Life cycle inventory of electricity production from biomass power plant system using life cycle assessment in Aceh Province, Indonesia

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Abstract. Biomass is important material sources as bioenergy for many purposes. Empty fruit bunch (EFB) is one of the rests of biomass from palm oil production that is underutilized in Aceh Province, Indonesia. In the previous research gasification technology was implemented in converting EFB biomass to be electricity using a gasification system. An environmental load of this electricity production needs to be evaluated using the Life Cycle Assessment (LCA) approach. LCA is a well-known method and quantitative approach to evaluate the environmental impact of the product. LCA process consists of goal and scope definition, life cycle inventory (LCI), impact assessment (IA), and interpretation. LCI is the most time consuming and important activity in the LCA calculation. Therefore, we proposed the life cycle inventory analysis of electricity production from EFB biomass using a gasification system. The result of this study was the developed data inventory of electricity production from EFB biomass using a gasification system. The total amount of 17 process units both in the EFB biomass production and electricity production in the gasification system including the distribution process to the user. The gas engine was the major process that contributed to the high global warming potential impact from electricity production. Multiple scenarios can be used to support decision-makers to evaluate the best scenario of the process.

1. Introduction
Palm oil is an important agroindustry product in Indonesia especially Aceh Province. The main product of the palm oil agroindustry is crude palm oil (CPO). In 2017, the production area of the palm oil industry is 534,245 ha and the CPO production are 911,697 tons [1]. The waste of the CPO production is an empty fruit bunch (EFB). EFB mainly are utilized and extracted as compost [2], fuel [3], lignin [4], and disposal to the environment. The utilization of EFB as important material has been
implemented by researchers such as composting, fertilizer, and electricity production using the gasification technology.

The previous study reported that EFB could be utilized to generate electricity using the gasification process. Gasification technology was the process to convert biomass to electricity by burning the biomass. The utilization of the EFB in the gasification process was reported by several researchers [5] [6]. In the previous study, the gasification technology was implemented in Aceh Province, Indonesia [7]. However, the evaluation of the environmental impact of the gasification process using the EFB has not been evaluated by another researcher.

Life Cycle Assessment (LCA) is the well-known method and quantitative approach to evaluate the environmental impact of the process. In Indonesia, LCA research has been applied for many applications [8]. The study of LCA application in the palm oil industry was conducted by researchers such as palm oil for biodiesel production [9], wastewater treatment [10], and others. LCA implementation consists of several activities such as goal and scope definition, life cycle inventory (LCI), life cycle impact assessment (LCIA), and interpretation. LCI is the most important activity to ensure data quality and comprehensiveness. The purpose of this research was the development of LCI of electricity production using an EFB biomass-based power plant in Aceh Province, Indonesia. The LCI dataset will be used for many research and application for evaluating the environmental impact.

2. Method
Life Cycle Inventory (LCI) is the activity to identify the input and output flow in the process of gasification. The LCI is part of the Life Cycle Assessment activities. There are 4 activities to have reliable data in the development of LCI activities such as goal and scope definition, data collection, data verification, and the development of LCI (Figure 1).

![Figure 1. The conceptual framework of LCI activity](image)

2.1. Goal and Scope Definition
This study is generated with a cradle to grave system boundary which is quantified the input and output process during the entire life cycle of the product. This study involved some processing activities from the raw material acquisition to the end-of-life phase which consists of land preparation, seedling, planting, fertilizing, protection, harvesting, palm oil mills, biomass tank, reactor, cyclone, wet tar scrubber, filter 1, blower, filter 2, gas engine, user, and the end of life. The functional unit (FU) of this study was one-kilowatt hours of electricity (kWh). The illustration of the boundary system of the study is presented in Figure 2.
2.2. **Data Collection**
This study used primary and secondary data. The data collection was based on the palm oil condition in Aceh Province Indonesia. The secondary data was collected from study conducted by Siregar et al [6] according to PTPN 1 Lhoksukon, PT. SPS 1 and 2, PT. Socfindo, PT. Kurnia Tanah Subur, PT. PKS and several smallholder palm oil plantations in Nagan Raya Districts, West Aceh Districts, East Aceh Districts, Bireun Districts, and Lhokseumawe Districts. Subsequently, primary data was obtained from direct measurement in the laboratory and the field. The electricity has been produced using EFB biomass and worked for 8 h in the workshop.

