# Life Cycle Assessment (LCA) in Palm Oil Plantation and Mill with Impact Categories Global Warming Potential, Acidification, and Eutrophication

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**Abstracts:** The aims are to capture the energy and materials data used to analyze the LCA results in PT. X Study oil palm plantations and mills in Indonesia to find out which stages have the greatest impact on global warming potential (GWP), acidification, and eutrophication. The method used is the LCA approach with the CML-Baseline method. The system boundary in this research is cradle-to-gate on the plantation and mill. The data collected from January to December 2019 exclude the land-use change in plantation, liquid waste and sludge, tools used in plantation, and the amount of water used in plantation and mill, the data proceeded on Microsoft Excel and SimaPro 9.0.0.49. The inventory data collected from plantations are fertilizers, pesticides during plant maintenance, and diesel fuel for transportation, also inventory data collected from mills are electrical energy, steam energy, and diesel fuel. The greatest emissions or hotspots at the plantations are on the usage of fertilizers NPK 15-7-24+1 (384 Kg CO2 equivalent/Ton CPO for GWP, 1.93 Kg SO2 equivalent/Ton for acidification, and 0.65 Kg PO4 equivalent/Ton CPO for eutrophication). The hotspots at the mills for GWP and acidification are on the usage of steam energy boiler no.1 (1,273 Kg CO 2 equivalent/Ton CPO and 10.4 Kg SO 2 equivalent/Ton CPO respectively), and the result for eutrophication is 0.64 Kg PO 4 equivalent/Ton CPO on the usage of electrical energy, Cummins 1 and Cummins 2. The total impact factor is 2.433 Ton CO2 equivalent/Ton CPO for GWP, 16.41 x 10-3 Ton SO2 equivalent/Ton CPO for acidification, and 2,65 x 10-3 Ton PO4 equivalent/Ton CPO for eutrophication.

**Keywords:** Acidification, Eutrophication, Global warming potential (GWP), Life cycle assessment (LCA), Palm oil industry, Simapro.

## 1. INTRODUCTION

One crop that produces oil for commercial purposes is palm oil (*Elaeis guneensis* Jacq.). Indonesia's palm oil is the largest agricultural industry and Indonesia has set a record as the world's largest palm oil producer. The highest area share has been identified on the island of Sumatra, which accounts for 80% of total production [1]. Palm oil fruits can be processed into several semi-processed ingredients such as crude palm oil (CPO) and palm kernel oil (PKO) which make it a plant with high economic value, however, environmental problems are inherent in palm oil plantations. At least half of the 8 million hectares of plantations currently in production are developed through deforestation [2].

Land-use change in woodland and agricultural land Pollution in oil palm plantations can lead to environmental problems such as greenhouse gas (GHG) emissions, air pollutant emissions, and biodiversity loss, animals, plants and species in forest ecosystems [3]. The accumulation of GHG in the atmosphere increases the global-mean temperature and climate change that affects people's livelihood, forest fire disasters and drought, loss of property, and infrastructure damage [4–8].

The production process, energy consumption, and waste degradation process in palm oil mills can produce greenhouse gases such as carbon ($CO_2$), methane ($CH_4$), nitrous oxide ($N_2O$), and other gases [9,10]. Methane gas is necessary to be processed into a biogas power plant that can generate electricity to be used for the production process [11,12]. As an alternative energy source, the need and the use of energy for the production process of Crude Palm Oil (CPO) itself needs to be identified, to know the number of emissions produced. In this research, a Life Cycle Assessment (LCA) will be conducted on the plantation and palm oil mill at PT. X Indonesia. Another literature has shown that LCA has been applied in several case studies to evaluate the impacts of crude palm oil production [13].

The assessment is carried out to analyze the environmental impact during the product life cycle, also, LCA can be used to help the company's business strategy in making decisions, improving product and process quality, and studying the environmental aspects of the product. The research focused on the scope of Cradle to Gate, which means assessing and analyzing the impact of the whole series of CPO production processes that begin from nursery activities to CPO production and have not been distributed to consumers. Three impact categories are used: Global Warming Potential, Acidification, and Eutrophication, this impact category is the most important and common environmental issue in the production of palm oil. LCA approach was chosen to find out the number and valid data on emissions produced during the CPO production process with impact categories that have been determined and know the next steps to improve environmental quality.

## 2. METHODS

This study uses the Life Cycle Assessment approach with the CML-Baseline method on the boundary of the Cradle to Gate system in the plantation and mill of PT. X Indonesia. The scheme of the system boundary can be seen in Figure **1**.

The stages of the research process are divided into four, the first stage is the definition, objectives, and scope, the second stage is the Life Cycle Inventory (LCI), the second stage is the collection of secondary data in the form of energy and material inventory of the entire set of Crude Palm Oil (CPO) production process activities within the cradle-to-gate limit obtained from the palm oil mill PT. X Indonesia. The third stage is Life Cycle Inventory Assessment (LCIA), in addition, the inventory data will be assessed, and additional information can help the process. The last stage is an interpretation that summarizes and discusses the result from LCI and LCIA stages that help to make recommendations and decisions.

