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Carbon Footprint Analysis in the Palm Oil Agroindustry Supply Chain in Bengkulu Province Using the Life Cycle Assessment (LCA) Approach

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Abstract

The palm oil industry is a strategic sector that significantly contributes to the national economy; however, it is also a major source of greenhouse gas (GHG) emissions. This study aims to identify emission sources, quantify the carbon footprint, and formulate mitigation strategies within the palm oil agroindustry supply chain in Bengkulu Province using a Life Cycle Assessment (LCA) approach with a cradle-to-gate system boundary. The analysis covers the cultivation stage, transportation of Fresh Fruit Bunches (FFB), and processing into Crude Palm Oil (CPO). The study utilizes secondary data from 2018–2025 obtained from statistical agencies, plantation offices, and scientific literature, with emission factors based on IPCC guidelines. The results indicate that total emissions reach 454.4 kg CO_2-eq per ton of FFB or equivalent to 2,065 kg CO_2-eq per ton of CPO. The processing stage is identified as the largest contributor (59.1%), primarily driven by methane emissions from Palm Oil Mill Effluent (POME), followed by the cultivation stage (38.1%) due to nitrogen fertilizer application, while transportation contributes only 2.8%. The dominance of emissions in the processing stage highlights inefficiencies in current waste management practices, particularly the use of open ponding systems that allow methane to be released directly into the atmosphere. Recommended mitigation strategies include the implementation of biogas capture technology for POME, optimization of fertilizer application based on crop requirements, and improvement of transportation efficiency. These findings demonstrate that the Life Cycle Assessment (LCA) approach is effective in identifying emission hotspots and provides a scientific basis for developing sustainable strategies in the palm oil agroindustry.

Keyword : carbon footprint, LCA, palm oil, GHG emissions, POME, sustainability

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INTRODUCTION

The palm oil industry is one of the strategic sectors in the global and national economy because of its contribution to the supply of vegetable oil, renewable energy, and foreign exchange of the country. Indonesia is currently the world's largest palm oil producer with a contribution of more than 55% of global production. Indonesia's Crude Palm Oil (CPO) production is recorded to reach around 47 million tons in 2023 and shows an increasing trend in recent years (Central Statistics Agency, 2024; Ministry of Agriculture, 2024). This increase confirms the importance of the palm oil industry as a driving force for the national economy as well as a source of livelihood for millions of farmers.

At the regional level, Bengkulu Province is one of the oil palm production centers on the island of Sumatra with a plantation area of more than 385 thousand hectares in 2023 (Central Statistics Agency, 2023). The land ownership structure is dominated by smallholder plantations which reach more than 70%, so the management pattern of production inputs such as fertilizers and pesticides tends to be non-uniform and has the potential to cause inefficiencies (Ministry of Agriculture, 2024). This condition has an impact on the variation in productivity and intensity of greenhouse gas (GHG) emissions produced at each stage of the supply chain.

On the other hand, the increase in palm oil production is also followed by increased attention to the environmental impact caused, especially related to global climate change. Greenhouse gas emissions from the palm oil agroindustry come from various stages, ranging from the use of nitrogen fertilizers in plantations that produce nitrogen oxide (N_2O) emissions, to fossil fuel consumption in transportation, to processing processes in factories that produce methane (CH_4) emissions from Palm Oil Mill Effluent (POME) liquid waste (IPCC, 2019; Harahap et al., 2019). Methane gas has 28 times greater global warming potential than carbon dioxide in a 100-year period, making its contribution to climate change very significant (IPCC, 2019).

A number of studies show that the palm oil supply chain is one of the largest contributors to GHG emissions in the agriculture and industrial sectors. A study by Choo et al. (2018) identified that the processing stage in the factory, especially the management of POME, is the largest contributor to emissions in the CPO production system. Meanwhile, Khasanah et al. (2020) stated that the use of nitrogen fertilizers at the cultivation stage contributes significantly to N_2O emissions. Other studies also show that total carbon emissions from CPO production in Indonesia range from 1.0 to 3.5 tons of CO_2-eq per ton of CPO, depending on the efficiency of technology and management practices applied (Harahap et al., 2019; Subramaniam et al., 2020).

In the global context, the demand for sustainable products is increasing, especially with regulations such as the European Union Deforestation Regulation (EUDR) which requires transparency of the carbon footprint and sustainability of the supply chain of land-based products (European Commission, 2023). Therefore, carbon footprint measurement is an important indicator in assessing the environmental performance of the palm oil agroindustry as well as a basis for the preparation of emission mitigation strategies.

