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Environmental Sustainability Assessment Approach for Palm Oil Production in Malaysia

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Abstract

Malaysia began introducing several sustainability practices to be able to fulfil requirements of foreign legislation that demands stringent measures in minimizing environmental impact of products and services throughout their life cycles. This includes participation during 2006 for the National Life Cycle Assessment (LCA) program to support national eco-labelling program. This voluntary-based action correlates with the government's aim to achieve United Nation's Sustainable Development Goals (SDGs) 12 and 13 which are responsible consumption and production and climate action in reducing carbon footprint while using processes that are environmentally friendly. This study demonstrates in general how LCA approach is applied to palm oil milling and refinery to determine the potential environmental impacts on these processes by using ReCiPe 2016 method and SimaPro 8.4.0 software. Primary data were retrieved via site-visit to a palm oil mill and a refinery plant. Data gap were supported by database from previous studies. Based on the findings, palm oil milling contributes the most significant impact which were global warming potential (GWP), freshwater eutrophication (FEP) and fossil fuel scarcity (FFP) at midpoint level. Alternative scenario of full utilization of biomass waste and biogas capture for palm oil milling showed a range of 10% to 20% reduction for ecosystem quality (ED) while 20% to 30% reduction for resource availability (RA) and human health (HH) at endpoint level. The survey on perception of LCA implementation at industrial level indicated that it is still uncommon due to lack of application and insufficient knowledge among industry players on its utilization.

Keywords: Life Cycle Assessment (LCA), Palm oil production, Sustainability, Sustainable development goals

1 Introduction

The start of a vigorous palm oil trading came from the search of biofuel, a promising renewable energy to replace the finite source of fossil fuel due to suitable weather conditions, high yield and cost-effective production. Malaysia saw the promising future of biodiesel and ventured into the business of palm oil and managed to rank second as a world palm oil producer [1] accounting for 39% of world production and 44% of world export. Consequently, the rapid growth of supply-demand caused Malaysia palm oil industry to face several environmental issues which often been raised by non-profit organizations (NGOs) and green activist [2] which triggered Malaysia's government to take a step further by introducing sustainability concept in order to provide possible solution to minimize existing problems.

The sustainability concept is adopted from the United Nation's Sustainable Development Goals (SDGs) Agenda 2030 whereby that focuses on SDG 12 and 13; responsible consumption and production and climate action. A sustainable supply chain system or product is achieved when the needs and aspirations of the current generation are attained without compromising the performance in meeting the needs of those in the future [3]. Malaysia palm oil industry began its sustainability initiatives with introduction of environmental law to protect the land from deforestation and land-use change, participation as a member of the established Roundtable on Sustainable Palm Oil (RSPO), sustainability schemes and implementation of Best Management Practices (BMP) for palm oil plantation. Recently, application of primary tools through environmental management and life cycle assessment (LCA) has further reflected the importance of environmental sustainability in palm oil industry [4].

1.1 Life Cycle Assessment (LCA)

A sustainability assessment tool namely LCA is utilized to monitor environmental trade-offs in a product or system. LCA is methodological assessment supervised by international series of ISO 14000 standards to assist in creating products and technologies that are environmentally friendly and for the purpose of impact evaluation on the environment [5]. Started in 2006, Malaysia participated in the National Life Cycle Assessment Project that prolonged for five years to execute several outputs

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when Ninth Malaysia Plan (2006-2010) ended [4].

Malaysia Palm Oil Berhad (MPOB) was the first to conduct full LCA on a crude palm oil production to serve as baseline information for any interested entities in the industry to implement LCA for their palm oil production [6]. Although there exist several LCA studies specifically focused on Malaysia's palm oil production, most of the studies targeted on nursery and plantation stages only due to the rise of deforestation and biodiversity loss issues. Malaysia palm oil industry cannot claim that their palm oil making processes are hundred percent sustainable if the whole processes are not equally monitored for their environmental performance on daily basis. Moreover, the insufficient environmental database on palm oil production could also be the reason implementation of LCA on industrial level in Malaysia palm oil industry is still a voluntary-based action. Hence, this paper intends to produce another LCA study of palm oil production in Malaysia particularly on other stages than nursery and plantation in palm oil production with the hope to broaden the availability of environmental database and a brief online survey is conducted to determine the current implementation of LCA in palm oil production in Malaysia.

