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LIFE CYCLE ASSESSMENT OF MICRO, SMALL, AND MEDIUM ENTERPRISES (MSMEs) FOR BILIH FISH PRODUCTS IN SOLOK REGENCY, WEST SUMATERA

PENILAIAN DAUR HIDUP (LIFE CYCLE ASSESSMENT) PRODUK UMKM IKAN BILIH DI KABUPATEN SOLOK SUMATERA BARAT

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ABSTRAK

Ikan bilih merupakan salah satu jenis ikan air tawar endemik yang hidup di perairan Danau Singkarak, Sumatera Barat dan dapat diolah untuk meningkatkan nilai tambah produk. Perkembangan industri perikanan tidak hanya memberikan manfaat ekonomis yang tinggi, tetapi juga menyumbang dampak bagi lingkungan sekitar. Penelitian ini bertujuan untuk penilaian daur hidup produk olahan ikan bilih krispi balado dari UMKM Tujuh Muaro (TM) dan ikan bilih goreng biasa dari UMKM Tabiang Biduak Lestari (TB) menggunakan metode Life Cycle Assessment (LCA). Ruang lingkup dari penelitian ini adalah cradle to grave mulai dari penangkapan ikan bilih, transportasi bahan baku dan kemasan, proses produksi, dan distribusi dengan unit fungsional 100 g/kemasan ikan bilih. Analisis dampak dilakukan menggunakan software SimaPro, berdasarkan metode CML 2001-IA baseline terhadap kategori dampak yaitu Global Warming Potential (GWP), Acidification (AP), dan Eutrophication (EP). UMKM menghasilkan dampak GWP dengan nilai normalisasi sebesar TM 6,51E-14 dan TB 1,28E-14, AP 3,86E-14 dan 1,19E-14, serta EP 5,81E-13 dan 7,96E-14 person equivalent. Skenario perbaikan pada unit produksi dilakukan dengan substitusi metode penggorengan untuk mengurangi penggunaan minyak goreng, yang menurunkan dampak dengan GWP 84,86% (TM) dan 51,89% (TB), AP 52,67% (TM) dan 17,77% (TB), serta EP 96,08% (TM) dan 81,30% (TB). Skenario unit transportasi melalui pemilihan supplier kemasan yang lebih dekat dengan UMKM TM, sehingga dapat mengurangi dampak GWP sebesar 94,25%, AP 94,25%, dan EP 94,24%. Pemanfaatan limbah minyak menjadi biodiesel juga menurunkan dampak GWP 90,48% (TM) dan 82,88% (TB), AP 97,50% (TM) dan 94,79% (TB), serta EP 98,80% (TM) dan 98,15% (TB).

Kata kunci: dampak lingkungan, ikan bilih, LCA

ABSTRACT

Bilih fish is a freshwater fish endemic at Lake Singkarak, West Sumatra, and can be processed to increase this added value. The development of the fishery industry provides significant economic benefits and contributes to environmental impacts. This research aimed to assess the life cycle of crispy balado bilih fish products from Tujuh Muaro (TM) micro-enterprise and regular fried bilih fish products from Tabiang Biduak Lestari (TB) micro-enterprise using the Life Cycle Assessment (LCA) method. The scope of this study is cradle-to-grave, covering bilih fish fishing, transportation of raw materials and packaging, production processes, and distribution, with a functional unit of 100 g/package of bilih fish product. The impact analysis was conducted using SimaPro software, based on the CML 2001-IA baseline method for impact categories, including Global Warming Potential (GWP), Acidification (AP), and Eutrophication (EP). The micro-enterprises generated GWP impacts with normalised values of TM 6.51E-14 and TB 1.28E-14, AP 3.86E-14 and 1.19E-14, EP 5.81E-13, and 7.96E-14 person equivalents, respectively. Improvement scenarios at the production unit were carried out by substituting frying methods to reduce cooking oil usage, which lowered impacts with GWP reductions of 84.85% (TM) and 51.93% (TB), and AP reductions of 52.63% and 17.86%, EP reductions of 96.08% and 81.35%. In the transportation unit, selecting packaging suppliers closer to TM reduced impacts by 94.22% for GWP, 94.23% for AP, and 94.25% for EP. Utilising waste oil as biodiesel further reduced GWP impacts by 90.48% (TM) and 82.87% (TB), AP by 97.50%, and 94.78%, EP by 98.80%, and 98.14% respectively.