The purpose of the research is to collect energy and material inventory data during 2019 from PT. X Indonesia, analyze the results of the Life Cycle Assessment (LCA) of PT. X Indonesia with impact categories from GWP, Acidification, and Eutrophication to find the location of phases with the greatest impact on GWP, acidification, and eutrophication and provide recommendations to improve environmental quality. At the LCI stage, the secondary data that was collected is a routine report on the company's internal use of energy and materials which is then verified by the author through field studies. Data that were collected proceeded using Microsoft Excel and SimaPro 9.0.0.49 software. The impact categories used are the most important and common environmental issues in palm oil production activities because palm oil production has the potential to pollute the air, soil, and water, there are GWP, Acidification, and Eutrophication. Global temperature changes due to greenhouse gases, and human activity is also one of the causes. Increased temperature conditions globally can cause climate change, desertification, rising sea levels, and the spread of disease. Climate change is one of the most important environmental impacts and the most difficult to manage because of its large scale. The Intergovernmental Panel on Climate Change (IPCC) has developed the characterization value. The factor is expressed as Global Warming Potential (GWP), the timeframe can vary, but the most commonly used is 100 years (GWP100) with the unit of function which is Kg $CO_2$ Equivalent [14]. Table **1** lists the impact category outline of climate change.

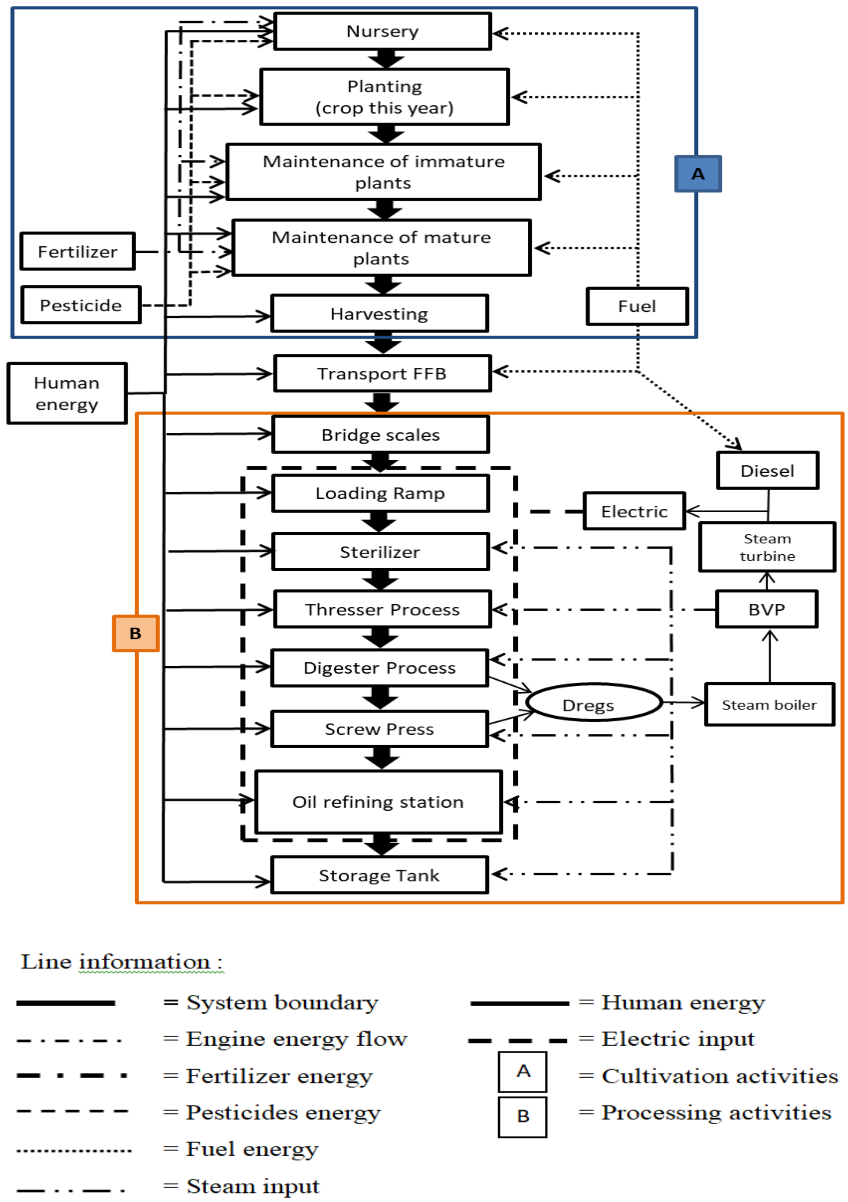


**Figure 1.** Research System Boundary.

**Source:** Edited and Inspired by [15].

**Table 1.** A Brief Description of the Most Commonly Used Impact Categories, Climate Change.

| **Impact Category: Climate Change** | |
|---|---|
| Definition | Changes in global temperature due to greenhouse gases |
| Impact indicator | Confusion of global temperature and climatic phenomena |
| Considerations | Greenhouse gases and their global warming potential (GWP), e.g., methane, sulfur hexafluoride, etc. |
| Damage categories (endpoint) | Crops, forests, coral reefs, etc. (loss of general biodiversity), temperature disturbances, climate phenomenon anomalies (e.g., more intense hurricanes, torrential rains, etc.) |
| Unit | Kg $CO_2$ Equivalent |

Acid gases such as $SO_2$ can react with water in the atmosphere to form acid rain and damage ecosystems. According to the Intergovernmental Panel on Change (IPCC), the use of fertilizers is included in the acidification of the function unit Kg $SO_2$ Equivalent [14]. Table **2** lists the impact category outline of acidification.

**Table 2.** A Brief Description of the Most Commonly used Impact Categories, Acidification.

| **Impact Category: Acidification** | |
|---|---|
| Definition | Decrease in pH value due to the acidifying effect of anthropogenic emissions |
| Impact indicator | Increased acidity of water and soil systems |
| Considerations | Possible acidification of nitrogen oxides and sulfur oxides |
| Damage categories (endpoint) | Degradation of ecosystem quality and loss of biodiversity |
| Unit | Kg $SO_2$ Equivalent |

Accumulation of chemical nutrient concentrations in ecosystems that cause abnormal productivity is called eutrophication. Not only to water, emissions such as ammonia, nitrate, nitrogen oxides, and phosphorus into the air also have an impact on eutrophication. The unit of function unit used is Kg $PO_4$ Equivalent [14]. Table **3** lists the impact category outline of eutrophication.