2 Material and methods

In this study, LCA framework is used to access environmental performance of milling and refinery stages in palm oil production. A brief survey also has been conducted via dispersing online questionnaire to a specific colony of respondents to determine the familiarity of LCA among people whose work are closely related to palm oil sector in Malaysia. There are basically four components involved in conducting LCA of palm oil production which are goal and scope definition, life cycle inventory (LCI), life cycle impact assessment (LCIA) and lastly, interpretation of the impact assessment [7]. The steps are illustrated in Figure 1.

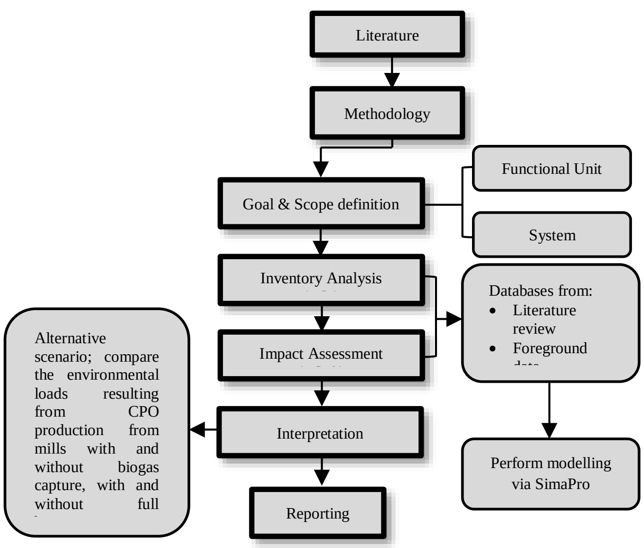

Figure 1: Process flowchart of LCA methodology

Based on Figure 1, the goal of this study was to build inventory for milling and refinery stages based on primary and secondary databases. To obtain primary data, site visit to a local palm oil mill and a palm oil refinery plant were conducted and data gaps were supported by relevant database from previous studies as well as background database located in the software that was used to produce environmental impact results. The scope of this study involved two system boundaries (SBs) which were milling and refinery stages. Both system boundaries involved private mills which do not have their own plantation and fresh fruit bunches (FFB) are obtained from other plantation companies. The databases were collected from input and output of milling stage (SB I) as well as input and output of refinery stage (SB II). Allocation assumption was necessary in attributional LCA modelling since both SBs produce co-products.

2.2 Database collection and analysis method

In inventory analysis, a functional unit (FU) served as a reference basis where all resources and emissions compiled are converted into a specific system under investigation [8]. For SB I and SB II, the FU were 1 ton of fresh fruit bunches (FFB) processed and 1 ton of crude palm oil (CPO) processed respectively. Product's mass was used for allocation process of the inputs and outputs flow. In terms of selection of mills and refinery plant, the factors include type of mills (with or without plantation), processing capacity and location to suits previous studies' conditions in order to make the secondary database relevant to the current study [6][8][9]. Figure 2 represents the input and output based on the functional units stated for SB I and SB II.

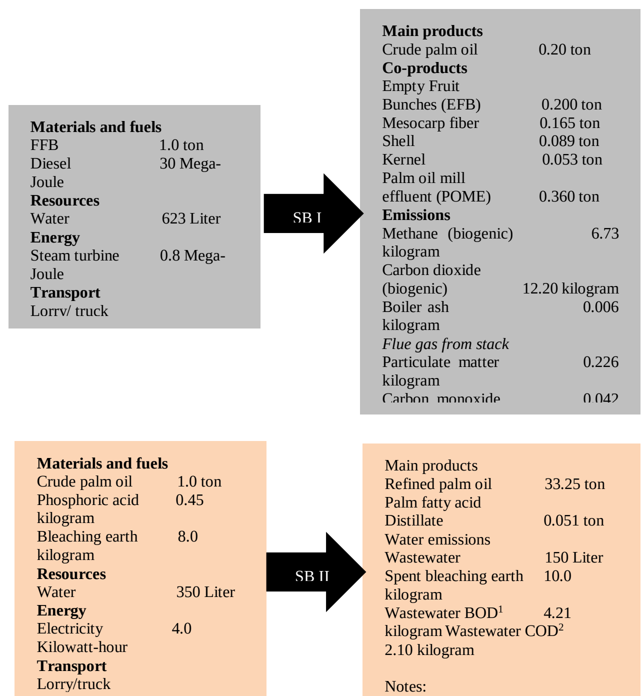

Figure 2: Inventory analysis of system boundary 1 (SB I) and system boundary 2 (SB II)

