Jurnal Teknologi Industri Pertanian, 36 (1): 28-37, April 2026
ISSN: 0216-3160 E-ISSN 2252-3901

Available online on
https://journal.ipb.ac.id/index.php/jurnaltin

Research Paper

LIFE CYCLE ASSESSMENT OF PINEAPPLE CHIPS PRODUCTS IN KAMPAR REGENCY RIAU

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Article Info

Received: October 14, 2025
Revised: January 22, 2026
Accepted: February 10, 2026
Published: April 2026

Keywords:

environmental emissions, life cycle assessment, pineapple chips

ABSTRACT. Pineapple chips are a snack from sliced pineapples that are deep-fried and contain permitted food additives. The production activities of pineapple chip agroindustry have the potential to cause environmental impacts. Therefore, a comprehensive assessment of emissions generated throughout the life cycle of pineapple chip production is necessary using the Life Cycle Assessment (LCA) approach. This study aims to calculate the environmental emission potentials from the life cycle of pineapple chips, covering stages from cultivation to distribution. The research stages include goal and scope definition, inventory analysis using the mass balance method, impact assessment using the Open LCA software, and interpretation. The life cycle of the pineapple chips begins with land preparation for cultivation, including nursery, maintenance, and harvesting. The harvested pineapples are then transported to the processing facility, where they are transformed into packaged pineapple chips and distributed to souvenir centres. The results of the environmental impact assessment for a functional unit of 100 grams of pineapple chips show emissions of 7.04E-01 kg CO_2-eq for global warming potential (GWP), 2.29E-03 kg SO_2-eq for acidification potential (AP), 1.42E-02 kg PO_4-eq for eutrophication potential (EP), and 1.08E-08 kg CFC-11 eq for ozone depletion potential (ODP). The life cycle analysis reveals that the production stage is the main contributor to emissions, with eutrophication potential (EP) identified as the hotspot. To reduce the environmental burden, three improvement scenarios are proposed: substitution of chemical fertilizers with compost, conversion of gasoline to gas fuel, and replacement of palm oil with coconut oil.

INTRODUCTION

Riau Province ranked as the fourth-largest pineapple producer in Indonesia after Lampung, South Sumatra, and East Java (BPS, 2024). In 2023, the province recorded a total production of 379,025 metric tons per year, of which Kampar Regency contributed 61% with a pineapple production of 243,256 metric tons annually (BPS, 2024). Pineapple is classified as a highly perishable fruit; thus, direct marketing without prior storage is required. Processing pineapple into value-added products can address this issue. Pineapple chips have become one of the most popular local souvenirs from Riau. The processing stages of pineapple chips include peeling, washing, slicing, and frying using a vacuum frying machine. However, the pineapple chip agroindustry has the potential to generate significant environmental impacts. The solid waste produced has not been properly managed during the production process and may cause environmental degradation if left unaddressed. Agro-industrial activities are expected to comply with the Sustainable Development Goals, particularly in terms of sustainable consumption and production (SDGs no.12) to support the vision of "Indonesia Emas 2045". Therefore, it is necessary to assess every emission generated by agro-industrial activities. One of the efforts to create a sustainable industry requires a

DOI: https://doi.org/10.24961/j.tek.ind.pert.2026.36.1.28

comprehensive life cycle assessment approach, such as life cycle assessment Furthermore, Sachie (2024) reported that the canned pineapple industry generates measurable environmental impacts, including a global warming potential (GWP) of 5.14E02 kg CO_2-eq/kg canned pineapple, an acidification potential (AP) of 2.62E-04 kg SO_2-eq/kg canned pineapple, and an eutrophication potential (EP) of 2.01E-04 kg PO_4-eq/kg canned pineapple.

Previous research conducted by Perdana *et al.* (2024) analyzed the environmental impacts of banana chip production using vacuum frying technology. The study reported that for a functional unit of 230 g of banana chips, emissions amounted to 6.3E-01 kg CO_2 -eq for the global warming potential (GWP) category, 2.3E-03 kg SO_2-eq for the acidification potential (AP) category, and 6.1E-03 kg PO_4-eq for the ozone depletion potential (ODP) category. Meanwhile, another study by Ulya *et al*. (2020) on tette chips made from cassava, with a functional unit of 500 g, showed emissions of 17.3 kg CO_2-eq for climate change, 6.63E-06 kg ethylene-eq for photochemical oxidation, and 5.43E-03 kg PO_4-eq for eutrophication. The government is promoting a green economy framework to ensure long-term economic stability. One of the strategies is to balance economic, social, and environmental aspects in line with the sustainable development goals (SDGs) and Indonesia's Vision 2045. Indonesia is expected to achieve a net-zero emissions (NZE) target by 2060 (Coordinating Ministry for Economic Affairs 2024). This creates a demand for all industries to adopt environmentally conscious and sustainable practices. Efforts to establish a sustainable industry require a comprehensive life cycle-based approach, such as life cycle assessment (LCA).

