LIFE CYCLE ASSESSMENT OF PALM OIL MILL

By

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14756

Dissertation submitted in partial fulfillment of the requirements for the Bachelor of Engineering (Hons)

(Chemical Engineering)

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Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Chemical Engineering Programme
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in partial fulfilment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(CHEMICAL ENGINEERING)

APPROVED BY,

....
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BANDAR SERI ISKANDAR, PERAK
JAN 2015

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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AHMAD AFIFUDDIN BIN ADENAN

ABSTRACT

Life cycle analysis is one of the most used methods to evaluate the environmental impacts caused by a certain product or system. It consists of four phases which follows the requirement set by ISO 14040, which are defining the goal and scope of the research, collecting relevant inventory data for life cycle inventory analysis, conducting the life cycle impact assessment, and interpretation, which can be carried out during the other three phases. There are also various methods to conduct this study, and the one that will be used for this study will be the ReCiPe method, which can display the environmental impacts in terms of 18 impact categories and the damage towards human health, ecosystem diversity, and resource cost. The system that will be studied will be the palm oil mill, the place responsible in production of crude palm oil and other products that may cause harmful effect to the environment. The study will be conducted using the SIMAPRO Version 8 software, which is dedicated towards life cycle analysis. From this research, the environmental impact from the palm oil mill can be assessed and evaluated.

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CHAPTER 1:

INTRODUCTION

1.1 Background

From 2006 to 2010, the amount of production of palm oil in the world per year increased by 6.41% (Kaewmai R, H-Kittikun A, Musikavong C, 2012). Palm oil is currently the most used vegetable oil in the world, with Indonesia and Malaysia as the world's two leading producers and exporters of palm oil. From the oil palms, two types of oils are produced; palm oil (93.4%) from the flesh or mesocarp and palm kernel oil (6.6%) from the seed or kernel inside the hard-shell mesocarp (Stichnothe H, Schuchardt F, 2010). Palm oil can be used as edible oils, cosmetics and detergents, and for biodiesel production. To produce 1 t of crude palm oil, 5 t of fresh fruit bunches (FFB) are needed. FFB is the bunch harvested from oil palm. It weighs around 5 to 50 kg, and may contain 1500 individual fruits. However, processing the FFB will lead to the production of residues, such as the empty fruit bunch (EFB) and the palm oil mill effluent (POME). These residues can cause harm to the environment, such as global warming due to the greenhouse gas (GHG) emissions, eutrophication where excess amount of nutrients sip into the water, promoting the growth of organic matter which will deplete the oxygen inside the water and kill the aquatic lives, and toxicity due to chemicals released during the process.

In this study, life cycle analysis (LCA) will be used to evaluate how far these harms can damage the environment. LCA is a method to assess environmental impacts related with all the stages of a product's life. LCA can assist in avoiding a constricted outlook on environment concerns by collecting the inventory data for important energy and material inputs and environmental releases, evaluating the potential impacts related with recognized inputs and releases, and interpreting the results to help make a more well-versed decision. LCA follows the requirements set by the International Organization of Standardization (ISO) in ISO 14040 and 14044, in which there are four separate phases; goal and scope, life cycle inventory (LCI), life cycle impact assessment

(LCIA), and interpretation. There are also types of LCA approach, such as cradle-to-grave, cradle-to-gate, and gate-to-gate. These types will decide the system boundary for the assessment.

1.2 Problem Statement

One of the key problems found in the previous researches is the inventory data or lack thereof. For example, emission data from the EFB dumping sites are not available (Kaewmai R, H-Kittikun A, Musikavong C, 2012), and the SimaPro software is European software with European data, so the researchers encounter a problem in which the background data for their study of Malaysian palm oil mill is limited (Lam M K, Lee K T, 2010). Another problem is the methods used to conduct the life cycle assessment provide limited impact categories. For example, CML 2 (2000) Baseline method (Chiew Y L, Shimada S, 2012) and Eco indicator 99 (Stichnothe H, Schuchardt F, 2011) were used in previous studies. These methods have limited amount of impact categories. No other researches have utilized the ReCiPe method, especially in the assessment of palm oil mills.

1.3 Objectives

The objectives of this study are:

1. To design an inventory data by collecting the relevant input and output from sources such as literatures and existing palm oil mills.
2. To use ReCiPe method to evaluate the environmental impact caused by the palm oil mills.

1.4 Scope of Study

The scope of this study relies on the method that will be used to conduct the life cycle assessment.

- The LCA approach will be the cradle-to-gate variant, where the system boundary will cover the nursery, plantation, and the palm oil mill itself.
- SimaPro version 8 will be used as the software to conduct the LCA, utilizing the ReCiPe method which can produce result in the form of 18 impact categories.

CHAPTER 2:

LITERATURE REVIEW

2.1 Palm Oil Mill

Malaysia is one of the leading producers of palm oil in the world, with 423 operating palm oil mills (Chiew Y L, Shimada S, 2012). Within the palm oil mill, there are several processes that will take place to extract the palm oil from the FFB (Subramaniam V. et al, 2008).

2.1.1 Unit Processes in a Palm Oil Mill (Rupani P F, Singh R P, Ibrahim M H, Esa N, 2010)

2.1.1.1 Sterilization

FFB are sterilized inside autoclave using steam at around 140^{o}C for duration of 75-90 minutes. This is to deactivate the hydrolytic enzymes accountable for the breakdown of oil to free fatty acids and to loosen the fruits from bunches. The mucilage will be coagulated due to breaking of oil cells.

2.1.1.2 Stripping or Threshing

The fruits are stripped and detached from the bunch in a rotary drum stripper. To release the fruits from the bunches, they are lifted and dropped through the stripper. The falling fruits are collected in a bucket conveyor and transferred to a digester. The waste produced in this process is EFB.

2.1.1.3 Digestion

The digester is a vertical cylindrical vessel fitted with rotating arms. The fruits are mashed up to break the mesocarp oil-bearing cells. Hot water is added to boost the flow of the oils. No residue is produced in this process.

2.1.1.4 Palm Oil Extraction

The crude palm oil from the digester is passed through a screw press followed by a vibrating screen, a hydrocyclone and decanters to get rid of the fine solids and water. The oil is purified by using centrifuge and vacuum drier before being sent to the storage tank, where the temperature is set at 60^{o}C. In this process, POME is produced. POME is a hot, acidic, brownish liquid that contains high amount of suspended solids, wastes, oil and grease.

2.1.2 Palm Oil Mill Residues

2.1.2.1 Empty Fruit Bunches

There are two ways to dispose of the EFB: to dump it or return it to the plantation as mulch (Stichnothe H, Schuchardt F, 2010). In the former, the EFB will be dumped as a waste material. Serious environmental impacts such as eutrophication and high toxicity in the soil can happen due to outflow of nutrients and heavy metals.

Mulch can also be utilized to recycle nutrients and organic matters; however there are few notable negatives in doing so.

i. Fruit harvesting will be disturbed due to restriction of nutrients.
ii. Increase in number of snakes and rats.
iii. Fire risk.
iv. Breeding spot of rhinoceros beetles, one of the most dangerous palm oil pests.
v. During rainy seasons, distributing the mulch will be hard.

2.1.2.2 Palm Oil Mill Effluent

POME is produced mainly during the process of oil extraction, washing and cleaning processes in the mill. It contains cellulosic material, fat, oil and grease (Subramaniam V. et al, 2008). Conventionally pond systems are used to keep the POME, and this system is the main cause of environment impacts from the palm oil mill (Stichnothe H, Schuchardt F. 2010). The anaerobic ponds produce a large amount of the potent greenhouse gas methane alongside the biogas and the waste of the ponds consists of nutrients accountable for pollution of surface and ground water. For 1 t of palm oil produced, 46 m^3, or 32.9 kg of methane is emitted, which also equal to 384 m^3 or 756 kg CO_2 equivalent (Schuchardt F, Wulfert K, Darnoko D, Herawan T, 2007).

2.2 Life Cycle Assessment (LCA)

LCA is an important evaluation that is carried out to study the environmental impacts that are caused by any system, by gathering an inventory data, carrying out the life cycle impact assessment, and to interpret the result from the assessment to better know the environmental impacts. LCA follows the standard set by ISO 14040:2006 and ISO 14044:2006, in which there are four distinct phases:

- **Goal and scope.** The goal of the study should clearly define the planned application, the reasons to do the assessment, and the planned audience for the study. While in the scope, various items should be considered, such as the functional unit, the system boundary, assumptions, and others.
- **Life cycle inventory analysis.** This phase includes data gathering and calculation steps to quantify the inputs and outputs of a system. This phase is iterative, which means that as more data is gathered, new limitations can be set to accommodate the data stated to produce accurate result.
- **Life cycle impact assessment.** In this phase, one needs to relate the inventory data and the environmental impacts to further understand the environmental burdens. This phase may include elements such as classification, in which inventory data is assigned to impact categories; characterization, that is to model inventory data within the impact categories; and others.
- **Interpretation.** In this final phase, the results from inventory analysis and impact assessment are combined, in line with the goal and scope defined earlier to produce the conclusions and thus coming out with the strategies to counter the environmental impacts.

2.3 Methods to Conduct LCA

There are various methods in order to conduct LCA. Some methods are better than the others in which there are more impact categories than others. Below are some of the methods applied to do the LCA.

2.3.1 CML-IA

This method is defined for the midpoint approach, or problem oriented approach. There are two versions of this method; the baseline method and the extended version. One of the studies conducted used the former approach [2]. The baseline method assessed the impacts thru ten impact categories; depletion of abiotic resources, climate change, stratospheric ozone depletion, human toxicity, fresh water aquatic ecotoxicity, marine ecotoxicity, terrestrial ecotoxicity, photo-oxidant formation, acidification and eutrophication (PRé, et al, 2014).