The Life Cycle Assessment (LCA) approach has been widely used to comprehensively evaluate the environmental impact of a product, from the upstream to downstream stages. This method allows the identification of key emission sources (hotspots) as well as provides a scientific basis for decision-making to improve the efficiency and sustainability of production systems (Yusoff & Hansen, 2021). However, the results of the LCA analysis are greatly influenced by local conditions such as the topography of the area, transportation distance, and the characteristics of plantation and factory management.

Although various studies related to the carbon footprint of palm oil have been conducted in Indonesia, most of them still focus on key production regions such as North Sumatra and Riau. Studies based on the specific conditions of the Bengkulu region are still limited, even though the hilly geographical characteristics, varied transportation infrastructure, and dominance of smallholder plantations have the potential to produce different emission profiles compared to other regions.

This study has novelty in (1) the preparation of an emission inventory based on the specific conditions of the Bengkulu region that has not been widely studied before, (2) consideration of the dominance of smallholder plantation structures (>70%) which affects production input patterns and emission intensity, and (3) quantitative analysis of carbon footprint using the Life Cycle Assessment (LCA) approach by considering hilly geographical conditions that have an impact on transportation efficiency. This study aims to (1) identify sources of greenhouse gas emissions at each stage of the supply chain, (2) calculate the total carbon footprint per production unit, and (3) formulate effective mitigation strategies to support the sustainability of the palm oil agroindustry in Bengkulu Province.

Although various studies related to the carbon footprint of palm oil have been conducted in Indonesia, most of them still focus on key production regions such as North Sumatra and Riau. Studies that integrate region-specific conditions such as the dominance of people's plantations, hilly topography characteristics, and the limitations of transportation infrastructure in Bengkulu Province are still relatively limited. Therefore, this study seeks to fill the gap through a Life Cycle Assessment (LCA) approach based on local conditions.

METHOD

2.1 Research Approach

This study uses the Life Cycle Assessment (LCA) approach to analyze the carbon footprint in the palm oil agroindustry supply chain. LCA is a systematic method used to evaluate the environmental impact of a product or system throughout its life cycle, from the upstream to downstream stages (ISO 14040, 2006; ISO 14044, 2006).

The approach used is attributional LCA, which aims to describe the emission contribution of each stage of the process in a production system (Finnveden et al., 2018). This method was chosen because it is suitable for identifying major emission sources (hotspots) and formulating mitigation strategies based on existing conditions.

2.2 System Limits and Scope

The limit of the system used in this study is cradle-to-gate, which is from the production stage in the garden to the product coming out of the factory in the form of Crude Palm Oil (CPO).

The system is divided into three main subsystems:

1. Cultivation Phase. Includes nursery activities, plant maintenance, and the use of inputs such as fertilizers and pesticides.
2. Transportation Phase. Includes the transportation of Fresh Fruit Bunches (FFB) from plantations to oil palm mills (PKS).
3. Milling Phase. It includes sterilization processes, oil extraction, energy use, and liquid waste management (POME).

Figure 1. Palm Oil Supply Chain LCA System Diagram

The cradle-to-gate approach is commonly used in LCA analysis in the palm oil industry because it focuses on the main production processes before product distribution (Harahap et al., 2019; Yusoff & Hansen, 2021).

2.3 Functional Units

The functional units used in this study are 1 ton of FFB (Fresh Fruit Bunches) and converted to 0.22 tons of CPO. The conversion ratio of 1 ton of FFB to 0.22 tons of CPO refers to the national palm oil industry standard which represents the average yield of the mill in Bengkulu Province. The selection of these functional units aims to facilitate comparison with previous studies as well as reflect production efficiency at the factory level (Choo et al., 2018).

2.4 Data Types and Sources

This study uses secondary data for the period 2018–2025 obtained from: Central Statistics Agency (BPS), Bengkulu Provincial Plantation Office, international scientific literature and journals, and database faktor emisi (IPCC, Ecoinvent).

The data collected includes: land area and FFB/CPO production, use of fertilizers (Urea, NPK), energy consumption (solar, electricity), POME waste volume, and distance and transportation consumption.

The use of secondary data in LCA is allowed as long as the data is sourced from a credible institution that is representative of the system under review (ISO 14044, 2006).

