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Assessing the Negative Impact of Palm Oil Industry in Malaysia through a Systemic Method

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ABSTRACT

This study investigates the environmental impact of palm oil production using a life cycle assessment (LCA). The LCA thoroughly examines the entire palm oil milling process, including components like kernels and shells. It evaluates environmental and human health impacts such as global warming, ecotoxicity, radiation, ozone layer depletion, and more. Key findings emphasise significant impacts, especially in the sterilising and milling stages. From a strategic perspective, it's crucial to prioritise interventions in areas like marine ecotoxicity and human non-carcinogenic toxicity for industry sustainability. Addressing impact categories like ozone depletion, fossil fuel scarcity, global warming, and human carcinogenic toxicity is essential for a comprehensive sustainability strategy. The research not only highlights environmental challenges but also emphasises strategic opportunities. By integrating sustainable practices, technological innovations, and responsible resource management, the palm oil industry can enhance its environmental performance, align with global sustainability goals, and ensure long-term resilience.

1. Introduction

Agriculture, fisheries, and forestry are crucial sectors in Malaysia's economy [1]. The combined employment of these sectors in Malaysia amounts to 10% of the workforce, while their contribution to the country's gross domestic product (GDP) is approximately 8% [2]. Palm oil, rubber, cocoa, and wood products are prominent sectors in the country, contributing significantly to almost 50% of the nation's total output [3]. Additionally, tropical fruits and rice are also important agricultural products in the economy. The Malaysian palm oil industry is a prominent player on the global stage, ranking second in both production and export of palm oil worldwide, with Indonesia being the only country ahead [4]. The palm industry in Malaysia is a significant economic force, with an annual production of over 13 million metric tonnes and approximately 11% of the country's land dedicated to palm plantations [5]. In 2020, Malaysia contributed approximately 25% of the global palm oil production and 33% of the worldwide palm oil exports [6].

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However, despite its economic success, the palm oil industry faces environmental problems, particularly pollution and a sizable carbon footprint [7,8]. This study aims to address and assess the urgent need to understand and mitigate these environmental impacts. The chosen title emphasises the significant role of the industry in Malaysia and the complex environmental issues it presents [9-11].

The palm oil industry is complex due to its three main sectors: agriculture (plantation), transportation, and industry (milling) [12]. The variety of operations in agriculture poses distinct environmental challenges that require careful monitoring and effective mitigation strategies. The industry heavily depends on fertilisers for productivity, employs a fleet of trucks for transportation, and produces harmful emissions such as carbon monoxide and sulphur oxides [13]. Additionally, wastewater is generated during the milling process. It is crucial for the industry to address these challenges in order to fulfil its environmental obligations [14].

This research aims to address these challenges and propose practical solutions to reduce the environmental impact of the industry. The environmental impact of palm oil becomes more pressing as its widespread use in various products continues to grow. The proposed systematic approach aims to address deforestation, waste management, and pollution control in the Malaysian palm oil industry. We strive to contribute to a sustainable and environmentally responsible future for this important sector. This study aims to raise awareness about the environmental impact of the palm oil industry and propose effective solutions to mitigate its negative effects through systematic evaluation.

2. Methodology

2.1 Flow chart for Processing Palm Oil (Milling, Physical Refining and Fractionation)

Figure 1 depicts the milling process' flowchart. Fresh fruit bunches (FFB) are received at the FFB hoppers and moved into the sterilising cages after being transported to the palm oil mills. The cages are then moved onto the next stage, which is the stripping of FFB, and rolled into the sterilisation chambers to sterilise the FFB. Live steam is circulated through these chambers for 90 minutes, and the sterilising procedure makes it easier to separate individual fruits from the stem or bunch. The steam will also deactivate the enzymes that cause the oil to break down into free fatty acids (FFA). There are several things undesirable in palm oil, and one of them is FFA. The industry aims to keep the growth of FFA to around 4%. The empty fruit bunches (EFB) are then delivered to a stripper, where the palm oil fruitlets are removed from the stalks or bunches. At this point, the FFB has been disinfected. EFB is typically returned to the plantations to be used as an alternative to fertiliser and for mulching [15].

