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LIFE CYCLE ASSESSMENT IN THE PRODUCTION PROCESS OF CRUDE PALM OIL (CPO) ON PALM OIL PLANTATION AND MILLS

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ABSTRACT: The increase in demand to land for oil palm plantations has led to the construction of many palm oil mills with large production capacities. These palm oil mills require a source of energy to operate. Life Cycle Assessment (LCA) can be used to determine the amount of energy, costs, and environmental impact caused by the stages of the product life cycle. The purposes of this research are to analyze the results of LCA and Crude Palm Oil (CPO) production with several impact categories such as Global Warming Potential, Acidification, and Eutrophication collected from data of energy and material inventory used in oil palm plantations and mills of PT Y in 2019, and furthermore to provide the recommendation on reducing emissions from CPO production based on the LCA results. In order to process data, this research uses SimaPro and Excel base with the CML-IA Baseline method. The system boundary used is cradle to gate. It was found that the biggest emission comes from the Mills with Global Warming Potential impact value is 2.16×10^7 kg CO_2-eq/kg CPO/year, Acidification value is 1.77×10^5 kg SO_2-eq/kg CPO/year, and Eutrophication value is 1.88×10^4 kg PO_4-eq/kg CPO/year. The results show that Global Warming Potential, Acidification, and Eutrophication were influenced by the emission from the mills more than the palm oil plantation.

Keywords: Acidification, Eutrophication, Global Warming Potential, Life Cycle Assessment, Oil Palm Plantations and Mills

1. INTRODUCTION

On 15 November 2022, a milestone in human development, the world's population is projected to reach 8 billion people. These growing populations come with consequences on how to fulfill their needs, satisfy their hunger, and provide room and opportunity to develop their capacity. In fulfilling their needs, humans have been using natural resources and their activities have an impact on the environment. In Indonesia, oil palm plantations are developing rapidly. The potential of oil palm plantations in the economic field is very large and Indonesia is the largest exporter of oil palm [1]. Oil palm plantations have several positive impacts, especially on poor people including income generation and job creation and have the potential to contribute to several sustainable development goals [2].

Currently, the demand to land for oil palm plantations is increasing, this has led to the construction of many palm oil mills with large production capacities. These palm oil mills require a source of energy to operate. Efforts to reduce dependence on the use of fossil fuels can be done by increasing renewable energy production capabilities [3]. The most economical and reliable source of energy is hydroelectric power. Electrical energy can also be said to be energy that is very easy to use because it is easy and efficient in converting electrical energy into other forms [4]. However, to reduce the use of fossil fuel as energy at palm oil mills, renewable energy from biomass is used. Types of biomass, namely those from soil, forest, and cultivated plants [5]. At the palm oil mill, palm fiber and shells are used to fuel the boilers. Another use of palm kernel shell is as the bio-adsorbent of lead waste [6]. In addition, palm oil fuel ash can be used as a material for concrete and brick [7][8].

Palm oil mills produce emissions from each process, one example of which is the emission of greenhouse gases such as carbon (CO_2), methane (CH_4), nitrous oxide (N_2O), and other gases [9]. In palm oil mills, the production process, energy consumption, and waste degradation process can produce greenhouse gases [10]. Other environmental impacts are Acidification and Eutrophication which can be harmful to the environment. Waste from palm oil mills is in the form of solid and liquid waste. Liquid waste comes from the sterilization and clarification process or commonly called Palm Oil Mill effluent (POME), the accumulation of this POME can trigger climate change because it produces methane gas [11].

PT Y is a palm oil mill in Indonesia that has a production capacity of 60 tons of fresh fruit bunches/per hour. This research was conducted on PT Y's plantations and palm oil mills using the Life

Cycle Assessment (LCA) method. The method can assess the environmental impact associated with each product, process, and activity. Life Cycle Assessment can be used to determine the amount of energy, costs, and environmental impact caused by the stages of the product life cycle. Starting from the time of taking raw materials until the product is finished being used by consumers [12]. A review of the literature found that LCA have been applied in several case studies to evaluate the impacts of crude palm oil production [13]. However previous study does not compare between mills and plantations, especially in the global warming potential, acidification, and eutrophication impact categories.