Keywords: bilih fish, environmental impact, LCA

INTRODUCTION

The bilih fish (*Mystacoleucus padangensis*) is an endemic freshwater species native to the waters of Lake Singkarak in West Sumatra, Indonesia. It can be processed to food dishes as enhanced product value. The uniqueness of this endemic fish lies in its exclusive presence in the region, its deep integration into the local community's culture, the distinct ecological, and climatic conditions that support its specialized breeding and living environment. These factors combined with its high market value. Bilih

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fish is commonly consumed in Indonesia, particularly in West Sumatra, where it is processed into traditional dishes such as crispy balado bilih fish and regular fried bilih fish. Several local SMEs have further innovated by transforming bilih fish into snack products, leveraging its economic value and nutritional benefits, such as protein, calcium, and zinc. Bilih fish is consumed locally and distributed Indonesia market, and exported to Malaysia and Singapore in processed forms. This has made bilih fish processing a vital source of income for communities around Lake Singkarak.

According to the Fisheries and Food Office of Solok Regency (2023), the production of bilih fish from 2018 to 2022 has shown an upward trend. In 2022, bilih fish production totaled 112 tons, with 67.8 tons sourced from gill nets and 44.2 tons from cast nets, an increase from 100.15 tons in 2021. However, production in Lake Singkarak had experienced a slight decline of 0.86% in 2019 compared to 2018. The development of the fisheries industry not only provides economic benefits but also contributes to environmental impacts. According to Avadi and Freon (2018), environmental impacts in the fisheries sector result from the production process of raw materials into consumable goods and the use of fuel for production processes, transportation, and fishing vessels.

One of the methods used to assess the environmental impacts generated by a product throughout its life cycle is Life Cycle Assessment (LCA) (BSN, 2016). A study by Athirafitri (2022) conducted an LCA for the cradle-to-gate scope of 1 kg of crispy seluang fish, revealing significant environmental impacts, including a Global Warming Potential (GWP) of 292.40 kg-CO_2 eq, Acidification Potential (AP) of 1.21 kg-SO_2 eq, and Eutrophication Potential (EP) of 0.34 kg-PO_4 eq. LCA estimates the cumulative environmental impacts generated across all stages of a product's life cycle, identifying the stages with the most significant environmental effects (Bacon, 2006). It begins with collecting raw materials from the earth to create a product and ends when all materials are returned to the earth. The results of an LCA can serve as a basis for improving the production process. Optimizing this process can reduce environmental impacts, helping SMEs in the bilih fish industry adopt more environmentally friendly practices. This study aims to identify the inputs and outputs from the bilih fish production process, calculate the environmental impact values throughout its life cycle, determine hotspots, and recommend improvements to reduce emissions and environmental impacts.

RESEARCH AND METHODS

Time and Place of Research

This research was conducted at the SMEs Tujuh Muaro (TM) and Tabiang Biduak Lestari (TB) in Solok Regency, West Sumatra. The research period spanned from September 2023 to November 2024, covering the observation phase and data analysis.

Type and Source of Data

The research data consists of primary and secondary data. Primary data were obtained through direct interviews with SMEs and relevant stakeholders and field observations using questionnaires administered to fishermen, transportation parties, SMEs, and distributors, with a total of 22 respondents. Secondary data include documents from SMEs related to inputs and outputs, such as raw materials, additives, packaging, energy, costs, labor, machinery and equipment, waste from the production process, and literature studies from previous research.

Research Stages

The framework for the Life Cycle Assessment (LCA) method is outlined in ISO 14040:2016, which includes four main components: goal and scope definition, inventory analysis, life cycle impact assessment, and interpretation of results, which form the basis for formulating improvement recommendations.

Goal and Scope Definition

The initial stage of this research involves defining the scope, which includes product selection, system boundaries, functional units, and impact categories. According to ISO 14040:2016, the functional unit represents the performance measurement of the product system, serving as a reference in the LCA study. Mass is the most commonly used functional unit for food products (Usubharatana and Phungrassami, 2017). Therefore, the functional unit established in this study is one package of bilih fish with a net weight of 100 g, by the label on the SME packaging. The system boundary follows a cradle-to-grave approach, encompassing all stages from capture, transportation, production, and distribution to retail centres.