The fruitlets from the stripper are then sent to the digester, where mechanical agitation transforms them into a uniform, greasy mush. The majority of the crude palm oil is subsequently extracted from the digested mash by pressing it with a screw press (CPO). CPO now consists of an oil, water, and fruit solids mixture that has been vibrated-screened to remove as many particulates as feasible. CPO is subsequently filtered via a continuous settling tank process. After being desander and centrifuged to remove any remaining particles, the decanted CPO is brought to the vacuum drier to remove the moisture. Before being sent to the refineries or exported, the CPO is then pumped into storage tanks. The fibre cyclone separates the nuts with squeezed mesocarp fibre. Once the nuts are cracked, they form kernels and shells. As boiler fuel, the shells and compressed mesocarp fibre are used, while the kernels are transferred to manufacturers that crush them to produce crude palm kernel oil (CPKO). The palm oil mill effluent (POME) is the main liquid waste, while the main solid wastes are boiler ash, EFB, and pressed mesocarp fibre. Gaseous emissions originate from the boiler stack, while biogas is discharged from the wastewater treatment ponds [16].

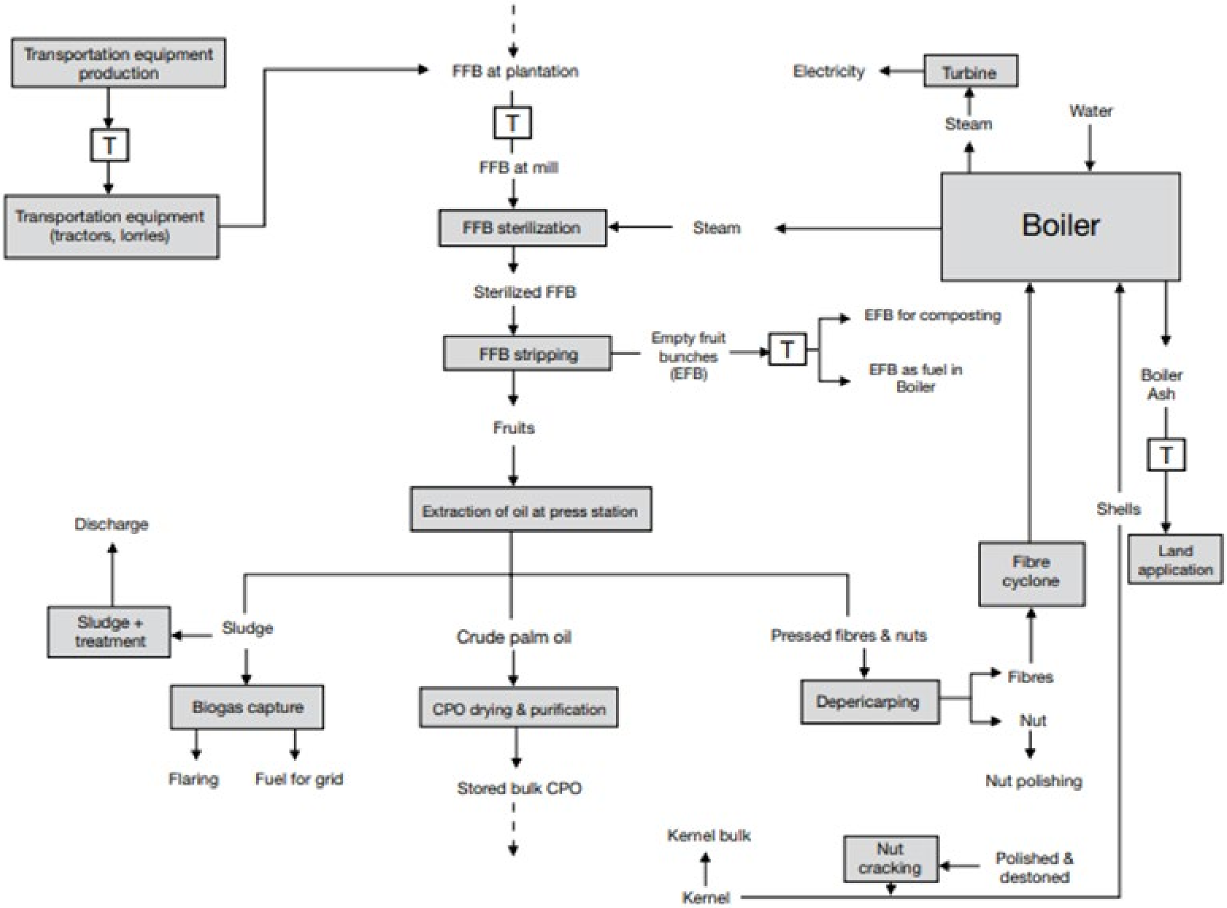

Fig. 1. Flow chart of palm oil milling

Figure 2 is the flowchart for the whole procedure of life cycle assessment. At the beginning of the LCA, the goal, scope, and system boundaries are established, followed by conducting the life cycle assessment and proceeding with the life cycle impact assessment. Once the impact assessment is completed, the results will be utilised in the interpretation part, providing an evaluation of the life cycle assessment [17].