The purpose of this research is to collect data on the energy and material inventory used in oil palm plantations and mills of PT Y in 2019. Then analyze the results of LCA and Crude Palm Oil (CPO) production with several impact categories such as Global Warming Potential, Acidification, and Eutrophication then compare the result between the mills and plantation. After the hotspots are found, so the recommendation for reducing emissions from CPO production based on the LCA results can be provided.

2. RESEARCH SIGNIFICANCE

The significance of the study is as a contribution to inventory using primary data regarding environmental impacts in the form of greenhouse gas emissions (GHG) from palm oil mills and plantation mills using LCA methods and comparing between mills and plantations which has not been done before. A hot spot process area can be found and efforts to reduce GHG could be done in those hotspot areas. Previous research on palm oil plantations and mills using the LCA method has been carried out with impacts on human health, ecosystem quality, climate change, and resources. So that further research with different impacts is needed in this study. The reported work can be used as benchmarks in the amount of GWP, Acidification, and Eutrophication impact on the environment from palm oil mills and plantations using the LCA method which has not been done before.

3. MATERIALS AND METHOD

This research was conducted with the Life Cycle Assessment (LCA) approach which has 4 stages, namely data collection, life cycle inventory, life cycle impact assessment, life cycle assessment, and interpretation. The data used in this study are secondary data obtained from routine company reports in 2019. The method used is the CML-IA Baseline. This method is an LCA methodology developed by the Leiden University Center for Environmental Sciences (CML) in the Netherlands and released by CML in April 2013 and has been standardized by the IPCC.

This study, uses 3 impact categories, namely Acidification, Climate Change, and Eutrophication. The system limit used is Cradle to the gate which covers all processes from raw material extraction through the production stage, used to determine the environmental impact of a product's production. Analysis through the LCA approach by entering inventory data derived from the cultivation process and the processing of oil palm in the SimaPro and Microsoft Excel software. Based on the analysis carried out, environmental impacts will be generated and alternative improvements in each production activity will be obtained.

4. RESULTS AND DISCUSSION

4.1 Palm Oil Plantation and Mill PT Y

PT Y's garden is divided into 4 Afdeling. Afdeling I area of 1,057 hectares, Afdeling II area of 709 hectares, Afdeling III covering 626 hectares and Afdeling IV covering 782 hectares. The land of PT Y's oil palm plantations before being turned into oil palm plantations was a rubber plantation. Meanwhile, geologically, the oil palm plantation area of PT Y is included in the tertiary formation (S3) with clay rock and sandstone [14]. The process of cultivating oil palm at PT Y is shown in Fig. 1.

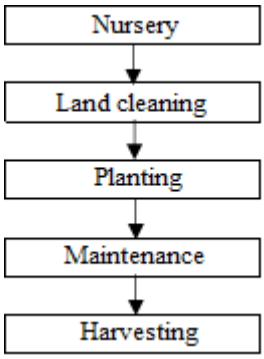

Fig.1 Flow chart of the process of oil palm cultivation at PT Y (SOP of PT Y Oil Palm Plantation)

The process of processing fresh fruit bunches into CPO at the PT Y palm oil mill in Indonesia is shown in Fig.2. Besides CPO, PT Y palm oil mill also processing Fresh Fruit Bunches (FFB) into Palm Kernel Oil (PKO). FFB that have been harvested are then transported by truck to the factory to produced Crude Palm Oil (CPO). In the factory, FFB were loaded to loading ramp, then the process of sterilization, threshed, and digested were taken subsequently. The screw press separates CPO and PKO. CPO went to the clarification tank while PKO went to the vibrating screen.