The questionnaire to obtain primary data directly from the representative of palm oil mill and refinery plant were developed according to the standard procedures in ISO 14041 (1998) [10]. Some of the necessary information include detailed process flowchart, the input and output flows of the analysed product. In general, the complete chain of palm oil production starts from germination of seeds (nursery), growing palm tree (plantation), FFB transportation to mill, oil extraction (milling), refining CPO (refinery), and waste management [11]. In this study, 1 t (1000 kg) of FFB were used to extract 0.2 t of CPO (SB I), and 1 t of CPO processed produced 33.25 t of RPO (SB II). Based on the information given by each representatives of palm oil milling and refinery plant as well as Malaysia Palm Oil Council (MPOC) official website [12], the processes involved in palm oil milling (SB I) and refinery plant (SB II) were as shown in Figure 3. For SB I, about 2-5 metric tons of FFB was transported in a minimum distance of 5 km travelled from plantation to mill.

Meanwhile, in SB II, a truck carrying CPO ranging from 30 to 40 metric ton was used to travel a minimum distance of 20 km from mills to refinery plant. The main product for SB I was CPO and the co-products consisted of 19-21% of empty fruit bunches (EFB), 16-18% of mesocarp fiber, 8-10% of shell, 4-6% of kernel, and 35-37% of palm oil mill effluent (POME). Kernel undergoes separate process to produce palm kernel oil (PKO) which was excluded in SB I. Referring to Subramaniam *et al.* (2008), based on the average of 12 palm oil mills, 1 ton of CPO will produce 85.55 m^3 of biogas [6] in which the content of methane in the biogas usually around 55-65% and 36% for carbon dioxide [6][8][11]. Therefore, for inventory of SB I, 0.36 t of POME produced 6.73 kg of methane and 12.2 kg of carbon dioxide. However, in alternative scenario done where biogas was harvested and biomass wastes were recycled, assumption made was there were no air emissions and zero solid waste.

For SB II, the main products were RPO and palm fatty acid distillate (PFAD). Similar to SB I, the allocation assumption for refinery process was based on mass of co-products. According to the data collected at refinery plant, 1 ton of CPO processed produced roughly 33.25 ton of RPO and 0.051 ton of PFAD based on 85-90% of PFAD purity. The efficiency of the refinery plant is about 95% for each ton of CPO processed. To processed 1 ton of CPO, about 0.8-1.2% of bleaching earth and 4.5% of phosphoric acid were used. Spent bleaching earth contained about 25% of oil loss which means in 0.8% of bleaching earth used, there were 8.0 kg of bleaching earth plus 2.0 kg of oil loss. In the case of amount of wastewater after biological oxygen demand (BOD) treatment and wastewater for chemical oxygen demand (COD) treatment, the original values were given as 1200 parts per million (ppm) and 600 ppm respectively. However, in order to synchronize with FU, both values were converted to unit of kilogram (kg).