Life Cycle Inventory Analysis

Inventory analysis includes data collection and calculation of the input and output associated with the product system, which serves to inventory resource use, energy consumption, and emissions released into the environment throughout the life cycle of the bilih fish SME product. These data are calculated quantitatively and then validated through mass and energy balances to assess the flow of materials and energy. The inventory calculations for each process stage refer to the functional unit defined earlier.

Life Cycle Impact Assessment

The impact analysis was conducted using SimaPro version 9.5.0.2 software, applying the Centre of Environmental Science of Leiden

University Impact Assessment (CML-2001-IA baseline) method, which includes ten impact categories (Dincer and Bicer, 2018). According to Silva *et al*. (2019), SimaPro is a widely used software tool for assessing the environmental impact of a product, utilizing a comprehensive database. The input and output data from each process stage are inventoried and entered into SimaPro, which then calculates the environmental impact values for each of the predetermined category.

Life Cycle Interpretation

The interpretation of the data results from SimaPro includes the potential impact categories, which are then further analyzed through literature studies to produce appropriate recommendations. This stage involves discussing the analysis results, identifying the causes of impacts, identifying key issues, concluding, explaining the study's limitations, making recommendations, and conducting evaluations transparently. The interpretation results will be analyzed to draw conclusions and provide improvement recommendations for reducing environmental impacts.

RESULTS AND DISCUSSIONS

Bilih Fish Processing

Bilih fish are traditionally caught by casting nets into the middle of the lake using a motorized boat, which measures 4 m x 60 cm x 33 cm and has a 100-200 kg capacity. The outboard motor is installed with a 3.5 HP engine at the rear of the boat. Most fishermen use langli nets with a mesh size of ¾ inch. The langli nets are operated at 10-15 meters at the lake bottom. Fishing is carried out without bait, as bilih fish are plankton feeders. According to Febriani (2010), the primary food of bilih fish consists of phytoplankton and zooplankton, while their supplementary food includes detritus, plant fragments, and other plant materials that fall into the water body. The average daily catch is 15-18 kg, depending on the weather and the lake's conditions. After being caught, the fish are weighed, then cleaned. Raw material transportation is done by motorcycle, while TM's packaging is delivered from Bandung via Light Commercial Truck (LCT). TB purchases packaging at the Solok market using a motorcycle.

The production process of crispy balado bilih fish and regular fried bilih fish consists of several key stages: washing, salting, drying, frying, and packaging. The primary difference lies in the number of frying stages and the type of coating. Crispy balado bilih fish undergoes a flour coating process and is fried twice to achieve a crispier texture and extend its shelf life. The bilih fish is washed two to three times using clean water. Salting is performed to enhance flavour and eliminate the fishy odour. Sun drying is performed for 10-15 minutes to reduce the moisture content by approximately 0.3% of the total fish weight. The frying process utilizes Liquefied Petroleum Gas (LPG), followed by a spinning process for one minute to remove excess oil. The final stage involves weighing 100 grams of the product and sealing it in appropriate packaging. Standing pouch aluminium foil is used for crispy balado bilih fish, while High-Density Polyethylene (HDPE) plastic is used for regular fried bilih fish. These packaging materials are selected for their ability to protect the product from air and light contamination, which could cause deterioration. The products are distributed to souvenir centres in Solok Regency via motorcycles, while cargo services manage shipments outside the region.

Goal and Scope Definition

The goal and scope represent the initial steps in the Life Cycle Assessment (LCA) study. This study aims to assess the environmental impact of the bilih fish product life cycle. The scope follows a cradle-to-grave approach, covering the fish capture process as the source of raw materials, transportation, production at SMEs, and final product distribution. The functional unit used in this analysis is 100 g per pack of bilih fish, ensuring a standardized measurement of the product system. Impact analysis is conducted using the CML 2001-IA method, focusing on Global Warming Potential (GWP), Acidification Potential (AP), and Eutrophication Potential (EP). These three impact categories were selected because they are the most relevant in LCA studies within the fisheries sector, as identified in previous research. Additionally, they are mandatory impact categories according to Regulation of the Minister of Environment and Forestry (Permen LHK) No. 1 of 2021. Figure 1 presents the system boundaries for the bilih fish LCA study, providing an overview of each process stage related to the product system.