Life cycle assessment (LCA) is an approach used to evaluate energy consumption, emissions, and environmental burdens associated with the various phases of a product's life cycle, from raw material extraction to end-of-life disposal. According to SNI ISO 14040:2016, the four stages of LCA include defining the goal and scope, conducting an inventory analysis of resource use, such as energy, water, fuel, and other inputs, assessing environmental impacts, and interpreting the results. Environmental emission assessment focuses on pollution sources as key evaluation indicators. One method to estimate total emissions is to evaluate the entire life cycle of pineapple chips, with the aim of minimizing environmental impacts as part of efforts to develop a sustainable industry. According to Wiloso *et al*. (2018), the application of LCA is beneficial for improving product quality, analyzing product ecology, reducing greenhouse gas emissions, and supporting ecolabeling schemes, green certification, or environmental declarations. This study aims to identify and analyze inputs and outputs based on inventory data of pineapple chip production and quantify the emissions generated throughout its life cycle. The LCA was conducted starting from the plantation stage, through transportation and production, up to the distribution of packaged product of pineapple chips.

RESEARCH AND METHODS

In accordance with SNI ISO 14040:2016 and SNI ISO 14044:2017, the life cycle assessment (LCA) process is comprised of four distinct phases: defining the goal and scope, performing an inventory analysis, conducting an impact assessment, and interpreting the results. This study employed OpenLCA software and selected the Center of Environmental Science of Leiden University Impact Assessment (CML 2001-IA baseline) as the impact assessment method. The CML methodology is acknowledged as one of the most commonly used impact assessment frameworks in LCA research related to the agricultural sector and food products (Merchan and Combelles, 2012).

Goal and Scope Definition

The goal and scope were determined based on literature studies and field observations to identify actual conditions and data limitations, thereby allowing the establishment of appropriate boundaries and scope. The definition of scope encompasses the specification of the product, boundaries of the system, and functional unit. Establishing a functional unit serves as a benchmark for normalizing both inputs and outputs. As noted by Phungrassami (2020), the functional unit most frequently employed for food products is grounded in mass.

Life Cycle Inventory Analysis

The inventory analysis encompasses the identification of inputs and outputs across the product life cycle in accordance with SNI 14044:2017. To conduct this analysis, the study employed a combination of interviews and field observations, supported by inventory questionnaires and company data requirement lists. Primary data were collected directly from field sources, whereas secondary data were obtained from company documentation covering input materials (raw materials, additives, and energy) and outputs (products, waste, and emissions). Additionally, literature studies and OpenLCA databases provided supplementary information. Through this comprehensive inventory analysis, the study determined the specific quantities of raw materials, energy, and emissions associated with number of functional unit. This approach aligns with Yusuf (2021), who noted that inventory analysis can be adapted to site-specific conditions and contributes to environmental impact minimization.

Environmental Impact Analysis

The purpose of the EIA is to quantify the potential environmental emissions based on the results of the IA. The CML-IA baseline method was selected because it belongs to the midpoint category, representing direct environmental impact categories (Yudha and Assomadi, 2022), and includes a database containing characterization factors to convert inventory data into LCIA data (Darmanik 2021).

Although the CML-IA baseline method comprises 11 impact categories, this study focused on only four categories. This selection is based on Agathe *et al.* (2014), who identified global warming potential (GWP), acidification potential (AP), eutrophication potential (EP), and ozone depletion potential (ODP) as the most relevant impact categories for food and agricultural products. The resulting impact values were further processed through normalization, which aims to express each impact in a uniform unit (Puspaningrum *et al.*, 2023).

Interpretation of Result

The interpretation stage is the final phase of an LCA study. According to Parameswari *et al*. (2019), impact interpretation consists of two steps: identification of significant issues and evaluation. This interpretation involves assessing the environmental impacts arising throughout the product life cycle as part of efforts to reduce environmental burdens. The results of this evaluation are then used to identify hotspots or processes that have the greatest impact on the environment.

RESULTS AND DISCUSSIONS

Goal and Scope

The objectives and scope were determined based on field observations that covered cradle-to-gate and distribution, including all stages from pineapple cultivation, transportation, pineapple chips production processes, and product distribution to centers. Perdana *et al.* (2024) conducted LCA research on banana chips and used a cradle-to-gate approach plus distribution, starting from banana plantation cultivation to the distribution of banana chips to souvenir centre. The functional unit was determined according to the guidelines for preparing life cycle assessment reports from regulation of the minister of environment and forestry (PERMEN LHK), which is based on weight units. Pineapple chips are produced and sold based on weight; therefore, the functional unit adopted was 100 g of pineapple chips per package.