**Table 3.** A Brief Description of the Most Commonly used Impact Categories, Eutrophication.

| **Impact Category: Eutrophication** | |
|---|---|
| Definition | Accumulation of nutrients in water systems |
| Impact indicator | Increased nitrogen and phosphorus concentrations, formation of biomass (e.g. algae) |
| Considerations | Nutrient transport (air, water, runoff from land) |
| Damage categories (endpoint) | Degradation of ecosystem quality |
| Unit | Depending on the model: Kg $PO_4$ Equivalent, Kg N Equivalent |

Energy, and material inventory data that will be collected starts from the cultivation activities and continues to the processing activities, such as the use of agricultural equipment and machinery, fuel oil, fertilizers, pesticides, steam energy, and electricity. The cultivation activities begin at the nursery stage. At the nursery stage, there is energy input from fuel used by transport vehicles, tools, and agricultural machinery, then there are material inputs in the form of fertilizers and pesticides, which then will be divided according to the type used.

The next stages are processing the land, planting, and maintaining plants, then continuing until the final refining process and the oil produced is stored in a storage tank.nAt the LCIA stage, the company's secondary data in the form of energy and material inventory at each stage that has been collected will be multiplied by the characterization factor of the CML-Baseline database based on impact categories, GWP ($CO_2$), Acidification ($SO_2$) and Eutrophication ($PO_4$). The characterization factor can be seen in the SimaPro software. Each data will be processed to produce an impact factor, then the number of the impact factor will show where is the location of the stages that produce the largest emissions or hotspots, and the last stage is interpretation, in this stage, inventory data calculations or Life Cycle Inventory Assessment (LCIA) results for each stage are collected according to the CML baseline method using characterization factors, then there will be seen hotspots from the results of the assessment of each stage according to impact categories and can be interpreted. This interpretation will be depending on the objectives and scope that have been set to obtain conclusions and recommendations that lead to improvements to reduce the environmental impact resulting from the observed system, product, or process.

## 3. RESULTS

The research was conducted at the cradle-to-gate limits and disregarded the land-use change in plantations, liquid waste, sludge, tools used in plantations, and the amount of water used in plantations and mills. The palm oil trees have become Producing Plants (PP) in 2019, hence the energy data can collect from the maintenance of Producing Plants (PP), harvesting, and transporting of Fresh Fruit Bunches (FFB) to the mill. The maintenance of Productive Plants (PP) such as giving fertilizer for six months, pesticides, also, cleaning of leaves or trash around the tree to prevent decreasing pH in soil, otherwise, the soil becomes acidic. Table **4** lists the inventory data of plantations every month in 2019.

**Table 4.** Plantation Inventory Data on 2019.

| Activities | Type of Activity | Type | Amount | Average | UNIT |
|---|---|---|---|---|---|
| Maintenance of mature plants | Fertilizer | Dolomite (CaO, MgO) | 546,500 | 45,541.67 | Kg |
| | | NPK 15.7.24+1 | 1,175,600 | 97,966.67 | Kg |
| | | NPK 14.7.25+1 | 1,041,250 | 86,770.83 | Kg |
| Maintenance of mature plants | Pesticide | Marshal 5G (Carbosulfan 5%) | 10 | 0.83 | Kg |
| | | Marshal 200EC (Carbosulfan 200 g/l) | 95 | 7.92 | Liter |
| | | Ratgone 0,005 BB (Brodifacoum 0,005%) | 41 | 3.42 | Kg |
| | | Marfu - P (Trichoderma koningii 2x107 cfu/gr) | 260 | 21.67 | Kg |
| | | Starane 480EC (Fluroxypyr methylheptyl ester 480 g/l) | 20 | 1.67 | Liter |
| | | Momento 20 WP (Methil metsulfuron 20%) | 51 | 4.25 | Kg |
| | | Best Up (IPA Glyphosate 480 g/l) | 1,878 | 156.50 | Liter |
| Diesel fuel | Transportation | Fuel | 262,470 | 21,872.50 | Liter |

Inventory data in the mills in 2019 are the use of electrical energy in supporting the operation of machine tools, the use of steam energy, also the use of fuel energy for diesel engines and vehicles such as small vehicles, trucks, and heavy equipment. Factory processing relies on fresh fruit bunches (FFB) that are harvested from the plantation sector and brought to the factory. This is because the quality of the fruit may be affected if these are not processed immediately. accumulation of all existing units in the mill every month for one full year. Lists inventory data on the mill for 2019. Afterward, inventory data were assessed using SimaPro software and/or used Microsoft Excel application as a manual calculation.