2.3. **Data Verification**
Data quality referred to the characteristics of the data related to its ability to meet specified requirements. To meet the data quality, data verification is needed to be conducted. Data verification is an important process to make sure data collection is appropriate and reliable to be analyzed also as justification quality of the data. The data has been verified according to the data quality parameter proposed by ISO 14044 [11] which consists of time-related coverage, geographical coverage, technological coverage, precision, completeness, representativeness, consistency, reproducibility, sources of the data, and uncertainty of the information.
3. **Results and Discussion**

3.1. Life Cycle Inventory of Empty Fruit Bunch (EFB) Biomass Production

Palm oil empty fruit bunch biomass derived from the CPO production in palm oil mill which is categorized as solid waste. Before producing an empty fruit bunch, FFB was produced from the palm oil plantation. There were various activities which were carried out along the production process to produce Fresh Fruit Bunch (FFB). The first activity was land clearing. Land clearing was conducted using to clear the aboveground vegetation as well as make a soil condition for the palm oil growth. In this stage, diesel as energy consumption was used for running the heavy equipment. Furthermore, material input such as herbicide also was used for clearing the weeds which can be a problem for palm oil growth.

In the nursery to the development stages of palm oil plantation, various utilities that have an important impact on the environment was the use of fertilizer, pesticide, herbicide, and energy consumption such as diesel and electricity [12]. The greater use of these utilities will also contribute to the high potential impact on the environment. Fertilizer use is one of the major emission contributors in the agricultural sector. It is important to control the use of the fertilizer and put extra attention [13]. There are two types of fertilizers commonly used in agriculture, namely synthetic fertilizers and organic fertilizers. Fertilizers that are often used in oil palm plantations are urea, NPK fertilizer, kieserite, MOP, dolomite, RP, and TSP. Synthetic fertilizers can cause emissions from the production of fertilizer itself (use of fossil energy during production), transportation of fertilizers to the field, direct emissions in the field, both physical and soil microbes, and indirect emissions due to re-deposition [12]. Pesticides and herbicides use also have a strong potential impact on the environment that is because they have significant conversion emissions [14].

Pesticides and herbicides were used only at certain times in the sense that they were not used regularly. Use of pesticides only when the farm was attacked by pests such as caterpillars and horn beetles. Herbicides were particularly used if the conditions around the palm oil plantations have a lot of weeds. Another inventory on plantations that has an environmental impact was the use of fossil fuels such as diesel [15]. Diesel was used as fuel for running the agricultural machinery or transportation during plantation. Before the palm oil milling, palm oil needs to be harvested.

![Mass balance of palm oil mill](image)

**Figure 3.** Mass balance of palm oil mill [16]
Table 1. Data inventory of palm oil plantation and milling process in producing EFB biomass for 1 kWh electricity in Aceh Province, Indonesia

