Visualization of the Sustainability Level of Crude Palm Oil Production: A Life Cycle Approach

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Abstract: The Malaysian palm oil is an important source of social development and economic growth in the country. Nevertheless, it has been accused of conducting unsustainable practices that may affect the sustainability of this industry. Thus, this study aims to identify the level of sustainability of crude palm oil (CPO) production. Environmental impacts were assessed using the International Organization for Standardization (ISO) standardized life cycle assessment (LCA). Economic impacts were evaluated using life cycle costing (LCC). Social impact assessment was identified based on the UNEP/SETAC Guidelines for social life cycle assessment (S-LCA). Life cycle sustainability assessment (LCSA) was used to combine three methods: LCA, life cycle costing (LCC) and S-LCA using the scoring system method. Finally, a presentation technique was developed to visualize the LCSA results. The results show that crude palm oil production requires more improvement to be a sustainable product. The study feasibly enables the decision-makers to understand the significant environmental, economic, and social hotspots during the crude palm oil production process in order to promote palm oil production.

Keywords: life cycle assessment (LCA); life cycle costing (LCC); life cycle sustainable assessment (LCSA); social life cycle assessment (S-LCA); sustainability; scoring system; palm oil production; LCSA

1. Introduction

In Southeast Asia, some countries such as Malaysia, Indonesia, and Thailand have been considered as the major crude palm oil (CPO) producers in the world [1]. According to [2], the total oil palm plantation area in Malaysia constitutes 50,000 km² and 423 mills of palm oil operate in this sector. The crude palm oil industry has developed interestingly, producing a diversity of products such as food, cosmetics, biofuels, and other goods. The palm oil industry stands as the fourth greatest contributing industry to the Malaysian economy and contributes 6.4% to gross national income [3]. As noted by [4], this industry reduces poverty and improves healthcare and education in rural areas. Thus, it is a significant industry for the social development and economic growth of Malaysia but although this is an important role, the rapid growth of the industry has negative environmental, economic, and social impacts.

Thus, the whole industry has been faced with the growing accusations made by Non-governmental Organizations (NGOs) as to how the potential palm oil production impacts the environment and the people. Moreover, this industry has faced negative reports from the international nongovernmental organizations on the sustainability subject [5]. These organizations stated that the palm oil industry is not run within the sustainable boundary of the business. Thus, it is necessary to establish a holistic sustainability assessment method for crude palm oil production based on the environmental, economic, and social dimensions to help decision-makers to monitor the industry for sustainable production [3]. A review of the literature found that life cycle assessment, life cycle costing, and social
life cycle assessment methods have been applied in several case studies to evaluate the impacts of palm oil production. Ref. [6,7] applied the life cycle assessment (LCA) tool to determine the environmental impacts of oil palm production in Germany and Philippines, respectively. Other studies have applied this tool to evaluate the environmental impacts of biodiesel produced from palm oil [8–13]. Moreover, ref. [1,13] applied the LCA tool to assess the environmental impacts related to crude palm oil production. Likewise, the life cycle costing method and externalities were conducted to identify the cost impacts of palm oil biodiesel in Thailand [14]. Ref. [15] implemented the life cycle costing and sensitivity analysis to determine the cost impacts of palm biodiesel production. For social approaches, there have also been studies without a complete sustainability approach but which have identified the social impacts of the palm oil production in Malaysia [16–18] and in Indonesia [18]. However, there is no study that has implemented the three sustainability dimensions (environmental, economic, and social) to evaluate the oil palm production sustainability [19].

For this purpose, this study evaluated the crude palm oil production impacts for a year utilizing the life cycle sustainability assessment (LCSA) which quantifies the impacts in the three dimensions of sustainability: environment, economy, and social. The study was carried out at two selected plantation mills in Johor, Malaysia from March to May 2019. A scoring system was applied for combining the inventory results for the three methods, namely, life cycle assessment (LCA), life cycle costing (LCC), and social life cycle assessment (S-LCA). Eventually, a presentation technique was developed to visualize the results of LCSA. Thus, the results will be helpful for the industry players to assess the environmental, economic, and social impacts and, hence, to understand the significant hotspots in order to promote the sustainability of this substantial product and to construct a reference point for further studies.

The objectives of the study were to:

- provide a holistic assessment of the crude palm oil production based on the environmental, economic, and social dimensions that are required by the decision makers to monitor the industry for sustainable production
- develop a scheme to evaluate the level of sustainability of the crude palm oil production through three dimensions (social, environmental, and economics).