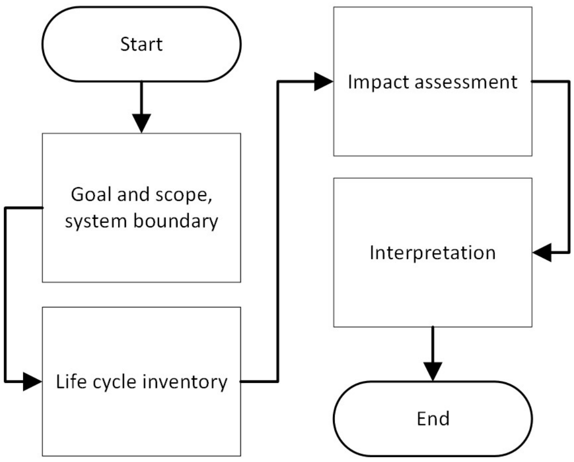

Fig. 2. Flow chart for LCA

Life Cycle Assessment (LCA) consists of four fundamental phases. Initially, the "Goal and Scope Definition" phase establishes the LCA's objective, scope, criteria for system comparison, and time constraints. Next, the "Inventory Analysis" phase focuses on tracking the flow of materials and energy within the product system, with an emphasis on its interactions with the environment [18]. In the subsequent "Impact Assessment" phase, data from the inventory analysis is utilised to quantify the environmental impact. It classifies indicator results by impact category, normalises data, and evaluates the significance of each category [19]. Lastly, the "interpretation" phase entails critical evaluation, sensitivity analysis of the data, and the presentation of results in an understandable manner [20].

Setting out the LCA's objectives and scope is the first step in putting it into practice. This study's goal is to determine the potential effects of palm oil production and use that information to assess the possibilities for mitigating such effects. This study will implement gate-to-gate system boundaries. The life cycle inventory in this study will look at the parameters used for one tonne (1T) of crude palm oil. There will be a few parameters being used, and some of the parameters will be based on the milling process. The questionnaires that will be created with the aim of collecting data will be used to directly solicit all inventory data from the palm oil millers. The data will also be gathered through measurements and quantification right at the site.

There are three main steps that will be taken when implementing life cycle impact assessment: selection, classification, and characteristics [21]. In this study, the gate-to-gate system boundaries will still be implemented. There shall be a reason for each effect choice, and all impacts will be tied to Malaysia, the research's study location. The last step of the life cycle impact assessment is the characterization, which represents the number of results that contribute to the impact category. During the interpretation step, the outcomes of the inventory analysis and impact assessment are condensed. The findings and suggestions for the study are often represented through the interpretation phase's output. The interpretation will include the Life Cycle Inventory (LCI) and Life Cycle Impact Assessment (LCIA), the evaluation of the study, and the conclusions. Finding the degree of confidence in the final results is the major goal of the interpretation phase.

3. Results

3.1 LCIA for Three Stages

Table 1 presents the life cycle impact assessment of the sterilising stage, milling stage, and drying stage of the palm oil milling process [21]. In the sterilising stage, the most critical impact is identified as marine ecotoxicity, followed by human non-carcinogenic toxicity [22]. Conversely, the impact category of ozone depletion has the least significant effect. Additionally, it is essential to focus on impact categories such as fossil fuel scarcity, global warming, and human carcinogenic toxicity, as they pose notable threats to the environment despite not reaching the same level of impact as human non-carcinogenic toxicity.

Moving on to the milling stage of the palm oil milling process reveals that marine ecotoxicity is once more the most significant impact, then human non-carcinogenic toxicity [23]. Similar to the sterilisation stage, ozone depletion has the least significant impact. It remains important to address impact categories like fossil fuel scarcity, global warming, and human carcinogenic toxicity.

In the life cycle impact assessment of the drying stage of the palm oil milling process. The most significant impact is, once again, marine ecotoxicity, followed by human non-carcinogenic toxicity. Additionally, it is crucial to pay attention to impact categories such as land use, global warming, and human carcinogenic toxicity [24,25]. Notably, the negative water consumption data at this stage is attributed to water evaporation during the drying process.