2.3.2 Eco-indicator 99

This method is the better replacement of Eco-indicator 1995. At first the assessment is divided into ten impact categories, such as acidification, ecotoxicity, and ozone layer depletion. However, it is difficult to come out with a conclusion within the confine of these categories. As such, this method will assess the system in the form of three types of damage that are caused to the environment; damage to human health, damage to ecosystem quality, and damage to resources (PRé, et al, 2014).

2.3.3 IPCC 2013

This method is an updated version of IPCC 2007 developed by International Panel on Climate Change. This method only assesses the factors associated with the direct global warming potential of air emissions. The timeframe of the climate change are 20, 100, and 500 years. This method is limited since it only evaluates the environmental impacts in the perspective of global warming potential only (PRé, et al, 2014).

2.3.4 ReCiPe (Goedkoop M, et al, 2009)

This method combines the midpoint and endpoint levels of assessment. In the midpoint level, or the problem oriented approach, the impact categories are defined. This makes the process of coming out with conclusion difficult due to the high number of impact categories. At the endpoint level, or damage oriented approach, the impact categories are divided into three types of damages. This method is better than the other methods since it can assess the environmental impacts in 18 different categories.

Table 1: Impact Categories for Recipe Method (Goedkoop et al, 2009)

Impact Category	Midpoint Indicators	Endpoint Indicators	Characterization Factors of Midpoint Indicators	Characterization Factor of Endpoint Indicators
Climate change	Climate change (CC)	Damage to human health (HH) Damage to ecosystem diversity (ED)	$GWP_{x,T} = \frac{\int_0^T a_x \times [x(t)dt]}{\int_0^T a_r \times [r(t)dt]}$	$\boldsymbol{CF_{HH} = TF \times DF_{HH} = LT_{CO2} \times \frac{dTempt}{\Sigma E_{CO2}} \times \frac{\Delta IMPACT}{\Delta TEMP}}$ $\boldsymbol{CF_{ES} = TF \cdot DF_{ES}}$
Ozone depletion	Ozone depletion (OD)	Damage to human health (HH)	Ozone Depletion Potential	$CF_j = \sum_{S=1}^{8} \frac{\int_{2007}^{2100} \Delta DALY_{j,s} dt}{\int_{2003}^{2040} \Delta OD_j dt}$
Acidification	Terrestrial acidification (TD)	Damage to ecosystem diversity (ED)	$TAP = \frac{FF_x}{FF_{SO_2}}$	$CF_{endpoint,x} = \frac{dSpecies}{dM_X} = SD_{terr} \cdot \sum_j A_j \cdot \frac{dDEP_j}{dM_x} \cdot \frac{dBS_j}{dDEP_j} \cdot \frac{dPDF_{added}}{dBS_j}$
Eutrophication	Freshwater eutrophication (FE) Marine eutrophication (ME)	-	FEP MEP	Unit of endpoint CF : yr / kg
Toxicity	Human toxicity (HT) Terrestrial ecotoxicity (TET) Freshwater ecotoxicity (FET) Marine ecotoxicity (MET)	Damage to human health (HH) Damage to ecosystem diversity (ED)	$F_{j,i,x} = \frac{\partial C_{j,x}}{\partial M_{i,x}}$ $\frac{\partial PDF_{tox}}{\partial C_x} = \frac{\partial PDF_{tox}}{\partial TU_k} \cdot \frac{\partial TU_k}{\partial C_x}$	$CF_{j,i,x} = SD_q \cdot \sum_j CF_{j,i,x} \cdot W_{j \in q}$

Health damage due to PM_{10} and ozone	Photochemical oxidant formation (POF) Particulate matter formation (PMF)	Damage to human health (HH)	$OFP = \frac{dC_{O3}/dM_x}{dC_{O3}/dM_{NMVOC}}$ $PMFP = \frac{iF_x}{iF_{PM10}}$	$CF_{endpoint,x} = \sum_i \left(IF_{pop,x,i} \cdot \sum_e (EF_{e,k,i} \cdot DF_{e,k}) \right)$
Ionizing radiation	Absorbed dose	Damage to human health (HH)	Ionizing radiation potential (IRP)	Damage to Human Health (HH)
Land use	Agricultural land occupation (ALO) Urban land occupation (ULO) Natural land transformation (NLT)	Damage to ecosystem diversity (ED)	Each land type has different CF.	Damage to ecosystem diversity (ED) Unit of endpoint CF: yr / m^2
Freshwater depletion	Water depletion (WD)	-	Water depletion potential (WDP) Water: $CF_{midpoint}(m^3/m^3) = 1$	-
Mineral resource depletion	Mineral depletion (MD)	Damage to resource cost (RC)	$CF_{c.kg.mid} = -\frac{M_c}{(C_c)^2} \times V_c^2 \times P_{c.kg}$	Damage to resource cost (RC) Unit of endpoint CF: $/ kg
Fossil fuel depletion	Fossil depletion (FD)	Damage to resource cost (RC)	$CF_{midpoint,i} = \frac{CED_i}{CED_{ref}}$	$CF_{kg,oil,end} = MCI_{kg}\ x\ P_{kg} x\ \sum_T \frac{1}{(1-d)^t}$ $CF_{end,i} = CF_{mid,i} x\ CF_{oil,end,kg}$

2.4 Types of LCA

A. Cradle to Grave

- The assessment starts from the making of the product or extracting the resource (cradle) until the part where it is disposed of (grave).

B. Cradle to Gate

- Similar to the previous type, except that it stops at the factory gate, this is before the product is distributed to the consumer.

C. Cradle to Cradle

- The end of the life of the product is a recycling process. This is usually known as the closed loop production.

D. Gate to Gate

- This type of LCA concentrates on a specific process alone.

CHAPTER 3:

METHODOLOGY

3.1 Research Methodology

1. The scope and the goal of the study were defined.
2. The scope of the study was focused from the production of seedling at the nursery, to the plantation where the palm oil tree is grown, until the production of the crude palm oil at the palm oil mill.
3. The goal is to identify the main problems within each stage of the process and to provide the suitable solution for the problems.
4. An early study on palm oil mills and the ReCiPe method used for life cycle assessment was carried out to gain a better understanding of the project.
5. The inventories for the life cycle assessment of palm oil mill were gathered from the literatures.
6. The tabulated inventories were converted in accordance with the functional unit of the assessment, which is 1 ton of crude palm oil produced. This was done across the whole scope of the study, which starts from the nursery to the palm oil mill.
7. The SIMAPRO software was first studied in order to get a better understanding of the software.
8. The life cycle assessment on the production of crude palm oil was done using the SIMAPRO software.
9. All the inventories were inputted into the software. The inventories were put according to the process flow of the palm oil production. The output of the process was initially entered by keying in the amount and selecting the appropriate unit. Then, the data for the input of the process was also entered.
10. The emission and other waste outputs of the process were then specified in the software. The inventory for the electricity, transport, and the emission from both the items was also entered into the system.

11. The data inventory for the production of crude palm oil was assessed using the ReCiPe method by doing a midpoint impact assessment on them, which is then translated according to three types of damages: damage on human health, ecosystem, and resource depletion.
12. Lastly, a report consisting of all the findings, analysis of data and future recommendations was written.

3.2 Key Milestone

- Final Year Project 1

Week 1-2
- Understanding the project.
- Identify the objectives and scope of study.

Week 3-4
- Conduct initial studies on existing researches to understand the concept of life cycle assessment of palm oil mills.
- Find the relevant inventory data for the palm oil mill and convert it according to the functional unit which is 1 ton of crude palm oil.

Week 5-6
- Study the SIMAPRO software to understand the software further.

Week 7-8
- Start to conduct life cycle assessment on production of palm oil using the software.
- Submission of extended proposal and proposal defence.

Week 8-12
- Continuation of project work using the software.
- Preparation of interim report.

Week 13-14
- Submission of interim report.

- Final Year Project 2

Week 1-4
- Continue to conduct the life cycle assessment on the production of palm oil.
- Obtain the midpoint, endpoint damage indicator and the single score results.

Week 5-7
- Summary of results.

Week 8
- Conclude the results and procide recommendations.
- Submission of Progress Report.

Week 9-12
- Preparation of Dissertation and Technical Paper.
- Pre-SEDEX poster presentation.

Week 13-14
- Submission of Dissertation and Technical Paper.
- Project Viva.

3.3 Gantt Chart

Final Year Project 1

No.	Detail	Week													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Title Selection and Supervisor Allocation	■													
2	Understanding the Project	■	■												
3	Identifying the Objectives and Scope of Study		■												
4	Conducting Preliminary Studies on the Project			■	■										
5	Developing Inventories Data			■	■										
6	Conducting Studies on SimaPro Software					■	■								
7	Preparation of Extended Proposal				■	■	■								
8	Submission of Extended Proposal						■								
9	Start Project Work Using SimaPro Software						■	■							
10	Proposal Defence								■	■					
11	Continuation of Project Work								■	■	■	■	■	■	■
12	Preparation of Interim Report										■	■	■	■	
13	Submission of Interim Report														■

Final Year Project 2

No.	Detail	Week													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Conduct LCA On Production of Palm Oil	■	■	■	■										
2	Comparison of Results					■	■	■							
3	Analysis and Interpretation of Results						■	■							
4	Conclude the Results with Recommendations								■						
5	Preparation & Submission of Progress Report								■						
6	Preparation of Dissertation									■	■	■			
7	Preparation of Technical Paper									■	■	■			
8	Pre-SEDEX										■				
9	Submission of Dissertation												■		
10	Submission of Technical Paper												■		
11	Project Viva													■	■

CHAPTER 4:

RESULTS AND DISCUSSION

The SIMAPRO Version 8 software has been installed and some tutorials have been carried out to further understand how the software works. Basically, the software evaluates a product or system from the start of the product's or system's life until its end; in simpler terms, studying its life cycle. First, the users are required to define their system boundary so that the limit of the study can be known. Then, they need to define the each and every materials and processes that they wanted to include in their study. This is crucial since every one of them can contribute to the overall environmental impact.