2.5 Inventori Analysis (Life Cycle Inventory – LCI)

The inventory stage is carried out by identifying all input and output flows in the system. Main inputs: fertilizer (Urea, NPK), fuel (diesel), electrical energy, and processed water. Main output: main product (CPO), liquid waste (POME), and greenhouse gas emissions (CO_2, CH_4, N_2O). This inventory is the basis for calculating carbon emissions at each stage of the process (Guinée et al., 2018).

Table 1. Input-Output Inventory at Every Stage

Stages	Parameter	Value	Units
Cultivation	**Input**		
	Pupuk Urea (Nitrogen)	15,2	kg/ton TBS
	NPK Fertilizer	18,5	kg/ton TBS
	Output		
	N_2O Emissions (Direct)	0,18	kg N_2O/ton TBS
Transportation	**Input**		
	Diesel Consumption	4,8	liter/ton TBS
	Output		
	Emisi CO_2 (Transport)	12,8	kg CO_2/ton TBS
Processing	**Input**		
	Fresh Fruit Bunches (FFB)	1.000	kg
	Solar (For Boilers)	12,5	liter/ton TBS
	Electricity	18,0	kWh/ton TBS
	Output		
	Crude Palm Oil (CPO)	220	kg/ton TBS
	POME Liquid Waste	0,67	m^3/ton TBS
	CH_4 emissions (from POME)	9,6	kg CH_4/ton TBS
	Shell & Fiber	220	kg/ton TBS

Table 1. presents activity data (input) and product/waste (output) for every 1 ton of Fresh Fruit Bunches (FFB) processed. This value is derived from the results of the inventory calculation (Life Cycle Inventory) based on secondary data from Bengkulu Province and scientific literature.

2.6 Greenhouse Gas Emission Calculation

Emissions calculation is carried out using an emission factor approach based on the IPCC Guidelines (2006) and Refinement, 2019 guidelines.
Common equations used:

$$E=\sum(Ai\times EFi)$$

Description:

- EEE = total emissions (kg CO_2-eq)
- AiA_iAi = activity data
- EFiEF_iEFi = emission factor

The calculation of greenhouse gas emissions was carried out using Microsoft Excel by integrating activity data and emission factors sourced from the IPCC (2019) and the Ecoinvent v3.9.1 database.

The conversion of greenhouse gases to CO_2-equivalent units is carried out using the 100-year Global Warming Potential (GWP) value:

- $CO_2 = 1$
- $CH_4 = 28$
- $N_2O = 298$ (IPCC, 2019)

2.7 Life Cycle Impact Assessment (LCIA)

The impact analysis is focused on the Global Warming Potential (GWP) category. This category was chosen because it is relevant to the issue of climate change and is a key indicator in carbon footprint assessments (Hauschild et al., 2018).

The following emission factors are used to calculate the Greenhouse Gas (GHG) emission burden of each activity in the supply chain. This value refers to the IPCC guidelines (2006, 2019) and the Ecoinvent database v3.9.1.

Table 2. Emission Factors Used in Research

Component	Activity	Emission Factor	Unit
Cultivation Stage			
Urea Fertilizer	N Fertilization	0.01 (N_2O-N)	kg N_2O-N/kg N
NPK Fertilizer	N Fertilization	0.01 (N_2O-N)	kg N_2O-N/kg N

Urea Fertilizer Production	Manufacturing	1.0	kg CO_2-eq/kg urea
NPK Fertilizer Production	Manufacturing	0.7	kg CO_2-eq/kg NPK
Transportation Stage			
Diesel	Fuel Consumption	2.68	kg CO_2-eq/liter
Processing Stage			
POME (Palm Oil Mill Effluent)	Anaerobic Decomposition	12.36	kg CH_4/ton POME
Electricity	Energy Consumption	0.84	kg CO_2-eq/kWh
Diesel for Boiler	Fuel Consumption	2.68	kg CO_2-eq/liter
GWP Conversion Values			
CH_4	GWP 100 years	28	kg CO_2-eq/kg CH_4
N_2O	GWP 100 years	298	kg CO_2-eq/kg N_2O

Notes:

1. The N_2O emission factor from nitrogen fertilizer refers to the IPCC Tier 1 default emission factor of 0.01 kg N_2O-N/kg N, converted to N_2O using a conversion factor of 44/28.
2. The POME emission factor was derived from field measurements at palm oil mills in Malaysia, with a value of 12.36 kg CH_4 per ton POME.
3. GWP values are based on the IPCC 2019 Refinement with a 100-year time horizon.