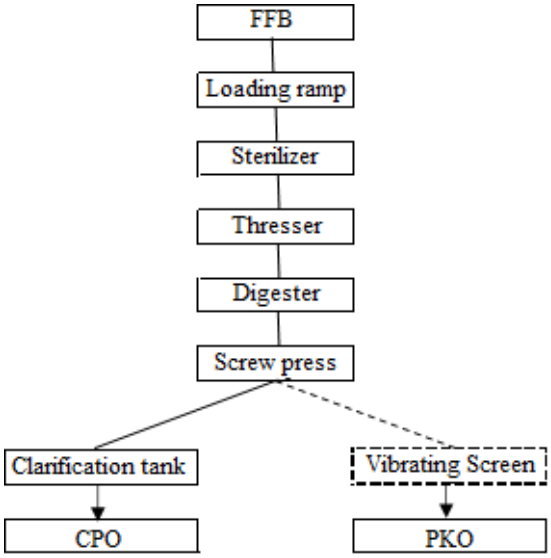

Fig.2 Flow chart of processing fresh fruit bunches into crude palm oil at PT Y (SOP of PT Y Oil Palm Plantation)

4.2 Life Cycle Inventory

The data obtained in this research are secondary data obtained from routine reports of PT Y's plantation and palm oil mill companies. The data are in the form of material and energy usage data in each process of oil palm cultivation to produce crude palm oil for one year, namely in 2019.

4.3 Life Cycle Impact Assessment

This study employs the Life Cycle Assessment technique with the CML-Baseline method on the boundary of the Cradle to Gate system in the plantation and mill of PT. Y Indonesia. 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), at 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. Y Indonesia. The third stage is Life Cycle Inventory Assessment (LCIA), in which the inventory data will be assessed, and additional information can help the process. The last stage is an interpretation that summarizes and discusses the outcome from LCI and LCIA stages that aid to create recommendations and decisions.

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 were 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 Global Warming Potential (GWP), Acidification, and Eutrophication. Changes in global temperature are caused by the effect of greenhouse gases, human activity is 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 main 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 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.

Reacted acid gases such as SO_2 with water in the atmosphere can form acid rain and causes ecosystem damage. 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. The accumulation of chemical nutrient concentrations in an ecosystem that causes 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**.**

Impact Assessment is carried out on PT Y oil palm plantations and mills by multiplying inventory data with characterization factors. The multiplication is done using SimaPro software and Excel base. Table 1 shows the results of the multiplication of inventory data for 2019 with the characterization factor of the Global Warming Potential, Acidification, and Eutrophication in PT Y's oil palm plantations and mills which produce impact factor values. In oil palm plantations which have the biggest impact of the 3 impact categories is the use of glyphosate herbicides, which is 7.95×10^3 kg CO_2-eq / kg cpo / year on Global Warming Potential, amounting to 52.9 kg SO_2-eq / kg cpo / year against Acidification and 37.5 kg PO_4-eq / kg cpo / year to Eutrophication. Glyphosate-type herbicides in oil palm plantations are used to eradicate weeds. Weed is one of the pests that have the potential to reduce the productivity of oil palm plants.

Whereas the palm oil mill has the biggest impact is the use of boilers that is equal to 2.16×10^7 kg CO_2-eq / kg cpo / year on Global Warming Potential, amounting to 1.77×10^5 kg SO_2-eq / kg cpo / year on Acidification and the use of electricity energy to 1.88×10^4 kg PO_4 -eq/kg cpo / year against Eutrophication. Boilers are closed vessels for turning water into high-pressure steam with the help of heating obtained from combustion.

Table 1 LCA Results on Global Warming Potential, Acidification, and Eutrophication at PT Y