**Table 5.** Mill Inventory Data on 2019.

| Activities | Type of Activity | Type | Amount | Average | Unit |
|---|---|---|---|---|---|
| Electrical energy | - | Turbine No. 1 | 1,384,798 | **115,399.83** | kWh |
| | | Cummins No.1 | 34,903 | **2,908.58** | kWh |
| | | Cummins No.2 | 220,708 | **18,392.33** | kWh |
| Steam energy | - | Boiler No.1 | 53,855 | **4,487.92** | m3 |
| Fuel energy | Diesel Cummins KTA-38 G 2 (250 KVA) | Fuel | 10,235 | **852.92** | Liter |
| | Diesel Cummins KTA-38 G 2 (750 KVA) | Fuel | 90,325 | **7,527.08** | Liter |
| | Small vehicles | Fuel | 2,310 | **192.50** | Liter |
| | Truck vehicles | Fuel | 27,928 | **2,327.33** | Liter |
| | Heavy equipment | Fuel | 19,620 | **1,635.00** | Liter |

Furthermore, the amount of energy used every month is summed into one year, subsequently, the amount of energy in one year is multiplied by the characterization factor according to impact categories. In one year, the plantation has produced Crude Palm Oil (CPO) of 11,715 tons. From the overall impact factor results obtained, it can be seen the location that has the biggest emissions or hotspots on plantations, for GWP in one year is 384 kg $CO_2$ equivalent/Ton of CPO of the use NPK fertilizer 15-7-24+1, meanwhile for acidification in one year is 1.93 Kg $SO_2$ equivalent/Ton of CPO obtained from the use of NPK fertilizers 15-7-24+1, and for eutrophication is 0.65 kg $PO_4$ equivalent/Ton of CPO obtained from the use of NPK fertilizers 15-7-24+1, with the same time measurements. Figure Error! Reference source not found., Figure Error! Reference source not found., and Figure Error! Reference source not found. shows the SimaPro LCIA results on the plantations, and Figure Error! Reference source not found., Figure Error! Reference source not found., and Figure Error! Reference source not found. shows the SimaPro LCIA results on the mills. Process the data in the mill are similar to the plantations, however, the use of fuel energy for small vehicles at the mill is assumed for January until June 2019, by adding up the usage in July until December 2019 then divided by six months for each month, hence for January until June is 385 liters per month. From the overall results of the impact factors, it can be perceived the location that has the biggest emissions (hotspots) at the mills for GWP in one year is 1,273 Kg $CO_2$ equivalent/Ton of CPO from the use of steam energy Boiler No.1, same for acidification, the hotspot is found in the use of steam energy Boiler No.1, the impact factor is 10.4 Kg $SO_2$ equivalent/Ton of CPO, and for eutrophication in one year is 0.64 Kg $PO_4$ equivalent/Ton CPO obtained from the use of electrical energy Turbine, Cummins 1, and Cummins 2 which used the same type of medium voltage electrical energy in the SimaPro software due to database limitations.

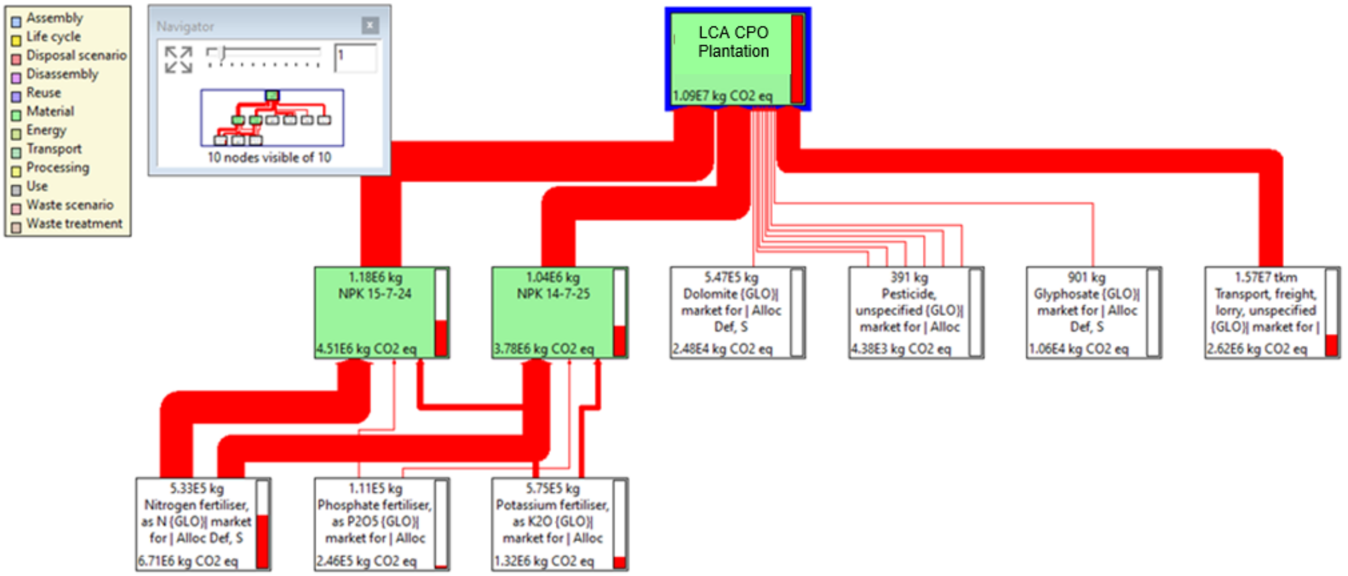


**Figure 2**. LCIA Results from Simapro Software for GWP in the Plantation.

The hotspot is in the use of fertilizer NPK 15-7-24+1 (the unit used in the SimaPro is Kg $CO_2$ equivalent, hence the unit used in the final result is Kg $CO_2$ equivalent/Ton CPO) the amount of hotspot was divided with total CPO produced in one year.