Life Cycle Inventory Analysis

The second phase of the LCA study is the inventory analysis, which aims to identify the inputs and outputs throughout the life cycle of the bilih fish SME product. This phase encompasses fish capture activities, transportation (raw materials and packaging), production processes, and product distribution. The inventory data are adjusted according to the production requirements of 100 g per pack of bilih fish, as presented in Table 1. The transportation and distribution inventory data are obtained by multiplying the load capacity by the distance travelled, expressed in ton-kilometres (tkm).

Life Cycle Impact Assessment

Impact analysis is the next stage in a Life Cycle Assessment (LCA) study, where impact categories are selected, and the impacts are classified and characterized. The purpose of impact analysis is to evaluate and identify potential environmental impacts using inventory data and provide information for interpretation in subsequent stages (Hermawan *et al*., 2013). The impact categories analyzed focus on three main categories: Global Warming Potential (GWP), Acidification Potential (AP), and Eutrophication Potential (EP). Table 2 presents the results of the environmental impact characterization of fish bilih activities.

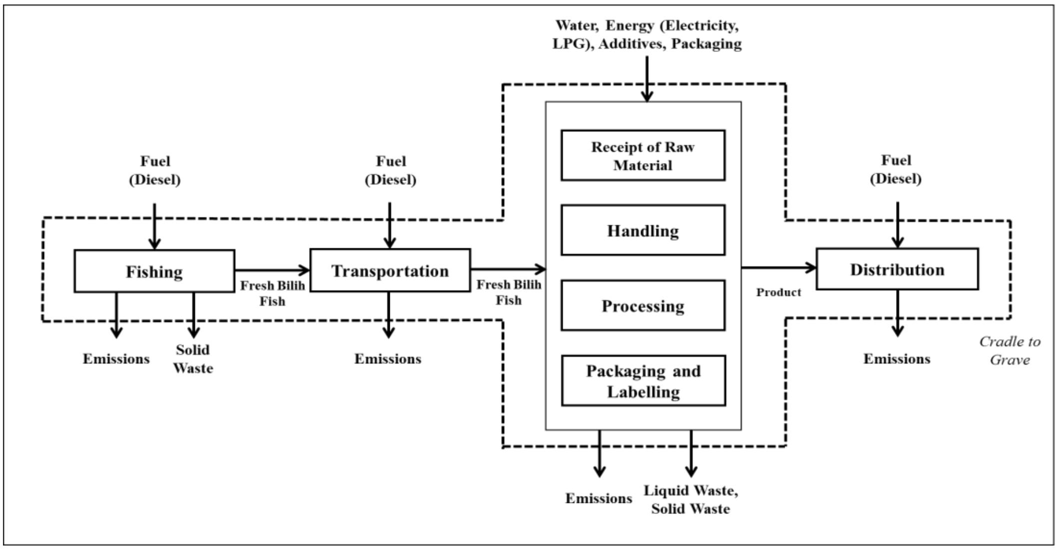

Figure 1. System boundaries of LCA for bilih fish SMEs

Table 1. Bilih fish inventory data per pack

Process	Input	Unit	Total	Output	Unit	Total
TM SME						
Fishing	Diesel	L	0.00812	Solid Waste	kg	0.0375
Transportation	Raw material	tkm	0.0003			
	Packaging	tkm	0.1642			
Production	Fresh Bilih Fish	kg	0.15			
	Cooking Oil	L	0.5	Used Cooking Oil	L	0.417
	Water	L	0.5191	Liquid Waste	L	0.438
	Salt	kg	0.0035	Solid Waste	kg	0.0451
	Egg	kg	0.00637			
	Royco	kg	0.0015			
	Rice Flour	kg	0.0313			
	Wheat Flour	kg	0.0313			
	Garlic	kg	0.0035			
	Chili	kg	0.0105			
	Electricity	kWh	0.00194			
	LPG	kg	0.03			
	Standing Pouch Packaging	kg	0.013			
Distribution	Distribution	tkm	0.01949			
TB SME						
Fishing	Diesel	L	0.00704	Solid Waste	kg	0.0323
Transportation	Raw material	tkm	0.000097			
	Packaging	tkm	0.0022			
Production	Fresh Bilih Fish	kg	0.129			
	Cooking Oil	L	0.0673	Used Cooking Oil	L	0.0561
	Water	L	0.539	Liquid Waste	L	0.539
	Salt	kg	0.00404			
	Electricity	kWh	0.00127			
	LPG	kg	0.0194			
	HDPE Packaging	kg	0.013			
Distribution	Distribution	tkm	0.08902			