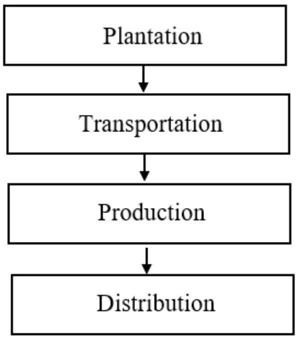

Figure 1. Scope of life cycle for assessment of environmental emissions in pineapple chips industry

Inventory Analysis

The purpose of the inventory analysis was to identify the inputs and outputs throughout the life cycle of pineapple chips. The processing of pineapple chips begins with pineapple cultivation on plantations, followed by the transportation of harvested fruits to the chip processing industry, where they are processed into packaged products for distribution to souvenir centers in Pekanbaru. Table 1 presents the inventory data adapted to the requirements for producing 100 g of pineapple chips.

Environmental Impact Analysis

This study assessed the environmental impacts of the pineapple chip industry using the Centre of Environmental Science of Leiden University Impact Assessment (CML 2001-IA baseline) method within the OpenLCA software. Input and output data from the life cycle inventory (LCI) were entered according to the database used in OpenLCA. The characterized impacts of pineapple chips per 100 g are presented in Table 2, whereas the total normalized contribution of pineapple chip impacts is illustrated in Figure 3. As shown in Figure 2, the life cycle of pineapple chips begins with

DOI: https://doi.org/10.24961/j.tek.ind.pert.2026.36.1.28

land preparation on the plantation, followed by pineapple cultivation and harvesting. The harvested pineapples are then transported to small and medium-sized enterprises (SMEs) that produce pineapple chips. The chips are processed using conventional methods, specifically vacuum frying. The packaged pineapple chip products are subsequently distributed to souvenir centre in Pekanbaru.

Table 1 presents the life cycle inventory analysis results for pineapple chips, revealing a production efficiency in which 2,010 kg of raw pineapples yields 120 kg of finished product per month. Using this inventory data as the foundation, environmental impact calculations were conducted with a functional unit of 100 g packaged pineapple chips. The comprehensive data collection encompassed four critical life cycle stages: plantation operations, transportation logistics, production processes, and distribution networks. Subsequently, the total environmental impact contribution was quantified across four key categories: global warming potential, acidification potential, eutrophication potential, and ozone depletion potential.

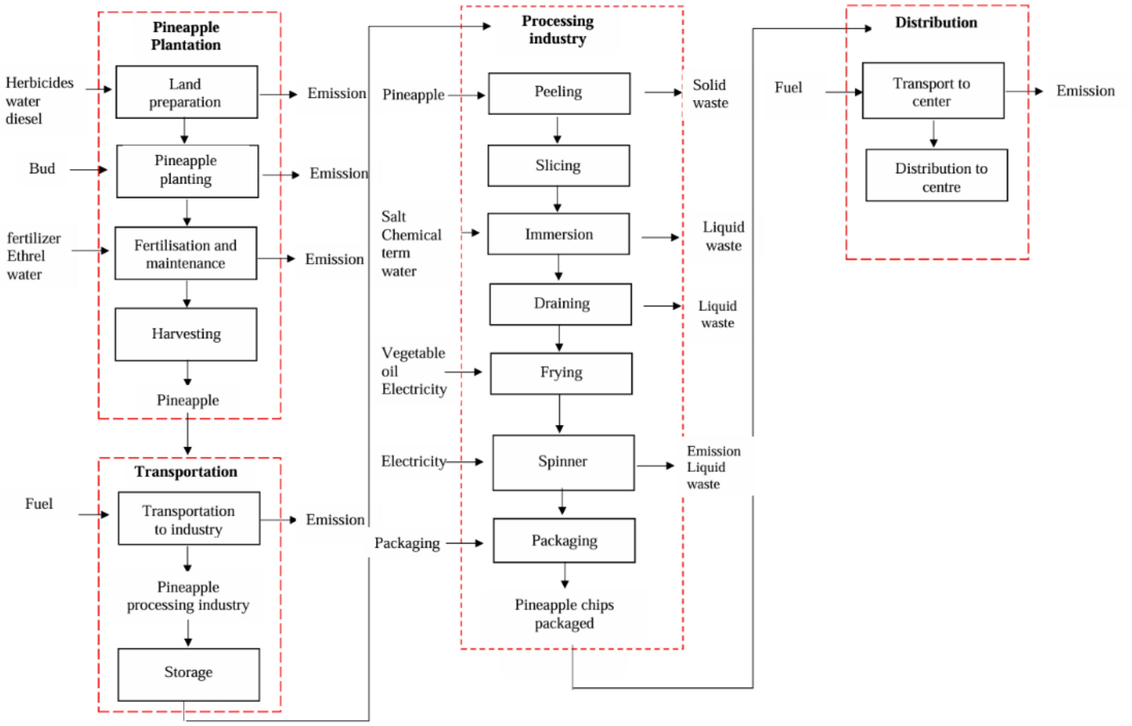

Figure 2. Life cycle of production stage of pineapple chips

Table 1. Inventory analysis for 100 grams of pineapple chips production

Process stages	Input	Unit	Amount	Output	Amount
Plantation	Solar	L	0.0006	Garden waste	0.16 kg
	Herbicide	L	0.00031		
	Urea	Kg	0.016		
	NPK	Kg	0.016		
	Ethrel	mL	0.017		
Transportation	Petrol	L	0.00076		
Production	Pineapple	Kg	1.6	Solid waste	0.67 kg
	Salt	Kg	0.006	Wastewater	2.25 L
	Chemical term	Kg	0.0015		
	Vegetable oil	Liter	0.069		
	Plastic packaging	Kg	0.008		
	Water	L	2.25		
	Electricity	Kwh	0.25		
	LPG	Kg	0.11		
Distribution	Petrol	L	0.00062		