The inventory data is filled in terms of inputs and outputs after defining the goal, scope and the system boundary of their research, so that they are in line with each other. Inputs can be specified as the materials required to produce the desired product or materials that are needed to be put inside the system in order for it to start operating. Meanwhile, the outputs can be classified as the product generated from the system and the "by-products" during the production itself, such as the emissions of environmentally dangerous gases to the air, land or water.

For this project, the inventory data was divided for the three systems involved in the palm oil milling process. The three systems are the nursery where the palm oil seedling is produced; the plantation where the palm oil tree is grown; and lastly the palm oil mill itself where the crude palm oil is produced. Three types of result are produced. The first one is the midpoint indicator graph where all the 18 impact indicators were addressed and the harm of each impact indicator is displayed for the whole process. The next graph would be the endpoint indicator graph where the damage to human health, ecosystems, and resources was displayed. The final graph displayed will be the single score graph where the 3 types of damages caused throughout the life cycle of the palm oil mill was converted into a single score value. The single score was analyzed in three different perspectives which are the individualist, hierarchist, and egalitarian.

4.1 Life Cycle Assessment for Palm Oil Mill

4.1.1 Inventories

The inventory data was compiled from the literature for the production of 1 ton of crude palm oil. The functional unit for the data obtained was already in the unit of per 1 ton of crude palm oil produced, so there is no need to convert the data anymore for the desired amount produced. However, the data was collected for 21 nurseries, 102 plantations, and 12 palm oil mills, so the averages for each data need to be calculated. Table 2 below shows the value for the nursery, Table 3 displays the inventory data for the plantation and the data for palm oil mill is presented in Table 4.

Table 2: Inventory Data for the Production of a Single Seedling in the Nursery (Muhammad H. et al, 2010)

Parameter	**Unit (per single seedling)**	**Value**
Electricity	kWhr	0.852
Diesel	L	0.568
Polybag	kg	0.2982
Water	L	213
Fertilizers		
N	kg	0.07242
P2O5	kg	0.03692
K2O	kg	0.02982
Pesticides		
Thiocarbamate	kg	1.59E-03
Pyrethoid	kg	5.03E-04
Organophosphate	kg	2.84E-03
Dithiocarbamate	kg	0.0136462
Unspecified pesticide	kg	1.92E-04

Urea/sulfonyl urea	kg	3.08E-03
Glyphosate	kg	1.26E-03
Transportation [Van (<3.5 t) B250]	kg	9.19E-07
Capital good		
Polyvinylchloride for pipes	kg	0.101246

Table 3: Inventory Data for the Production of 1 ton FFB at the Plantation (Zulkifli H, et al, 2010)

Plantation Characteristics	**Unit (per t FFB)**	**Value**
FFB yield (t/ha.yr)	t/ha.yr	20.7
Planting density (palm/ha)	palm/ha	142
Soil characteristics	-	Mineral soils
Plantation lifetime	yr	25
No of plantations	-	102
Total area	ha	1.1 mil

Table 4: Inventory Data for the Production of 1 t Crude Palm Oil in the Palm Oil Mill (Vijaya S et al, 2010)

Parameter	**Unit (per 1t CPO)**	**Value**
FFB	t	3.100
Power consumption from turbine	MJ	224.080
Power consumption from grid	MJ	1.760
Diesel consumption for mill	MJ	100.330
Transportation of diesel to mill	tkm	0.540
Fuel used in boiler		
Mesocarp fibre	t	0.360
Shells	t	0.090
Boiler water consumption	t	1.570
Water for processing	t	2.170
Kernels	t	0.410
Mesocarp fibre	t	0.000

Shells	t	0.230
EFB	t	0.710
POME	t	1.860
Methane gas	kg	22.210
CO2 from POME pond	kg	36.040
Boiler ash	t	0.010
Steam input to turbine	t	1.620
Steam input for sterilization	t	1.560
Flue gas from stack		
Particulate matter	kg	0.120
CO	kg	0.040
CO2	kg	41.280
SO x	kg	0.001
NO x	kg	0.070
Capital goods		
Buildings, steel	kg	1.000
Buildings, concrete	kg	3.140
Oil mill machinery	kg	2.830
Tractors	kg	0.020

4.1.2 Network

Figure 1 below shows the network or the tree of palm oil production where it shows the three processes involved to produce the palm oil. Since there are a lot materials and processes involved in the production of crude palm oil, only the materials that had the highest contribution towards the production of the palm oil were displayed in the network.

In order to produce 1 ton of crude palm oil, the processes involved will be at the nursery where the seedling is nurtured, which will then be transported to the plantation to be planted to produce the FFB. The FFB will then be transported to the palm oil mill where it will undergo several processes to be transformed into crude palm oil and two other co-products; palm kernels and palm shells. Even though the nursery part was included in the assessment, since it have low contribution to the production of palm oil, it is not displayed in the network.

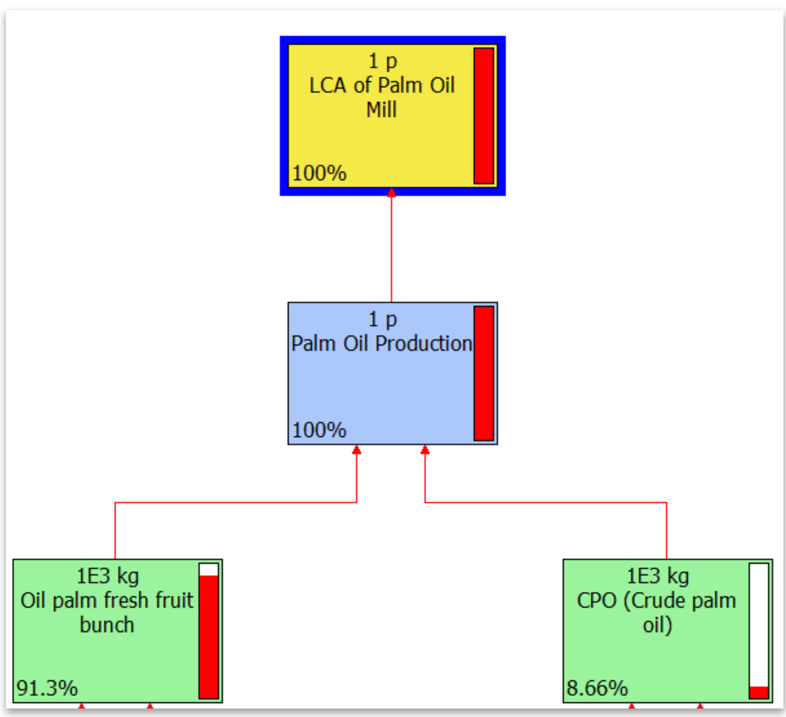

Figure 1: Palm Oil Production Network

4.1.3 Midpoint Indicator

The midpoint indicator for ReCiPe method contains 18 impact indicators or in other words, it addresses 18 types of environmental impact. The environmental impacts do not have the same unit so it is hard for us to compare one impact from another. In order to find out the magnitude of each environmental impact, the SimaPro software normalizes the data using European normalization.

During normalization, the quantity of substance that contributed towards the impact category indicator is divided with a reference value or normalization reference. The reference value is the average yearly environmental load in a country or a continent. In other words, it is the quantity of specific substance emitted yearly that causes the potential impact divided with the number of capita in a country or continent. After normalization, the impact indicators will be dimensionless form which indicates the magnitude of each impact indicator. Through this, the impact indicators can be easily compared with one another.

Figure 2 below shows the graph of the normalized midpoint impact indicator for the production of crude palm oil. From the Figure 3 below, it can be observed that terrestrial ecotoxicity contributes the most in the life cycle of palm oil production with a normalized value of 3.17, followed by natural land occupation with a normalized value of 1.74. Water depletion has no value since it is not affected in the life cycle of palm oil production.