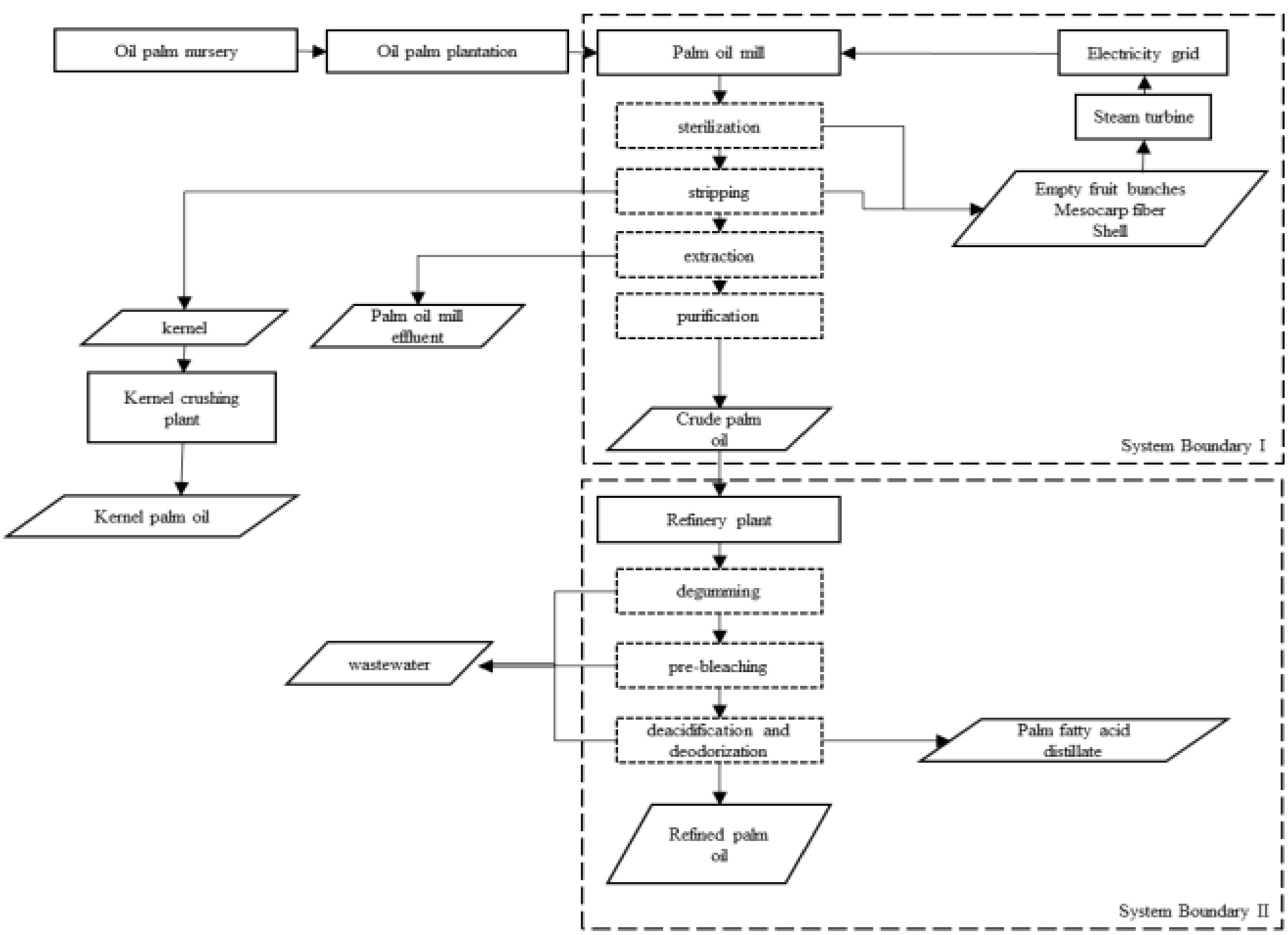

Figure 3: Processes involved in each system boundaries (SBs)

A software that implemented LCA framework called SimaPro version 8.4.0 was used to conduct impact assessment method (LCIA) and Ecoinvent 3.0 [13], Agri-footprint 3.0 [14][15][16], ELCD 3.2 [17] were selected as background data sources. This software can be used to keep track of the environmental sustainability performance through identifying potential impacts in products or services throughout their life cycle. ReCiPe 2016 was chosen as the calculation method to conduct the impact assessment because it is the latest updated method that combined two popular methods [18] in LCA study which were CML methodology and Eco-indicator 99 to create broader impact categories [19]. There are 18 different impact category indicators developed at midpoint level in ReCiPe 2016 [20] which can be further classified into three areas of protection at endpoint level as shown in Tables 1 and 2.

