are mainly CO2, CH4, N2O, SOx, and Particulate Matter (PM). These emissions may increase global warming and decrease air quality which affects humans and the environment. This study identifies the impacts that occur from the activities of electricity production with coal using the Life Cycle Assessment (LCA) approach. LCA is an analytical method that is used to evaluate and compare the environmental impacts of a product. Identification of environmental impacts was carried out using the SimaPro 8.5.2 software. The cycles of coal production activities analyzed include coal bunkers, coal mills, boilers, turbines, and generators. The results of emission calculation, obtained in the production process of the steam power plant boiler unit at one of the coal power plants in East Java, are as follows: 1.085 kgCO2/kWh; 1.01 x 10^-5 kgCH4/kWh; 1.52 x 10^-5 kgN2O/kWh; 3.18 x 10^-4 kgSO2/kWh; 1.12 x 10^-4 kgNOx/kWh; 1.19 x 10^-5 kgPM/kWh.

Keywords: coal power plant, environmental impact, life cycle assessment

1. Introduction
The electricity demand is increasing along with the development of the industrial sector and the growing population in Indonesia. With the increase in population, the amount of electricity consumption is increasing rapidly. Electricity capacity sold in 2017 according to the statistics of PT. PLN (Persero) in Indonesia reached 221,574.66 GWh, up by 2.58% percent compared to that of 2016 (Electricity Statistics, 2018)[1].

According to the Indonesian Environment Status 2010, the contribution of steam powered power plant (PLTU) activities to air pollutants in the form of carbon dioxide (CO2) amounted to 11,279.621 tons/year (Ministry of Environment, 2010)[2]. CO2 gas is one of the greenhouse gases (GHG) and the main contributor to global average temperature rising. In an effort to reduce GHG emissions, Presidential Regulation No. 61 of 2011 concerning the National Action Plan for Reducing Greenhouse Gas Emissions (RAN-GRK) and Presidential Regulation No. 71 of 2011 concerning the Implementation of the National GHG Inventory were released, and Indonesia aims to reduce GHG...
emissions by 26% from the Business as Usual (BaU) level with its own efforts to be achieved in 2020 or 41% if it receives international support (Fadhila, 2016)[3].

In a coal power plant, greenhouse gases (CO₂, CH₄, N₂O) and air pollutants (SOₓ, NOₓ, PM) are generated in its main processes (coal bunkers, coal mill, boilers to turbines and generators) in the production scheme, as shown in Figure 1.

Based on the above conditions, it is necessary to have an alternative or a way to reduce emissions released from the PLTU production process, for example, by modifying the existing machines and operating systems (Erdhiyan, 2018)[4]. A method proposed to analyze the impacts from production process activities is the Life Cycle Assessment (LCA) (Jatmiko, 2017)[5]. LCA provides information on impacts that are discharged into the environment by the product cycle, from extracting raw materials, production processes, product use and waste from products produced from production activities (Hermawan, 2013)[6]. LCA is developed to examine the environmental impacts caused by factories and production processes such as global warming, ecotoxicity and smog formation (Haas, 2005)[7]. SimaPro 8.5.2 software is used as a tool to analyze energy savings and reduction of greenhouse gas emissions, energy audits and the global environment that focuses on the life cycle of a product, as well as the efficient use of resources in the form of land, water, energy and other natural resources. LCA can also be used to determine the global warming potential of each biomass utilization process (Rosmeika, et al, 2010)[8].

2. Material and Methods:
LCA analysis requires data relating to raw materials, production results and by-products of products studied such as functional unit data, emission data, and other secondary data. The boundaries system studied are coal bunkers, coal plants, boilers, turbines, and generators. First, data were obtained from the company's secondary data and data on the calculation of greenhouse gas emissions (CO₂, N₂O, CH₄) and pollutants (NOₓ, SOₓ, and particles) based on the Minister of Environment Regulation No.12 of 2012 [9] with the following formula:

\[
\text{Fuel energy} = \text{LHV} \times \text{fuel flow rate} \times \text{operating time} \quad (1)
\]

\[
E = A \times EF \quad (2)
\]

Next, the LCA method was used to identify the impact of the production process. The analysis carried out in this study included analysis of raw materials, fuels, emissions and products produced from electricity production activities. The LCA analysis used SimaPro 8.5.2 application. An analysis on the estimated impact of the LCA analysis was then done using the TRACI method. TRACI (the Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts) is a midpoint oriented methodology developed by the Environmental Protection Agency (EPA) in the USA, with the aim of assisting in the assessment of impacts on process design and achieving pollution prevention (Menoufi, 2011)[10]. Some categories of impacts that can be analyzed using the TRACI approach include global warming 100a, ecotoxicity, smog, acidification, carcinogenic, respiratory effect, fossil...
fuel depletion, and eutrophication. The TRACI method provides two stages of impact assessment, namely characterization and normalization. Characterization is a chemical compound in a process that contributes to the impact category found in LCA, while Normalization is an assessment by comparing the results of impact category indicators with normal values.