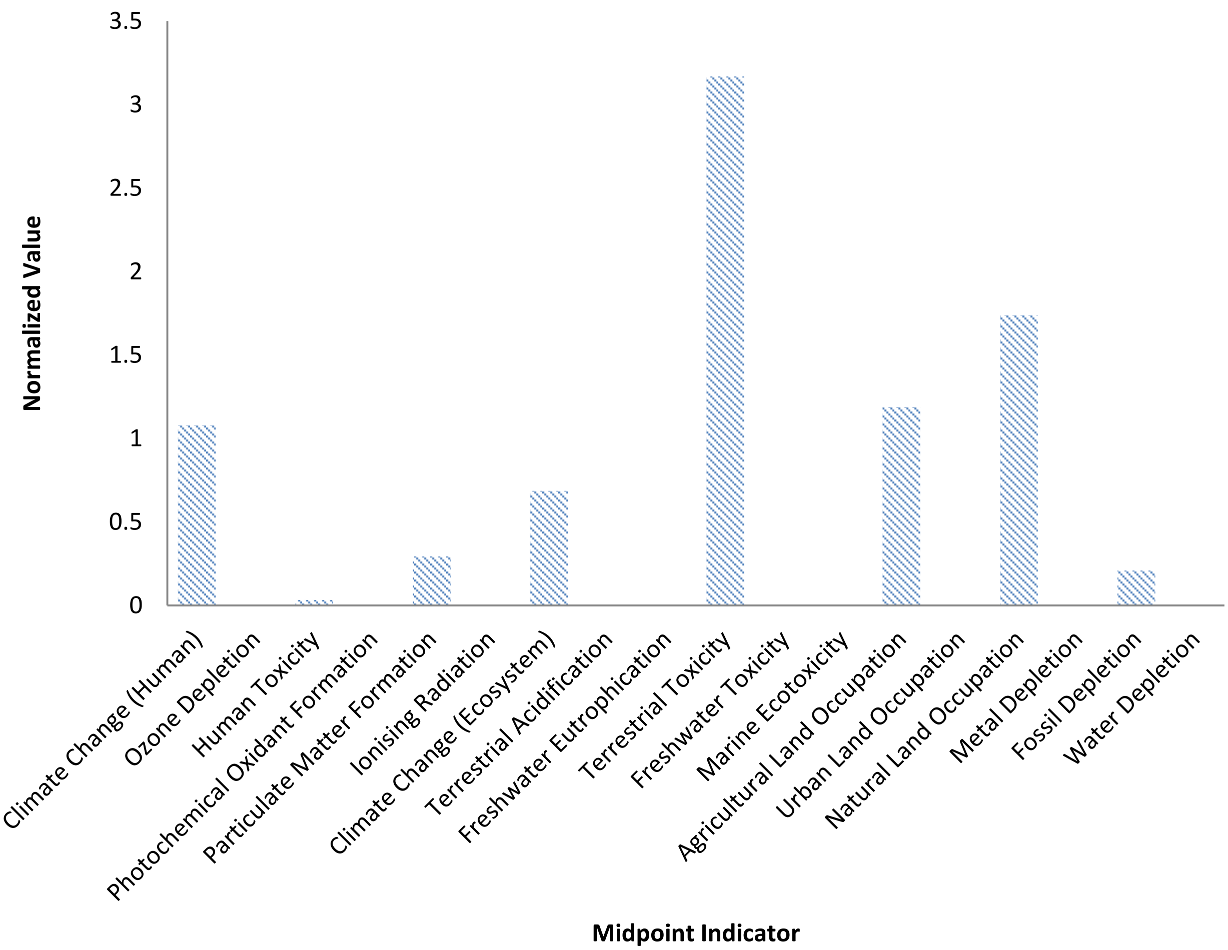

Figure 2: Normalized Midpoint Impact Indicators for Production of Crude Palm Oil

The impact indicators for each of the three processes; nursery, plantation, and palm oil mill were also assessed to observe the impact of each processes. Figure 3 shows the graph of midpoint impact indicators for the processes. For the oil palm seedling production, the highest contributor is the fossil depletion with a value of 0.00000506, while the lowest contributor is ozone depletion with a value of 0.0000000000458. For the FFB production, the highest contributor is terrestrial ecotoxicity with a value of 2.91, while the lowest contributor is ozone depletion with a value of 0.000000904. Lastly, for the palm oil production at the palm oil mill, the highest contributor is terrestrial ecotoxicity with a value of 0.258, while the lowest contributor is ozone depletion with a value of 0.000000205.

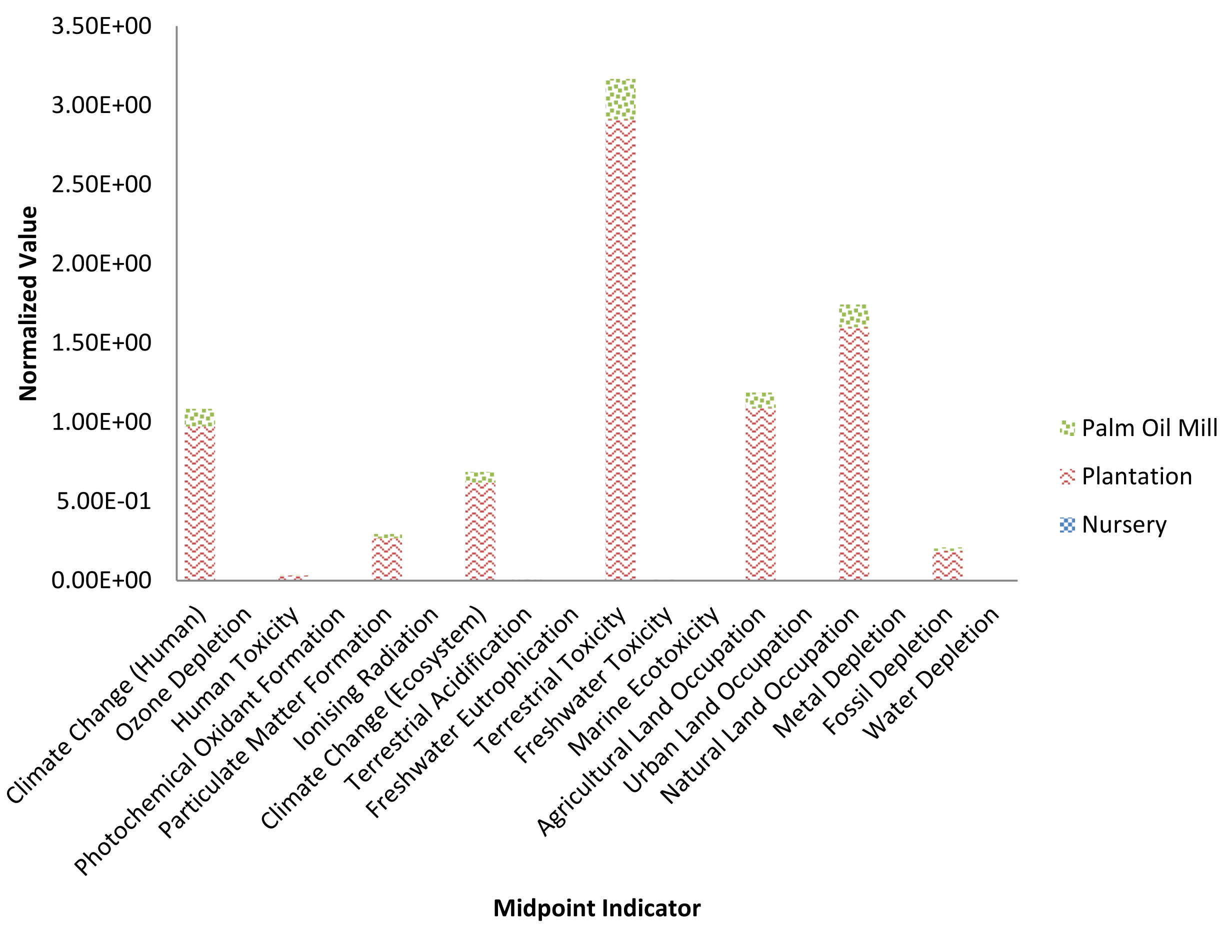

Figure 3: Normalized Midpoint Indicators for each Processes in the Production of Crude Palm Oil

4.1.4 Endpoint Damage Indicator

After the analysis for each impact indicator is done, the data will be focused towards the damages each impact indicator can cause towards human health, ecosystem, and resources. The damage indicator will also go through normalization since each damage indicator has their own unit and cannot be compared to one another without undergoing normalization. Figure 4 shows the graph of damage indicators of the production of crude palm oil. From Figure 5 below, it can be observed that the palm oil production inflict the highest damage to the ecosystem with a value of 6.79, while has the least damage to resources with a value of 0.211.

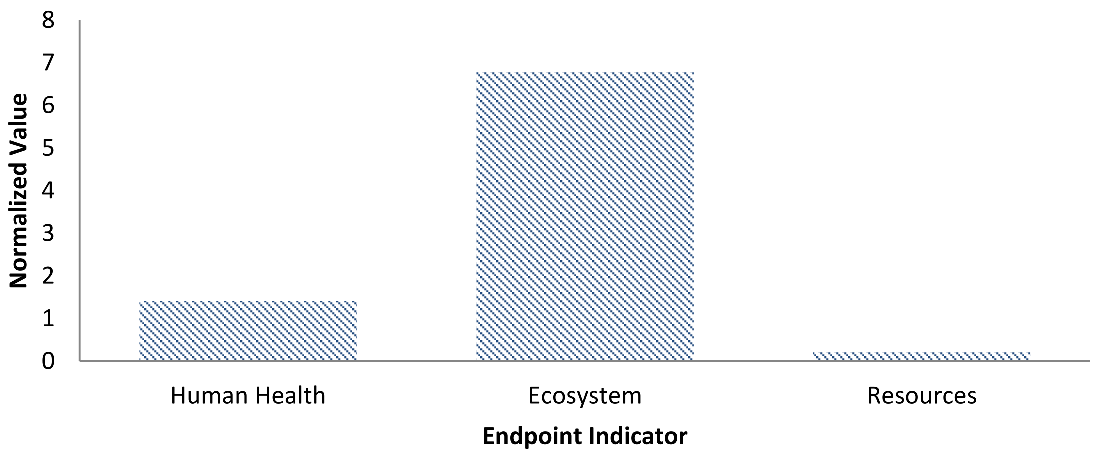

Figure 4: Normalized Damage Indicators for Production of Crude Palm Oil

The damage assessment for the processes was also carried out to analyze the damage each processes cause to the human health, ecosystem and resource. Each processes damage values were also normalized so that they can be compared to one another. Figure 5 shows the graph of damage assessment for the processes. For the damage to human health, the highest contributor is the plantation, with a value of 1.27, while the lowest contributor is the nursery with a value of 0.0000016. As for the damage to ecosystem, the highest contributor is the plantation with a value of 6.22, while the lowest contributor is the nursery with a value of 0.00000064. Lastly, for the damage to resources, the highest contributor is plantation with a value of 0.186, and the lowest contributor is nursery with a value of 0.0000055.