2. Methodology

Life cycle sustainability assessment (LCSA) is the most accepted framework that combines the three dimensions in order to identify the impacts and benefits of products in a combined manner [20,21]. The first proposal for the LCSA framework was developed by [22]. Kloepffer integrated the three life cycle techniques accordingly where: LCSA = LCA + LCC + S-LCA, in response to the need for a more holistic life cycle-based assessment towards sustainability by integrating the three life cycle techniques. Thus, this study proposed a LCSA methodology to determine the level of crude palm oil production sustainability. The guidelines for “Towards a Life Cycle Sustainability Assessment”, states that the LCSA technique involves four steps: goal and scope, inventory, impact assessment, and interpretation [23]. The proposed methodology follows a life cycle approach and takes into consideration environmental, economic, and social dimensions. The procedures applied to identify the level of sustainability of crude palm oil production were as follows:

1. Carry out LCA to determine the environmental impacts of crude palm oil production using the methodology based on [24,25];
2. Conduct LCC to determine the economic impacts applying the methodology proposed by the recent Code of Practice on LCC [26];
3. Perform S-LCA to assess the social impacts of utilizing the methodology based on the UNEP/SETAC Guidelines for S-LCA of products [27];
4. Determine LCSA by integrating LCA, LCC, and S-LCA using the scoring system method;
5. Visualize the results to evaluate the level of crude palm oil sustainability;
The steps taken are explained in detail in the following sections.

2.1. Goal and Definition of Scope

The goal of this LCSA study was to evaluate the level of sustainability of crude palm oil production in two selected palm oil mills in Johor Bahru/Malaysia. The state of Johor was preference and logical choice for carrying out the study because of two reasons: firstly, it was the higher plantation area among other peninsulas in Malaysia states, and secondly, it was the higher crude palm oil production in peninsular Malaysia. Through the premier phase of data collection, the researcher contacted the main palm oil companies in Johor. All of these companies either declined the cooperation or did not reply. The procedure repetition resulted in getting approval from just one company. This company has five based plantation mills, which are included in planting, harvesting, and processing palm oil crops. Thus, this study was conducted in two selected based plantation mills in Johor, Malaysia. The two selected based plantation mills were selected because they were near to the residential area. Thus, the researchers could easily conduct the study. The scope of this LCSA method focused on the production of CPO where most impact occurs. The system boundary included the palm oil plantation and the crude palm oil production at mills. In other words, this is a cradle-to-gate study (Figure 1). The functional unit of the study was 1 (one) MT of crude palm oil produced. This LCSA was carried out using the financial appraisal analysis to evaluate the economic impacts. In the case of environmental dimension, the environmental impacts were assessed using the International Organization for Standardization (ISO) standardized LCA. Eco-indicator 99, which is the endpoint approach, was applied in this study. For social impact assessment, the methodology, as described by the UNEP/SETAC Guidelines for S-LCA of Products, was used. Two groups of stakeholders (workers and the local community) were considered in this study. Stakeholder categories chose in this study were based on the UNEP/SETAC working group list and prior studies on palm oil production [17,18]. Moreover, based on [28], the local community and the workers are the stakeholders categories that are mostly considered by authors. Whereas this study focused on upstream processes of the palm oil supply chain, the stakeholders, such as consumer, value chain actor, and society stakeholders are excluded in this study because they are not involved or otherwise directly affected in this process. The chosen subcategories relating to local community and workers categories were also used by others’ social assessments on products [18,29]. Nine subcategories relating to the chosen stakeholders were found to be associated with the palm oil production. Inventory analysis.

2.2. LCA Methodology

A special data collection sheet was developed to collect the data from the two selected palm oil mills in Johor Bahru/Malaysia for the year 2019. The data were collected for the following items: consumption of water, fresh fruit bunch FFB crops yield, power consumption from turbine, chemical fertilizers and pesticides, consumption of energy, diesel and water for mills processes, a quantity of FFB transported to the mills, and the respective average distances, consumption of diesel, and waste production included in the crude palm oil production’s life cycle. The data gaps have been filled by information obtained from last scientific literature, or calculated utilizing published models. The N2O emission due to the fertilizers use was calculated based on the establishment of nutrient balances, and by the use of the N2O emissions models [30]. The emissions from the stack are evaluated by the use of the SOX, NOX, PM, CO emissions models, and for CO2 from the generated energy from the use of fossil fuels [31]. CH4 emissions from POME were determined according to [32]. The background data, i.e., the chemical production, fertilizer production, energy production, and transportation were based on the ecoinvent database of SimaPro 8.0 using SimaPro 8.0 software. The inputs and outputs for the production of 1 MT crude palm oil were based on the data obtained from two selected plantation oil palm mills (see Supplementary Appendix SA1).
2.3. LCC Methodology

In this study, the production costs of crude palm oil were calculated for the year 2019 in order to assess the costs along the cradle-to-gate of crude palm oil as identified in the goal and the scope step. The data for costs were collected using a spreadsheet, which included the data for all costs associated with materials, energy, labor, fuel, operation, and maintenance. One of the serious challenges in applying an LCC study was to capture all cost categories [26]. In this study, four types of cost categories were taken into account: initial investment cost, operational costs, maintenance costs, and the end of life cost. Due to the issues of data availability, all other internal costs, including research and development costs, financial costs, were not taken into account. According to [26], only real money flows should be considered if both costs and environmental impacts are determined in a LCSA study. Thus, conventional LCC has been used in this study. The economic data obtained were inserted into an Excel spreadsheet created to calculate the various cost categories. The financial appraisal analysis was conducted in this study. There were only two financial indicators, which are payback period and Net Present Values (NPV) indicators that were included in this study. (see Supplementary Appendix SA2 for a detailed description of LCC inventory data collection).
2.4. S-LCA Methodology