| Process                  | Mass and Energy | Unit    | Quantity  | Source                      |
|--------------------------|-----------------|---------|-----------|-----------------------------|
| Land clearing            | Herbicide       | kg      | 2.90 x 10^3 | Secondary Data [9]          |
|                          | Diesel for toppling & clearing | L       | 1.61 x 10^5 | Secondary Data [9]          |
| Seedling                 | Fungicide       | kg      | 1.85 x 10^5 | Secondary Data [9]          |
|                          | Insecticide     | kg      | 1.27 x 10^6 | Secondary Data [9]          |
|                          | Meister of Fertilizer | kg     | 1.93 x 10^6 | Secondary Data [9]          |
|                          | Urea 0.2 %      | L       | 2.68 x 10^5 | Secondary Data [9]          |
|                          | Organic fertilizer | kg     | 8.12 x 10^5 | Secondary Data [9]          |
|                          | TSP/SP36        | kg      | 2.55 x 10^6 | Secondary Data [9]          |
|                          | Muriate of Potash (K) | kg   | 2.20 x 10^8 | Secondary Data [9]          |
|                          | Dolomite        | kg      | 4.39 x 10^8 | Secondary Data [9]          |
|                          | N-P-K-Mg (mixing) | kg     | 1.48 x 10^5 | Secondary Data [9]          |
|                          | Electricity for water pump | kWh | 6.38 x 10^4 | Secondary Data [9]          |
|                          | Pesticide       | kg      | 4.37 x 10^6 | Secondary Data [9]          |
| Transportation           | Diesel fuel for truck 5 tons | L       | 1.17 x 10^4 | Secondary Data [9]          |
| Planting                 | TSP/SP36        | kg      | 2.30 x 10^4 | Secondary Data [9]          |
|                          | Organic fertilizer | kg     | 3.87 x 10^6 | Secondary Data [9]          |
|                          | Rock Phosphate (RP) | kg | 2.91 x 10^5 | Secondary Data [9]          |
|                          | KCl             | -       | -         | Secondary Data [9]          |
| Fertilization            | Urea            | kg      | 4.41 x 10^3 | Secondary Data [9]          |
|                          | TSP/SP36        | kg      | 1.78 x 10^3 | Secondary Data [9]          |
|                          | Rock Phosphate (RP) | kg | 3.67 x 10^3 | Secondary Data [9]          |
|                          | Sulphate Ammonia (ZA) | kg       | 1.09 x 10^3 | Secondary Data [9]          |
|                          | Muriate of Potash (K) | kg | 4.82 x 10^3 | Secondary Data [9]          |
|                          | Kieserite (MgSO₄) | kg     | 2.84 x 10^3 | Secondary Data [9]          |
|                          | HGF-B (HGF-Borate) | kg | 1.83 x 10^4 | Secondary Data [9]          |
|                          | CuSO₄         | kg      | 8.72 x 10^5 | Secondary Data [9]          |
|                          | ZnSO₄         | kg      | 3.78 x 10^5 | Secondary Data [9]          |
|                          | LSD            | kg      | 1.31 x 10^3 | Secondary Data [9]          |
|                          | Organic fertilizer | kg     | -         | Secondary Data [9]          |
| Protection for           | Insecticide     | kg      | 6.35 x 10^5 | Secondary Data [9]          |
|                          | Pesticide       | kg      | 7.53 x 10^5 | Secondary Data [9]          |
|                          | Diesel sprayer & fogging | L     | 1.32 x 10^5 | Secondary Data [9]          |
| Harvesting               | Diesel fuel for truck | L       | 1.20 x 10^4 | Secondary Data [9]          |
| Palm oil mill            | Electricity from grid | kWh | 1.05 x 10^3 | Secondary Data [9]          |
|                          | Steam consumption | kg     | 1.43 x 10^3 | Secondary Data [9]          |
|                          | Water consumption | m³  | 2.11 x 10^5 | Secondary Data [9]          |
|                          | PAC            | kg      | 6.37 x 10^7 | Secondary Data [9]          |
|                          | Flocculants     | kg      | 2.20 x 10^9 | Secondary Data [9]          |
|                          | NaOH           | kg      | 5.49 x 10^7 | Secondary Data [9]          |
|                          | H₂SO₄/HCl      | kg      | 5.49 x 10^7 | Secondary Data [9]          |
|                          | Tannin concentrate | kg | 2.42 x 10^7 | Secondary Data [9]          |
|                          | Poly Perse BWT 302 | kg | 2.42 x 10^7 | Secondary Data [9]          |
|                          | Alkali BWT 402  | kg      | 2.20 x 10^7 | Secondary Data [9]          |
|                          | Fiber/shell    | kg      | 6.86 x 10^4 | Secondary Data [9]          |
The process of palm oil harvesting consists of cutting the ripen bunch, picking the fruits, and transport the harvested bunch to the collection point and to the mill. At this stage, squat with dodos was used to harvest palm oil with 2-5 m height, standing using axe tool is used to harvest palm oil with 5-10 m height, and a sickle with a long handle (egrek) was used to harvest palm oil with more than 10 m height. For ease of harvesting, the stem should be cut first and orderly arranged in the middle of wicket. In this stage, the only emission release was from the diesel consumption to transport the harvested bunch using a truck. In the palm oil mill, harvested fresh fruit bunches (FFB) should be immediately processed. FFB processed consists of weighing, sorting, and separating between palm oil fruit and the empty fruit bunch. Energy consumption such as electricity and fuel use, steam, and material consumption such as water use and chemical material has a potential impact to the environment. Electricity was used in running the processing machine. Diesel was used as a generator fuel to generate electricity when electricity needs was not met. Steam was used in the FFB boiling process. At this stage, there was several wastes produced, including EFB, Fiber, Shell, PKM, and Effluent (POME). The EFB was then utilized as biomass for power generation.