Table 1: Midpoint category indicators according to their respective areas of protection

Midpoint impact category	Abbreviation	Areas of protection
Water consumption potential	WCP	Human Health (HH)
Human toxicology carcinogenic potential	HTPc	
Human toxicology non-carcinogenic potential	HTPnc	
Ozone depletion potential	ODP	
Ionization radiation potential	IRP	
Ozone formation potential	HOFP	
Particulate matter formation potential	PMFP	
Global warming potential	GWP	
Global warming potential (terrestrial and freshwater ecosystem)	GWP	Ecosystem quality (ED)
Ozone formation (terrestrial ecosystem)	EOFP	
Water consumption potential (terrestrial and freshwater ecosystem)	WCP	
Terrestrial acidification potential	TAP	
Terrestrial ecotoxicity potential	TETP	
Freshwater ecotoxicity potential	FETP	
Marine ecotoxicity potential	METP	
Land use change	LUC	
Freshwater eutrophication potential	FEP	
Marine eutrophication potential	MEP	
Fossil fuel scarcity	FFP	Resource availability (RA)
Mineral resource scarcity	SOP	

Table 2: Endpoint categories indicators

Midpoint categories	Endpoint	Unit
GWP (human health), WCP (human health), HOFP (human health), HTPc, HTPnc, ODP, IRP and PMFP	Damage to health	Disability-adjusted loss of life years (DALY)
GWP (terrestrial ecosystem), GWP (freshwater ecosystem), WCP (terrestrial ecosystem), WCP (freshwater ecosystem) EOFP (terrestrial ecosystems), TAP, TETP, FETP, METP, LUC, FEP and MEP	Damage to ecosystem quality	Time-integrated species loss (species · year)
SOP and FFP	Damage to resource availability	Surplus cost (Dollar, $)

2.3 Survey study

A Likert-scale questionnaire has been developed where the key points to be raised were assessed via United Nation's Development Program annual report 2018 for Malaysia [21], Eleventh Malaysia Plan Midterm Review: Chapter 5 on "Pursuing Green Growth for Sustainability and Resilience" [22], and previous studies that focused on the perception of sustainability practices in Malaysia palm oil industry [23][24][25]. Likert-scale instrument was chosen as it is often used to measure psychological form, which reflects a person's affect or cognition [26]. Initiation of questionnaire development came from a deep understanding of the target construct, mainly by reading academic literature on the specified topic. A respondent's perception and knowledge on the studied matter are conceptualized from one extreme to another – low to high, small to large, negative to positive, or weak to strong [25].

In this survey, 19 questions were established with the first five questions involving personal information of the respondents such as names, designation, email address, organization or company and years of experience. Several likert-scale options were chosen in developing the questionnaire as shown in Table 3. A total of 14 questions have been developed with 12 questions using likert-scale option and the remaining questions were given multiple choice-based questions. The key points emphasized in the questions include implementation of UN's Sustainable Development Goals (SDGs), effectiveness of Roundtable Sustainable Palm Oil (RSPO) and International Sustainable Carbon Certification (ISCC), familiarity of LCA in palm oil industry in Malaysia, and lastly, actions related to environmental sustainability that highly reflect a palm oil company's image worldwide. This survey study was intended for a specific colony of respondents whom are closely related to Malaysia palm oil industry. Therefore, snowball sampling method was used to obtain target respondents within a six-month period. According to Kamarudin *et al.* (2019) [27], snowball sampling can be used when research respondents are hard to find. It is a technique for selecting respondents in a network, where it begins with one or a few people. Interviews and field notes during site-visit to MPOB and events organized by palm oil organizations also became the supporting materials to develop the questionnaire. The questionnaire was largely operated online via a platform called SurveyMonkey [28].

Table 3: Classification of questions with its respective type of answer choices

Question number	Type of likert-scale
6, 7, 8, 9, 10, 11, 17, 18	Strongly disagree, disagree, slightly disagree, slightly agree, agree, strongly agree
14	Not at all familiar, not so familiar, somewhat familiar, very familiar, extremely familiar
16	Not at all effective, not so effective, somewhat effective, very effective, extremely effective
13, 15	Yes or No