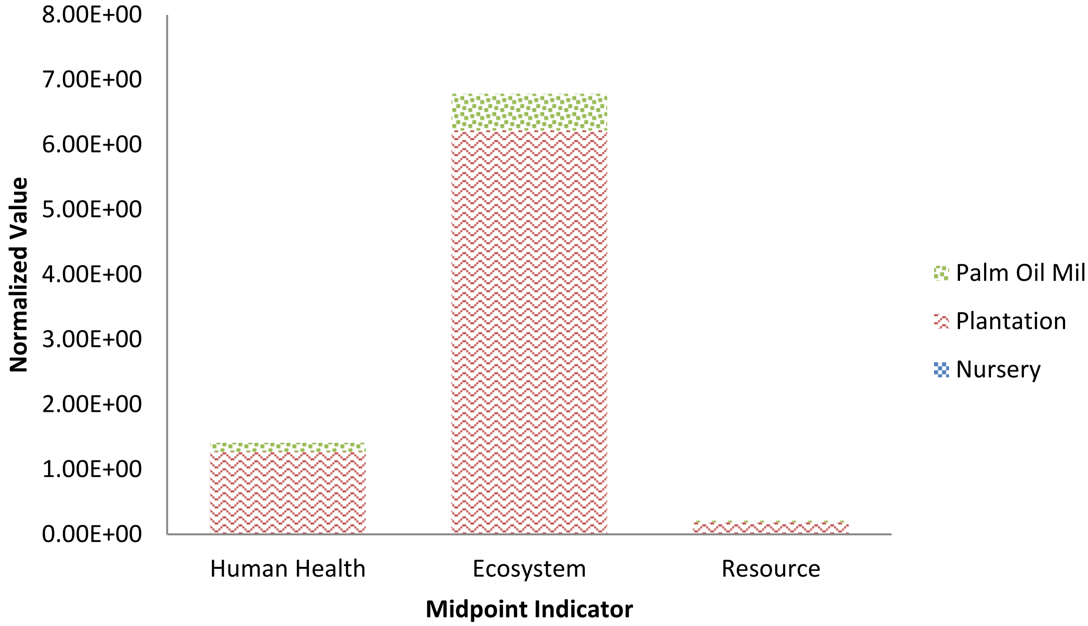

Figure 5: Normalized Damage Indicators for Processes in the Production of Crude Palm Oil

4.1.5 Single Score

The damage indicators done earlier will then go through a weighing process where each of the damage indicators is multiplied with the weighing factor to form a single score for the crude palm oil production. The data is displayed in terms of point (Pt). The single score was then assessed in three types of perspective which are individualist, hierarchist, and egalitarian. These perspectives display a set of choices on issues like time or expectations on proper management or future technology development that can prevent any damages in the future.

Figure 6 shows the graph of single score for the three perspectives. The first one is the hierarchist perspective which is the most typical policy principles with regards to time-frame and other issues. It has a total score of 3320 Pt. The single score is the total of the damage scores where the damage to human health has an indicator score of 565

Pt, the damage to ecosystems has an indicator score of 2710 Pt and finally the indicator score for the damage to resources is 42.1 Pt.

The next single score is based on the individualist perspective. It is based on short-term interest, impact types that are undisputed, technological optimism as regards to human adaptation. The graph shows that the individualist perspective has a single score of 2980 Pt. If the single score were to be divided based on the damages it causes, then for damage to human health the indicator score is 482 Pt, the indicator score for the damage to ecosystems is 2470 Pt, while the indicator score for the damage to resources is 30.9 Pt.

The last single score is based on the egalitarian perspective. This is the most precautionary perspective which considers the longest time-frame. The single score for this particular perspective is 3070 Pt. For the damage to human health, it has an indicator score of 565 Pt, the damage to ecosystems has an indicator score of 2460 Pt, while the damage to resources has an indicator score of 42.1 Pt.

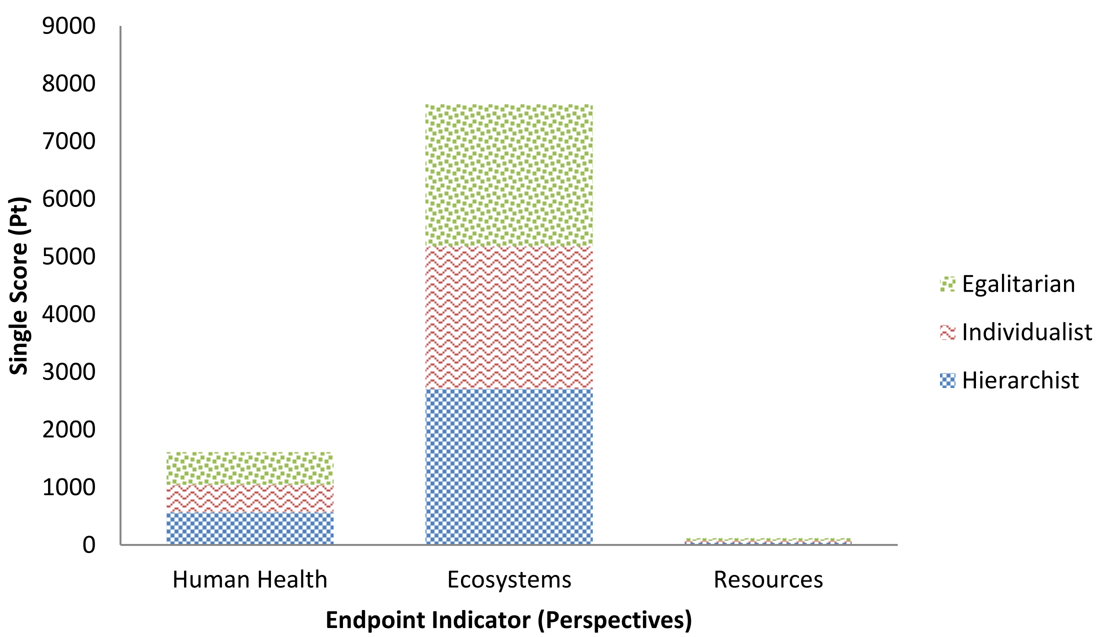

Figure 6: Single Score Based on Perspectives for Production of Crude Palm Oil

The single score assessment for the processes were also carried out. Figure 7 shows the graph of single for each of the processes. The assessment was carried out based on the hierarchist perspective. The nursery has a single score of 0.002 Pt, with the damage to human health having an indicator score of 0.00064 Pt, the score for damage to ecosystems is 0.000256 Pt, and the damage to resources having a score of 0.0011 Pt. The plantation has a single score of 3030 Pt, with the damage to human health having a score of 509 Pt, damage to ecosystems having a score of 2490 Pt, while the damage to resources having a score of 37.2 Pt. Finally for the palm oil mill, the single score is 288 Pt, its damage to human health has a score of 55.8 Pt, the score for damage to ecosystems is 227 Pt, and the score for damage to resources is 4.87 Pt.

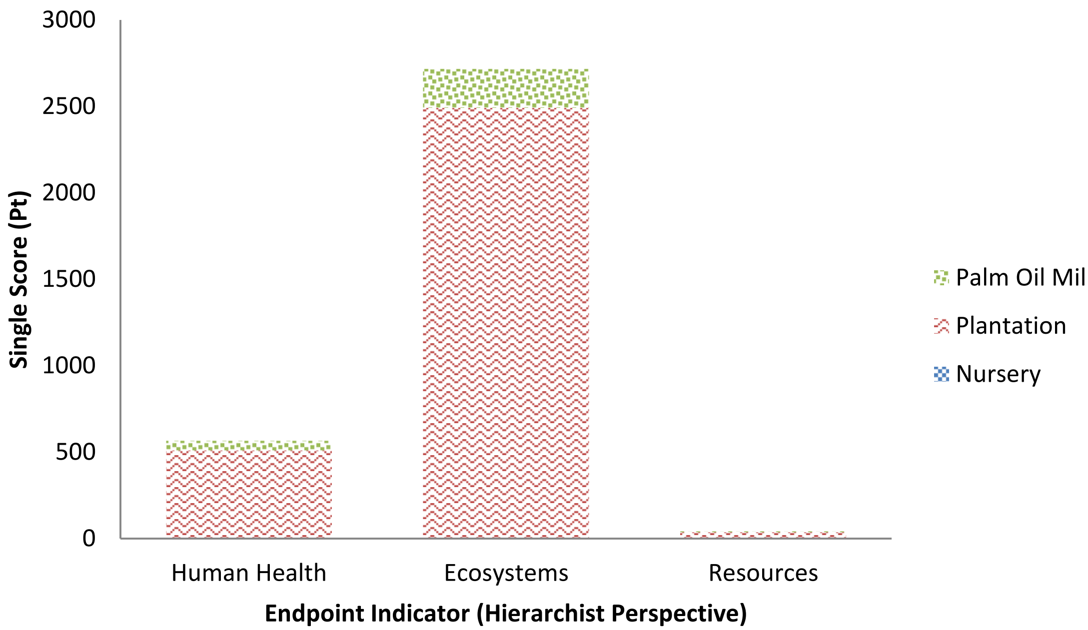

Figure 7: Single Score Based on the Hierarchist Perspective for Processes in Production of Crude Palm Oil

Another single score assessment was carried out based on the individualist perspective. Based on Figure 8, nursery has a total single score of 0.00000176 kPt, where its damage to human health is at 0.00000052 kPt, damage to ecosystems at 0.00000030 kPt, and damage to resources at 0.00000095 kPt. As for the plantation, it has a single score of 2.71345 kPt, where the damage to human health is at 0.42769 kPt, damage to ecosystems at 2.25843 kPt, and the damage to resource at 0.02733 kPt. Lastly, the palm oil mill has a single score of 0.27010 kPt, where the damage to human health having a score of 0.05441 kPt, the damage to ecosystems having a score of 0.21209 kPt, and the damage to resources having a score of 0.00360 kPt.