Activity	Type of Activity	Type	Amount in 2019	Unit	Impact factor		
					GWP (kg CO_2 eq/kg cpo/year)	Acidification (kg SO_2 eq/kg cpo/year)	Eutrophication (kg PO_4 eq/kg cpo/year)
Maintenance	Fertilization	NPK 15-7-24	618	kg	2.38×10^3	12	4.06
		Dolomite	293	kg	13.3	0.09	0.02
	Herbicide	Glyphosate	679	kg	7.95×10^3	52.9	37.5
Fuel Energy (Solar)	Transport	D 1048 AAF	3.69×10^3	liter	5.07×10^4	202	48
		D 8178 DT	1.51×10^3	liter	2.08×10^4	83	20
		D 8643 EJ	7.09×10^3	liter	9.75×10^4	388	92
		D 8808 EZ	5.93×10^3	liter	8.16×10^4	325	77
		D 8809 EZ	7.22×10^3	liter	9.94×10^4	396	94
		D 8807 EZ	8.39×10^3	liter	1.15×10^5	460	109
		Loader	2.76×10^4	liter	3.79×10^5	1.51×10^3	358
		Excavator	1.44×10^4	liter	1.99×10^5	791	187
Electrical Energy			1.47×10^7	MJ	4.21×10^6	2.41×10^4	1.88×10^4
Biomass	Fuel	Shell	1.24×10^7	kg	8.99×10^5	7.62×10^3	2.76×10^3
		Fiber	2.06×10^7	kg			
	Water Energy	Factory Washing Water	9.74×10^3	m^3	8.28×10^4	248	59
		Boiler feed	7.82×10^4	m^3	6.64×10^5	1.99×10^3	475
		Process	1.09×10^5	m^3	9.23×10^5	2.76×10^3	660
		Domestic	1.14×10^5	m^3	9.68×10^5	2.89×10^3	692
		Boiler	7.82×10^7	kg	2.16×10^7	1.77×10^5	6.96×10^3

The fuel used by PT Y's palm oil mills is shells and fibers. Boilers are the main provider of energy needs in palm oil mills. The results of networking using SimaPro software in PT Y's oil palm plantations and mills are depicted in Figs.3-8. The results of networking for oil palm plantations show differences in the thickness of the red line. The thickness of the line shows the percentage of volume or material flow ratio, which means that the process or stage has more use than the other processes and has the greatest impact on the environment.

5. DISCUSSION

After an LCA analysis, it is known that the biggest impact produced from such an activity. The following are the linkages between the activities and their impacts, as well as providing alternative improvements in the future.

5.1 Palm Oil Plantation

In oil palm plantations, herbicide use are activities with the greatest environmental burden. This is an activity to eradicate weeds. Where this weed will potentially cause a decrease in productivity of oil palm plants. Herbicide with active glyphosate is widely used by farmers and planters in Indonesia because it is effective, inexpensive and safe. Another research shown that the use of pesticide and herbicides for palm oil plantation in the fertilization stage provides the highest impact on ecosystem quality [15].

However, excessive use of herbicides will cause soil fertility to reduce and be able to give symptoms to farmers such as eye irritation, blurred vision, burning or itchy skin, nausea, sore throat, asthma, difficulty breathing, headaches, nosebleeds and dizziness. An alternative that can be used to reduce the use of herbicides is to pay attention to the dose used. Farmers need to be educated with knowledge about the selection, preparation, handling and application of herbicides on oil palm lands.

5.2 Palm Oil Mill

At the palm oil mill, the use of boilers is the activity with the greatest environmental burden. The use of steam boilers has the greatest impact on global warming potential, one example of which can cause greenhouse gases. Climate change can cause losses for farmers because it can cause land drought, reduced water sources, crop failure and unpredictable rainfall [16]. Similar result was also shown in previous research that the use of diesel fuel in generators and boilers in generating electricity for palm oil mills is the highest contributor to global warming [15].

