Life cycle assessment analysis of empty oil palm fruit bunches waste from palm oil mill activities

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Abstract. The process of utilizing existing empty oil palm fruit bunches is a process of utilization commonly carried out in various oil palm plantation industries. Palm oil liquid and solid waste is an environmental burden that produces global warming potential (GWP) emissions. This study aims to determine the magnitude of the environmental impact of using empty fruit bunches. The method used in this study is the ISO 14040 life cycle assessment (LCA) CML-Baseline IA method. The results showed that the existing use of empty fruit bunches in the plantation and the furnace showed that the furnace's global warming potential impact value was much higher than that of the plantation, which was 234.719 kg CO_2 eq and 234.689 kg CO_2 eq, respectively. The eutrophication impact is 0.951 kg PO_4 eq for furnace and plantation and an acidification effect of 0.525 kg SO_2 eq and 0.523 kg SO_2 eq. This concluded that they reduced the most dominant environmental impact by reducing raw materials by up to 80% of empty fruit bunches, which can be processed into co-composting and other technologies.

1 Introduction

The increase in world consumption of palm oil is due to the increasing use of world vegetable oil in line with the high number of the world population who use vegetable oil as food, cosmetics, and detergents [1]. The prospect of palm oil commodity in the world vegetable oil trade has encouraged the Indonesian government to spur the development of oil palm plantation areas. The area of oil palm land in Indonesia reached 16.03 million hectares in 2020 [2]. Production results in palm oil processing in the form of crude palm oil (CPO) continue to increase along with the increasing area of the oil palm plantation.

The palm oil industry consists of several stages, such as oil palm nurseries, oil palm plantation, CPO processing, and processing of derivative products [3, 4]. All of these stages have the potential to impact the environment. It is because the process requires several materials or materials that have potential. The activities of the palm oil production process, especially in palm oil mills, will generate waste. There are types of waste generated in this process, including liquid waste and solid waste. The solid waste generated at the palm oil mill is in the form of empty palm fruit bunches, fiber, and shells, while the liquid waste

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produced is in the form of sludge and is commonly referred to as palm oil mill effluent (POME) [5]. Another environmental impact generated by this processing is in the form of greenhouse gases. The greenhouse gases emitted are CO_2 expressed in CO_2 equivalent units. According to research [6], palm oil liquid and solid waste are environmental burdens that produce global warming potential (GWP) emissions. Effective waste treatment of this waste can reduce the value of greenhouse gases by 110 kg CO_2 eq/ton FFB. The processing of palm waste, mainly empty fruit bunches, is processed by spreading the empty fruit bunches in the plantation, which functions as organic material to add nutrients to the plants.

Furthermore, processing the second empty fruit bunches by burning the empty fruit bunches in a furnace produces burning ash used as fertilizer because it contains much potassium for the growth of oil palm plants on peatlands. Therefore, it is essential to analyze the environmental impact of the life cycle of the palm oil production process, primarily related to the solid waste of empty fruit bunches produced using the life cycle Assessment (LCA) approach. The boundary of the research system starts from the processing of FFB at the palm oil mill to the existing solid waste (gate to grave) treatment of empty fruit bunches. The purpose of this study was to determine the environmental impact of utilizing existing empty palm fruit bunches.

2 Methodology

This research is a non-experimental study included in quantitative analysis. The research was conducted at a palm oil mill (POM), POM A, with a 30 tons/hour capacity in the Riau region. This study measured primary and secondary data on energy and environmental impact emissions from using empty palm oil fruit bunches. Analysis of environmental impacts using the life cycle assessment (LCA) method by ISO 14040 standards using software [7-9]. In the life cycle assessment method, there are four stages, including:

2.1 Determination of objectives and scope

This study aims to analyze the environmental impact of the CPO processing process on the utilization of the existing solid waste of empty palm oil fruit bunches. Environmental impact analysis measured in this research is global warming, acidification, and eutrophication. The scope of this research is the gate to the grave, starting from the processing of FFB to the utilization of empty palm fruit bunches. This research needs to cover the transportation of FFB from plantation to mills, and research limitations focus on the use of solid waste, especially empty oil palm fruit bunches. The database used in this study is the ecoinvent 3.9 database utilizing the open LCA software. The limit of the research and the boundaries of the system can be seen in Figure 1.

