Life cycle Assessment of natural gas combined cycle steam power generation systems in Indonesia: case Study on Gresik power plant

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Abstract. The study aims to provide a comprehensive environmental life cycle assessment of electricity production from a steam power plant fuelled only by natural gas. LCA includes the complete phases of the gate to gate, from raw material acceptance until electricity produced as a gate to gate approach. The LCA study was performed using manual calculation and Open LCA 1.9, where the selected impact assessment methodology is CML. A Combined cycle steam power plant is used in generating electricity due to its efficiency by re-using flue gas from the gas turbine by a steam turbine. This LCA study divided all boundaries into four Subsystems: energy preparation package, water production package, electricity production, and support Subsystem. From the calculation, it was found that Acidification Potential (AP) is the most impact, and 50.22% comes from NOx as the most significant resource from the combustion chamber process, followed by Photochemical Oxidant Potential (POCP) and Global Warming Potential (GWP).

1. Introduction
The pollutant nature of conventional fuel combustion directed people to examine cleaner energy conversion applications [6]. It happens from time to time while finding a more efficient and more possible fuel used. The Combined cycle steam power plant operates in Indonesia to generate electricity due to its efficiency with HSD and natural gas as their fuels. Gresik steam power plant is one of the steam power plants that used natural gas only as their fuel.
To find the impact of a combined cycle steam power plant with natural gas as fuel requires a comprehensive study. One of the methods used is the Life Cycle Assessment, for it follows the process to calculate the impact.
LCA is the set and evaluation from the input, output, and the potential impact through its life cycle [1] [2]. LCA is a framework that refers to ISO 14040 and 14044 and also stated in ISO 14001 (Environment Management System [3]. In other words, LCA is a tool to examine the environmental performance of all different stages of the product that can identify during its life-cycle [5]. All inputs and outputs need to be estimated to evaluate the significance of the impact on the environment.
A primary strength of LCA is its comprehensiveness in terms of its coverage of environmental issues. However, the comprehensiveness is also a limitation and required simplifications and generalizations in the modeling of the product system and the environmental impacts that prevent LCA from calculating its actual [4]. Therefore, we can set the boundary of the LCA based on the objective of the study. The
research is conducted at Gresik Power Plant since it uses a combined cycle for generating electricity, and focused on a combined cycle power plant process and describes the process of Subsystems. [6].

2. Method
This study methodology using the LCA method as follows:

LCA consist of several stages [5]:
- Defining the functional unit: quantitative description of the function or service for which the assessment performed and determining the reference flow of product that scales the data collection in the inventory analysis.
- We were scoping the product system, deciding which activities and processes belong to the product's life cycle that is studied.
- Selecting the assessment parameters
- It selected the geographical and temporal boundaries and settings of the study and the level of technology relevant to the processes in the product system.
- Deciding the relevant perspective to apply in the study: should it be a consequential study assessing the impacts, choosing one alternative over another, or an attributional study.

2.1 Preliminary Identification
The study was conducted at Gresik Power Plant. The combined cycle power plant consists of three blocks with a capacity in each block is 526 MW and using natural gas. The goal and scope are:
- Object: Combined Cycle Power Plant
- Location: Gresik, East Java, Indonesia
- Purpose: Quantifying Environmental Impact
- Functional Unit: KWh (Kilo Watt Hours)
- Scope: Gate to Gate (from raw material receiving until electricity production)
- Product: Electricity

The scope is in Figure 3 below.

---: Boundary

**Figure 3** Graphic representation of the Electricity life cycle from feedstock to end-user (Icons made by Flaticon)

The process divided into four Subsystems, as follows [9]. To be noted, these three blocks (Block 1, 2, and 3) has the same process:

1. Energy Preparation Package Sub System
   The Energy preparation package Subsystem is the Subsystem that contains the process for preparing the natural gas. Process units in this Subsystem are Gas Station, CNG Plant, and Combustion Chamber.

2. Water Production Package Sub System
   The Water production package Subsystem is the Subsystem that manages water for the process. There are several process units involved, which are Intake, Desalination, Demineralization, and Condenser. There are also support unit processes, the pump house, chlorination plant, raw water tank, make-up tank, Auxiliary cooling system, H₂ plant, and water-cooling system.

3. Electricity Production Sub System
   The Electricity production Subsystem is the Subsystem for producing electricity. It consists of a compressor, combustion chamber, turbine and steam turbine, HRSG, Generator, and transformer.

4. Supporting Sub System
   The supporting Subsystem is the parts supporting the electrical production process. It consists of office, transportation, heavy equipment, safety support, EDG, Lighting system, Freon consumption, and Instrument air supply.

2.2 Collecting Data
The data source is recorded documents, interviews, and field observations, with a range of time from 2018-2019. Collected data is the input and output from each unit process in each Subsystem.

2.3 Implementing LCA Method
The implementation consists of The Life Cycle Inventory (LCI) and Life Cycle Impact Assessment (LCIA). The LCIA consists of:

a. Determining the impact category and classification that refers to LCI. This stage is mandatory [3]. The classification is in Fig. 4.

b. Determining the characterization from conversing the emission data to impact value has been defined previously [3]. This characterization calculated with the formula:
\[ I_c = \sum s CF_s \times M_s \]  

(1)

Where:
- \( I_c \) Indicator result for impact category c
- \( CF_s \) Characterization factor from compound s
- \( M_s \) Mass of compound.

c. Normalizing the value from characterization for comparison purposes [8]. This stage is optional.
d. Weighting by converting all the impact into a single score for decision making. The formula is:

\[ W = \sum c WF_c \times I_c \]  

(2)

Where:
- \( WF_c \) Weighting factor from impact category c.