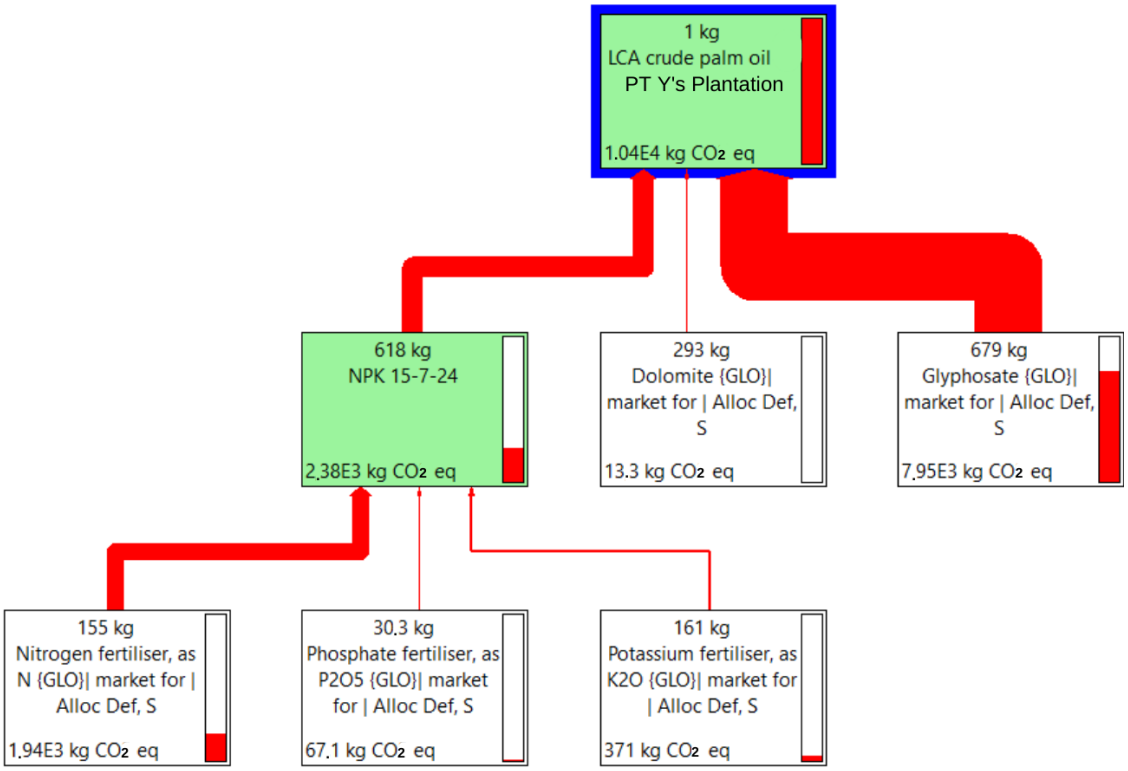

Fig 3. Results of SimaPro networking software on oil palm plantations on Global Warming Potential