2.2 Life cycle inventory

Inventory or data collected in this study are primary and secondary company data. The data is collected from each stage of the respective activity process on a 2019-2021 basis, data collection using a questionnaire. Data collection is carried out to obtain various input and output sets for each business unit through the stage of searching for and receiving data that describes the life cycle inventory in the supply chain of the palm oil industry and various conversion factors to take into account life cycle assessment.

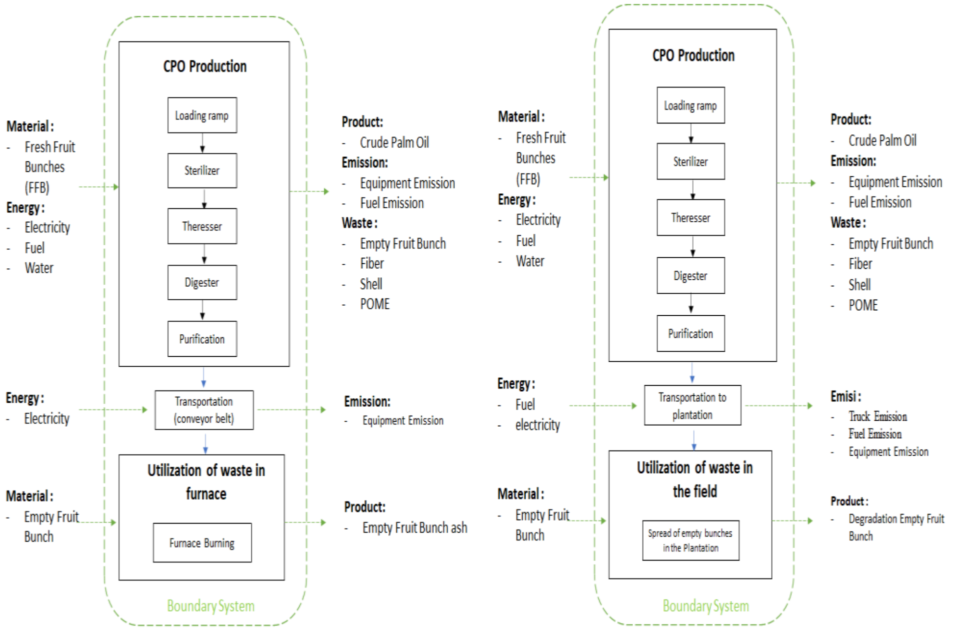

Fig. 1. Boundary system utilization for empty fruit bunches in furnace and plantation

2.3 Life cycle inventory analysis

The data that has been collected is then processed using the open LCA software, and the results of the environmental impact assessment from the calculation of the open LCA software. The method used in measuring the impact is the CML-IA Baseline method. The effects counted in this study are global warming potential (GWP), eutrophication, and acidification values.

2.4 Interpretation

Based on the inventory analysis and impact analysis carried out, it is possible to interpret the results of the LCA study based on the magnitude of the impact arising from the existing waste treatment process. The analysis used in interpreting the results is contribution analysis and sensitivity analysis.

3 Results and discussion

The process of utilizing the existing waste of empty palm oil bunches in POM A has a capacity of 30 tons/hour from processing palm oil/CPO production. The open LCA software calculations show the magnitude of the environmental impact of using empty fruit bunches from using energy and materials.

3.1 Impact analysis

Based on the impact calculation using the open LCA Software CML-Baseline IA method, it is known that the impact was caused by using existing empty oil palm fruit bunches on the furnace and plantation (Figure 2).