Table 2. Characterization of the environmental impact of 100 g/pack of bilih fish

Process	TM SME			TB SME		
	GWP (kg-CO_2 eq)	**AP (kg-SO_2 eq)**	**EP (kg-PO_4 eq)**	**GWP (kg-CO_2 eq)**	**AP (kg-SO_2 eq)**	**EP (kg-PO_4 eq)**
Fishing	1.11E-02	7.02E-05	3.88E-05	9.58E-03	6.07E-05	3.34E-05
Transportation	1.20E-01	1.06E-03	2.27E-04	6.08E-03	1.67E-05	4.43E-06
Production	2.57E+00	7.92E-03	9.16E-02	4.51E-01	2.19E-03	1.24E-02
Distribution	1.83E-02	1.52E-04	3.25E-05	6.64E-02	5.76E-04	1.23E-04
Total	2.72E+00	9.20E-03	9.19E-02	5.33E-01	2.84E-03	1.26E-02

The results show the Global Warming Potential (GWP) category has the highest value, 2.72E+00 kg-CO2 eq for the TM SME and 5.33E-01 kg-CO2 eq for the TB SME. This indicates that bilih fish production activities contribute the most to global warming emissions compared to other impact categories. GWP reflects the imbalance of Earth's ecosystems due to the increase in the average temperature of the atmosphere, oceans, and land. The potential for global warming is driven by human activities, primarily using fossil fuels and land conversion. Global warming emissions refer to the total release of greenhouse gases into the atmosphere over a certain period, usually 100 years. This leads to climate change, which has significant impacts on human life as a whole (Gunawan, 2019). According to Hegerl *et al.* (2007), greenhouse gas emissions will form a layer in the Earth's atmosphere that prevents solar energy from being reflected into space, increasing Earth's temperature or global warming.

One of the main factors contributing to the most significant impact on the production process is cooking oil. The smoke produced from the combustion of cooking oil released during the frying process disperses and interacts with other pollutant compounds in the air. Additionally, the diesel fuel used in fishing bilih, gasoline for transporting fresh bilih from the fishing site to the SMEs, and packaging transportation from the supplier to the SME also contribute to this impact. Using fuel in transportation and distribution activities leads to global warming (Laso *et al*., 2007; Iribarren *et al*., 2010). The CO_2 emissions produced significantly contribute to global warming and can trigger climate change. Several factors, including the travel distance and the type of fuel used, influence the magnitude of CO_2 emissions. The use of vehicles with large loads significantly contributes to carbon emissions. The larger the vehicle's load, the higher the fuel consumption (Nosita, 2023). The condition of the vehicle also affects the emissions produced. Well-maintained vehicles generate fewer emissions compared to poorly maintained ones.

The Eutrophication Potential (EP) impact contributes the second-largest value, with 9.19E-02 kg-PO_4 eq and 1.26E-02 kg-PO_4 eq. The wastewater generated from washing bilih fish is one of the main factors contributing to the EP impact, as it is discharged directly into the environment, thereby increasing the concentration of nutrients in the water. Eutrophication is a pollution process caused by excess nutrients in aquatic ecosystems, leading to explosions in phytoplankton and zooplankton populations. This results in water turbidity and reduced sunlight penetration (Clark *et al*., 2013). According to Amann *et al*. (2018), waste from industries is one of the factors causing water body pollution. Nitrogen (N) and phosphorus (P) are the two main contributors to eutrophication (Davis and Koop, 2006). Eutrophication is caused not only by one type of pollutant but by several types, including NO_3^- (nitrate), P (phosphorus), NOx (nitrogen oxides), NH_3 (ammonia), and PO_4^{3-} (phosphate) (Rinaldo *et al*., 2023). The NOx pollutant comes from electricity and fuel consumption. Sources of NO_3^- and PO_4^{3-} pollutants are generated from wastewater treatment (Sofiah *et al*., 2017).