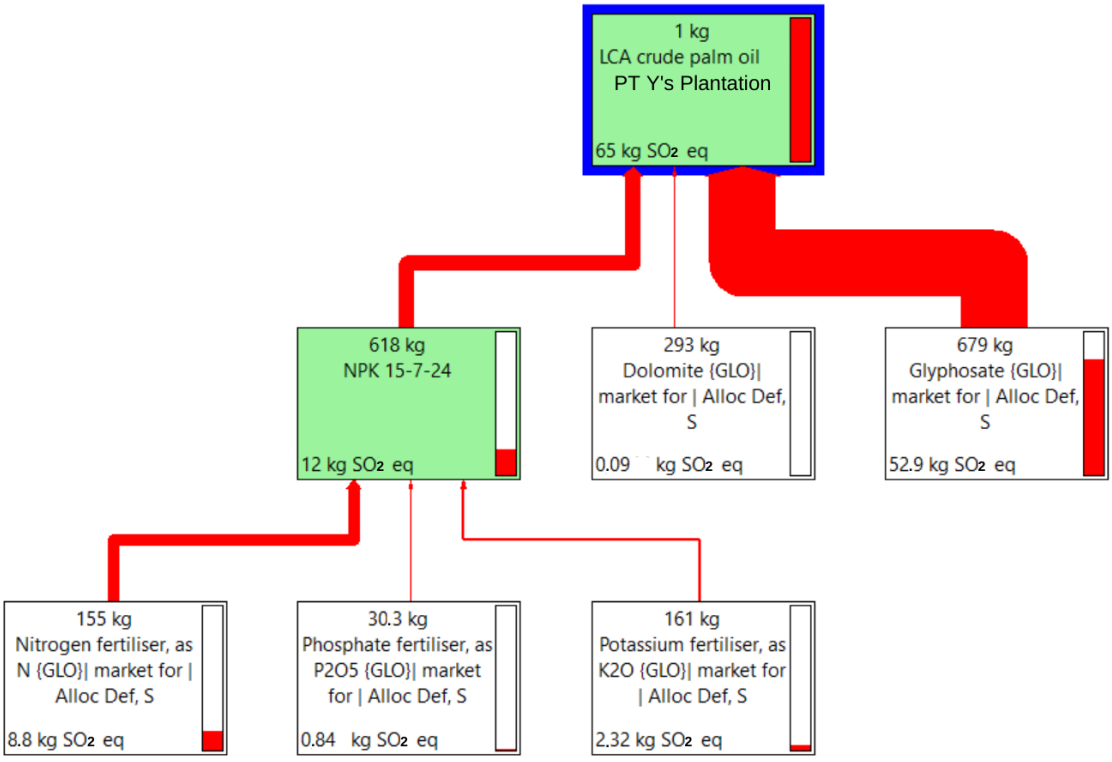

Fig 4. Results of SimaPro networking software on oil palm plantations on Acidification

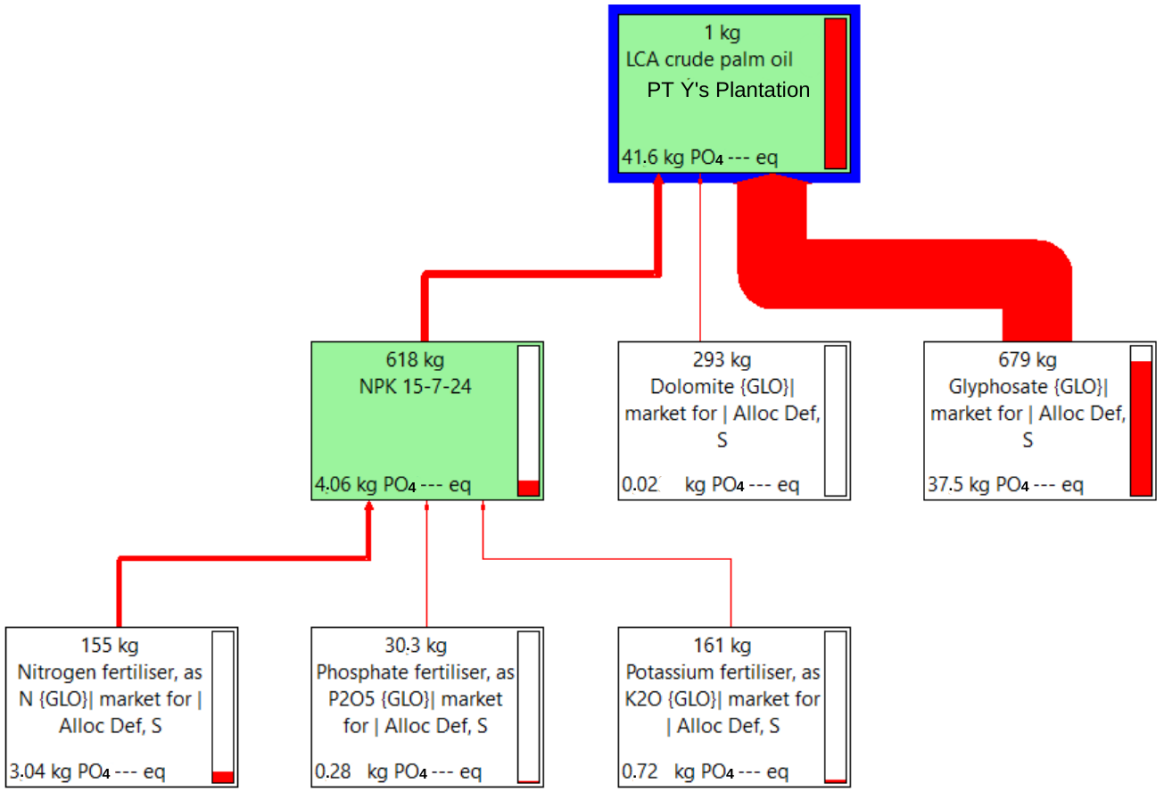

Fig 5. Results of SimaPro networking software on oil palm plantations for Eutrophication