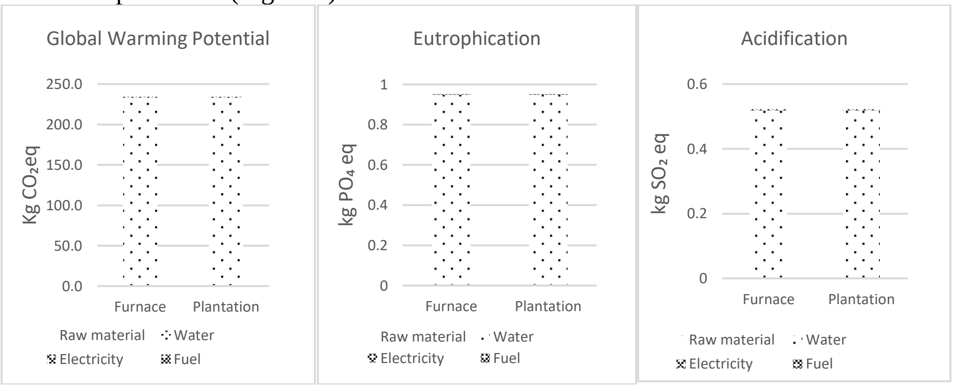

Fig. 2. Graph of the impact of CPO production for furnace and plantation

Figure 2 shows that in the furnace user's life cycle inventory analysis (LCIA), the total potential global warming environmental impact produced is 234.719 kg CO_2 eq and the eutrophication impact is 0.951 kg PO_4 eq, and the acidification impact is 0.525 kg SO_2 eq. The total potential global warming environmental impact produced for plantation is 234.687 kg CO_2 eq and the eutrophication impact is 0.951 kg PO_4 eq, and the acidification impact is 0.523 kg SO_2 eq.

Details on the composition of the potential global warming factors for CPO production to furnace and plantation are same (raw materials 233.002 kg CO_2 eq, water use 0.0002 kg CO_2 eq, electricity use 0.74 kg CO_2 eq, fuel use 0.25 kg CO_2 eq). Details on the composition of the eutrophication impact factors for CPO production to furnace and plantation are same (raw materials 0.948 kg PO_4 eq, water use 3.329 $x10^{-7}$ kg PO_4 eq, electricity use 0.00158 kg PO_4 eq, fuel use 0.000166 kg PO_4 eq). Details on the composition of acidification impact factors for CPO production to furnace and plantation are same (raw materials 0.518 kg SO_2 eq, water use 1.015 $x10^{-6}$ kg SO_2 eq, electricity use 0.00293 kg SO_2 eq, fuel use 0.00102 kg SO_2 eq). It shows that the magnitude of the environmental impact of the raw material composition produces a more significant effect than the others.

Meanwhile, the transportation and processing system distinguishes the two existing treatment (by burning and spreading them on the plantation) (Figure 3). Details the potential global warming factors for transportation and existing treatment to furnace were 0.63 kg CO_2 eq, and 0.089 kg CO_2 eq. Eutrophication impact factors were 1.66 $x10^{-6}$ kg PO_4 eq, and existing treatment 1.17 $x10^{-5}$ kg PO_4 eq. Acidification impact factors were 0.00207 kg SO_2 eq, and existing treatment 0.00047 kg SO_2 eq.

Details the potential global warming factors for transportation and existing treatment to plantation were transportation 0.693 kg CO_2 eq, and existing treatment 1.21 $x10^{-8}$ kg CO_2 eq. Eutrophication impact factors were transportation 1.47 $x10^{-5}$ kg PO_4 eq, and existing treatment $1.46x10^{-11}$ kg PO_4 eq. Acidification impact factors were transportation $4.44x10^{-5}$ kg SO_2 eq, and existing treatment $3.724x10^{-11}$ kg SO_2 eq. It shows that the magnitude of the environmental impact existing treatment of plantation was lower than furnace.

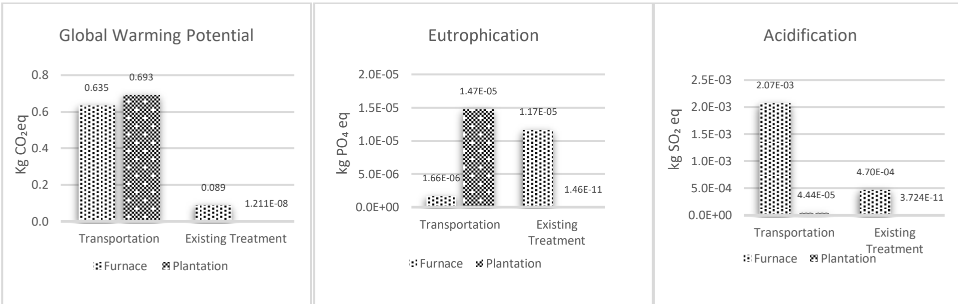

Fig. 3. Graph of the impact of transportation and existing treatment for furnace and plantation

3.2 Interpretation of results

The impact of global warming is the most significant impact of each processing unit of existing empty palm oil fruit bunches. Interpretation of the LCA study results as an effort to recommend improvements to reduce environmental impact. The interpretation of the results consists of the following contribution analysis and sensitivity analysis.