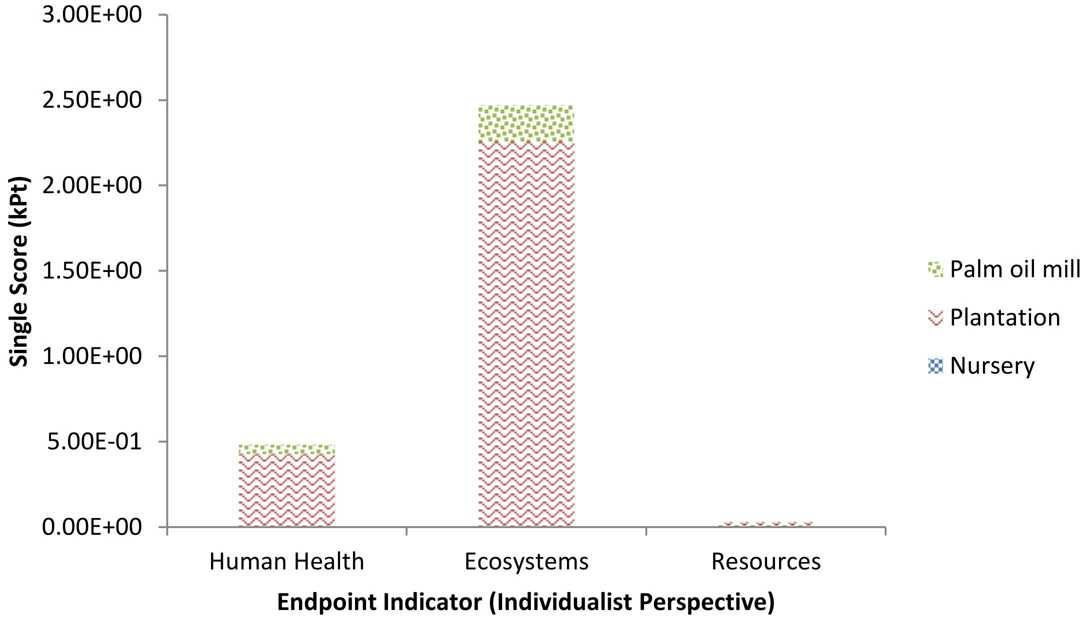

Figure 8: Single Score Based on the Individualist Perspective for Processes in Production of Crude Palm Oil

The last analysis is the single score based on the egalitarian perspective. Based on Figure 9, nursery has a total single score of 0.0000099 kPt, where its damage to human health is at 0.0000083 kPt, damage to ecosystems at 0.00000042 kPt, and damage to resources at 0.0000011 kPt. As for the plantation, it has a single score of 2.80095 kPt, where the damage to human health is at 0.51152 kPt, damage to ecosystems at 2.25219 kPt, and the damage to resource at 0.03723 kPt. Lastly, the palm oil mill has a single score of 0.26423 kPt, where the damage to human health having a score of 0.05349 kPt, the damage to ecosystems having a score of 0.20588 kPt, and the damage to resources having a score of 0.00487 kPt.

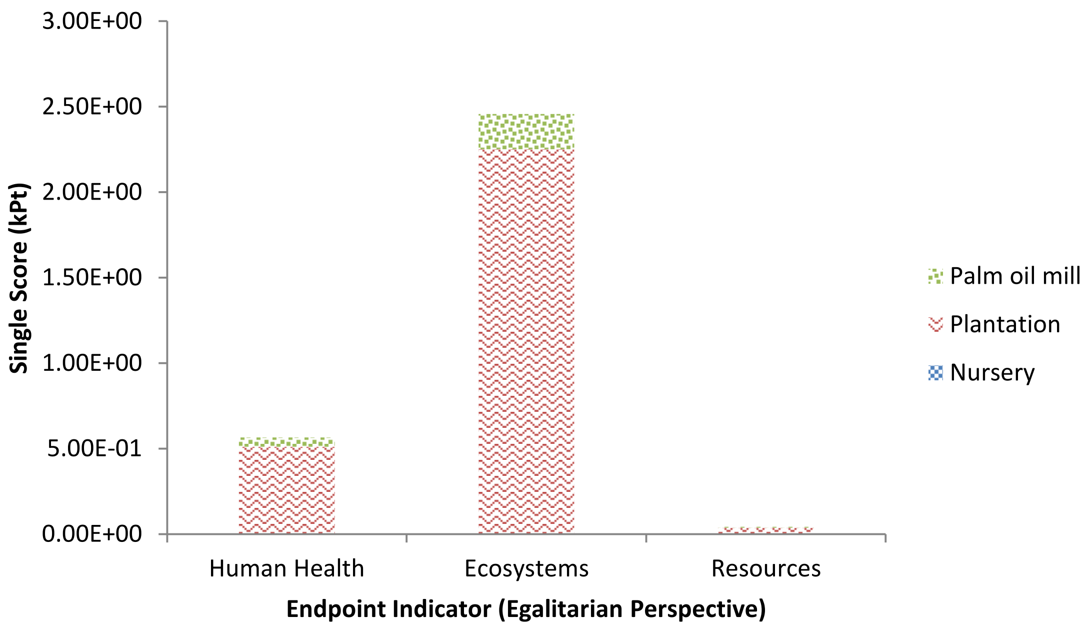

Figure 9: Single Score Based on the Egalitarian Perspective for Processes in Production of Crude Palm Oil

4.2 Discussion

Based on Figure 2 above, one can see that the production of crude palm oil contributed the most towards terrestrial ecotoxicity. Ecotoxicity is the potential for biological, chemical, or physical stressors to affect ecosystems. Such stressors may occur in the natural environment at densities, concentrations or levels high enough to disrupt the natural biochemistry, physiology, behavior and interactions of the living organisms within the ecosystem.

The second highest impact is at the natural land occupation. Many production processes require a certain area of land. This is no different in the production of crude palm oil, where lands are needed to construct the nursery, plantation, and the palm oil mill itself. This land occupation shows the damage to ecosystems done by a certain system or product. Usually, occupation follows a transformation of land, but normally occupation occurs in an area that has already been transformed.

The third highest contributor is towards the climate change which affects human. This midpoint indicator causes a few environmental mechanisms that affect both the endpoint human health and ecosystem health. This can be related to the release of greenhouse gases such as methane and carbon dioxide, where it leads to the phenomena of global warming when the Earth's temperature rises, causing the planet to become hotter and hotter.

First analysis is done on the nursery, where palm oil seedling is produced. Figure 10 below shows the result based on the normalized value of midpoint indicators for nursery.

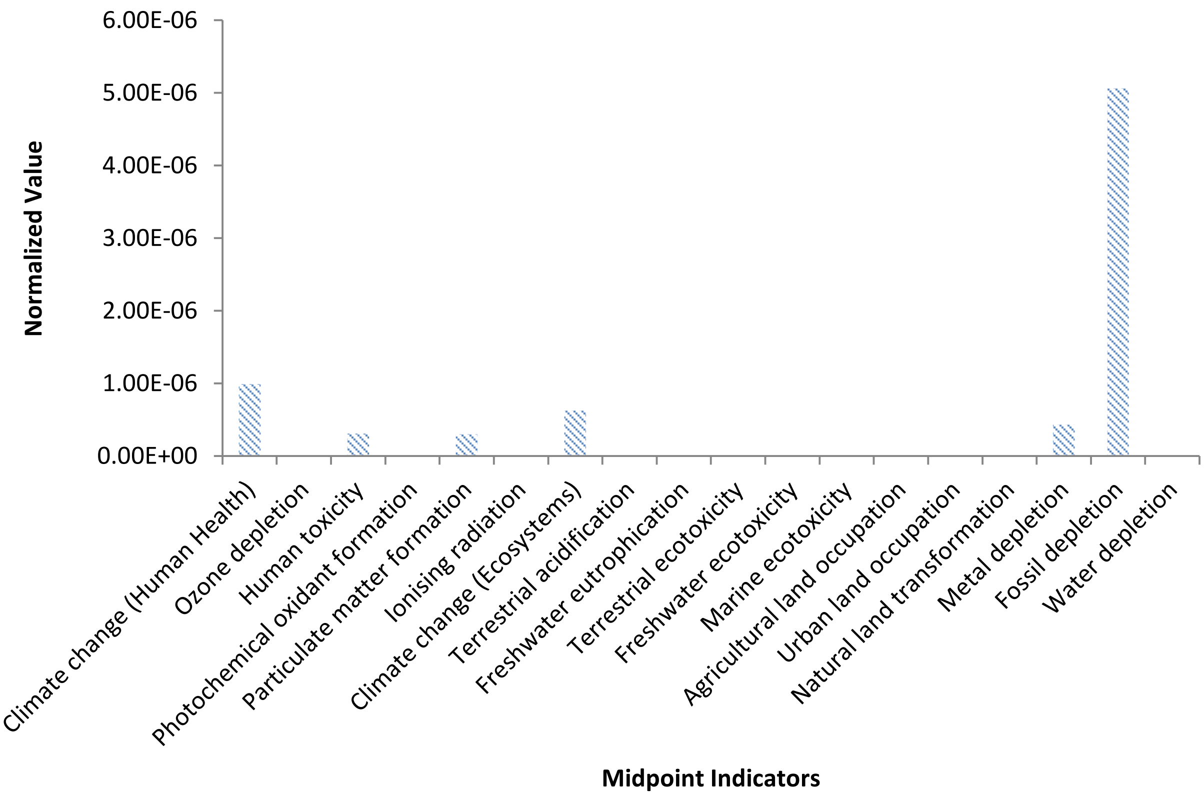

Figure 10: Normalized Value of Midpoint Indicators for Nursery

As can be seen in Figure 10 above, fossil depletion contributes the highest toward environmental impact with a normalized value of 0.00000506, and the lowest contributor is towards ozone depletion with a normalized value of 0.000000000046. Looking further into fossil depletion, it has the highest value due to the diesel used in the nursery. This diesel is related to the power source in the nursery, where it is used for the pump to water the seedlings in the nursery. Since diesel is a type of fossil fuel, it is understandable that high usage of diesel in the nursery caused the fossil to be reduced. The next data to be analyzed is the endpoint indicators, related to the damages to human health, ecosystem, and resources. Figure 11 below shows the normalized value of endpoint indicators for the nursery.