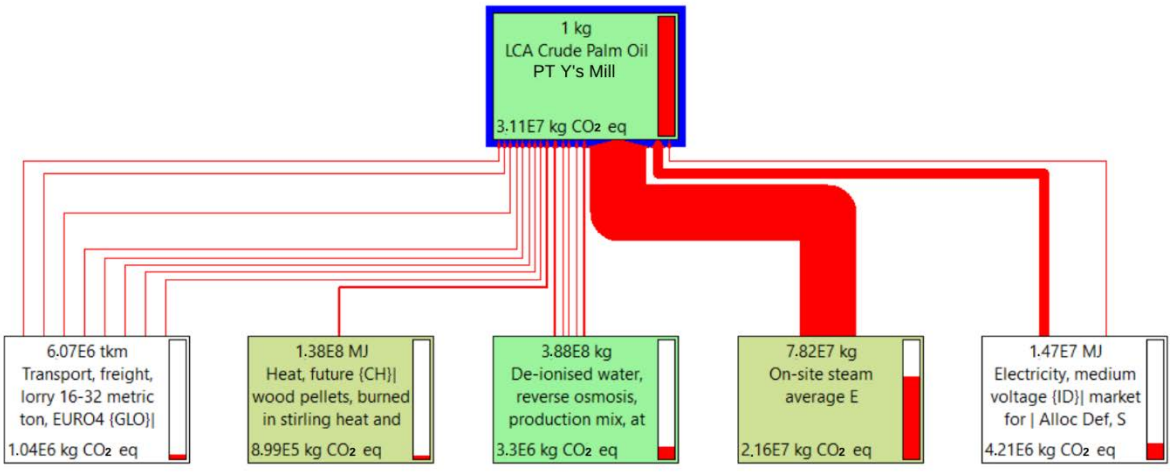

Fig 6. Results of SimaPro networking software on palm oil mills on Global Warming Potential

6. CONCLUSIONS

Data on energy and material inventory used in oil palm plantations and mills are collected from PT Y in 2019. Data on inventory on oil palm plantations are obtained from the use of fertilizer and herbicide. Fertilizers used during 2019 are NPK 15-7-24 with 618 kg and 293 kg of dolomite. The herbicide used was 679 kg of glyphosate-type herbicide. Data on the inventory on palm oil mills are obtained from the use of solar energy, electricity, fuel, and water energy.

In palm oil plantations, hotspots that have the greatest impact is the use of glyphosate herbicides, which is 7.95×103 kg CO_2-eq / kg cpo / year on Global Warming Potential, amounting to 52.9 kg SO_2-eq / kg cpo / year against Acidification and 37.5 kg PO_4-eq / kg cpo / year to Eutrophication. In palm oil mills, hotspots that have the greatest impact is the use of boilers in the amount of 2.16×10^7 kg CO_2-eq/kg cpo/ year for the Global

Warming Potential impact factor, 1.77×10^5 kg SO_2-eq /kg cpo / year for impact factor Acidification and the use of electricity energy in the amount of 1.88×10^4 kg PO_4-eq/kg cpo/year for impact factor Eutrophication. So, the results show that Global Warming Potential, Acidification, and Eutrophication was influenced by the emission from the mills more than the palm oil plantation.