Table 2. Characterized impact categories for the plantation stage

Stages	**Input**	**Amount (kg)**	**Impact**			
			GWP kg CO_2 eq	**AP kg SO_2 eq**	**EP kg PO_4 eq**	**ODP kg CFC-11 eq**
Plantation	Herbicide (L)	0.00031	3.59E-03	1.49E-05	1.90E-05	5.40E-10
	Solar (L)	0.006	2.01E-03	1.16E-05	3.31E-06	2.51E-11
	Water	0.05749	1.70E-05	7.01E-08	3.43E-05	9.22E-14
	Urea	0.016	2.70E-02	1.16E-04	4.09E-05	4.87E-10
	NPK	0.016	2.30E-02	9.67E-05	4.05E-05	2.41E-10
	Ethrel (mL)	0.017	1.97E-04	8.35E-07	1.74E-06	1.41E-11
	Output					
	Garden waste	0.16	2.50E-03	5.35E-06	3.50E-06	-
Amount			5.83E-02	2.45E-04	1.09E-04	1.30E-09

Table 3. Characterized impact categories for the transportation stage

Input	**Amount (L)**	**Impact**			
		GWP kg CO_2 eq	**AP kg SO_2 eq**	**EP kg PO_4 eq**	**ODP kg CFC-11 eq**
Petrol	0.001	7.10E-04	3.88E-06	4.50E-07	3.30E-11

Table 4. Characterization of environmental impacts in the production stage

Input	**Amount (kg)**	**Impact**			
		GWP kg CO_2 eq	**AP kg SO_2 eq**	**EP kg PO_4 eq**	**ODP kg CFC-11 eq**
Salt	0.0065	2.75E-04	1.92E-06	3.80E-07	3.76E-12
Baking soda	0.0015	1.86E-03	1.82E-05	4.98E-06	1.27E-11
Vegetable oil (L)	0.063	0.328	6.53E-04	0.013	3.27E-09
Plastic packaging	0.008	0.024	9.07E-05	2.54E-05	2.76E-10
Electricity (Kwh)	0.375	1.70E-01	7.26E-04	1.01E-03	6.72E-10
LPG	0.1125	0.105	5.25E-04	6.15E-05	5.22E-09
Wastewater	2.25	9.27E-04	4.63E-06	1.56E-06	9.54E-12
Solid waste	1.05	1.40E-02	2.24E-05	2.01E-05	-

At the plantation stage, the main contribution to environmental impacts originates from the use of chemical fertilizers, specifically urea and NPK, which affect the GWP, AP, EP, and ODP categories. This is due to the large amounts of chemical fertilizers applied during pineapple cultivation. The use of urea and NPK releases greenhouse gases, such as nitrous oxide (N_2O), during soil decomposition. N_2O is a potent greenhouse gas that contributes significantly to GWP (Rajaniemi *et al*., 2011). A study by Gonzales *et al*. (2020) also examined the life cycle assessment of pineapple production in Mexico. The findings indicate that emissions from pineapple plantations are predominantly attributed to the use of NPK fertilizer. Chemical fertilizers were identified as the largest contributors to CO_2 emissions, with a total GWP impact of 0.47 kg CO_2 eq per 1 kg of pineapple. Variations in impact values are attributed to differences in cultivation methods and the scope of inputs and outputs considered. The impact categories for the transportation stage are presented in Table 3.

In the transportation stage, the largest impact was observed in the global warming potential (GWP), mounting to 7.10E-04 kg CO_2 eq, primarily due to fuel combustion in vehicles transporting pineapples from the plantation to the processing facilities. Transportation emissions were identified based on three parameters: fuel type, weight of the transported goods, and distance traveled (Rouhi *et al*., 2023). The vehicles used in this study were two-wheeled motor vehicles powered by gasoline. The GWP from transportation mainly results from greenhouse gas (GHG) emissions, particularly CO_2 and N_2O, generated from fossil fuel combustion, which directly contributes to global warming (Rouhi *et al*., 2023). According to Puspaningrum *et al*. (2024), the longer the transportation distance, the higher the emissions generated. The research by Nandar *et al*. (2025) on the LCA of Sanjai chips, in the stage of transporting cassava to MSMEs, produced the highest GWP impact which was influenced by the combustion of fossil fuels in vehicles. The environmental impact analysis for the production stage is presented in Table 4

The production stage is the largest contributor across all impact categories: GWP, AP, EP, and ODP. The impact values are 6.44E-01 kg CO_2 eq for GWP, 2.29E-03 kg SO_2 eq for AP, and 1.41E-02 kg PO_4 eq for EP. These emissions result from the use of palm cooking oil, electricity consumption, and LPG fuel usage. According to Ahmad *et al.* (2019), global warming potential (GWP) arises from human activities that release substantial amounts of carbon into the atmosphere from energy utilization, contributing to global warming over a 100-year period. Meanwhile, the ODP value is 9.46E-09 kg CFC-11.