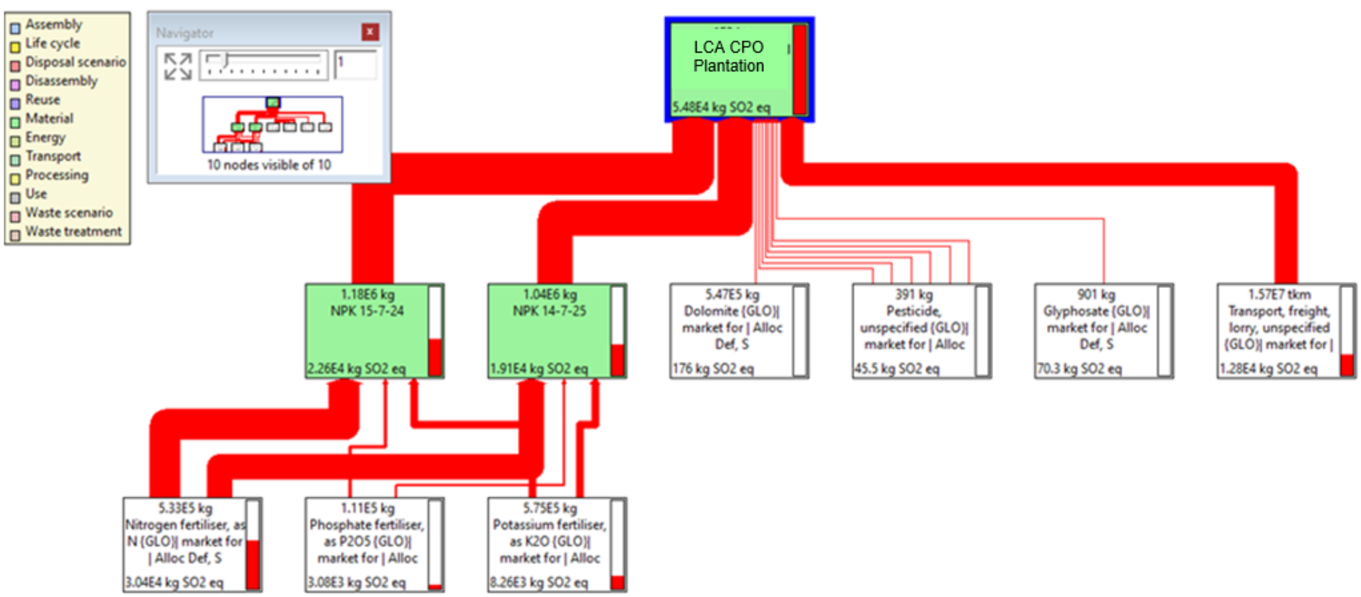


**Figure 3**. LCIA Results from SimaPro Software for Acidification in the Plantation.

The hotspot is in the use of NPK fertilizer 15-7-24+1 (the unit used in the SimaPro is Kg $SO_2$ equivalent, hence the unit used in the final result is Kg $SO_2$ equivalent/Ton CPO) the amount of hotspot was divided with total CPO produced in one year.

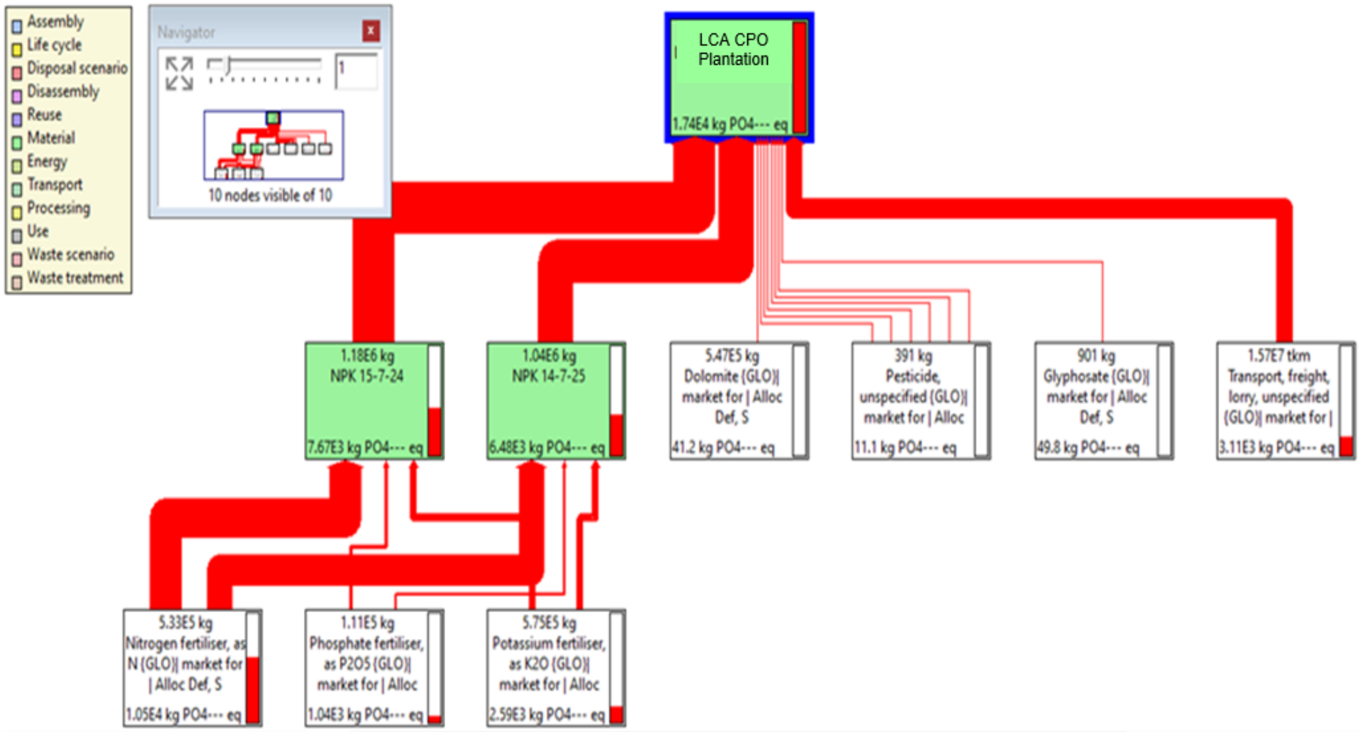


**Figure 4**. LCIA Results from SimaPro Software for Eutrophication in the Plantation.

The hotspot is in the use of fertilizer NPK 15-7-24+1 (the unit used in the SimaPro is Kg $PO_4$ equivalent, hence the unit used in the final result is Kg $PO_4$ equivalent/Ton CPO) the amount of hotspot was divided with total CPO produced in one year.