Table 1
LCIA result for three stages

Impact category	Result of sterilising	Result of milling	Result of drying	Unit
Fine particulate matter formation	9.26	148.84	6.65	kg PM 2.5 eq
Fossil resource scarcity	1385.79	22119.63	132.83	kg oil eq
Global warming	4166.82	69001.02	9603.98	kg CO_2 eq
Human carcinogenic toxicity	5076.96	15767.11	1942.01	kg 1,4-DCB
Human non-carcinogenic toxicity	585284.19	1213393.12	195129.01	kg 1,4-DCB
Land use	38.70	2099.18	3731.68	m2a crop eq
Marine ecotoxicity	672029.96	1411188.77	226584.96	kg 1,4-DCB
Marine eutrophication	0.112	6.49	2.73	kg N eq
Mineral resource scarcity	10.39	19.61	70.39	kg Cu eq
Stratospheric ozone depletion	0.0073	0.1334	0.0228	kg CFC11 eq
Water consumption	11.24	138.79	-68988.22	m^3

3.1.1 Fine Particulate matter formation

The data of Table 1 illustrates that the milling stage exhibits the highest fine particulate matter formation, totalling 148.841kg. In contrast, the sterilising stage contributes around 9.25kg, and the drying stage approximately 6.65kg of fine particulate matter. This indicates that the drying process has the least environmental impact, while the milling stage significantly influences the environment, particularly concerning this indicator.

3.1.2 Fossil resource scarcity

The data of Table 1 illustrates that, during the milling stage of the milling process, fossil fuel scarcity is most significant, with a usage of 2212kg of oil. Following this, the sterilising stage has the highest impact on fossil fuel scarcity at 1386kg, while the drying stage exhibits the lowest impact at 132.83kg.

3.1.3 Global warming

As shown in Table 1, it is evident that during the milling stages of the milling process, the impact of global warming is the highest at 69,001, whereas during the sterilising stages, the impact of global warming is the lowest at 4,166. The impact of global warming during the drying stages is moderate compared to the other two stages, with a result of 9,603.

3.1.4 Human carcinogenic toxicity

As per Table 1, it is evident that during the milling stages of the milling process, the impact on human carcinogenic toxicity is the highest, resulting in 15,767 kg. The drying stages caused the least impact on human carcinogenic toxicity, with a result of 1,942 kg, while the sterilizing stage caused 5,076 kg of human carcinogenic toxicity.

3.1.5 Human non-carcinogenic toxicity

According to Table 1, it is evident that during the milling stages of the milling process, the impact on human non-carcinogenic toxicity is the highest, resulting in 1,213,393 kg. The drying stages caused the least impact on human non-carcinogenic toxicity, with a result of 195,129 kg. The sterilising stage caused a moderate impact among the three stages, with a result of 585,284 kg.

3.1.6 Land use

According to Table 1, it is evident that during the drying stages of the milling process, the impact on land use is the highest, covering an area of 3,731.72 m^2. The sterilising stages caused the least impact on land use, with a result of 38.7 m^2. The milling stage caused a moderate impact among the three stages in land use, covering an area of 2,099.17 m^2.

3.1.7 Marine ecotoxicity

Based on Table 1, it is evident that during the milling stages of the milling process, the impact on marine ecotoxicity is the highest, amounting to 1,411,188 kg. The drying stages caused the least impact on marine ecotoxicity, with a result of 226,584 kg. The sterilising stage caused a moderate impact among the three stages, with a result of 672,029 kg.

3.1.8 Marine eutrophication

According to Table 1, it is evident that during the milling stages of the milling process, the impact on marine eutrophication is the highest, totalling 6.491 kg. The sterilising stages caused the least impact on marine eutrophication, with a result of 0.1118 kg. The drying stage caused a moderate impact among the three stages, with a result of 2.7279 kg.

3.1.9 Mineral resource scarcity

According to Table 1, it is evident that during the drying stages of the milling process, the impact on mineral resource scarcity is the highest, totalling 70.398 kg. The sterilising stages caused the least impact on mineral resource scarcity, with a mass of 10.399 kg. The milling stage caused a moderate impact among the three stages, with a mass of 19.612 kg.

3.1.10 Ozone depletion

According to Table 1, it is shown that during the milling stages of the milling process, the impact on ozone depletion is the highest, with a result of 0.1333 kg. The sterilising stages caused the least impact on ozone depletion, with a result of 0.0073 kg. The drying stage caused a moderate impact among the three stages in ozone depletion, with a result of 0.0228 kg.