In the palm oil mill, each 1 ton of fresh fruit bunches processed producing 0.24 tons of CPO (24%) and 0.023 tons (2.3%) of PKO, and the rest was solid waste. The solid waste produced was in the form of EFB (21%), mesocarp fiber (14.4%), and palm kernel shell (6.4%) [16]. The mass balance produced by the palm oil mill is shown in Figure 3. Mass and energy balance of those process was collected from secondary data that was collected from previous research conducted by Siregar [9]. The allocation procedure was enforced in this case when various by product was produced. The allocation procedure has been done by distributing the input and output flows of a process or system according to its certain product. In this study, the solid waste utilization only in the form EFB as biomass for electricity generation so it would be unfair if all input flow from land preparation to palm oil mill were only charged by EFB product. Furthermore, it is necessary to carry out an allocation procedure. From 100% processed FFB, it produced 21% of EFB. Therefore, the inventory data of all input and output flow for FFB production starting from land preparation to EFB separation in the palm oil mill process were divided into 21% of EFB. The detail data inventory of EFB biomass production is shown in Table 1.

3.2. Life Cycle Inventory electricity production using Empty Fruit Bunch (EFB) Biomass

In this study, 25 kW of electricity generation using gasification has been developed. Gasification is a clean technology that converts different carbonaceous feedstocks such as natural gas, coal, petroleum, coke, biomass, and municipal solid wastes in a limited supply of air to gaseous products or called as synthesis gas such as H\textsubscript{2}, carbon monoxide (CO), CO\textsubscript{2}, water (H\textsubscript{2}O) as well as gaseous hydrocarbons at high temperatures [17]. Gasification technology is designed to produce combustible gas (CO, H\textsubscript{2}, CH\textsubscript{4}). These combustible gaseous are produced to replace fossil fuel as an engine fuel to generate electricity so that the gas content is attempted to be high with low tar content. In the current study, we gasified empty fruit bunch (EFB) biomass, the waste from fresh fruit bunches of the oil palm. Ogi et al [18] reported that EFB was gasified well enough in the presence of H\textsubscript{2}O alone to produce a product gas enriched in H\textsubscript{2} gas.

The design of the gasification system is an important factor to produce electricity and releasing some environmental impact. It is related to the efficiency of the system. More efficient system performance will reduce the environmental impact of the products produced. In other words, the minimum input can result in high electricity production so that the resulting environmental impact is low. The design of the gasification system consists of a biomass tank, reactor, cyclone, wet tar scrubber, gas filter, and gas engine. The biomass tank was an open hopper system. The top of the tank can easily open so that it was easy to put the biomass into the biomass tank. The reactor type was down craft type that purpose to have low tar content. Cyclone and wet tar scrubber were used to capture the tar that was still contained in the combustion gas. The gas filter was designed to remove the less tar after passing
through the wet tar scrubber. The gas engine was used with a capacity of 25 kW. The gasification system is shown in the Figure 4.