The production of cooking oil also generates greenhouse gas emissions during the cultivation, processing, and transportation of raw materials. Krisi *et al*. (2022) reported that the environmental impacts from palm oil production result in GWP emissions of 0.00117 kg CO_2 eq per ton. In the distribution stage, the environmental impacts are relatively small compared to those in other stages. The largest contribution in this stage is GWP, with a value of 4.31E-04 kg CO2 eq. The impact values in the distribution stage are lower than those in the transportation stage because of lower fuel consumption, resulting in reduced emissions.

Table 6 presents the total impacts across all life cycle stages, from plantation, transportation, and production to distribution. Figure 3 illustrates the normalized impact values. The normalized impact values are characterized to enable comparison across the four impact categories by standardizing the magnitudes, thereby highlighting the relative significance of each result. Normalization is based on person equivalents, which represent the annual per capita impact globally. The total normalized values are presented in Figure 3.

Figure 3 reveals a clear hierarchy among the environmental impact categories, with Eutrophication Potential (EP) dominating at 77.14%, followed by Global Warming Potential (GWP) at 14.51%, Acidification Potential (AP) at 8.33%, and Ozone Depletion Potential (ODP) contributing minimally at 0.04%. This distribution identifies EP as the critical hotspot requiring immediate intervention strategies. Although eutrophication occurs naturally in freshwater ecosystems, anthropogenic activities, including agriculture, urban development, and industrial operations, significantly accelerate this process. In the context of pineapple chip production, the elevated EP impact stems primarily from the production stage, where cooking oil usage during frying emerges as the dominant contributor. This substantial impact can be traced to the comprehensive oil production chain, encompassing emissions from initial palm plantation cultivation through final processing operations, thereby creating a cascading environmental burden that ultimately manifests in the aquatic nutrient enrichment measured as EP.

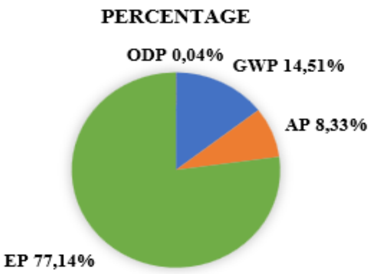

Figure 3. Percentage of impact emission of total normalized of impact value of pineapple chip production

This activity contributes to increased concentrations of nutrients, including phosphorus and nitrogen, in aquatic environments, leading to excessive algal growth (Dodds *et al*., 2009). Perdana *et al.* (2024) also indicated that high EP impact in banana chip production arises from the use of cooking oil during the production stage.

Table 5. Characterized impact values distribution stage per 100 g of pineapple chips

Input	Amount (L)	Impact			
		GWP kg CO_2 eq	AP kg SO_2 eq	EP kg PO_4 eq	ODP kg CFC-11 eq
Petrol	0.0006	4.31E-04	2.35E-06	2.72E-07	1.99E-11

Table 6. Characterized impacts per 100 g packaged of pineapple chips

Stages	GWP (kg CO_2 eq)	AP (kg SO_2 eq)	EP (kg PO_4 eq)	ODP (kg CFC-11 eq)
Plantation	5.83E-02	2.45E-04	1.09E-04	1.31E-09
Transportation	7.15E-04	3.89E-06	4.50E-07	3.30E-11
Production	6.44E-01	2.04E-03	1.41E-02	9.46E-09
distribution	4.31E-04	2.35E-06	2.72E-07	1.99E-11
Total value	7.04E-01	2.29E-03	1.42E-02	1.08E-08

At the plantation stage, the largest contributor to EP is the application of chemical fertilizers, specifically urea and NPK. This is due to the substantial amount of fertilizers used for crop maintenance, particularly NPK, which contains nitrogen and phosphorus. According to Tagliaferri and Lettiero (2019), these elements significantly contribute to eutrophication, altering species composition, and increasing biological productivity.

The second-largest impact category is global warming potential (GWP), which is primarily driven by the use of cooking oil. The high GWP is attributed to the substantial energy consumption during the frying process, both for heating the oil and maintaining a stable temperature, using fossil-based energy sources, resulting in CO_2 and other greenhouse gas emissions (Babel and Thushari, 2022). For the acidification potential (AP) category, the largest contribution comes from the production stage, specifically electricity use. This is due to the continuous operation of water pumps for cooling during the vacuum frying process. The impact with the lowest contribution in this study is ozone depletion potential (ODP), which measures the depletion of the stratospheric ozone layer caused by anthropogenic emissions (Zou *et al*., 2018). The primary contributor to ODP is the use of herbicides during land preparation at the plantation stage. In general, compounds containing chlorine and bromine are known to accelerate ozone layer depletion.