3.1.11. Water consumption

According to Table 1, it is evident that during the milling stages of the milling process, the impact on ozone depletion is the highest, resulting in 138 m^3. The drying stages caused the least impact on ozone depletion, with a result of 68,988 m^3. The sterilising stage also contributed a minimal impact among the three stages in ozone depletion, with a result of 11.24 m^3.

3.2 Comparison of LCIA Results from The Sterilising, Milling, and Drying Stages

The results that are shown in Table 1 are taken from 3 different stages of the milling process of the milling plant, which are: the sterilising process, the milling process, and the drying process. The indicator from the impact assessment is determined and then used in the impact assessment. There are 11 impact assessment indicators in the results. From Figure 3, it was revealed that most of the impact was caused during the milling stages. This is due to the fact that there are many processes happening in the milling stages. The drying stages of the milling plant caused the least impact, and this might be due to the fact that this is already the last and final stage of the milling process, so the impact isn't that critical. The sterilising stages had moderate amounts of impact on the environment, based on the graph.

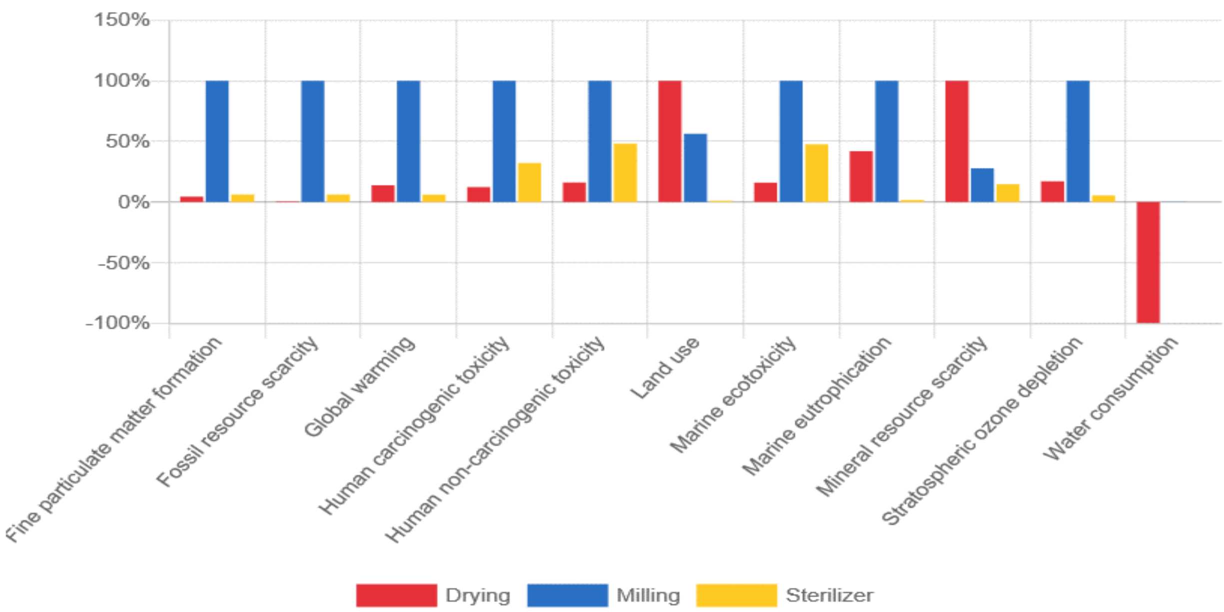

Fig. 3. Characterisation in life cycle impact assessment (LCIA) for 1t CPO

3.3 Discussions

The significant impact from the life cycle impact assessment results is primarily associated with the sterilising and milling stages of the palm oil milling process. In both stages, marine ecotoxicity and human non-carcinogenic toxicity emerge as the most notable environmental impacts. These findings underscore the potential harm to marine ecosystems and human health posed by the palm oil milling process. Other impact categories, such as ozone depletion, fossil fuel scarcity, global warming, and human carcinogenic toxicity, while not reaching the same level of significance, still demand attention due to their potential threats to the environment and human well-being. The drying stage, being the final step in the milling process, exhibits the least impact. However, it's essential to note that even in this stage, marine ecotoxicity and human non-carcinogenic toxicity remain noteworthy impacts, emphasising the need for comprehensive environmental management practices throughout the entire palm oil milling process.