Two specific sets of questionnaires were specifically developed and used to collect social inventory data. The questionnaire is a very useful tool to get a wide range of data from the study population in a short period of time [33,34]. The questionnaires included the two stakeholders (workers and the local community) and the nine subcategories of indicators. These questionnaires involved four types of questions: quantitative, semiquantitative (yes/no), qualitative, and Likert scale. The reason for using the different types of questions was to get a subjective evaluation of the respondents’ feelings or satisfaction level. Expert consultation in sustainability, as well as the reliability test, was carried out to ensure that the questionnaires were suitable for the data collection. The data was collected during the period between March and May 2019 from two selected plantation-based mills in Johor, Malaysia. The total number of workers who were working at the mills and plantations were 696, while the total number of the members of the local community who were living in the surrounding area was 248. The representative sample size for workers was found to be 529 using the Krejcie and Morgan formulation [35]. Consequently, the self-administrated questionnaires were filled out directly by the workers on-site. The respondents were chosen randomly in each based plantation mill. While for the local community, the number in the local community population of those who were 18 years of age and above was around 248 persons. Thus, the self-administrated questionnaires were completed by the whole population. The number of copies received from the workers and the local community respondents was 480 and 228, respectively. The sampling technique used in this study was probability sampling method, which is simple random sampling. This sampling method is considered as the most appropriate method for this type of research as all individuals are equally likely to be selected as a sample. The inventory results of all the related indicators for workers and the local community are shown in Supplementary Appendixes SA3 and SA4, respectively.

2.5. Life Cycle Impact Assessment (LCIA)

2.5.1. Environmental LCIA

Life cycle impact assessment (LCIA) was conducted to evaluate which material contributed the most to the environmental impacts of a crude palm oil production. SimaPro 8.0 software (PhD version) was used to calculate the Life cycle impact assessment. Eco-indicator 99 method was chosen as the life-cycle impact method because it gives the lowest uncertainty compare with various life cycle impact assessment methods [36]. It was applied to estimate the environmental impacts created from this CPO production system. The Eco-indicator 99 method uses a damage endpoint approach. The researchers sometimes mention to the indicators that are chosen between the inventory results and the endpoints as indicators at the “midpoint level”. However, the life cycle impact assessment method midpoint provide the assessing of outcomes as a group of indicators for numbers of impact categories. Such detailed outcomes make the impact assessment results difficult to interpret [37,38]. The endpoint approach applied in this study has three damage categories: human health endpoint impact category (unit: DALY = Disability adjusted life years), ecosystem quality endpoint impact category (unit: PDF*m2yr; PDF = Potentially Disappeared Fraction of plant species), and resources use endpoint impact category (unit: MJ surplus energy additional energy requirement to compensate lower future ore grade).

2.5.2. Economic LCIA

According to UNEP/SETAC guidelines, the impact assessment is not useable in the LCC method as the cost gathering is considered enough to assess the economic impacts [39]. Thus, all costs collected from the inventory analysis step were classified into cost categories such as initial investment cost, maintenance cost, operational cost, and end of life cost.
2.5.3. Social LCIA

According to the UNEP/SETAC guidelines [27], S-LCA has two types of impact assessment methods which can be deemed as characterization models for the life cycle impact assessment phase [40]. In type one, the social impacts are combined with a scoring system and it does not include causal relationships [41]. Type two is similar to the environmental life cycle impact assessment approach. In this study, the scoring system methodology was adopted from [42] to convert and combine qualitative social inventory data into quantitative inventory data.

2.6. Life Cycle Sustainability Assessment (LCSA) Using Scoring System

In this study, it has been assumed that the three dimensions (environmental, economic, and social) have the same weight, but the chosen indicators for these dimensions have different percentages of contribution to product sustainability. A scoring system has been applied in this study to estimate the crude palm oil production sustainability. The scoring system facilitates the combination of indicators into a single score to assist decision-making. The scoring system methodology applied in this study was adopted from [42], [39] using scoring system to convert qualitative data into quantitative data and then combining them to get a single score, and to get the information, ref. [39] used a questionnaire including “yes” or “no” questions for data collection. In this study, different type of questions were utilized besides “yes or no” type questions. The reason for using these different type of questions was the subjective assessment of the respondents about their satisfaction level and feelings. It would be hard for them to give their answers in only two levels “yes” and “no”. Inventory data obtained from the three dimensions were estimated as a percentage. Then these inventory data results were converted to numerical scores scaled from 0 to 4 scores. It has been distinguished between negative and positive indicators as shown in Table 1. Finally, the equal weighting was used to assign the inventory outcomes into a single score. The scores of inventory data under the same subcategory were averaged and this average score was assigned to the corresponding subcategory. Then, the scores of the subcategories under the same impact category level were averaged and this average score was assigned to the corresponding impact category. Eventually, the scores of impact categories were averaged and this average score was assigned to total impacts.