Interpretation

The final stage of this analysis is interpretation. Based on the results from the OpenLCA software, the stage contributing the highest emissions is the use of palm cooking oil during the frying process in the production phase. The most significant impact identified is eutrophication, followed by global warming potential, acidification, and ODP. Therefore, several alternative improvement scenarios can be proposed to mitigate emissions.

Alternative 1: Substitution of Chemical Fertilizers with Compost Fertilizers

The improvement scenario was developed by analyzing the impact assessment data. The findings indicated that solid waste generated from pineapple peels during processing is not utilized and is instead discarded into the environment. Therefore, this solid waste can be converted into compost fertilizer to replace the use of chemical fertilizers at the plantation stage. The inventory data show that the use of chemical fertilizers in a one-hectare pineapple plantation amounts to 600 kg. According to Yuwono *et al.* (2021), the compost yield from pineapple peel waste is approximately 60%, with a total plantation waste potential of 1,260 kg. The formulation of fertilizer improvement recommendations is presented in Table 7.

Table 7 shows that utilizing pineapple chip solid waste as a substitute for chemical fertilizers with compost can reduce all impact categories by more than 50%. This indicates that implementing this alternative scenario can significantly lower the ecological footprint of the pineapple chip life cycle.

Alternatives 2: Subsitution of Vehicle Fuel Oil with Gas Fuel

Based on the analysis, the transportation stage produced the highest emissions, particularly GWP at 7.15E-04 kg CO_2 eq. This was caused by the repeated use of two-wheeled vehicles, which required relatively high amounts of gasoline fuel. As a result, not all of the fuel undergoes complete combustion, and unburned fuel is released together with exhaust gases into the atmosphere (Rusdiani, 2018). The exhaust gases consist of carbon monoxide (CO), nitrogen oxides (NO_x), and carbon dioxide (CO_2). Liquefied petroleum gas (LPG) is a potential alternative to gasoline. The impact values resulting from the substitution of gasoline with LPG fuel are presented in Table 8.

Table 7. Normalized impact values for the chemical fertilizer subtitution scenario

Impact	Before scenario	After scenario	Impact reduction	Persentase
GWP	1.41E-15	1,.8E-16	1.27E-15	90.14%
AP	1.02E-15	1.14E-16	9.06E-16	88.82%
EP	6.89E-16	1.51E-16	5.38E-16	78.08%
ODP	5.77E-18	2.55E-18	3.22E-18	55.81%

Table 8. Normalized impact values for the fuel subtitution scenario per 100 g of pineapple chips

Impact	Before scenario	After scenario	Impact reduction	Persentase
GWP	1.01E-17	7.01E-18	3.09E-18	30.59%
AP	1.63E-17	6.27E-18	1.003E-17	61.53%
EP	2.84E-18	1.14E-18	1.70E-18	59.86%
ODP	1.45E-19	6.27E-20	8.82E-20	60.83%

According to Hartono (2024), LPG has a higher octane rating (RON 112), making it more efficient and producing lower CO and NOx emissions. Yamin *et al*. (2024) reported that the fuel consumption rate of gasoline-powered vehicles is 12.88 cc/min, whereas that of LPG-powered vehicles is 9.36 cc/min. Based on these data, the monthly gasoline consumption is 1.2 L to support the transportation of pineapples from the plantation to the processing industry. When gasoline is substituted with LPG, the equivalent requirement is 0.382 L for the same travel distance of 40 km per month.

Table 8 demonstrates that the use of LPG provides a significant reduction in environmental impact compared to that of gasoline. The GWP category decreased by 3.09E-18 person equivalent, equivalent to 30.59%, indicating a reduction in greenhouse gas emissions. This finding is consistent with Yamin *et al*. (2024), who stated that LPG contains a higher proportion of hydrogen relative to carbon, thereby producing lower carbon dioxide (CO_2) emissions during combustion than gasoline. The AP category decreased by 1.003E-17 person equivalent or 61.53%, indicating a reduction in air pollutants contributing to acid rain. Meanwhile, the EP and ODP categories decreased by 59.86% and 60.83%, respectively, reflecting a lower potential for nutrient pollution in aquatic systems and reduced ozone layer depletion. Overall, this scenario suggests that substituting gasoline with LPG not only reduces the volume of fuel consumption but also has a positive impact on emissions reduction.

Alternatives 3: Subtituting Palm Oil with Coconut Oil

Based on the analysis, the production stage generated the highest impacts sequentially for GWP, EP, AP, and ODP. Therefore, the proposed improvement scenario involves replacing palm oil with coconut oil. In 2024, Riau Province recorded a coconut production volume of 407.79 metric tons per year (BPS Riau Province, 2025). This indicates the potential availability of coconut oil in Riau through partnerships between pineapple chip producers and local copra industries to ensure a sustainable supply of coconut oil. According to Wulandari *et al.* (2017), fruit chips such as apple and banana fried with coconut oil have better taste, aroma, and crispness, as preferred by panelists. The calculated impact results after substitution are presented in Table 9.