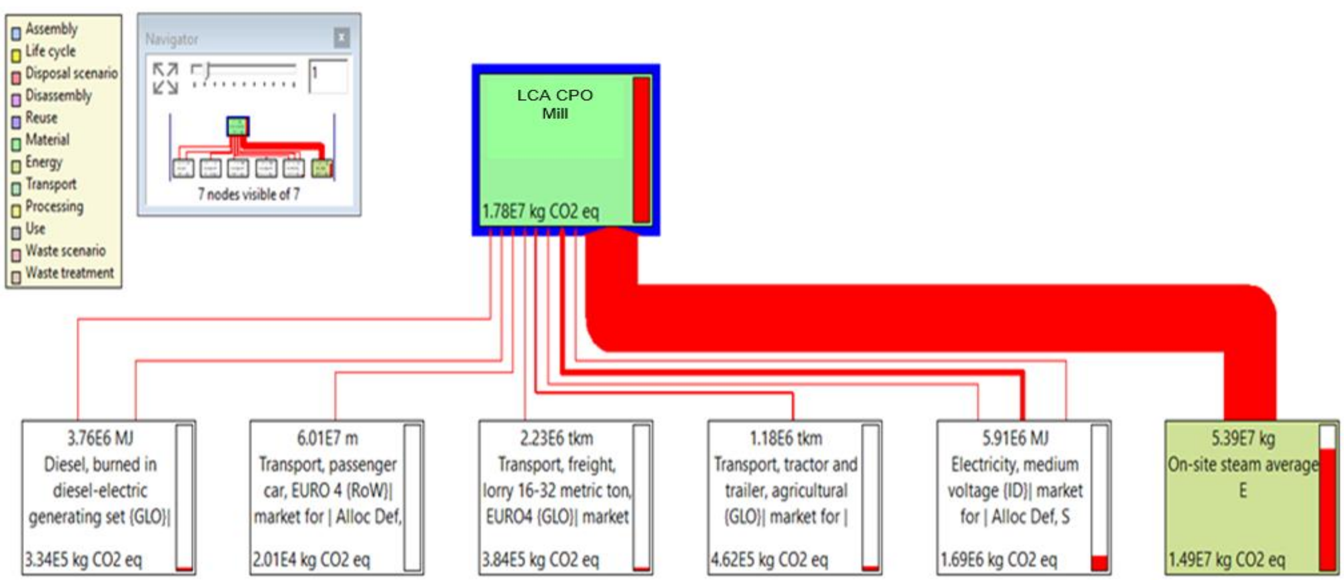


**Figure 5.** LCIA Results from SimaPro Software for GWP in the Mill.

The hotspot is in the use of steam energy (the unit used in the SimaPro is Kg $CO_2$ equivalent, hence the unit used in the final result is Kg $CO_2$ equivalent/Ton CPO) the amount of hotspot was divided by total CPO produced in one year.

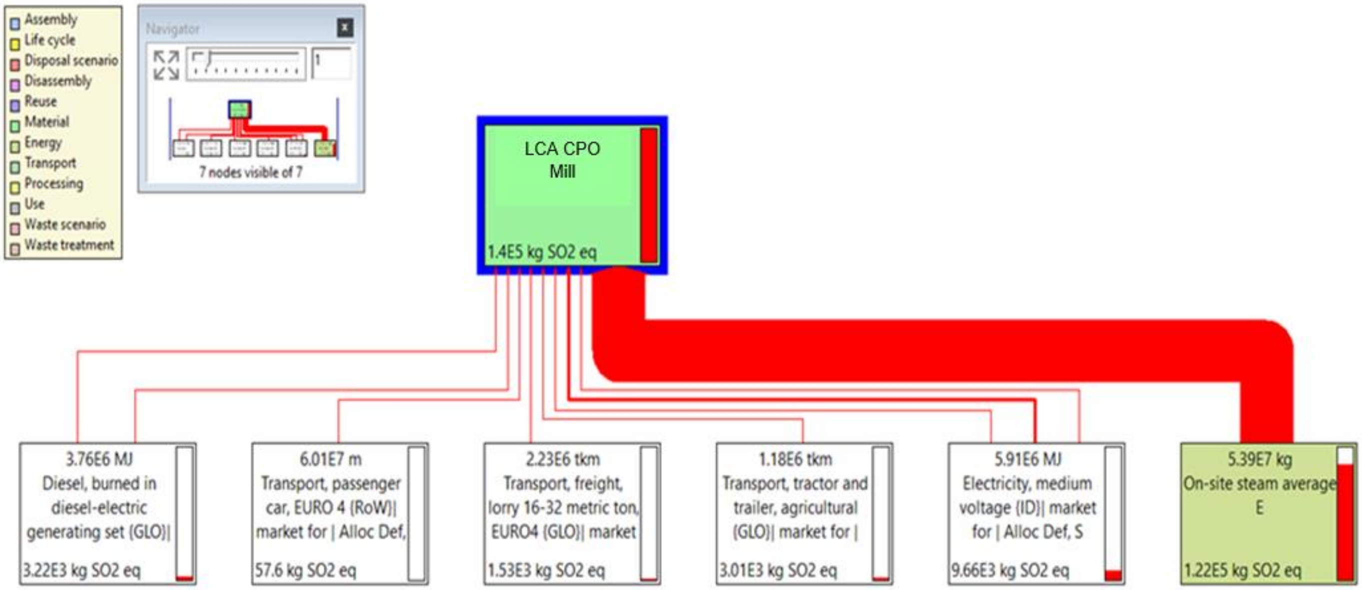


**Figure 6**. LCIA Results from SimaPro Software for Acidification in the Mill.

The hotspot is in the use of steam energy (the unit used in the SimaPro is Kg $SO_2$ equivalent, hence the unit used in the final result is Kg $SO_2$ equivalent/Ton CPO) the amount of hotspot was divided by total CPO produced in one year.