The third-lowest impact with the least significance is Acidification Potential (AP), with values of 9.20E-03 kg-SO_2 eq and 2.84E-03 kg-SO_2 eq for the SMEs. This is primarily caused by the combustion of fossil fuels occurring throughout the life cycle of bilih fish. Acidification is the process of water acidification caused by air pollution. Acidification impacts arise from the emission of pollutants such as sulfur dioxide (SO_2), sulfur trioxide (SO_3), nitrogen oxides (NOx), nitrogen monoxide (NO), and ammonia (NH_3), which pollute the atmosphere (Brilianty *et al*., 2022). Oxidation reactions in the gas pollutants produce sulfuric and nitric acid compounds, ultimately triggering acid rain (Kusnadi *et al*., 2023). Acidification indirectly threatens the sustainability of ecosystems and fisheries productivity. Rain and fog play a role in trapping atmospheric pollutants, causing fish death, releasing toxic metals from soil and rocks, and damaging forests and buildings (Tagliaferri and Lettieri, 2019). The results of the impact analysis in this study indicate that the environmental impact values are lower compared to the study by Athirafitri (2022), which used a cradle-to-gate scope with a functional unit of 1 kg of crispy seluang fish for the three impact categories: GWP, AP, and EP.

Life Cycle Interpretation

Results interpretation is made by analyzing all the unit processes involved to identify the highest emission impacts (hotspots) and formulate potential improvements to reduce the impacts generated throughout the bilih fish production life cycle. Based on inventory analysis and impact analysis for SMEs, the entire production chain, from bilih fish capture, transportation of raw materials and packaging, bilih fish production, to product distribution, is normalized to identify the most significant impacts and evaluate their level of environmental influence (Puspaningrum *et al.*, 2023). The normalization results were expressed in person-equivalent units to represent the average annual global per capita impact within specific categories.

Figure 2 shows the percentage of impacts from all production activities. The most significant impact category is Eutrophication (EP), with values of 84.85% for TM and 76.35% for TB. The highest impact in the bilih fish production process significantly contributes to environmental pollution. This is primarily due to the use of cooking oil in the frying process, which generates various gas emissions such as CO_2, which are directly released into the atmosphere and not fully utilized. Additionally, emissions produced during palm oil production for cooking oil can increase phosphorus (P) and nitrogen (N) levels. The improper disposal of used cooking oil also contributes to the high EP impact.

Improvement Scenarios

The improvement scenarios aim to review and consider solutions to reduce the contribution of the most significant impacts generated at each stage of the bilih fish production process in the SMEs. The recommended process stages are determined based on the interpretation of the results of bilih fish production. The improvement scenarios are determined through literature studies to minimize the generated impacts.

Application of Vacuum Frying to Reduce Cooking Oil Usage

Both SME TM and TB show the most significant impact or hotspot in the production stage. Conventional frying methods are the main factor causing the high cooking oil consumption. The vacuum frying method requires less oil compared to conventional frying. This is because the vacuum frying process lowers the air pressure inside the frying chamber, thus reducing the boiling point of the oil to below 90°C (Afrozi *et al.*, 2018). Vacuum frying works by sucking air out of the chamber using a water jet vacuum pump. Vacuum frying is suitable for bilih fish because it helps maintain texture and flavour quality, reduces nutrient and oil degradation, and results in a product with lower oil content.

The application of the vacuum frying method in both SMEs is based on research by Perdana (2024) regarding energy consumption. It is assumed that producing bilih fish requires a vacuum frying machine with 15 kg of raw material per frying cycle capacity. This machine has a 1,500-watt pump to circulate 70 litres of cooking oil. The time required to fry one batch of raw material is approximately 1.5 hours. Table 3 shows that TM experienced a 96.08% reduction in EP impact, and TB experienced an 81.35% reduction.