As shown in Table 9, the simulation results indicate a significant reduction in the impacts at the production stage. Reductions were observed in three impact categories: GWP, EP, and ODP. Replacing palm oil with coconut oil during production reduced the impacts by 25.97% for GWP, 81.69% for EP, and 16.13% for ODP. In contrast, the Acidification Potential (AP) increased by 29.23%. The increase in acidification is attributed to the production process, specifically the use of additional acid, such as acetic acid (CH_3COOH), to facilitate the separation of oil from coconut milk (Susanto, 2012). Moreover, differences in fatty acid composition between coconut oil and palm oil can influence waste characteristics and emissions generated during production. Overall, the impact reductions from this improvement scenario are substantial and feasible for implementation in the pineapple chip industry.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The potential emissions from the production of 100 g of pineapple chips result in a GWP impact of 7.04E-01 kg CO_2 eq, acidification of 2.29E-03 kg SO_2 eq, eutrophication of 1.42E-O_2 kg PO4 eq, and ozone depletion of 1.08E-08 kg CFC-11 eq. The normalized hotspot in this study is eutrophication. This high eutrophication value is mainly related to the production stage, particularly the use of cooking oil during frying and the application of chemical fertilizers at the plantation level. To reduce this environmental burden, three improvement scenarios are proposed: (1) replacing chemical fertilizers with compost, (2) switching from gasoline to LPG as a fuel source—both of which can reduce all impact categories (GWP, AP, EP, and ODP), and (3) replacing palm oil with coconut oil, which reduces three impact categories, except for AP. Overall, these scenarios are feasible and offer effective strategies for comprehensively reducing the environmental footprint of the pineapple chip industry.

Table 9. Normalized impact values for the production stage scenario

Impact	Before scenario	After scenario	Impact reduction	Persentase
GWP	1.54E-14	1.14E-14	4.00E-15	25.97%
AP	8.59E-15	1.11E-14	-2.51E-15	-29.23%
EP	8.86E-14	1.62E-14	7.24E-14	81.69%
ODP	4.17E-17	3.49E-17	6.80E-18	16.31%

Recommendations

Further research from this study is the need to conduct a social impact analysis to comprehensively assess the sustainability of pineapple chips in order to support the implementation of the three dimensions of sustainability as a whole. If the three aspects of environment, economy, and society are combined, they can form a holistic life cycle sustainability assessment (LCSA) framework. Recommendations related to the implementation of each scenario need to be further analyzed in terms of technical and technological feasibility

REFERENCES

Ahmad S, Wong, KY, Ahmad, R. 2019. For food production and manufacturing: recent trends global applications and future prospects. *Journal Procedia Manufacturing*. 3(4):49–5.

Babel S and Thushari I. 2022. Comparative study of the environmental impacts of used cooking oil valorization options in Thailand. *Journal of Environmental Management*. 3(10). doi:10.1016/j.jenvman.2022.114810.

Badan Pusat Statistik Provinsi Riau. 2024. Provinsi Riau Dalam Angka 2024. (1102001.14). BPS Privinsi Riau.

Badan Standardisasi Nasional. 2016. SNI ISO 14040:2016. Manajemen lingkungan – Penilaian Daur Hidup – Prinsip dan Kerangka Kerja. Badan Standarisasi Nasional. https://bsilhk.menlhk.go.id/standarlhk/wp.

Damanik MQA. 2021. Life cycle assessment (LCA) *cradle to gate* produksi batu bara di pt xyz Kalimantan Selatan [tesis]. Bogor: Sekolah Program Pascasarjana, Institut Pertanian Bogor.

Dodds WK, Bouska WW, Eitzmann JL, Pilger TJ, Pitts K L, Riley AJ, Schloesser JT, Thornbrugh DJ. 2009. Eutrophication of us freshwaters: analysis of potential economic damages. *Journal Environtmental Science Technology*. 43(1):12–19. doi:10.1021/es801217q.

González CE, Giraldi-Díaz MR, Medina-Salas L. 2020. Environmental impacts associated to different stages spanning from harvesting to industrialization of pineapple through life cycle assessment. *Journal Applied Science*. 10(19):1–21. doi:10.3390/app10197007.

Hartono SM. 2024. Pengaruh penggunaan gas elpiji terhadap performa mesin sepeda motor 4 tak 100 *cc. Education Sains Technology Engineering Mathematic Seminar Unisvet*. 17-27.

Kemenko Perekonomian. 2024. Kebijakan dan strategi ekonomi hijau menuju indonesia emas dan *net zero emissions* 2060. Kementerian Koordinator Bidang Perekonomian Republik Indonesia. Jakarta.