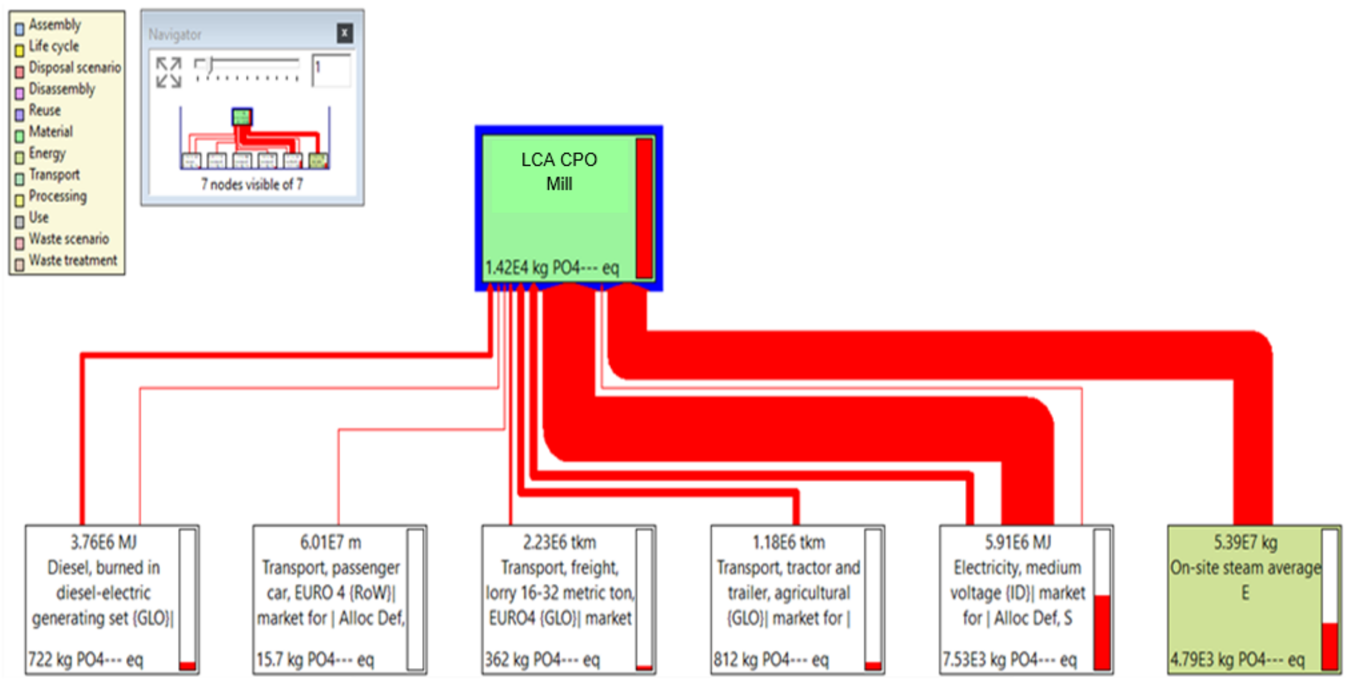


**Figure 7**. LCIA Results from SimaPro Software for Eutrophication in the Mill.

The hotspot is in the use of electrical energy Turbine, Cummins 1, and Cummins 2 (the unit used in the SimaPro is Kg $PO_4$ equivalent, hence the unit used in the final result is Kg $PO_4$ equivalent/Ton CPO) the amount of hotspot was divided with total CPO produced in one year.

## 4. DISCUSSION

The Interpretation phase summarizes the results of emission calculations performed on Microsoft Excel and SimaPro software which has shown the same results. The biggest emissions (hotspots) are obtained at:

a. Global warming potential
- Plantation: Obtained from the use of NPK fertilizer 15-7-24+1 in one year, the impact factor is 384 kg $CO_2$ equivalent/Ton of CPO.
- Mill: Obtained on the use of steam energy in Boiler No.1, in one year, the impact factor is 1,273 kg $CO_2$ equivalent/Ton of CPO.

b. Acidification
- Plantation: Obtained from the use of NPK fertilizer 15-7-24+1 in one year, the impact factor is 1.93 Kg $SO_2$ equivalent/Ton of CPO.
- Mill: Obtained on the use of steam energy in Boiler No.1 in one year, the impact factor is 10.4 kg $SO_2$ equivalent/Ton of CPO

c. Eutrophication
- Plantation: Obtained on the use of NPK fertilizer 15-7-24+1 in one year, the impact factor is 0.65 kg $PO_4$ equivalent/Ton of CPO.
- Mill: Obtained on the use of electrical energy Turbine, Cummins 1, and Cummins 2 which used the same type of medium voltage electrical energy in the SimaPro application due to database limitations in one year, the impact factor is 0.64 Kg $PO_4$ equivalent/Ton CPO

The following is a recapitulation of each energy that produces the largest emissions, Table **6** lists the impact factor in the plantation, and Table **7** lists the impact factor in the mill.