From a strategic point of view, the life cycle impact assessment results highlight key areas that demand attention and intervention in the palm oil milling process. The strategic focus should be on mitigating the significant environmental impacts identified, particularly in the sterilising and milling stages. Strategically addressing the issues of marine ecotoxicity and human non-carcinogenic toxicity is imperative to align the palm oil milling process with sustainability goals. Implementing targeted measures to reduce these impacts can contribute to the industry's long-term viability and enhance its environmental performance. Furthermore, considering the strategic implications of impact categories such as ozone depletion, fossil fuel scarcity, global warming, and human carcinogenic toxicity is crucial. A holistic approach that integrates sustainable practices, technological innovations, and responsible resource management should be adopted to mitigate these impacts effectively. Incorporating these strategic considerations into the overall sustainability strategy of the palm oil industry can lead to more resilient and environmentally friendly practices, aligning with global sustainability goals and enhancing the industry's reputation.

Advantages arising from the proposed systemic method can be outlined as follows:

i. Identification of Significant Environmental Impacts: The life cycle impact assessment results pinpoint the specific stages of the palm oil milling process, namely sterilising and milling, where the most significant environmental impacts occur. This knowledge allows for targeted interventions and focused environmental management practices.
ii. Awareness of Environmental Threats: The findings underscore the potential harm to marine ecosystems and human health posed by the palm oil milling process. This awareness is crucial for stakeholders to understand the implications of their activities on the environment and human well-being.
iii. Strategic Focus on Key Areas: The strategic point of view emphasizes focusing interventions on mitigating the significant impacts, particularly in the sterilising and milling stages. This strategic approach ensures that resources and efforts are directed towards the most critical aspects of the palm oil milling process.
iv. Alignment with Sustainability Goals: Strategically addressing the issues of marine ecotoxicity and human non-carcinogenic toxicity is imperative to align the palm oil milling process with sustainability goals. This alignment enhances the industry's commitment to environmental responsibility and ethical practices.
v. Long-Term Viability of the Industry: Implementing targeted measures to reduce significant environmental impacts contributes to the industry's long-term viability. This proactive approach ensures that the industry remains resilient and adaptive to evolving environmental standards and regulations.
vi. Enhanced Environmental Performance: By considering the strategic implications of various impact categories, including ozone depletion, fossil fuel scarcity, global warming, and human carcinogenic toxicity, the industry can adopt a holistic approach to enhance its overall environmental performance.
vii. Integration of Sustainable Practices: The call for a holistic approach encourages the integration of sustainable practices, technological innovations, and responsible resource management. This integration is key to effectively mitigating environmental impacts and fostering a more sustainable palm oil industry.
viii. Reputation Enhancement: Incorporating strategic considerations into the sustainability strategy enhances the industry's reputation. This proactive stance communicates a commitment to environmental responsibility, contributing to positive public perception and stakeholder trust.

In summary, the benefits include targeted environmental management, awareness of impacts, strategic focus, alignment with sustainability goals, long-term viability, enhanced performance, integration of sustainable practices, and reputation enhancement for the palm oil industry.

The key takeaway from this study is the identification of significant environmental impacts, primarily associated with the sterilising and milling stages of the palm oil milling process. Notably, marine ecotoxicity and human non-carcinogenic toxicity emerge as major concerns, emphasizing the potential harm to marine ecosystems and human health. While other impact categories like ozone depletion, fossil fuel scarcity, global warming, and human carcinogenic toxicity are of lesser significance, they still warrant attention due to their potential threats. The strategic perspective emphasizes the need to address these environmental impacts strategically, particularly in the sterilising and milling stages. Mitigating issues like marine ecotoxicity and human non-carcinogenic toxicity is crucial for aligning with sustainability goals and enhancing the industry's long-term viability. Implementing targeted measures and adopting a holistic approach that integrates sustainable practices and technological innovations can effectively mitigate these impacts, contributing to a more resilient and environmentally friendly palm oil industry.

4. Conclusions

The study successfully achieved its objective of utilising life cycle assessment to evaluate the adverse effects of the palm oil industry in Malaysia. Employing 11 indicators or impacts in the assessment revealed that the most critical impacts stem from marine ecotoxicity, followed by human non-carcinogenic toxicity. To mitigate the impact on human health, particularly non-carcinogenic toxicity, a viable approach involves minimizing the use of chemicals in the palm oil industry. Chemicals are extensively used during critical stages like sterilization and milling, contributing to the negative impact. Additionally, addressing marine ecotoxicity entails implementing improved waste treatment practices. It is imperative for the government to enforce strict regulations on waste disposal, ensuring responsible treatment rather than indiscriminate disposal into rivers. The findings from this study provide actionable insights for reducing the environmental impact of the palm oil industry, emphasising the importance of chemical reduction and enhanced waste management practices.

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