2.8 Data Analysis and Hotspot Identification

The results of the emission calculation were analyzed descriptively quantitatively to calculating the total carbon footprint, determining the contribution of each stage, and identify emission hotspots. Emission hotspots are defined as the stages with the largest emission contribution in the production system (Choo et al., 2018).

2.9 Literature Validation and Comparison

To improve the reliability of the results, a comparison was made with the results of previous research on the palm oil industry in Indonesia and other countries. Validation was carried out by comparing the emission intensity value to the reported literature range, which is around 1-3.5 tons of CO_2-eq per ton of CPO (Harahap et al., 2019; Subramaniam et al., 2020; Mofijur et al., 2022).

RESULTS AND DISCUSSION

3.1 Overview of Palm Oil Agroindustry in Bengkulu Province

Bengkulu Province is one of the oil palm production centers on the island of Sumatra with a plantation area of around 385,412 hectares in 2023. Most of the plantations are managed by smallholder farmers (±73%), while the rest are large state and private plantations (Central Statistics Agency, 2023). The production of Fresh Fruit Bunches (FFB) reaches around 5.2 million tons per year, which is processed by dozens of palm oil mills with an average capacity of 45-60 tons of FFB per hour.

The dominance of smallholder plantations led to variations in cultivation practices, especially in fertilizer use and land management, which ultimately affected the intensity of greenhouse gas (GHG) emissions. In addition, the hilly topography of Bengkulu and the varied transportation infrastructure also have an impact on the efficiency of FFB distribution to the factory.

3.2 Inventory and Emission Source Analysis

Based on the results of the Life Cycle Inventory, the main source of emissions in the palm oil agroindustry supply chain in Bengkulu consists of three main stages, namely cultivation, transportation, and processing.

a. Cultivation Stage

At this stage, the main source of emissions comes from the use of nitrogen fertilizers (urea) which produce nitrogen oxide (N_2O) emissions through the process of nitrification and denitrification in the soil. In addition, indirect emissions also come from the fertilizer production process in industry (Khasanah et al., 2020).

Total emissions at the cultivation stage were recorded at 172.7 kg CO_2-eq/ton FFB or around 38.1% of total emissions. This value indicates that the use of fertilizers is one of the dominant factors in increasing the carbon footprint, especially in smallholder plantation systems that have not implemented fertilization based on specific land needs.

b. Transportation Stage

The transportation stage produces emissions from the burning of fossil fuels (diesel) by FFB transport vehicles. Based on the calculation results, transportation emissions were recorded at 12.8 kg CO_2-eq/ton FFB or around 2.8% of total emissions.

This relatively small contribution is in line with previous research that stated that transportation emissions in the palm oil supply chain are generally lower than those at the cultivation and processing stages (Harahap et al., 2019). However, the hilly geographical conditions of Bengkulu can increase fuel consumption so that it has the potential to increase emissions if not managed efficiently.

c. Milling Phase

The processing stage is the largest contributor to emissions with a calculated value of 268.9 kg CO_2-eq/ton of FFB or around 59.1% of total emissions. The main emissions come from palm oil mill effluent (POME) liquid waste which undergoes anaerobic decomposition and produces methane gas (CH_4). This shows inefficiencies in waste management systems, especially the use of open ponding methods that allow the release of methane directly into the atmosphere.

Methane gas has a much higher global warming potential than CO_2, so although its volume is relatively small, its contribution to total emissions is very significant (IPCC, 2019). These results confirm the findings of Choo et al. (2018) who stated that POME management is a major hotspot in the palm oil industry.

3.3 Total Carbon Footprint and Emission Intensity

The total carbon footprint produced in this study is 454.4 kg CO_2-eq per ton of FFB or equivalent to 2,065 kg of CO_2-eq per ton of CPO.

Table 3. Contribution of GHG Emissions at Every Stage of the Supply Chain

Stages of the supply chain	**Emissions (kg CO_2-eq/ton FFB)**	**Kontribusi (%)**
Cultivation	172,7	38,1
Transportation	12,8	2,8
Processing	268,9	59,1
Total	**454,4**	**100**