**Table 6.** Recapitulation of the Biggest Emission Produced in Plantation for Each Impact Category.

| **Impact Factor Plantation** | | |
|---|---|---|
| **Type** | **Amount** | |
| GWP (Kg $CO_2$ Eq/Ton CPO) | NPK 15.7.24+1 | 384 |
| Acidification (Kg $SO_2$ Eq/Ton CPO) | NPK 15.7.24+1 | 1.93 |
| Eutrophication (Kg $PO_4$ Eq/Ton CPO) | NPK 15.7.24+1 | 0.65 |

**Table 7.** Recapitulation of the Biggest Emission Produced in Mill for Each Impact Category.

| **Impact Factor Mill** | | |
|---|---|---|
| **Type** | **Amount** | |
| GWP (Kg $CO_2$ Eq/Ton CPO) | Boiler No. 1 | 1,273 |
| Acidification (Kg $SO_2$ Eq/Ton CPO) | Boiler No. 1 | 10.44 |
| Eutrophication (Kg $PO_4$ Eq/Ton CPO) | Electric energy | 0.64 |

On the plantations, the use of NPK 15-7-24+1 fertilizer is the biggest emission (hotspot) in the category of GWP, acidification, and eutrophication, this can be caused by the maintenance activities of Producing Plants (PP). The greenhouse gases produced $CO_2$, if the concentration of $CO_2$ is high in the atmosphere, it can cause climate change or an increasing global temperature. Besides, $SO_2$ pollutants that cause acidification in the soil can cause acid rain, then the use of NPK fertilizers 15-7-24+1 in the plantation is a cause of eutrophication's biggest emission due to high usage or needs in a year. The high usage of fertilizer can also be caused by the extensive area of land in the plantation which is divided into six afdeling. At the mill, the largest emission (hotspot) in the category of GWP and acidification is the steam energy in boiler No. 1, this can be caused by the high demand for steam energy also the heat needed along the CPO process. The biggest emission (hotspot) at the mill for eutrophication is electricity usage. The device used during the process requires electrical energy, hence the amount of electrical usage becomes high and has the potential to cause eutrophication. Other research shows that the use of fertilizer for palm oil plantations provides the highest impact on ecosystem quality and electrical usage for palm oil mills is the highest contributor to global warming [16].

## 5. CONCLUSION

In the plantation, data are obtained from the use of fertilizers and pesticides during crop maintenance and the use of diesel for vehicles. At the mill, data was obtained in the form of electricity, steam, and solar energy usage. Overall total impact factor at PT. X Indonesia in 2019 is 2.433 Ton $CO_2$ equivalent/Ton CPO for Global Warming Potential, 16.41 x $10^{-3}$ Ton $SO_2$ equivalent/Ton CPO for acidification, and for eutrophication 2.65 x $10^{-3}$ Ton $PO_4$ equivalent/Ton CPO for eutrophication.

The total number of Impact Factors on plantations in 2019 for Global Warming Potential is 933,48 Kg $CO_2$ equivalent/Ton CPO, for acidification is 4,68 Kg $SO_2$ equivalent/Ton CPO, and for eutrophication is 1,48 Kg $PO_4$ equivalent/Ton CPO. The total number of Impact Factors on the mill in 2019 for Global Warming Potential is 1.499,46 Kg $CO_2$ equivalent/Ton CPO, for acidification is 11,73 Kg $SO_2$ equivalent/Ton CPO, and for Eutrophication is 1,17 Kg $PO_4$ equivalent/Ton CPO

The biggest impact factor results (hotspots) on plantations in 2019 for Global Warming Potential is the use of fertilizer NPK 15-7-24+1 is 384 Kg $CO_2$ equivalent/Ton CPO, for acidification is the use of fertilizer NPK 15-7-24+1 is 1,93 Kg $SO_2$ equivalent/Ton CPO, and for eutrophication is the use of fertilizer NPK 15-7-24+1 is 0,65 Kg $PO_4$ equivalent/Ton CPO. The biggest impact factor results (hotspots) on the mill in 2019 for Global Warming Potential is the use of steam energy, obtained 1.273 Kg $CO_2$ equivalent/Ton CPO, for acidification is the use of steam energy, obtained 10,4 Kg $SO_2$ equivalent/Ton CPO, and for eutrophication is the use of electricity in a turbine, Cummins 1 and 2, obtained 0,64 Kg $PO_4$ equivalent/Ton CPO.

After knowing the number of emissions produced, there will be the biggest emissions (hotspots). One function of doing LCA is to help companies improve their environmental quality. Recommended efforts that can be made in reducing emissions produced are as follows:

a. Plantation

The use of NPK 15-7-24+1 fertilizer is more than that of NPK 14-7-25+1, so the emissions produced will be greater, besides, the characterization factor of NPK 15-7-24+1 is also greater than with NPK 14-7-25+1. One effort that can be done is to replace using organic fertilizer or using empty fruit bunches. However, if it is not possible from several aspects, a ratio can be made using organic fertilizer to achieve the same efficiency or maybe better but can reduce the emissions produced.

b. Mill

- The use of steam energy and electrical energy cannot be avoided at the mill to process raw materials and produces a product, hence saving usage may help to reduce emissions
- Another alternative could be in the form of time management and capacity management
- If possible, a filter can be used in an air stove/chimney before releasing emissions into the air.

However, further research and discussion are needed in determining decisions to reduce emissions in the use of energy and materials in palm oil plantations and mills. There is a need for detail regarding the quantity or amount of energy input used in each processing unit, also need further research to reduce emissions produced with the Cradle-to-Grave system limitation.

## 6. ACKNOWLEDGMENTS

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