3 Results and discussion

3.1 Life cycle impact assessment (LCIA)

In LCIA phase, successfully built inventories are further characterized into several environmental impact scores to identify potential environmental impacts. Characterization factors that signify environmental impact per unit stressor were used to determine the potential impacts. For example, per kg of resource used or emission released [20]. Derivation of midpoint characterization factor (CF_m) with a constant midpoint to endpoint factor per impact category (F) will lead to endpoint values (Equation [1]):

$$CF_e = CF_m \times F \qquad [1]$$

Detailed description for the derivation of constant global midpoint to endpoint factors are included in ReCiPe2016 method's guidelines. Based on the findings, palm oil milling contributed the most significant environmental impacts whereby refinery process was found to have minor impact on the environment in comparison [6, 9]. Characterization of LCIA for 1 ton of FFB discovered that FFB production (plantation stage) affects most impact assessment results with percentage of relative contribution more than 50% except for impact category of GWP, FEP and FFP. For these three impact categories, excluding plantation stage, palm oil milling was the main contributor. According to a review study by Izah *et al.* (2016) [29], palm oil processing emits three major waste streams; (i) gaseous (pollutant gases), (ii) liquid such as POME and, (iii) solid such as mesocarp fibre, palm kernel shell and empty fruit bunch. This explains that untreated POME and gases emissions from POME treatment may have contributed to GWP while solid wastes had majorly influenced FEP and FFP as shown in Figure 4.

At endpoint level, the damage assessment showed that palm oil milling had impacted HH, ED and RA at 1.71 x10^{-3} DALY, 2.43 x10^{-5} species·year and 40.68 dollars respectively and the relative contribution is shown in Figure 5. These results were parallel to previous studies where climate change (GWP) and fossil fuels (FFP) were the main impacts identified in palm oil milling and it is highly associated with plantation stage [8][9][30]. For midpoint level, there are specific units according to the type of indicators. For resource depletion and emission-based impact categories, mass (kg) reference substance to a specific environmental section is used. Meanwhile, the unit for land use is represented by area and time-integrated for one type of land use [8].

Referring to IPCC 2013 for GWP of time horizontal of 20 years for each greenhouse gas emission (kg CO_2-eq/ kg emission), 1 kg of carbon dioxide (CO_2) equal to 1 kg CO_2-eq and 1 kg of methane (CH_4) equivalent to 84 kg CO_2-eq [20]. This means, for 1 ton of FFB processed to extract 0.2 t of CPO, 102.9 kg CH_4 and 8645 kg CO_2 were released to the atmosphere. An alternative scenario was conducted to show the impact results if biogas was fully harvested and biomass waste such as EFB, mesocarp fiber and shell were fully recycled. As a consequence, damage assessment values of palm oil milling stage in terms of HH and RA had been reduced about 20-30% to 1.36 x10^{-3} DALY and 2.18 x10^{-5} species·year respectively while ED experienced 10-20% reduction to 28.90 dollars. Figure 6 shows the comparison in the amount of methane and carbon dioxide gases released to the atmosphere between default situation and alternative scenario. It can be said that GWP value reduced significantly from 8645 kg CO_2-eq to 4268 kg CO_2-eq (40-50 % reduction) proving the source of GWP that is POME treatment has rather became a saving to the environment [6].

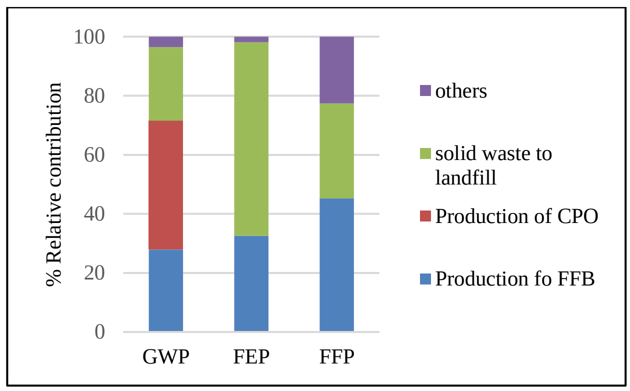

Figure 4: Relative contribution of palm oil milling for impact categories at midpoint level