![Table 1. Scoring systems based on [42].](image)

| Indicator         | Percentage | Marks |
|-------------------|------------|-------|
| Positive indicators | 0–20       | 0     |
|                   | 21–40      | 1     |
|                   | 41–60      | 2     |
|                   | 61–80      | 3     |
|                   | 81–100     | 4     |
|                   | 0–20       | 4     |
|                   | 21–40      | 3     |
| Negative Indicators | 41–60     | 2     |
|                   | 61–80      | 1     |
|                   | 81–100     | 0     |

2.7. Visualization

Since the LCSA results require a simple and clear presentation, the scores obtained from the three dimensions were visualized during the adapted presentation technique proposed by [43]. Ref. [43] used the presentation technique of the LCA polygon and amoeba indicator to estimate the company’s sustainability performance through the five dimensions of sustainability (environmental performance, economic performance, societal performance, organizational performance, and technical aspects).

This study focused on the three sustainability dimensions: environmental, economic, and social dimensions. Thus, the triangle was applied to present the three dimension scores.
The values of various scores of the dimensions were plotted on the corresponding axes. For visualization purposes, all scores were connected by a line which formed a new three-sided triangle. The estimate of the sustainability was conducted based on the area estimate of the new triangle. The larger the area, the better the product sustainability performance.

3. Results and Discussion

The inventories of the environmental, economic, and social were presented in Supplementary Appendixes SA1, SA2, SA3, and SA4, respectively. The impact outcomes of the three dimensions are detailed as follows.

3.1. Environmental Dimension Results

The characterization results of various impact categories based on the function unit (FU), i.e., 1 MT crude palm oil applying the Eco-Indicator 99 method are shown in Table 2. Based on the results, it can be seen that the impact categories with significant impacts were from climate change, respiratory inorganics, carcinogens, land use, and fossil fuels in both selected mills. This is similar to the work by [14,34] who reported that fossil fuels, respiratory inorganics, climate change, and acidification/eutrophication were the significant impact categories. The use and production of fertilizers in the plantation phase were the main impact of the fossil fuel and respiratory inorganic categories. This result is consistent with the findings of [44] study on the determination of the environmental impact of the biodiesel production. Moreover, the boiler emissions from the mill were the other main impact of respiratory inorganics. This result is consistent with the findings of [45,46]. For the carcinogens impact category, the results found that Cadmium, Arsenic, Chromium VI, and Particulates were the main carcinogens that were likely to be released into the air from the crude palm oil production. This result is consistent with [47] findings who determined that the environmental impacts of the biodiesel from three waste oils. The major impact of the land use category came from the fresh fruit bunch (FFB) production at the plantation phase. The climate change category impacts can be associated with the emission of greenhouse gases such as carbon dioxide and methane which caused the phenomena of global warming (see Supplementary Appendix SB1).

Table 2. Impact characterization results for crude palm oil production at two mills.

| Impact Category | Subcategory                  | Units    | Results of LCA (Mill A) | Results of LCA (Mill B) |
|-----------------|------------------------------|----------|-------------------------|-------------------------|
| Human Health    | Carcinogens                  | DALY     | 256                     | 99.42                   |
|                 | Resp. organsics              | DALY     | 0.599                   | 0.231                   |
|                 | Resp. inorganics             | DALY     | 757                     | 453                     |
|                 | Climate change               | DALY     | 176                     | 97.2                    |
|                 | Radiation                    | DALY     | 0.673                   | 0.313                   |
|                 | Ozone layer                  | DALY     | 0.059                   | 0.0238                  |
| Ecosystem       | Acidification/Eutrophication| pdf*m2yr | 3.04 × 10^8             | 1.09 × 10^7             |
|                 | Land use                     | pdf*m2yr | 5.61 × 10^7             | 4.68 × 10^7             |
|                 | Minerals                     | MJ surplus | 5.31 × 10^7            | 2.16 × 10^7             |
| Resources       | Fossil fuels                 | MJ surplus | 9.25 × 10^8            | 3.10 × 10^8             |

However, in order to obtain a clear overview of the subcategory that contributed most to the environmental damage, the subcategories obtained from the characterization step were expressed in percentages (%). The methodology used to calculate the percentages for environmental dimension based on the calculation described by [42] but in this study, the percentages were evaluated by comparing the subcategory values under the same impact category, so the subcategory that has the highest value under the same impact category has a contribution of 100% and the other subcategories obtained a proportional percentage. The results for mill A showed that for human health endpoint impact category, respiratory inorganic was assigned 100% to the damage substances emitted because it
had the highest total amount (757 DALY) of such substances that caused human health endpoint impact category, while 23.24 (176 DALY) and 33.81% (256 DALY) of the substances were emitted from climate change and Carcinogens subcategories, respectively. This result is consistent with the outcomes of [36,46]. Moreover, land use was assigned 100% to the damage substances emitted. It had the highest amount \((2.11 \times 10^9 \text{ pdf}\text{m}^2\text{yr})\) of such substances emitted into the environment that belonged to the ecosystem quality endpoint impact category, while 2.64\%\((5.61 \times 10^7 \text{ pdf}\text{m}^2\text{yr})\) and 14.33\%\((3.04 \times 10^8 \text{ pdf}\text{m}^2\text{yr})\) of the substances were emitted from acidification/eutrophication and ecotoxicity subcategories, respectively. Regarding resources use endpoint impact category, the substances emitted \((9.25 \times 10^8 \text{ MJ surplus})\) was 100\% of the substances emitted into the environment from fossil fuels, while 5.74\%\((5.31 \times 10^7 \text{ MJ surplus})\) of the substances emitted were from the minerals subcategory.