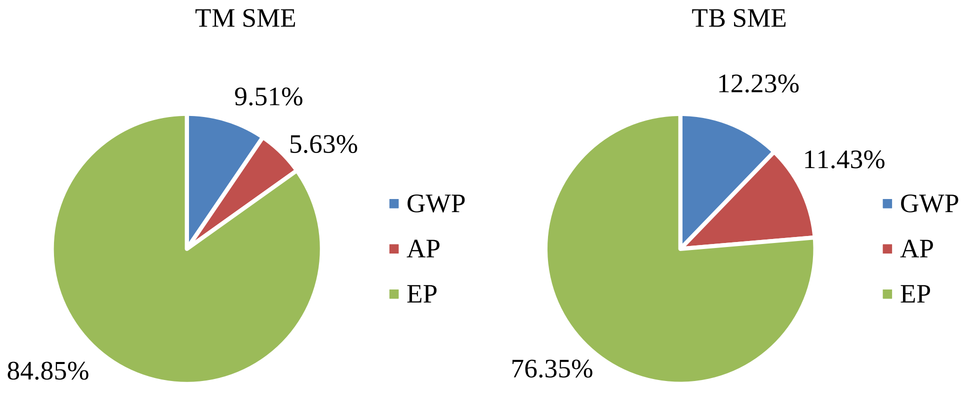

Figure 2. Percentage of impacts on processed bilih fish products

Table 3. Percentage reduction from production scenario

Impact Category	Unit	TM SME			TB SME		
		Before	After	Percentage (%)	Before	After	Percentage (%)
GWP	kg-CO_2 eq	2.57E+00	3.90E-01	84.85	4.51E-01	2.17E-01	51.93
AP	kg-SO_2 eq	7.92E-03	3.75E-03	52.63	2.19E-03	1.80E-03	17.86
EP	kg-PO_4 eq	9.16E-02	3.59E-03	96.08	1.24E-02	2.32E-03	81.35

Table 4. Percentage reduction from packaging transportation scenario for TM SME

Impact Category	Unit	Amount		Percent Change (%)
		Before	After	
GWP	kg-CO_2 eq	1.19E-01	6.88E-03	94.22
AP	kg-SO_2 eq	1.06E-03	6.12E-05	94.23
EP	kg-PO_4 eq	2.26E-04	1.30E-05	94.25

Table 5. Percentage reduction from production scenario

Impact Category	Unit	TM SME			TB SME		
		Before	After	Percentage (%)	Before	After	Percentage (%)
GWP	kg-CO_2 eq	3.90E-01	3.71E-02	90.48	2.17E-01	3.72E-02	82.87
AP	kg-SO_2 eq	3.75E-03	9.37E-05	97.50	1.80E-03	9.39E-05	94.78
EP	kg-PO_4 eq	3.59E-03	4.31E-05	98.80	2.32E-03	4.31E-05	98.14

Switching Packaging Suppliers Closer to TM SME

The packaging for bilih fish products is ordered from Bandung and shipped via cargo services. The delivery is made using two modes of transportation: Light Commercial Truck (LCT) and ferry for the journey from Java Island to Sumatra Island. The total transportation distance for this packaging delivery is 1,391 km, with 1,358 km using LCT and 33 km using the ferry. The recommended improvement scenario is to switch the packaging supplier's location from Bandung to Padang. Packaging transport from Padang is conducted twice a year or every six months using LCT, with a travel distance of 78.3 km. Table 4 shows that implementing this improvement scenario results in a significant reduction in environmental impact. The changes in transportation distance and time for TM SME packaging delivery are expected to reduce the environmental impact.

Utilization of Cooking Oil Waste for Biodiesel Production

Reusing cooking oil generates waste that pollutes the environment and poses health risks by forming carcinogenic compounds during frying. However, its benefits can be enhanced by converting it into biodiesel through esterification and transesterification reactions with methanol, producing biodiesel and glycerol (Suirta, 2009). Biodiesel from used cooking oil holds great potential as an efficient and easily convertible renewable energy source, offering a sustainable alternative for SMEs in the bilih fish processing industry to reduce their environmental impact (Rahayu, 2005).