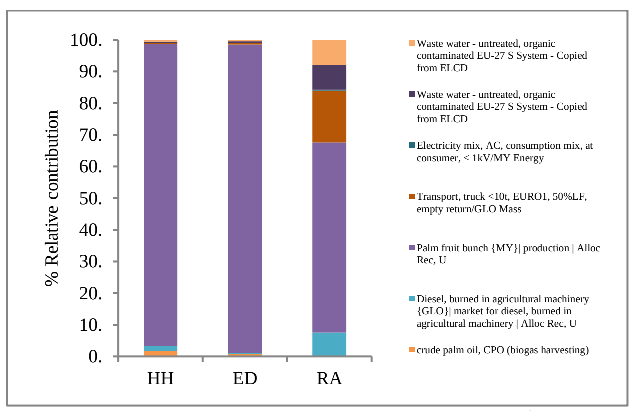

Figure 5: Relative contribution in palm oil milling for damage assessments towards human health (HH), ecosystem quality (ED) and resource availability (RA) at endpoint level.

In reality, there exists palm oil mills that are very self-sufficient generating their own energy by fully utilizing valuable by-products. However, in terms of biogas harvesting, only 10% of palm oil mills have biogas plant up to this date [31]. Government should adopt a friendly biomass supply chain system with minimum logistic cost and optimized performance as suggested by Salleh *et al.* (2019) [32].

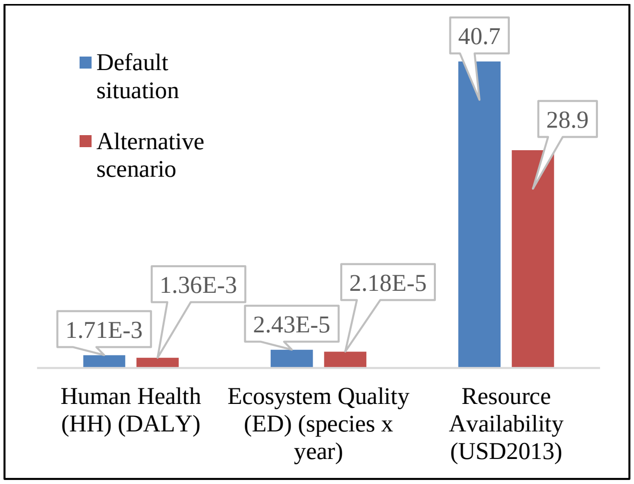

Figure 6: Comparison of GWP, methane (CH_4) and carbon dioxide (CO_2) values for LCIA of without biogas capture and with biogas capture in palm oil milling

3.2 Perception of LCA in the palm oil industry

A total of 140 people consisting of palm oil production researcher, palm oil grower and manufacturer as well as corporate people in palm oil-related organizations were approached to be the respondents of the survey study. Despite this, only 26 respondents decided to share their opinions through this survey. Based on the survey, more than 70% of the total amount of respondents have more than six years' experience in the industry which indicates the feedbacks may be useful for further reference in improving the policy in Malaysia palm oil industry.

Based on the survey, Questions 6 and 7 touched upon recognizing government's effort in introducing SDGs concept in palm oil industry as well as the importance of environmental assessment in palm oil production. Referring to Figure 7, it showed that most respondents were aware on the purpose of sustainable development goals and realized the importance of integrating SDG 12 into the palm oil industry. This action is parallel to the 11th Malaysia Plan Midterm Review [22] where Malaysia adopted sustainable consumption and production (SCP) concept to enable environment for green growth, to improve the awareness on environmental issues towards achieving sustainable development. Other than that, Questions 8 to 11 evaluated the effectiveness of existing sustainability practices in the palm oil industry such as establishment of RSPO and ISCC, local code of practices in milling operation, current natural conservation surrounding palm oil millings and the need to create a standardised measurement tool to monitor environmental performance of palm oil production processes continuously. A total of 20% of the respondents agreed that RSPO and ISCC implementation do not give enough impact towards environmental sustainability of palm oil production in Malaysia. Certification schemes like RSPO and ISCC have some flaws as it certifies palm oil plantation not on the basis of overall performance of plantation companies but selection of specific plantation areas [33].