3. Results and Conclusions:

3.1 Goal and Scope
One of the research’s aims is to analyze the environmental impacts caused by greenhouse gases and air pollutants during the electricity production process. The scope of the research covers the main processes of electricity production, starting from the bunker, coal mill, boiler to turbines and generators. The method used is TRACI, and various impact limits were examined in this study, namely global warming 100a, ecotoxicity, smog, acidification, carcinogenic, respiratory effect, fossil fuel depletion, and eutrophication.

3.2 Inventory Data
Data analysis requires input data that contains mass and specific balance data obtained from the company itself. Below is the data on life cycle inventory:
1. Coal Bunkers
   The bunker is a coal storage unit from the dock that will be transferred to a coal plant using a conveyor. One of the purposes of the coal bunkers is to be a provider of coal stock.

   \[
   \begin{align*}
   \text{Coal} & \quad 2.193.340 \text{ ton} \\
   \text{Electricity} & \quad 3.378.176 \text{ kWh}
   \end{align*}
   \]

   \textit{Figure 2. Mass Balance Coal Bunker}

   In this process the amount of coal that is inputted and that which comes out of the coal bunker is equal because there is no material reduction in this process.

2. Coal Mill
   Coal Mill is a tool used to grind large sized coal into coal powder. The purpose of this grinding is to make it easier for coal to be blown into the coal burner to be then burned with hot air. Coal is milled with a size of 200 mesh. At that size coal will be flammable.

   \[
   \begin{align*}
   \text{Coal} & \quad 2.193.340 \text{ ton} \\
   \text{Electricity} & \quad 16.283.864 \text{ kWh}
   \end{align*}
   \]

   \textit{Figure 3. Mass Balance Coal Mill}

   In this process the amount of coal and the outflow is the same because there is no waste or product left over in the grinding process.
3. Boilers
A steam boiler or kettle is a closed vessel-shaped device used to produce steam. Steam or water vapor is formed by heating water in the heating boilers using fuels such as coal. Steam will then be transported to the turbine and turn the turbines and generators on.

The process of heating water in the boiler will produce emissions in the form of CO$_2$, CH$_4$, N$_2$O, SO$_x$, NO$_x$, and particulates that come from the combustion process of coal and fuel oil. Besides, this process also produces fly ash and bottom ash.

4. Turbine
Turbine is a device used to convert energy from water vapor to mechanical energy. The rotation of the turbine (mechanical energy) will be converted into electrical energy by the generator.

This process will generate electricity and emit water vapor which will then be channeled to the condenser to be cooled to become water again.
3.3 Life Cycle Impact Assessment

3.3.1 Interpretation
The life cycle impact assessment was applied to the data and existing processes in the electricity production process. The purpose of using the data is to discover the biggest impact of a series of electricity production processes at the studied coal power plant company. The results of the LCA analysis were obtained using simaPro 8.5.2.

3.3.2 Characterization
Characterization is a stage where the contribution will be relative to the environmental impact. This stage will measure the contribution of the product or activity on each impact indicator. This stage directly compares the results of life cycle inventory in each category. Many impact assessment methodologies in TRACI are based on "midpoints" with characterization approaches (Bare et al. 2003)[11]. The values of the characterization impact obtained from the simaPro calculation are presented in Table 1.