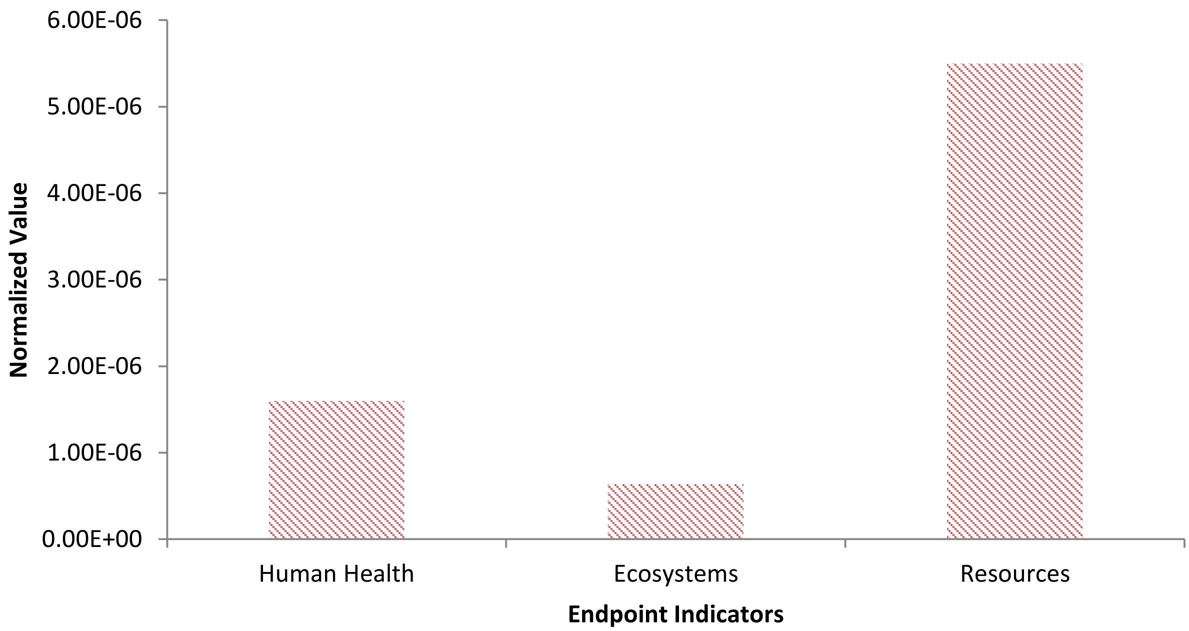

Figure 11: Normalized Value of Endpoint Indicators for Nursery

Based on Figure 11 above, it can be seen that damage to resources contributed the most, with a normalized value of 0.0000016, while the lowest contributor with a normalized value of 0.00000064 is the damage to ecosystems. Again, this can be related to the use of diesel in the nursery, since it leads to the reduction of resources available.

The next analysis is for the plantation part. Figure 12 and Figure 13 below shows the midpoint indicators, and the endpoint indicators for the plantation respectively. From Figure 12 below, it can be seen that the highest contributor is towards terrestrial ecotoxicity with a normalized value of 2.91, and the lowest contributor is towards ozone depletion with a normalized value of 0.000000904. The high contribution to terrestrial ecotoxicity is due to the use of pesticides in the plantation to keep out the fungi, insects, and other pests that threaten the growth of the palm oil tree.

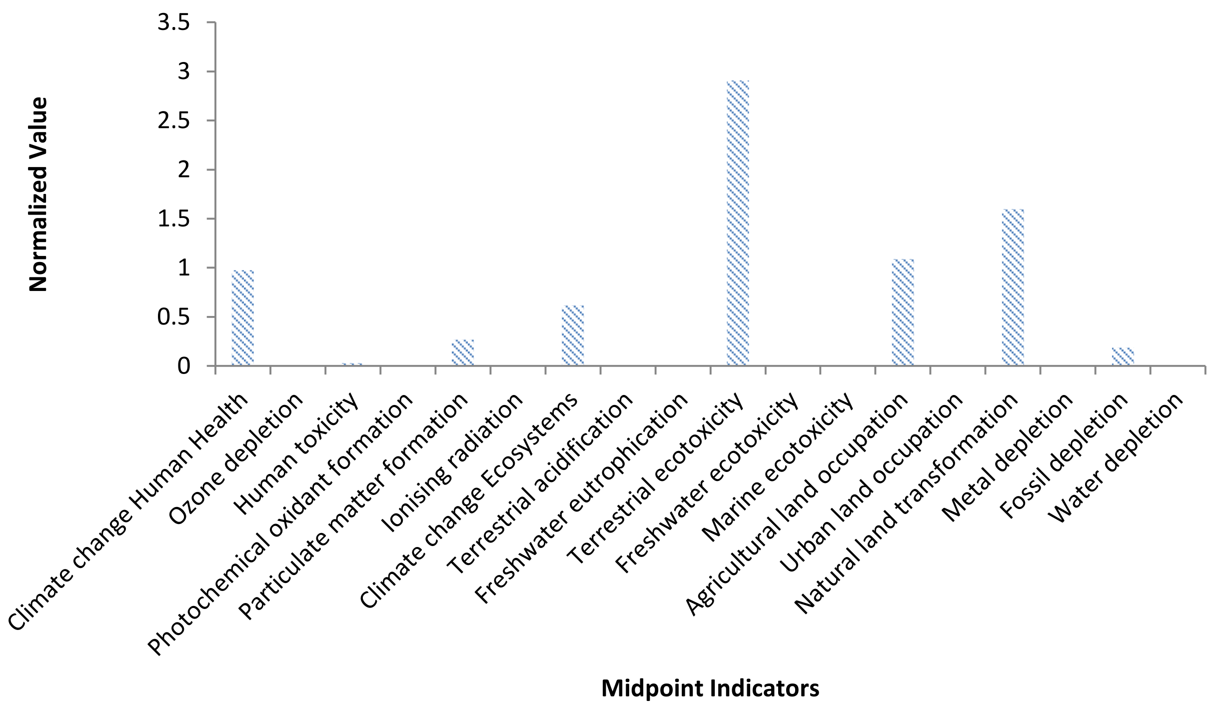

Figure 12: Normalized Value for Midpoint Indicators of Plantation

Based on Figure 13 below, it can be seen that for the endpoint indicators, damage to ecosystems has the highest value with a normalized value of 6.2195091, and the damage to resources is the lowest with a normalized value of 0.1861735. This can be related to the high impact to terrestrial ecotoxicity, where it damages the surroundings the most than the damages to human health or resources.

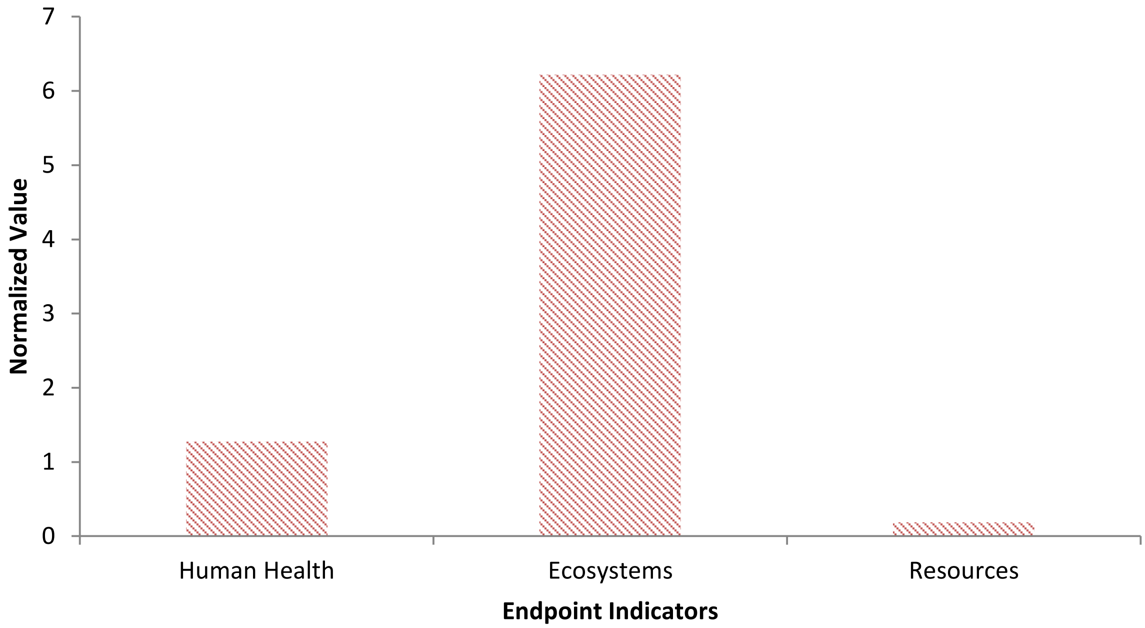

Figure 13: Normalized Value for Endpoint Indicators of Plantation

The last analysis is for the palm oil mill itself. Figure 14 and Figure 15 shows the midpoint indicators, and the endpoint indicators for the palm oil mill respectively. Based on Figure 14 below, it can be seen that the highest contributor among the environmental impacts is terrestrial ecotoxicity, with a normalized value of 0.258. The reason behind the high value at terrestrial ecotoxicity can be related with the production of POME, which is highly toxic. POME is produced alongside the production of crude palm oil, palm kernels, and palm shells. They are usually stored in ponds and emit high amount of methane to the environment. This pond can also corrode the environment, thus the high value towards the terrestrial ecotoxicity.