For mill B, respiratory inorganics had 100\% allocation to the damage substances emitted because it had the highest total value (453 DALY) of such substances emitted into the environment that related to the human health endpoint impact category, while 21.45\%\((97.2 \text{ DALY})\) and 21.94\%\((99.42 \text{ DALY})\) of the substances were emitted from climate change and carcinogens subcategories, respectively. For the damage to the ecosystem quality endpoint impact category, land use had 100\% assigned to the damage substances emitted because it had the highest total value \((1.97 \times 10^9 \text{ pdf}\text{m}^2\text{yr})\), while the slight percentage was assigned to the damage substances emitted from acidification/eutrophication and ecotoxicity subcategories. Considering the resources use endpoint impact category, the substances emitted \((3.10 \times 10^8 \text{ MJ surplus})\) were 100\% of the substances emitted into the environment from fossil fuels, while 6.96\%\((2.16 \times 10^7 \text{ MJ surplus})\) of the substances was emitted from the minerals subcategory. However, the damage substances emitted from subcategories such as, radiation, ozone layer, and respiratory inorganics were given a small percentage for both mills. Figure 2 shows the outcomes of the environmental impacts percentage of the two selected plantation-based mills.

![Figure 2](image-url)  
**Figure 2.** The contribution of impact categories toward environmental impact.
The results in Table 2 show that Mill A has the highest environmental impact in all categories; this is because this based plantation mill has a larger plantation area than Mill B. Thus, it requires more use of fertilizers and pesticides and more diesel, power, and water consumption to produce the FFB. In addition, Mill A has the higher mill capacity than Mill B and it requires more amount of FFB to produce the CPO. Thus, it generates more waste, such as shell, fiber, and empty fruit bunch EFB and causes more gas emission from the stack.

3.2. Economic Dimension Results

For LCC, initial investment cost, operational and maintenance costs, and the end of life cost were considered when evaluating the economic impacts of the crude palm oil production. Initial investment costs involve the plants’ instrumentation and equipment and the required land area. The operational and maintenance cost refers to the cost incurred among the operational and maintenance phase, which considers the cost of operational and maintenance, fuel, water consumption, supervision, chemical energy used, administration, and transportation. Maintenance costs also involve costs related to sanitation service. The end of life cost refers to the costs associate with solid biomass waste collection, waste-water treatment, and disposal inspections costs.

The following formula [48] was used in this study to calculate the inventory cost data.

\[
\text{NPV} = \sum_{t=0}^{n} \frac{CF}{(1+r)^t}
\]

where: CF—the cash flows that can be obtained in the year t, n—the number of years in the study period, r—real discount rate applied to adjust cash flows and bring them to an existing value.

As presented in Table 3, the initial investment cost was the major contributor of the LCC for both mills and this is due to the raw materials (fresh palm fruits) cost, which was 22,687,104.024 RM/MT for mill A and 85,500,000 for mill B. This is in line with the study by [14] who reported that the cost of fresh palm fruits contributed to 88% of the total production costs. These costs are followed by machine costs, which were 6,162,542.90 RM/MT and 29,815,563.07 RM/MT for both mills, respectively. The operational costs were incurred during the operational phase. The major contributor item for this phase was the production process costs which were 9,579,606.07 RM/MT for mill A and 8,395,810 RM/MT for mill B. This is followed by the labor costs, which were 8,936,940 RM/MT for mill A and 6,186,192 RM/MT for mill B. For the maintenance costs, the machinery maintenance costs were the major contributor at mill A, which were 7,269,084 RM/MT, followed by the costs of management which were 5,996,004 RM/MT. On the other hand, management costs were the major contributor at mill B with the amount (12,264,000 RM/year). This is followed by the costs of machinery maintenance which were 2,196,000 RM/year.