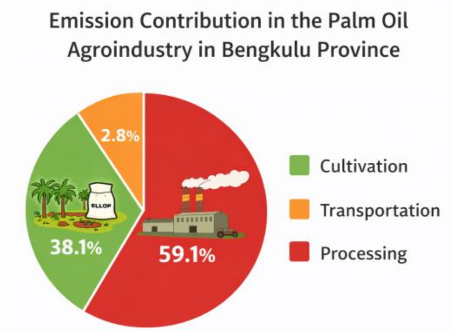

Figure 2. Emissions Contribution Graph

This value is still within the range reported in the literature, which is between 1.0 to 3.5 tons of CO_2-eq per ton of CPO (Harahap et al., 2019; Subramaniam et al., 2020; Mofijur et al., 2022). However, this value (2,065 tonnes CO_2-eq/tonnes of CPO) is still above the global best practice average (<1.5 tonnes CO_2-eq/tonnes of CPO). This condition indicates that the level of management efficiency in Bengkulu Province is still relatively low and there is a great opportunity to reduce emissions through technological and management interventions.

3.4 Emission Hotspot Analysis

Based on the results of the study, the two main emission hotspots are:

1. POME (Treatment) Waste. Accounts for more than 50% of total emissions. Waste treatment systems that still use open ponds cause the release of methane directly into the atmosphere.

2. Use of Nitrogen Fertilizer (Cultivation). Accounts for about 38% of total emissions due to direct emissions of N_2O from soils and indirect emissions from fertilizer production

These results are in line with previous research that confirms that these two factors are major contributors to the oil palm production system (Khasanah et al., 2020; Santika et al., 2023).

3.5 Comparison with Previous Studies

When compared to other studies: Indonesia: 1.0 – 3.5 tonnes CO_2-eq/ton CPO, Malaysia: ±1,5 ton CO_2-eq/ton CPO, and Best practice global: <1,5 ton CO_2-eq/ton CPO. Therefore, the results of this study (2,065 tons of CO_2-eq/ton CPO) show that the palm oil agroindustry in Bengkulu is still at a medium level. This difference is caused by suboptimal waste treatment systems, inefficient fertilizer use, and variations in cultivation practices in smallholder plantations (Subramaniam et al., 2020; Yusoff & Hansen, 2021; Rahman et al., 2024).

3.6 Implications and Mitigation Strategies

The results of the identification of emission hotspots that have been described previously are the main basis in the formulation of mitigation strategies. Since the treatment stage is the largest contributor (59.1%) dominated by methane emissions from POME, the main priority for mitigation is on the waste management system. Furthermore, a significant contribution from the cultivation stage (38.1%) shows that the efficiency of nitrogen fertilizer use is the second key factor that must be immediately optimized, especially in smallholder plantations. Based on the results of the analysis, some mitigation strategies that can be applied include:

1. Biogas Capture Technology. The application of a methane capture system from POME can reduce emissions by up to 60-80% and produce alternative energy (biogas) (Yusoff & Hansen, 2021; Santika et al., 2023).
2. Fertilization Optimization. The application of site-specific nutrient management can reduce the excessive use of nitrogen fertilizers and reduce N_2O emissions by 20-30% (Khasanah et al., 2020; Rahman et al., 2024).
3. Biomass Utilization. The use of solid waste (shells and fibers) as fuel can reduce dependence on fossil fuels and lower emissions from energy consumption.
4. Transportation Efficiency. Optimization of routes and carrying capacity can reduce fuel consumption by up to 10-15%.

3.7 Sensitivity Analysis

To test the influence of the main assumptions on the total carbon footprint, a sensitivity analysis was conducted with two scenarios:

- Scenario 1: Nitrogen Fertilizer Reduction. If the use of nitrogen fertilizers in smallholder plantations can be reduced by 10% through the application of precision fertilization, then total emissions from the cultivation stage have the potential to decrease by ∼17.3 kg CO_2-eq/ton FFB, or reduce the overall total emissions by about 3.8%.
- Scenario 2: Implementation of Biogas Capture. If biogas capture technology is applied to the entire plant with an efficiency of 70%, then emissions from the processing stage can be reduced to ∼188 kg CO_2-eq/ton FFB, or reduce total overall emissions by 41.4%.

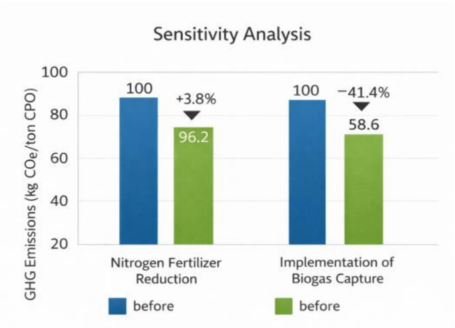

Figure 3. Sensitivity Analysis Graph

These results show that interventions in POME management provide the most significant emission reduction potential compared to other interventions.