![Gasification System](image)

**Figure 4.** The gasification system of 25 kW electricity generation from EFB biomass

The method of working instrument during the gasification system consisting of the following stages. The EFB biomass needs to be prepared before the process. The EFB biomass was dried condition and cut to a certain size then inserted into the biomass tank. The amount of 1.6 kg EFB biomass inserted to the operation of 1 kWh. The operation of a tank top biomass consisted of a tank opened completion of the biomass, biomass included, biomass filling the tank back and closed the drawer opened, then stirrer rotated to ensure that biomass down with perfect and the drawers closed back. The gasifier panel turned on, all turned water pump, ensure that water can circulate. The gas generators are ready, valve with a new source of gas to which the vote, and pressed the button to open the generator will be able to operate on the use of gas fuel gasifier.

Various material was used to produce electricity in the gasification process. The EFB biomass was carried out from the palm oil plantation using a truck. This activity needs diesel as fuel for transportation. From the 100% EFB processed in the gasification system, 4% of husk charcoal was generated as by product. In the wet tar scrubber energy consumption such as electricity for a water pump and water consumption were used in the process. This wet tar scrubber contributed to generating waste such as tar and wastewater. Zeolite and glass wool were used as material consumption in each filter 1 and filter 2. These activities also produced waste tar, waste zeolite, and waste glass wool. Electricity was also used in the blower system. Blower which serves to direct the flow of air and gas from the machine of the scheme stratified downdraft gasification.
Table 2. Data Inventory of gasification system from EFB Biomass for 1 kWh electricity production

| Process          | Mass and Energy | Unit   | Quantity    | Source       |
|------------------|-----------------|--------|-------------|--------------|
| Transportation   |                 |        |             |              |
|                  | *Input:*        |        |             |              |
|                  | Diesel fossil fuel | L      | 1.13 x 10^-4 | Primary Data |
| Biomass Tank     |                 |        |             |              |
|                  | *Input:*        |        |             |              |
|                  | Empty Fruit Bunch | kg     | 1.60        | Primary Data |
|                  | *Output:*       |        |             |              |
|                  | Husk Charcoal   | kg     | 0.08        | Primary Data |
| Reactor          | -               |        |             |              |
| Cyclone          | -               |        |             |              |
| Wet tar Scrubber | *Input:*        |        |             |              |
|                  | Electricity for water pump | kWh | 9.50 x 10^-3 | Primary Data |
|                  | Water consumption | m³  | 7.13 x 10^-2 | Primary Data |
|                  | *Output:*       |        |             |              |
|                  | Waste tar       | kg     | 1.52 x 10^-3 | Primary Data |
|                  | Waste water     | m³     | 6.40        | Primary Data |
| Filter 1         | *Input:*        |        |             |              |
|                  | Zeolite         | kg     | 3.30 x 10^-4 | Primary Data |
|                  | *Output:*       |        |             |              |
|                  | Waste tar       | kg     | 1.52 x 10^-4 | Primary Data |
|                  | Waste zeolite   | kg     | 3.95 x 10^-2 | Primary Data |
| Blower           | *Input:*        |        |             |              |
|                  | Electricity     | kWh    | 1.19 x 10^-2 | Primary Data |
| Filter 2         | *Input:*        |        |             |              |
|                  | Glass wool      | kg     | 9.90 x 10^-6 | Primary Data |
|                  | *Output:*       |        |             |              |
|                  | Waste glass wool | kg    | 2.37 x 10^-2 | Primary Data |
|                  | Waste tar       | kg     | 1.52 x 10^-4 | Primary Data |
| Gas Engine       | *Input:*        |        |             |              |
|                  | Lead acid battery | unit   | 1.08 x 10^-5 | Primary Data |
|                  | Lubricant oil   | L      | 1.32 x 10^-4 | Primary Data |
|                  | Radiator coolant | L     | 1.39 x 10^-3 | Primary Data |
|                  | Filter          | unit   | 2.20 x 10^-5 | Primary Data |
|                  | *Output:*       |        |             |              |
|                  | Waste lubricant oil | L      | 2.37 x 10^-2 | Primary Data |
|                  | Waste radiator coolant | L    | 2.21 x 10^-1 | Primary Data |
|                  | Waste filter    | unit   | 3.96 x 10^-3 | Primary Data |
|                  | CO₂             | kg     | 5.13 x 10^-3 | Primary Data |
|                  | CH₄             | kg     | 2.08 x 10^-7 | Primary Data |
|                  | N₂O             | kg     | 4.15 x 10^-8 | Primary Data |
| User             | Cable connector | km     | 2           | Primary Data |