### Table 3. Summary of total cost and payback period of crude palm oil production.

| Impact Category           | Mill A (RM)          | Mill B (RM)          |
|---------------------------|----------------------|----------------------|
| Initial investment costs  | 30,606,822.364 (45.3%) | 118,541,898.8 (79%) |
| Operation costs           | 23,296,451.21 (34.54%) | 16,738,514.62 (11%) |
| Maintenance costs         | 13,347,145.08 (19.7%)  | 14,640,000 (9.76%) |
| End of life costs         | 188,908.65 (0.2%)     | 52,105.62 (0.03%)    |
| Total cost                | 67,439,327.30         | 149,972,519.04       |
| Net Precent Value (NPV)   | 357,546,693.55        | 452,107,923.99       |
| Pay back period (PBP)     | 3.6                  | 2.16                 |

However, the sanitation service costs were negligible for both mills. Based on these evaluations, the total cost of crude palm oil production through the year 2019 was 67,439,327.3 RM and 149,972,519 RM for mill A and mill B, respectively. The end of life phase was the lowest contributor phase of LCC where it was 188,908.65 for mill A and 52,105.62 for mill B. However,
Table 3 shows the total cost and their respective contributions as well as the crude palm oil production payback period (PBP). The cost category percentages were obtained by dividing the amount of each cost impact category by the total cost and then multiplying the outcomes by 100. The high percentage of cost impact category refers to the passive impact for this impact category on the overall economic impact. The payback period for the two mills was found to be 3.6 years and 2 years for mill A and mill B. This result, being less than one-third of the 10 year project life, showed that the project is financially viable. Moreover, the NPV value was positive for both mills.

Since the based plantation mill A has a larger plantation area and mill capacity than Mill B, it presents the highest economic impacts. Mill A has the highest operation costs because it requires a higher number of workers, and more costs of fertilizers, electricity, fuel, and water. Moreover, it presents higher maintenance and the end of life costs because this mill needs more costs for machinery maintenance, sanitation service, waste treatment, and water disposal.

3.3. Social Dimension Results

The impact category for workers aimed to cover the social impacts on crude palm oil production such as job satisfaction, fair salary, health and safety, discrimination/equal opportunities, and social benefits/social security. Table 4 shows the results of all the related subcategories for workers expressed in percentages. There were 529 respondents for both mills, and the percentage for each indicator was obtained by dividing the answers for the indicator given by the stakeholder by the total number of respondents. The average of these results was taken to obtain the percentage of the subcategories. As shown in Table 4, all social indicators had almost different percentages. Job satisfaction reflects the satisfaction of workers on the task given and the relationship with their supervisor. Similar to the study by [49], the study found that most workers were satisfied with their work at the palm oil based plantation mills, 92.5% of workers at mill A and 90% at mill B were satisfied with their work. The study showed that the high percentage of workers’ satisfaction showed that the mills provided good working treatment and conditions for their workers.

Table 4. The subcategories percentages of worker stakeholder.

| Stakeholder Categories | Subcategory                                      | Subcategory Percentage | plantation-based mill (A) | plantation-based mill (B) |
|------------------------|-------------------------------------------------|------------------------|---------------------------|---------------------------|
| Worker                 | Job satisfaction                                | 92.5%                  | 92.5%                     | 90%                       |
|                        | Fair salary                                     | 89.05%                 | 87.3%                     |                           |
|                        | Health and safety                               | 87.66%                 | 98.4%                     |                           |
|                        | Nonexistent Discrimination/Equal opportunity    | 95%                    | 95%                       |                           |
|                        | Social benefits/social security                 | 91%                    | 91.5%                     |                           |

Based on the findings for the fair salary subcategory, the workers at both the plantation-based mills were satisfied with their current wages, where the satisfaction of the wages paid by the organization was 89.05% and 87.3% at mill A and mill B, respectively. This finding was supported by the findings of other studies [3,4], where the employment with companies had led to an overall positive change to workers’ livelihoods. The next subcategory assessed in this study was the health and safety. The results revealed that the workers were fully aware of the procedures to follow in case of an emergency/accident. The results also showed that the mills took immediate actions whenever accidents happened. In addition, the mills provided the necessary protective equipment to the workers. This is supported by a similar study conducted by [16]. Most of the workers stated that they were satisfied with the health and safety in their workplace. Based on the finding, it is worth noting that there was not any gender, racial, political, nationality, training, or social class discrimination.
Moreover, the mill does not discriminate against the workers in terms of development and training, promotional opportunities, holidays, working hours, access to physical facilities at the workplace, and medical facilities from the mills. This means that the discrimination percentage in both mills was extremely low. This is confirmed by a similar studies carried out by [16,18] who stated that, the discrimination does not become a significant issue in the palm oil mills. The majority of the workers at mill A and only 89% of the workers at mill B were exhibited high level of satisfaction regarding social security organization (SOCSO) scheme. Most of the workers enjoyed social benefits that they received from the mills. These results were similar to the findings of [17]. The impact category for the local community aimed to cover social impacts on crude palm oil production such as safe and healthy living condition, culture and heritage, local community involvement, and local community job opportunities. Table 5 shows the results in percentages of all the related subcategories for the local community. Based on the questionnaires, 99.2% of the respondents were satisfied with their community and considered it a healthy community. The reason for this high percentage could be due to the programs and regulations that the mills had in place to reduce pollution in the area.