CONCLUSION

This study shows that the carbon footprint in the palm oil agroindustry supply chain in Bengkulu Province is 454.4 kg CO_2-eq per ton of FFB or equivalent to 2,065 kg CO_2-eq per ton of CPO. The main source of greenhouse gas (GHG) emissions comes from the treatment stage (59.1%) which is dominated by methane emissions from factory liquid waste (POME), followed by the cultivation stage (38.1%) due to the use of nitrogen fertilizers, and the transportation stage (2.8%) with a relatively small contribution. These results confirm that waste treatment and fertilizer use are the main hotspots in the oil palm production system in Bengkulu. Therefore, the most effective mitigation strategies include the application of biogas capture technology in POME, optimization of fertilization based on plant needs, and improvement of transportation efficiency. Thus, the Life Cycle Assessment (LCA) approach is able to provide a scientific basis in identifying emission sources and formulating mitigation strategies, so as to support the improvement of the sustainability of the palm oil agroindustry at the regional level.

REFERENCE

Badan Pusat Statistik. (2023). Provinsi Bengkulu dalam Angka 2023. Bengkulu: BPS Provinsi Bengkulu.

Badan Pusat Statistik. (2024). Statistik Kelapa Sawit Indonesia 2023. Jakarta: BPS.

Choo, Y. M., Muhamad, H., Hashim, Z., Subramaniam, V., Puah, C. W., & Tan, Y. A. (2018). Determination of Greenhouse Gas Contributions by Subsystems in the Oil Palm Supply Chain Using the LCA Approach. Journal of Cleaner Production, 200, 694-703.

European Commission. (2023). Regulation (EU) 2023/1115 on Deforestation-Free Products (EUDR). Brussels: European Union.

Finnveden, G., Hauschild, M. Z., Ekvall, T., Guinée, J., Heijungs, R., Hellweg, S., & Suh, S. (2018). Recent Developments in Life Cycle Assessment. Journal of Environmental Management, 91(1), 1-21.

Guinée, J. B., Heijungs, R., Huppes, G., Zamagni, A., Masoni, P., Buonamici, R., & Rydberg, T. (2018). Life Cycle Assessment: Past, Present, and Future. Environmental Science & Technology, 52(4), 123-135.

Harahap, F., Silveira, S., & Khatiwada, D. (2019). Greenhouse Gas Emissions from Palm Oil Production: A Review of Life Cycle Assessment Studies. Journal of Cleaner Production, 237, 117756.

Hauschild, M. Z., Rosenbaum, R. K., & Olsen, S. I. (2018). Life Cycle Assessment: Theory and Practice. Springer.

IPCC. (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Intergovernmental Panel on Climate Change.

IPCC. (2019). 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Intergovernmental Panel on Climate Change.

ISO. (2006a). ISO 14040: Environmental Management - Life Cycle Assessment - Principles and Framework. International Organization for Standardization.

ISO. (2006b). ISO 14044: Environmental Management - Life Cycle Assessment - Requirements and Guidelines. International Organization for Standardization.

Kementerian Pertanian Republik Indonesia. (2024). Statistik Perkebunan Indonesia: Kelapa Sawit 2023-2025. Jakarta: Direktorat Jenderal Perkebunan.

Khasanah, N., van Noordwijk, M., & Ningsih, H. (2020). Carbon Footprint of Oil Palm Production in Indonesia. Sustainability, 12(3), 1024.

Mofijur, M., et al. (2022). A Comprehensive Review on the Environmental Impacts of Palm Oil Production. Journal of Cleaner Production, 350, 131456.

Rahman, A., et al. (2024). Carbon Footprint Assessment of Smallholder Oil Palm Plantations in Indonesia: A case study. Sustainable Production and Consumption, 41, 123-135.

Santika, W. G., et al. (2023). Mitigation of Greenhouse Gas Emissions from Palm Oil Industry: A Review of Current Practices and Future Pathways. Science of the Total Environment, 856, 159171.

Subramaniam, V., May, C. Y., & Muhammad, H. (2020). Environmental Performance of the Palm Oil Industry in Malaysia and Indonesia. Journal of Environmental Management, 260, 110-123.

Yusoff, S., & Hansen, S. (2021). Feasibility of Performing Life Cycle Assessment on Crude Palm Oil Production. Renewable Energy, 170, 109-120.