Merchan A and Combelles A. 2012. Comparison of life cycle impact assessement methods in a case of crop in northern france. *Journal Life Cycle Approaches*. (1):3–6.

Nandar RH, Ismayana A, and Yani M. 2025. Environmental assessment study based on the life cycle of sanjai chips products in Payakumbuh West Sumatera. *Jurnal Teknologi Industri Pertanian*. 35(2):177-185.

Ketnawa SA, Theppakorn, Chaiwut, Rawdkuen S. 2009. Partitioning of bromelain from pineapple peel by aqueous two phase system. *Asian Journal of Food Agro-Industry*. 2(4): 457-468.

Krisi SA, Jami'in M, Abu, Apriani M. 2022. Potensi dampak lingkungan pada industri minyak goreng sawit dengan metode *life cycle assessment*. *Jurnal Ilmu Lingkungan*. 20(3):672-677. doi:10.14710/jil.20.3.672-677.

Perdana R, Ismayana A, and Yani M. 2024. Analisis penilaian daur hidup (*life cycle assessment*) agroindustri keripik pisang di bandar Lampung. *Jurnal Teknologi Industri Pertanian*. 34(1):8796. doi:10.24961/j.tek.ind.pert.2024.34.1.8.

Puspaningrum T, Indrasti NS, Indrawanto C, Yani M. 2023. Life cycle assessment of coconut plantation, copra, and charcoal production. *Global Journal Of Environmental Science And Management*. 9(4):653-672. doi: 10.22035/gjesm.2023.04.01

Rizki F, Ismayana A, and Yani M. 2025. Life Cycle Assessment of Granulated Coconut Sugar Production Farmers Level in Purworejo. *Jurnal Teknologi Industri Pertanian*. 35(1):1-7. doi:10.24961/j.tek.ind.pert.2025.35.1.1.

Rouhi K, Motlagh MS, and Dalir F. 2023. Developing a carbon footprint model and environmental impact analysis of municipal solid waste transportation: a case study of Tehran Iran. *Journal of The Air & Waste Management Association*. 73(12): 890-901. doi:10.1080/10962247.2023.2271424.

Sachie SYF. 2024. Analisis penilaian daur hidup (*life cycle assessment*) nanas kaleng di Sumatera, Indonesia. Bogor: Sekolah Program Pascasarjana, Institut Pertanian Bogor.

Susanto T. 2012. Kajian metode pengasaman dalam proses produksi minyak kelapa ditinjau dari mutu produk dan komposisi asam amino blondo. *Jurnal Dinamika Penelitian Industri*. 23(2):124-130.

Tagliaferri C and Lettieri P. 2019. Methane from waste: thermal and biological technologies compared under a life cycle assessment perspective substitute natural gas from waste. *Journal Sustainable Energy and Fuels*. 3(12):3235-3252.

Ulya M, Mu'tamar MFF, and Firmansyah RA. 2022. Life cycle assessment of raw and fried tette chips production. *Journal Advances in Food Science, Sustainable Agriculture and Agroindustrial Engineering.* 3(1):11–16.doi:10.21776/ub.afssaae.2020.003.01.2.

Wiloso EI, Nazir N, Hanafi J, Siregar K, Harsono SS, Setiawan AAR, Muryanto, Romli M, Utama NA, Shantiko B. 2018. Life cycle assessment research and application in indonesia. *The International Journal of Life Cycle Assessment*. 24(3): 386-396. Doi: 10.1007/s11367-0811-1459.

Wulandari S, Riyanto R, and Mistianah M, 2017. Variasi ketebalan irisan, jenis minyak dan suhu penggorengan terhadap rasa dan kerenyahan keripik apel yang diolah dengan *vacuum frying*. *Jurnal Edubiotik Pendidikan, Biologi dan Terapan*. 2(1):37-42.

Yamin OM, Nasution DMS, Noer Z, Lubis H, Sofie TM. 2024. Comparative analysis of gasoline and liquefied petroleum gas (lpg) on motorcycle engine performance. *Journal of Technomaterial Physics*. 06(2):127-131.

Yudha A and Assomadi AF. 2022. Kajian dampak emisi udara pada produksi minyak bumi di perusahaan a menggunakan metode *life cycle assessment* (LCA). *Jurnal Purifikasi.* 21(2):52-60.

Yusuf MA. 2021. *Life cycle assessment* (LCA) pati sagu: studi kasus proses tradisional di Marauke proses semi-mekanis di Bogor dan proses mekanis di Sorong Selatan [disertasi]. Bogor: Sekolah Program Pascasarjana, Institut Pertanian Bogor.

Zou X, Xiao X, Zhou H, Chen F, Zeng J, Wang W, Huang X. 2018. Effects of soil acidification on the toxicity of organophosphorus pesticide on eisenia fetida and its mechanism. *Journal of Hazardous Materials*. 365-372

.

DOI: https://doi.org/10.24961/j.tek.ind.pert.2026.36.1.28