Table 5. The subcategory percentages for the local community stakeholder.

| Stakeholder Categories | Subcategory Indicators                  | Score  |
|------------------------|-----------------------------------------|--------|
| Local Community        | Safe and healthy living condition        | 95.2%  |
|                        | Culture and heritage                     | 90.2%  |
|                        | Local involvement                        | 93.39% |
|                        | Local community job opportunities        | 79.5%  |

Moreover, 98.14% of the respondents noted that there were no serious social problems among the local community. The results of the questionnaire also revealed that the mills provided social and religious programs to raise the aesthetics, recreation, and values for the local community. The mills also created culturally specific activities to strengthen intercultural dialogue. In spite of these contributions of the mills, 68% of the respondents were satisfied with the way the management of mills dealt with the cultural and heritage conservation issues such as demographic change, the life style, and the local culture. The results obtained showed that the majority of the workers in the mills and plantations were from the local community. The mills also frequently held collaborative activities that engaged the people in the local community. These activities strengthened relations between the mills and the community. This result is similar to the findings of [17] who reported that the manufacturing companies always involved the local community in their activities. The respondents who stated that the mills contributed to the local development in consultation with the local community was 99.6%.

3.4. Sustainability Assessment Results

For the environmental dimension, the increase in the environmental indicators percentage means that it is a negative impact for these indicators on the total environmental impact. Thus, the scale of the environmental scores were determined as 4 points for 0–20%, 3 points for 21–40%, 2 points for 41–60%, 1 point for 61–80%, and 0 points for 81–100%. As shown in Table 6, the percentage for land use, respiratory inorganic, and fossil fuels subcategories were 100%. Thus, these subcategories were signed with the score 0. The percentage for climate change and carcinogens subcategories was in the range 21–40%. Therefore, these subcategories were signed with the score 3. The other subcategories were in the range 0–20%. Thus they were signed with the score 4. However, the scores for land use, respiratory inorganics, and fossil fuels subcategories were the least scored with the score of 0 point for mill A and mill B. The scores for climate change and carcinogens subcategories were 3 points at both the mills. In contrast, the other impact categories such as radiation, respiratory organics, ecotoxicity, ozone layer, minerals, and acidification/eutrophication had more positive impacts with a score of 4 at mill A and mill B.
Table 6. Environmental impact categories results based on the proposed scoring system.

| Impact Category | Subcategory          | Results of LCA (Mill A %) | The Percentage Range | Score | Results of LCA (Mill B %) | The Percentage Range | Score |
|-----------------|----------------------|---------------------------|----------------------|-------|---------------------------|----------------------|-------|
| Human Health    | Carcinogens          | 33.82                     | 21–40                | 3     | 21.94                     | 21–40                | 3     |
|                 | Resp. organics       | 0.079                     | 0–20                 | 4     | 0.05                      | 0–20                 | 4     |
|                 | Resp. inorganics     | 100                       | 81–100               | 0     | 100                       | 81–100               | 0     |
|                 | Climate change       | 23.28                     | 21–40                | 3     | 21.45                     | 21–40                | 3     |
|                 | Radiation            | 0.085                     | 0–20                 | 4     | 0.06                      | 0–20                 | 4     |
|                 | Ozone layer          | 0.007                     | 0–20                 | 4     | 0.005                     | 0–20                 | 4     |
|                 | Ecotoxicity          | 14.33                     | 0–20                 | 4     | 0.55                      | 0–20                 | 4     |
| Ecosystem       | Acidification/Eutrophication | 2.64               | 0–20                 | 4     | 2.37                      | 0–20                 | 4     |
|                 | Land use             | 100                       | 81–100               | 0     | 100                       | 81–100               | 0     |
|                 | Minerals             | 5.74                      | 0–20                 | 4     | 6.96                      | 0–20                 | 4     |
|                 | Fossil fuels         | 100                       | 81–100               | 0     | 100                       | 81–100               | 0     |

However, to obtain the total score for the environmental impact, the subcategories scores under the same impact category level were averaged. Then, the impact categories scores were averaged and this average score was assigned to the total environmental impact. This simplify the indicators aggregation into a single number. The total environmental scores for mill A and mill B were 2.5 points.

For the economic dimension, Scores from 0 to 4 were assigned to each cost impact category based on the percentage of contribution given Table 7. For economic indicators, the increase in the economic indicators percentage means that there is negative impact for these indicators on the total economic impact. However, the initial investment cost impact category had the lowest rating which was 2 points at mill A and 1 point at mill B while the operating cost impact category received a higher score with 3 points at mill A and 4 points at mill B. The most positive impacts were end-of-life cost and maintenance costs impact categories with a score of 4 points each. To obtain the total score for the economic impact, the subcategories scores under the same impact category level were averaged. Then, the impact categories scores were averaged and this average score was assigned to the total economic impact. This facilitated the aggregation of the indicators into a single number. The total economic score for both mill A and mill B was 3.25 points.