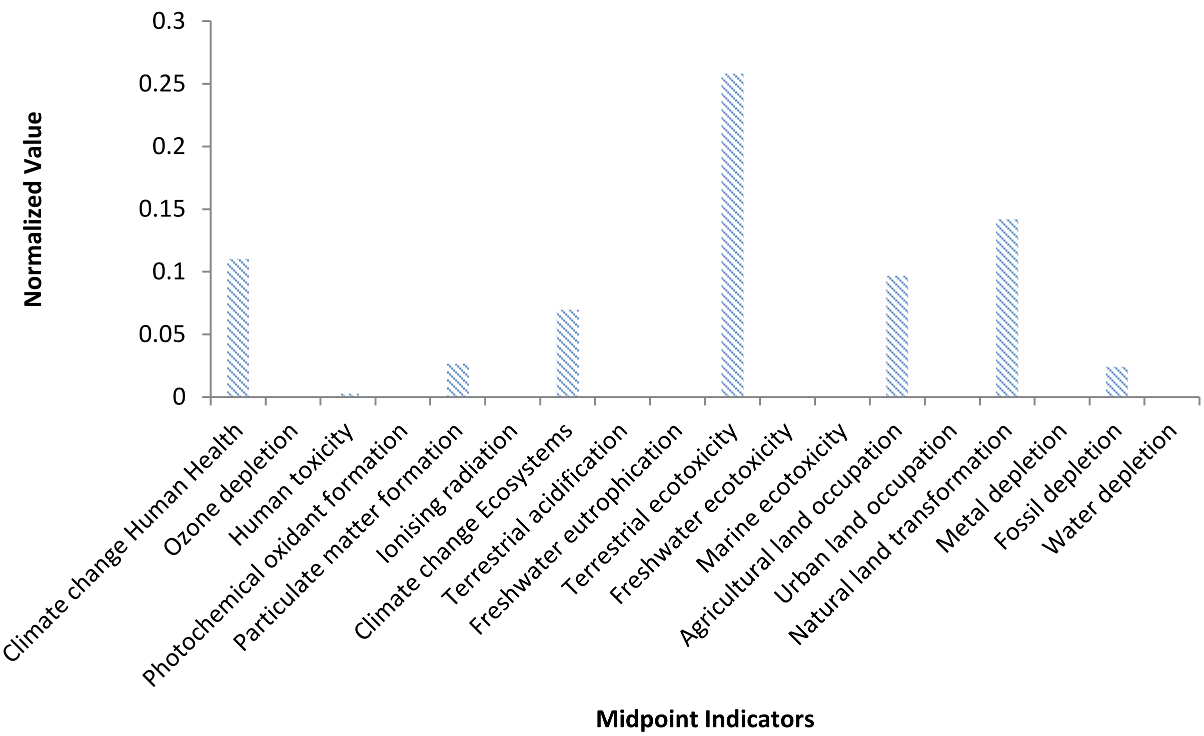

Figure 14: Normalized Value for Midpoint Indicators of Palm Oil Mill

Based on Figure 15 below, it can be seen that the highest damage is towards ecosystem, with a normalized value of 0.5671986. Figure 8 also shows a similar pattern in which the highest damage is done to the ecosystem, with a single score of 226.87944Pt. This is due to the high value of terrestrial ecotoxicity which does more harm to the surrounding environment than to the human health or to the resources.

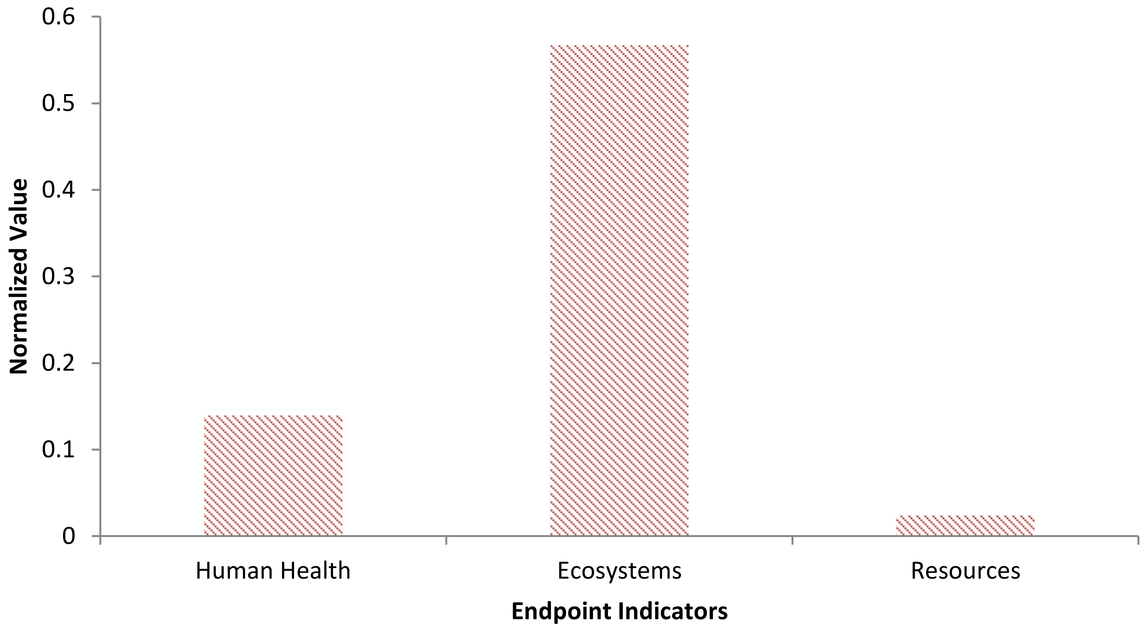

Figure 15: Normalized Value for Endpoint Indicators of Palm Oil Mill

One of the major concerns that can be found from the analysis is the use of pesticides on the plantation to keep out the insects that destroy the palm oil trees, leading to the increase of terrestrial ecotoxicity. These pesticides are toxic to living organisms, and some can even accumulate in the water supply, contaminating it and also the air. It can even damage the plantation by killing the beneficial insect species, soil microorganisms, and worms which naturally limit pest populations and maintain soil health. To help solve this problem, bio-pesticides can be applied in the plantation. Bio-pesticides are known to be less toxic than conventional pesticides, and it only affect the target pest and closely related organisms, contrary to a wide spectrum of a conventional pesticides which affects the entire ecosystem indiscriminately. They also decomposed quickly, resulting in lower exposures and evading pollution problems.

Another major concern is the use of petrol as the power source for the operation of nursery. This has an adverse effect on fossil fuel depletion since petrol is also derived from fossil fuel found in the Earth. Generally, fossil fuels are fuels produced by natural processes such as anaerobic decomposition of buried dead organisms. It consists of high percentages of carbon and also includes coal, petroleum, and natural gas. Since the source of petrol is already reducing to an alarming state, one can opt to use other alternatives to be used as the power source for the nursery. One of the alternatives is the application of green energy which comes from natural sources, such as using a solar panel. Since the nurseries are already harvesting the sunlight for the growth of their seedlings, they can also utilize it for their power source purpose.

Lastly, the final concern is regarding the emission of greenhouse gases, or biogas, from the palm oil mill effluent to the atmosphere. The gas in question is methane. This particular gas, if released to the atmosphere, can cause global warming. As the solution, one can opt to capture or recover the biogas to be used to generate energy for the palm oil mill. This can be done by recovering the methane gas in the palm oil mill effluent treatment facility by changing the anaerobic lagoons to closed or covered digesting ponds or sealed digesting tanks. After that, combustion of the methane gas in the gas turbine can be carried out to harvest the energy from the gas generated from the effluent.

CHAPTER 5:

CONCLUSION AND RECOMMENDATIONS

As a conclusion, the project managed to reach its objectives of designing an inventory data for the life cycle assessment of palm oil mill and carrying out the assessment using the ReCiPe method. Palm oil mill is important to the country since it is also one of the main contributors to the nation's economy, so it is important to figure out what can be done in order to make it less harmless to the environment.

This project conducted LCA on particularly 3 systems that end with the palm oil mill, starting from the nursery to the plantation. Besides that, the materials or emissions in the inventory that lead to the environmental burdens were also discussed. This analysis can assist the decision making process of palm oil mill constructors on building a mill that produces less dangerous impact to the environment.

From the LCA, it can be observed that each systems leading to the palm oil mill has their own problems that need to be addressed. Specifically, the problems found are in terms of the use of pesticides at the plantation, the use of petrol at the nursery, and the emission of greenhouse gases from the palm oil mill effluent. All of these problems has been given the solutions in hope that they can be solved immediately and will not occur in the future.

As for the future recommendations, researches can be done on the various types of products that can be made from the palm oil mill, so that the inventory data can be expanded to include these data as well. For example, one of the products that can be made is crude palm oil in the form of briquette. Perhaps future LCA can be conducted using this newfound data since most of the data available as of now is incomplete. This can provide more insight into the palm oil mill and new problems can arise to be solved.

Environmental awareness is important in order to preserve the nature. The drastic development of technologies had caused a burden to the environment. One of the main contributors to this dangerous situation is the palm oil mills. Therefore, it is important to carry out the life cycle assessment to evaluate the environmental impacts associated with palm oil mills. The result of this study can be used to further develop strategies to reduce the negative impacts caused to the environment.

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