The largest inventory load from electricity production through EFB biomass gasification is the gas engine. The engine burns syngas and produces power. In the gas engine process lead acid battery, lubricant oil, radiator coolant, and filter were used as consumable material for supporting the gas engines in processing syngas to be power. The result of the syngas combustion process through the gas engine instead of power is the emission release through the gas engine exhaust. Several emissions to air such as particulate, SO₂, NO₂, CO, CO₂, CH₄, and N₂O are emitted during the process. CO₂, CH₄, and N₂O are the important emission contributed as GHG which causes a global warming potential. Some waste such as lubricant oil waste, radiator coolant waste, and filter waste were also released.
during the process. For the power distribution to the user, 2 km cable connector was used in the system. The detail data inventory in the gasification system using EFB Biomass is shown in the Table 2.

3.3. GWP of electricity production using EFB Biomass through gasification system

Biomass is a promising renewable alternative to decarbonize and to secure energy production in a small areas as most insular power generation systems rely heavily on imported fossil fuels which are costly or using coal which both responsible for greenhouse gas (GHG) emissions. Ever since the lack of petroleum resources began with the global energy crisis and the increasing concerns of rising greenhouse gas emissions, considerable attention has been focused on the development of alternative fuels. Unlike fossil fuel, biomass as renewable fuel has an advantage in maintaining a closed carbon cycle with no net increase in atmospheric CO$_2$ levels [19]. According to the inventory analysis conducted from this research. It is considered that the gas engine is the major of inventory load during the system. The gas engine process was the highest environmental impact in terms of global warming potential as presented in the Figure 5.

![Figure 5. Global warming potential impact of electricity production using EFB Biomass](image)

Gas engine contributed 58% of emission released following the fertilizing process 22%, blower 9%, wet tar scrubber 7%, protection 2%, and other processes less than 2%. Generally, emission from the gasification process plays a major contribution instead of biomass production itself. Lettner et al [20] stated that Products from incomplete combustion in exhaust gas engine or from producer gas slip (predominantly CO and CxHy) and high-temperature or fuel-nitrogen combustion (NOx) necessitate the operation of secondary treatment systems with regard to stipulated emission limits insofar as engine-specific measures are insufficient for minimizing pollutants in the engine gas. Treatments with various techniques involving catalytic converters or post-combustion techniques, which guarantee compliance with emission limits, are principally possible. Some balancing of emission controls may be necessary to achieve acceptable emission levels for different pollutants. Greenhouse CO$_2$ is reduced by the degree of substitution of biomass-based syngas for diesel as biomass is considered carbon neutral [21]. The utilization of EFB biomass using the gasification process of syngas powered engine is applicable and possible to be developed.
4. Conclusions and Future Work
The life cycle inventory of electricity production using gasification technology from an empty fruit bunch in Aceh Province, Indonesia was investigated. The life cycle inventory data has been developed based on the data criteria proposed by ISO 14044. Gas engine was the highest environmental load in terms of global warming potential in the gasification system to produce electricity from EFB biomass. In the future, multiple scenarios of the plantation, palm oil mill, and utilization of all waste to valuable material should be evaluated. Multiple scenarios can be used to support decision-makers to evaluate the best scenario of the process.

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