Table 7. Economic impact categories results based on the proposed scoring system.

| Impact Category   | Results of LCC (Mill A %) | The Percentage Range | Score | Results of LCC (Mill B %) | The Percentage Range | Score |
|-------------------|---------------------------|----------------------|-------|---------------------------|----------------------|-------|
| Initial investment costs | 45.3%                    | 41–60                | 2     | 79%                       | 61–80                | 1     |
| Operation costs   | 34.54%                    | 21–40                | 3     | 11%                       | 0–20                 | 4     |
| Maintenance costs | 19.7%                     | 0–20                 | 4     | 9.76%                     | 0–20                 | 4     |
| End of life costs | 0.2%                      | 0–20                 | 4     | 0.03%                     | 0–20                 | 4     |

For the social dimension, most of the indicators scored by workers for aspects such as satisfaction in wages, work satisfaction, the safety risk of the system, presence of protective equipment, health and safety awareness, the presence of discrimination, presence of equal opportunity and the presence of social security were expressed as good level of satisfaction and the scores of these indicators were reflected in the range between 3.8 and 4, while the indicators such accident/injury and the social benefits were classified in the least level of satisfaction. Thus, the mills need to improve these indicators to achieve the sustainability of the product. For the local community stakeholder, the local community involvement subcategory was the only category with a score of 4.

The scores for healthy and safe living conditions and respect for cultural heritage subcategories were 3.5 points and 3.9 points, respectively. The local community job opportunities subcategory had the least score with 3.2 points. This means that these subcategories
need pressing improvement. However, once the scores of all impact categories were obtained, the scores for the impact categories under the same dimension were averaged to get the total score for the dimension. The results presented for the scores for the three dimensions at mill A and mill B were not different, which were 2.5, 3.25 points and 3.7 points for environmental, economic, and social dimensions, respectively. The combined inventory results for the impact categories under the proposed scoring system as well as the total scores obtained for the three dimensions are showed in Table 8.

Table 8. The subcategory scores for Impact categories.

| Dimension         | Impact Category                | Score (Mill A) | Score (Mill B) |
|-------------------|--------------------------------|----------------|----------------|
| Environmental     | Human health                   | 3              | 3              |
|                   | Ecosystem                      | 2.6            | 2.6            |
|                   | Resources                      | 2              | 2              |
|                   | Environmental Score            | 2.5            | 2.5            |
| Economic          | Initial investment costs       | 2              | 1              |
|                   | Operation costs                | 3              | 4              |
|                   | Maintenance costs              | 4              | 4              |
|                   | End of life costs              | 4              | 4              |
|                   | Economic Score                 | 3.25           | 3.25           |
| Social            | Job satisfaction               | 3.8            | 3.8            |
|                   | Fair salary                    | 3.8            | 3.8            |
|                   | Health and safety              | 3.7            | 3.7            |
|                   | Discrimination/Equal opportunity| 4              | 4              |
|                   | Social benefits/social security| 3.8            | 3.8            |
|                   | Safe and healthy living condition| 3.9           | 3.9            |
|                   | Culture and heritage           | 3.5            | 3.5            |
|                   | Local involvement              | 4              | 4              |
|                   | Local community job opportunities| 3.2           | 3.2            |
|                   | Social score                   | 3.7            | 3.7            |

3.5. Visualization

Figure 3 presents the scores of the three dimensions at mill A and mill B. According to the outcomes obtained, the social dimension score was the best among the dimensions with a score of 3.7, followed by the score for the economic dimension with 3.25 and then the score of environmental dimension with a score of 2.5 at both the mills. The environmental dimension was given the lower score because of the low scores of respiratory inorganics and fossil fuels impact categories at both the mills, which were 1 and 0, respectively. However, the level of sustainability of the crude palm oil production was determined based on the estimation of the new triangle area. The new triangle area was equal to 3.9. This result shows that the new triangle area was much smaller than the main triangle area which was equal to 6.9. Moreover, if the area of the percentage of the new triangle is calculated by comparing the area that each triangle had, the main triangle would have the largest area assigned with 100% and the new triangle percentage obtained would have been proportional. The percentage of the new triangle area was 56.5%, which denotes that crude palm oil production requires more improvement to be a sustainable product. However, it will be possible to apply this adapted presentation technique to observe the sustainability level progress of a given product by repeating these steps. The increase in the triangle area denotes the improvement of the sustainability level of the product. Otherwise, the area will remain constant or decrease.
4. Conclusions

The work presented in this study attempted to develop a scheme to evaluate the level of sustainability of crude palm oil production through the three sustainability dimensions. The study, therefore, carried out LCA, LCC, and S-LCA to assess the environmental, economic, and social impacts. The results of the three methods were then combined using the scoring system to determine the LCSA. Generally, this study found that respiratory inorganics, fossil fuels, and climate change impact categories were the most significant environmental impacts of crude palm oil production. As regards the economic impacts, the initial investment cost impact category was the main economic impact of crude palm oil production. For the social dimension, the accident/injury and social benefits impact categories were the most significant social impacts of crude palm oil production. The scoring system method has been successfully applied in the study. The results of scores obtained from the three dimensions found that, among the three dimensions, the score for the social dimension was the best with a score of 3.7, followed by an economic score of 3.25 and an environmental score of 2.5. Furthermore, the adapted presentation technique used to visualize the results allowed the researcher to determine the level of sustainability of the crude palm oil production based on the area of evaluation of the new triangle. With regard to the visualization results, crude palm oil production needs more improvement to be a sustainable product. However, further applications are needed to be able to fully assess the applicability of the method to various types of products.

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