3.2.1 Contribution analysis

Contribution analysis in LCA is an analysis that has the most significant impact on a process. It is consistent with Mayjen (2014) that in carrying out an interpretation in determining essential issues, the approach used is the contribution method which aims to identify data that has the most significant contribution to the impact results so that decision-making and improvement of the system become appropriate and effective [10]. In the existing utilization of empty fruit bunches (furnace and plantation), the contribution of the most dominant environmental impact can be seen in Figure 4.

Figure 4 shows that the environmental impact on potential global warming between the furnace and the plantation can be seen existing treatment which is higher in the furnace compared to the use of the plantation. However, transportation in the plantation is more dominant in producing a global warming potential environmental impact. In the transportation activity to the plantation, emission calculations are calculated using fuel, the type of truck, and the distance from the POM to the plantation.

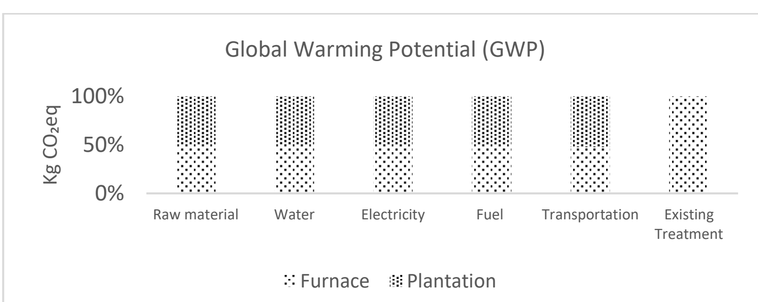

Fig.4. Global Warming Potential of Furnace and Plantation

The effect of eutrophication is one of the environmental problems that occur in aquatic ecosystems, which causes oxygen depletion, which can damage marine ecosystems due to the loss of phosphorus [11]. The impact of eutrophication on the existing utilization of POM

A, with a capacity of 30 tons/hour, can be seen in Figure 5. Figure 5 shows that transportation is the most significant sources of eutrophication in the life cycle of an existing plantation. It indicates that the processing process in the plantation emits phosphate pollutants which are high at the hotspots of fuel oil compared to furnace. While using hotspot furnace, the highest expenditure of phosphate is found in existing treatment because burning empty fruit bunch. Based on research by Pamintos et al. (2022), in the production of biodiesel from oil palm, the total impact of eutrophication was 1.24 kg PO_4 eq, 67.6% of which came from the plantation stage. Eutrophication from the plantation process was 0.84 kg PO_4 eq, and CPO production was 0.32 kg PO_4 eq [12].

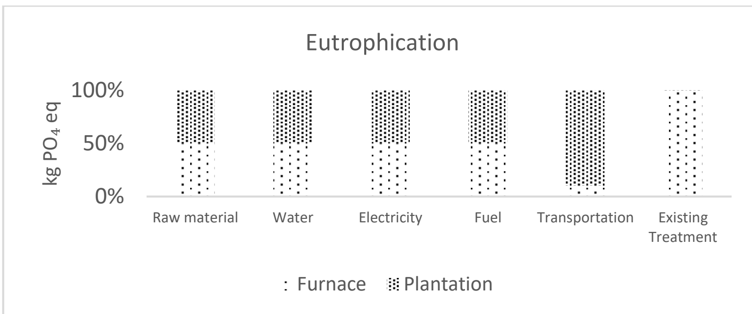

Fig. 5. Potential eutrophication of furnace and plantation

The environmental impact of water acidification is counted as SO_2 and NOx, which reach the atmosphere and react with water vapor that can produce SO_2 pollutants. The impact of acidification on furnace and plantation is shown in Figure 6. In the effect of acidification in the furnace, the most dominant factors that have SO_2 are transportation and existing treatment use. Previous studies for the production of biodiesel produced an acidification effect of 0.42 kg SO_2eq, so it can be said that the development of acidification in this study was relatively high [12].