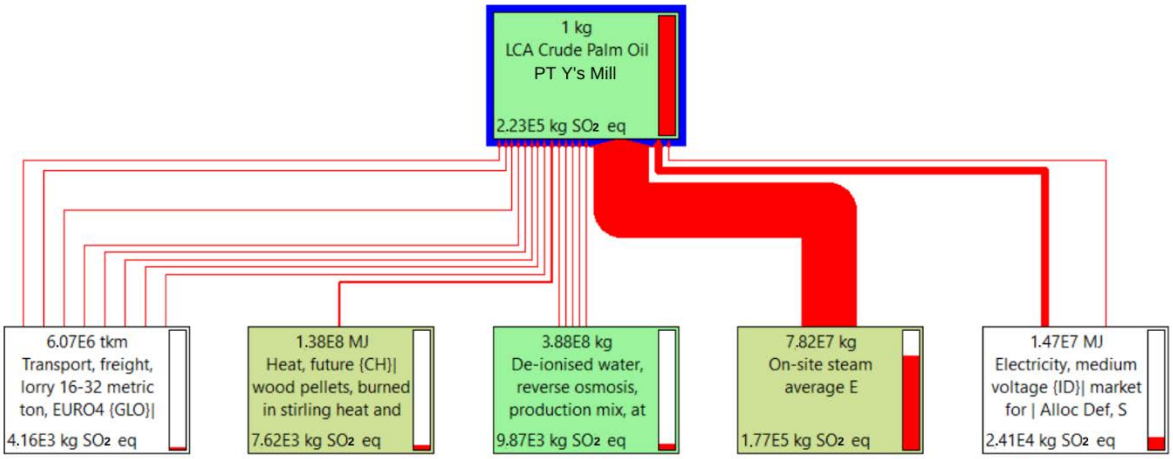

Fig 7. The results of SimaPro networking software on palm oil mills on Acidification

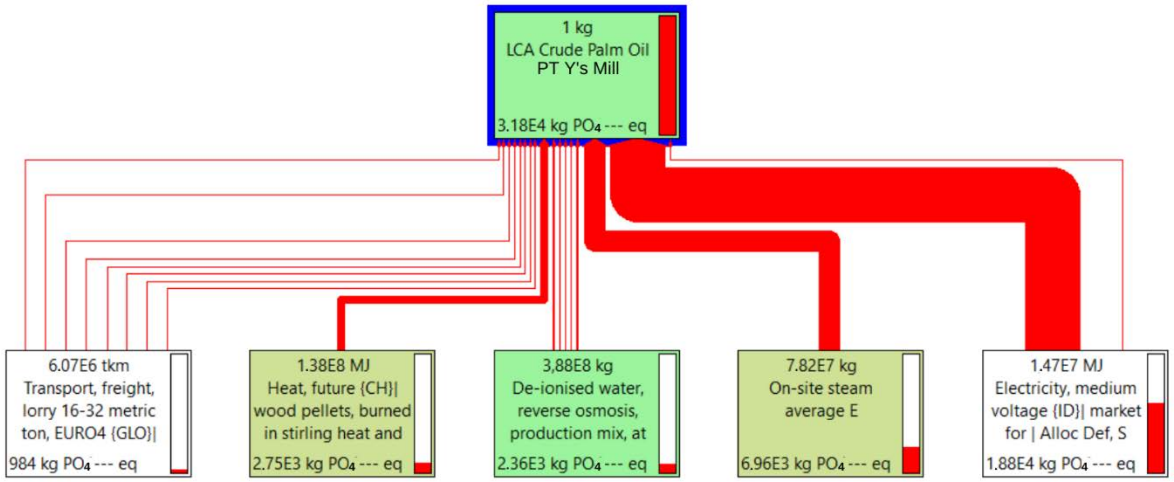

Fig 8. Results of SimaPro networking software on a palm oil mill for Eutrophication

7. RECOMMENDATION

From this research, it can be given recommendations that are expected to be useful for companies, among others, as follows: The use of glyphosate-type herbicides during 2019 has the greatest impact on the environment, so it is necessary to educate or disseminate the information to farmers about the use of herbicides for oil palm land that has the greatest impact for the environment. The use of boilers during 2019 had the greatest impact on the environment, it is necessary to use an air filter in the boiler chimney so that emissions released are more environmentally friendly.

For further research in this field, the need for the interrelation of all parties to ensure the availability of complete data is required. Those data are in the form of material and energy use data and emission loads released. Further research needs to be done on alternatives that can be used to reduce the impact on the environment.

8. ACKNOWLEDGEMENTS

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