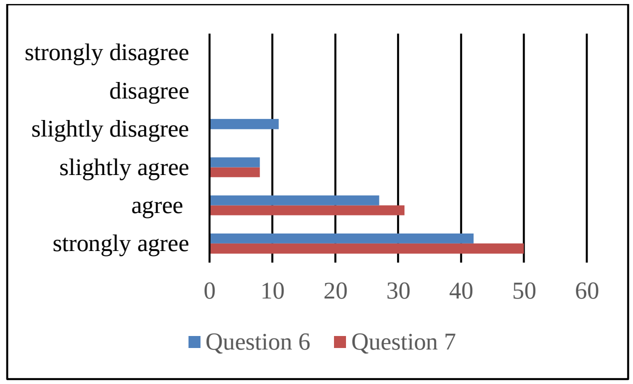

Figure 7: The feedback for topics related to importance of SDGs concept and environmental assessment in palm oil production

Moreover, 42% of the respondents voted for the needs to establish a standardised measurement tool to appraise environmental sustainability in producing palm oil. Malaysia palm oil industry ought to continue the national LCA project established in Ninth Malaysia Plan (2006-2010) [4] to support the goals in Eleventh Malaysia Plan Midterm Review on pursuing green growth for sustainability and resilience. On top of that, implementation of LCA as part of the mandatory policy instruments in the palm oil industry could help the country in overcoming challenges in terms of developing comprehensive policy planning, establishing a systematic mechanism to report, monitor and evaluate environmental-related policies and programme and to increase the awareness among public on environmental issues [22].

For Questions 13 to 18, introduction to LCA and familiarity of LCA among industry people in the palm oil sector were raised to see the amount of people who have first-hand experience on LCA and the extend of its implementation in the Malaysia palm oil industry. As expected, nationwide database availability has yet to be achieved which make LCA implementation at industrial level somewhat infeasible. This signals the more reason for government to push forward LCA to be a compulsory action at industrial level especially when establishment of MSPO Supply Chain Certification Standard (SCCS) has been commenced in December 2019 [34]. A study by Jaafar *et al.* (2020) [35] concluded that legislation and regulation have the most positive impact towards environmental performance out of five variables in green supply chain management practices gives a clearer purpose for government to critically consider the possibility of LCA as mandatory policy instrument in palm oil industry.

4 Conclusions

In this study, an environmental sustainability assessment was conducted via LCA approach to determine potential environmental impacts that can be avoided or improved in the processes involved in palm oil production. The focus of LCA applies in two processes which were palm oil milling and refinery due to lack of LCA studies in this area. The characterized results were investigated at two level namely midpoint and endpoint level. For both levels, refinery plant was found to contribute insignificant environmental impacts. Therefore, the impact assessment result was focused on palm oil milling. At midpoint level, three potential environmental impacts were found, and they were global warming potential (GWP), freshwater eutrophication (FEP) and fossil fuels scarcity (FFP). An alternative scenario was done where it was assumed biogas were fully captured and all biomass waste were recycled to generate electricity to operate the mill. Significant reduction around 40-50% of GWP was detected when the assumptions were applied. Due to palm oil milling and refinery were closely related to upstream activities, it can be said that most environmental impacts were originated from them. Hence, it is vital to implement environmental-friendly practices in the upstream activities to avoid or reduce major environmental hotspots. Moreover, implementation of biogas capture at palm oil mills on a larger scale should be seen as a positive move towards sustainable palm oil production.

In terms of the perception of LCA implementation in Malaysia palm oil industry, it seems that people in this industry especially palm oil manufacturers and planters are still lacking knowledge about the advantage of LCA implementation. However, they are aware of the importance of sustainable palm oil production and government's pledge on sustainable development goals (SDGs) especially SDG 12 on responsible consumption and production as well as SDG 13 on climate action. Currently, most of the actors playing important role in the palm oil industry only recognized the existence of RSPO, ISCC, BMP and green technologies as the way to achieve environmental sustainability in palm oil industry.

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Ethical issue

Authors are aware of, and comply with, best practice in publication ethics specifically with regard to authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests and compliance with policies on research ethics. Authors adhere to publication requirements that submitted work is original and has not been published elsewhere in any language.

Competing interests

The authors declare that there is no conflict of interest that would prejudice the impartiality of this scientific work.

Authors' contribution

All authors of this study have a complete contribution for data collection, data analyses and manuscript writing.

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