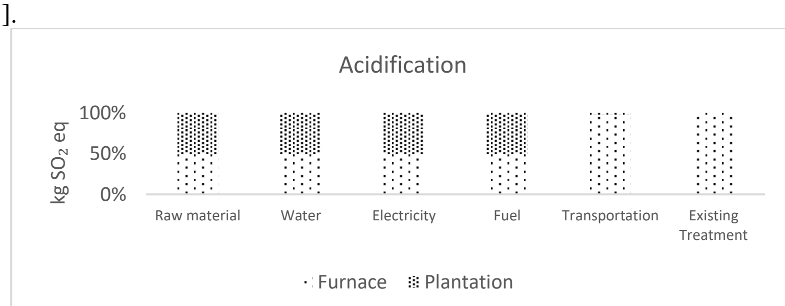

Fig.6. Potential acidification of furnace and plantation

3.2.2 Sensitivity analysis

Raw materials are this study's most dominant materials in producing environmental impacts. The sensitivity analysis results of reducing raw materials for environmental effects on furnaces and plantation with a reduction of 80% can reduce the environmental impact of global warming potential, eutrophication, and acidification (Figure 7).

The percentage pattern of reduction of raw materials at 80% shows a significantly lower impact than the pattern of decline of 20% and 50% in the utilization of empty fruit bunches from the furnace and plantation. If seen from the percentage of 0%, a reduction of 80% of raw materials can reduce GWP emissions by 46.60 kg CO_2 eq in the furnace and plantation. The justification for reducing raw materials by 80% is when there is an application technology for utilizing empty fruit bunches with a co-composting system[13-15]. The empty fruit bunches resulting from the oil production are not entirely processed in the plantation or the furnace but can be processed with other technologies in 80% of the raw material waste. The literature [6, 16] shows that effective waste treatment of this waste can reduce the value of greenhouse gases (GHG) by 110 kg CO_2 eq/ton FFB or the equivalent of 220 kg CO_2 eq/ton CPO. Another factor in the justification for the decrease in empty fruit bunch's raw material, when viewed from the production side of fresh fruit bunches, is a decrease in plantation productivity. It means yield productivity affects the impact because the input waste generated comes from fresh fruit bunches, which are processed into CPO. If the productivity of the plantation decreases, the quantities of the fruit produced are reduced, and directly proportional to the empty fruit bunches produced will also be reduced. According to Yanita dan Suandi (2021), decreased productivity occurs due to old oil palm plants, lack of nutrients, land area, fertilizers, and pesticides [17].

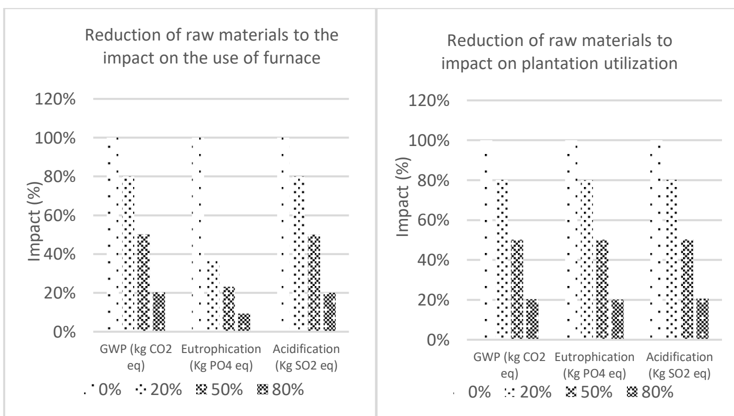

Fig. 7. Percentage of influence of raw materials on impact

4 Conclusion

The results of POM A calculations with a capacity of 30 tons/hour, the existing use of empty fruit bunches in the plantation and the furnace show that the value of the global warming impact on the furnace is much higher than the plantation, which is 234.719 kg CO_2 eq and 234.687 kg CO_2 eq, respectively. The eutrophication impact of the two utilizations was same 0.951 kg PO_4 eq. Compared with previous research on biodiesel production, it produced a eutrophication effect of 1.24 kg PO_4eq, so the eutrophication impact for two existing treatment was lower. The acidification impact was 0.525 kg SO_2 eq and 0.523 kg SO_2 eq, respectively. This research, raw materials are the main contribution to the CPO production stage, followed by transportation and treatment of existing stages. The sensitivity analysis results of an 80% reduction of raw materials show a significant decrease in GWP values, namely 46.60 kg CO_2 eq for existing treatment. Using existing furnace and plantation, GWP's environmental impact can be reduced by using raw materials for other technological applications, such as co-composting applications.

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