| Impact category       | Unit     | Electricity (Turbine and Generator) | Steam (Boiler)     | Coal (Mill)   | Coal (Coal Bunker) | Total          |
|-----------------------|----------|-------------------------------------|--------------------|---------------|--------------------|----------------|
| Global warming        | kg CO2 eq| 19.100                              | 4.285,836,380      | 19.322,940    | 84.372,180         | 4,389,550,600  |
| Fossil fuel depletion | MJ surplus| 1.900                              | 226,588,480        | 1.923,720     | 208,492,900        | 437,007,000    |
| Acidification         | kg SO2 eq| 69                                  | 15,469,487         | 70,801        | 543,392            | 16,083,749     |
| Eutrophication        | kg N eq  | 2                                   | 337,048            | 1.535         | 10,100             | 348,684        |
| Carcinogenics         | CTUh     | 0,00007                             | 15,05              | 0,07          | 0,65               | 16             |

3.3.3 Normalization
Normalization is a process of data analysis, which compares the impact of indicators with impact categories. The purpose of the equivalence unit is that it can be compared with each other. In this stage, the electricity production process is then converted into the same unit by dividing it by the reference value chosen by the normalization results presented in Figure 3.6. Normalization factors are presented in Table 2:

| Impact Category      | Normalization Factor |
|----------------------|----------------------|
| Ecotoxicity          | 7.6 x 10^7          |
| Carcinogenics        | 5.5 x 10^-6         |
| Global Warming       | 2.4 x 10^4          |
| Acidification        | 9.1 x 10^-4         |
| Eutrophication       | 2.2 x 10^-4         |
| Smog                 | 1.4 x 10^-4         |
| Respiratory Effects  | 2.4 x 10^-4         |
| Fossil Fuel Depletion| 1.7 x 10^-4         |

Source: Ryberg et al., 2013[12]

The normalization impacts obtained from the simaPro is presented in Table 3.
Table 3. Normalization Value

| Impact category     | Electricity (Turbine and Generator) | Steam (Boiler) | Coal (Coal Mill) | Coal (Coal Bunker) | Total     |
|---------------------|-------------------------------------|----------------|------------------|-------------------|-----------|
| Carcinogenic        | 1.30                                | 285.560        | 1.317            | 12.347            | 299.226   |
| Global warming      | 0.79                                | 176.927        | 798              | 3.483             | 181.209   |
| Acidification       | 0.77                                | 170.313        | 779              | 5.983             | 177.075   |
| Fossil fuel depletion| 0.10                               | 12.040         | 102              | 11.078            | 23.220    |
| Eutrophication      | 0.07                                | 15.593         | 71               | 467               | 16.131    |

Carcinogenics are substances that can cause cancer. One of the causes of cancer is particulate matter (PM), which is contained in coal residual fly ash. Inhaling particles might cause dangerous diseases, including chronic obstructive pulmonary disease (COPD) and lung cancer (Cornell, 2016)[13]. Carcinogenics had an impact value of 299.226.

Global warming is an ecosystem imbalance on earth due to the increasing temperature of the atmosphere, sea, and land on earth (Forest, 2017)[14]. The impact value of global warming was 181.209. The cause of the large impact of global warming was due to coal burning. Results of this research showed global warming causing green house gases such as CO₂, CH₄, and N₂O was present in coal burning.

Acidification is an increase in acidity in the environment caused by the entry of acid into the environment. Emissions from PLTU in the form of SOx and NO produce acid when they react with water. This event often occurs when they react with SOx and NOx contaminants in the occasion of rains, resulting in acid rain. In addition, CO₂ can also cause acidification. The increase of CO₂ release will result in further acidification of sea by 0.4 units in 2100 (Turley, 2008)[15]. This can happen because when CO₂ reacts with temperature, chemical changes occur which cause the concentration of bicarbonate (HCO₃⁻) and carbonic acid (H₂CO₃) to increase with increasing concentration of CO₂ in the atmosphere, while the average amount of carbonate ions (CO₃²⁻) and pH in the sea water is reduced. Acidification impact had an impact value of 177,075.

Eutrophication is a type of pollution in the environment in which plants grow very rapidly in bodies of water. The cause of eutrophication is the entry of excessive substances in the body of water. Eutrophication had an impact value of 16,131. In this case, N and P substances that caused eutrophication originated from coal and boiler water.

Fossil fuel depletion occurs because of the waste of fossil fuels used in the production process. In the characterization analysis of the boiler unit, fossil fuel depletion had an impact value of 23,220.

4. Conclusion

Based on the life cycle assessment (LCA) analysis, the process that has the highest impact on the environment is the process in the boiler unit. Meanwhile, the biggest impact that occurs in the production of steam power plant is the impact of carcinogenic. Therefore, environmental program for reducing carcinogenic impact in the boiler should be a priority.

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