Some methods can use in the LCIA (Life Cycle Impact Assessment) i.e. CML, EPS, EDIP, ILCD, and Recipe [9]. This study will use CML as the characterization method and the world 2000 since it uses a midpoint indicator. The Midpoint indicator is the indicator of problem-oriented where the approach involves direct environmental problems from a substance's existence. More of the LCIA process is:

![Figure 4 LCIA Stages](image)

3. Results and discussions

3.1 Life-Cycle Inventory

The result of the life cycle inventory for the process of a combined cycle power plant is following, being remembered that Block 1, 2, and 3 have a similar unit process. Nevertheless, in this diagram, all values showed in all blocks.

Subsystem 1 diagram showed there are four sources of natural gas in a different pipeline. All-natural gas will flow into Gas Station and to the Combustion chamber. However, a small amount of gas will flow to the CNG (Compressed Natural Gas) plant. Gas from the CNG plant will also flow to Combustion Chamber based on the operational needed.
Subsystem 2 has a function to calculate the amount of product water produced by the Condenser that will flow to HRSG. In this produce water treatment, several stages need to flows through by seawater until becoming feed water. All units in this Subsystem using electricity. Therefore, it produces air emissions from electricity consumption by using emission factors from EPA.

Produce water treatment started from intake that has a bar screen as a waste filter. After that, water flows into a desalination plant to decrease its salinity. A small amount from the desalination plant will also flow to the chlorination plant, a service water tank, and a cooling water system. In this unit process, another input water from HRSG (Heat Recovery Steam Generator) and by-product brine water. The main product of this unit is water that will flow into the demineralization plant. In this process unit, raw water from desalination treats so the quality will be compatible with the Condenser unit. By product of this unit is wastewater treated in WWTP (Waste Water Treatment Plant) before disposing of the sea. In the condenser, there is input from demineralization and steam turbine. This feed water will flow into HRSG.
Figure 6 LCI of Subsystem 2

Subsystem 3 has the primary function in this industry, which is to produce electricity as a product. In this plant, electricity produce from Gas Turbine and Steam Turbine. In the gas turbine, natural gas is burned in a combustion chamber with support from the compressor. In this process unit, flue gas will be produced as a by-product and used by HRSG. This process is named the combined cycle.

Figure 7 LCI of Subsystem 3

The support system’s environmental impact is also calculated because whether it is not included in the central business operation, it supports all electricity production activities. In an office, there are some activities, like administration activity, laboratory, and workshop. Other support is transportation, safety support (Ambulance, Firetruck, Fire Water Pump), Emergency Diesel Generator (EDG), Lighting system, Freon consumption, and instrument air supply.
This study uses two methods in inventory analysis, which is using manual calculation and Open LCA v1.10.

![Figure 8 Inventory Analysis Input in Open LCA](image)

3.2 Life Cycle Impact Assessment

The first step of LCIA is classification to choose the potential impact that is calculated in the next step. This stage adjusts the environmental impact and LCI results [1].

![Figure 9 Classification](image)

The next step is characterization, where impacts from all emissions and natural resources consumption quantitative modeled. The primary purpose is to converse emission data into impact value that has been determined [4]. In almost every impact, Subsystem 3 is the most significant impact contributor.
GWP: Global Warming Potential; AP: Acidification Potential; EP: Eutrophication Potential; POCP: Photochemical Oxidant Potential; MAETP: Marine Aquatic Eco Toxicity Potential; TETP: Terrestrial Eco Toxicity Potential; HTP: Human Toxicity Potential; RDP: Resource Depletion Potential.

Figure 10 Characterization (a) per Impact (b) per Subsystem

The characterization conducted in both methods, by software and manual calculation, use CML-IA Baseline method. Both methods provided a similar result.

Table 1 Characterization Result

| Impact Category                        | Unit          | Open LCA Results | Manual Calculation |
|----------------------------------------|---------------|------------------|--------------------|
| Acidification Potential (AP)           | kg SO₂ eq     | 1.03E-04         | 1.03E-04           |
| Eutrophication Potential (EP)          | kg PO₄ eq     | 1.47E-05         | 1.47E-05           |
| Global warming Potential (GWP)         | kg CO₂ eq     | 5.61E-03         | 4.98E-03           |
| Human toxicity Potential (HTP)         | kg 1.4-DB eq  | 1.38E-04         | 1.34E-04           |
| Marine aquatic Eco toxicity (MAETP)    | kg 1.4-DB eq  | 4.14E-03         | 3.54E-04           |
| Ozone layer depletion (ODP)            | kg CFC-11 eq  | 2.68E-09         | -                  |
| Photochemical oxidation Potential (POCP)| kg C₂H₄ eq    | 1.21E-05         | 1.46E-05           |
| Terrestrial Eco toxicity (TETP)        | kg 1.4-DB eq  | 1.81E-07         | 2.44E-08           |

In LCIA, the mandatory steps are classification and characterization. The optional stage is normalization; it has a purpose to know the highest impact or the hotspot of this LCA study. The normalization showed in Figure 10.

Figure 11 Normalization per Impact

The Normalization Figure shows that acidification potential is the most impact, and NOₓ is the most significant impact from the combustion chamber with a presentation of 50.22%.
4. Conclusions
Using the LCA method, the environmental quantification of a combined cycle power plant in Gresik calculated. The study found that the Acidification Potential (AP) is the highest impact and comes from NOx as the most significant resource from the combustion chamber process. Therefore, this study’s highlight issue is the Combustion chamber operation, and the hotspot is NOx emission from the unit. This study also conducted a sensitivity analysis and resulted from the same hotspot. It uses two inventory analysis methods, which are using manual calculation and Open LCA v1.9, and both resulted in the same significant issue and hotspot.

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