Using waste oil as a biodiesel feedstock refers to research by Setiadi and Miefthawati (2023). Based on the average annual production, the volume of used cooking oil generated by the TM and TB SMEs is 46,364.89 litres and 3,592.82 litres, respectively. The biodiesel production process uses a ratio of 20% methanol and 0.5% NaOH catalyst to the volume of used cooking oil. A transesterification efficiency of 75% is expected to achieve the ideal target for micro-SMEs, ensuring adequate biodiesel production while maintaining affordable production costs. The most significant environmental impact reduction occurs in the EP category, as shown in Table 5. TM experienced a 98.80% reduction, while TB experienced a 98.14% reduction.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The inputs and outputs were identified comprehensively, covering the stages of fish capture, raw material and packaging transportation, production, and product distribution. Inputs include fresh bilih fish, additives, packaging, LPG, and electricity. The outputs generated are crispy balado bilih fish, fried bilih fish, solid waste, liquid waste, used oil, and environmental emissions. The impact analysis was performed using SimaPro software with the CML 2001-IA method. Calculations were made based on a functional unit of 100 g/pack of bilih fish, using inventory data for one year. The TM SME generated a GWP of 2.72 kg-CO_2 eq, AP of 9.20E-03 kg-SO_2 eq, and EP of 9.19E-02 kg-PO_4 eq/pack of crispy balado bilih fish. The TB SME generated a GWP of 5.33E-01 kg-CO_2 eq, AP of 2.84E-03 kg-SO_2 eq, and EP of 1.26E-02 kg-PO_4 eq/pack of fried bilih fish. The interpretation revealed that EP was the most significant environmental impact category (hotspot) in both SMEs, due to the use of cooking oil. Improvement scenarios include substituting frying methods, selecting closer packaging suppliers, and utilizing used oil for biodiesel production. Implementing these scenarios could reduce both SMEs' GWP, AP, and EP impacts.

Recommendations

Based on the results of this research, the author recommends further studies on the social and economic impact analysis related to other LCA approaches. Further research is also needed to assess the feasibility of the proposed improvement scenarios, considering technical, technological, and economic aspects. Technical assistance for SMEs, such as training on the use of environmentally friendly technologies and waste management, as well as government policy support in the form of subsidies or incentives, is expected to help implement improvement measures to reduce environmental impacts.

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REFERENCES

Afrozi S, Mufarida AN, and Sofiyah. 2018. Hubungan optimalisasi suhu dan waktu penggorengan pada mesin vacuum frying terhadap peningkatan kualitas keripik pisang kepok. *Jurnal Proteksion*. 2(2):43–52.

Amann A, Zoboli O, Krampe J, Rechberger H, Zessner M, Egle L. 2018. Environmental impacts of phosphorus recovery from municipal wastewater. *Journal Resource, Conservation and Recycling*. 130:127–139.

Athirafitri N. 2022. Penilaian Daur Hidup (Life Cycle Assessment) Produk Olahan Ikan Seluang (Rasbora sp.) [Tesis]. Bogor (ID): Institut Pertanian Bogor.

Avadi A, Freon P. 2018. Life cycle assessment of fisheries: a review for fisheries scientist and managers. *Fisheries Research*. 143:21–38.

Bacon R. 2006. Life Cycle Assessment: Principles and Practice. Scientific Application International Corporation (SAIC). Ohio: National Risk Management Research Laboratory.

Brilianty SL, Suprihatin, and Purwoko. 2022. Penilaian daur hidup produk susu sapi segar: studi kasus di KPBS Pangalengan. *Jurnal Teknologi Industri Pertanian*. 32(3):220–228.

[BSN] Badan Standardisasi Nasional. 2016. Manajemen Lingkungan Penilaian Daur Hidup Prinsip dan Kerangka Kerja (ISO 14040:2006, IDT), SNI ISO 14040:2016. Jakarta: BSN.

Clark CM, Bai Y, Bowman WD, Cowles JM, Fenn ME, Gilliam FS, Phoenix GK, Siddique I, Stevens CJ, Sverdrup HU, *et al*. 2013. Nitrogen deposition and terrestrial biodiversity. *Encycl Biodivers Second Ed*. 5:519–536.

Davis JR and Koop K. 2006. Eutrophication in Australian rivers, reservoirs and estuaries - a southern hemisphere perspective on the science and its implications. *Hydrobiologia*. 559(1):23–76.

Dincer I and Bicer Y. 2018. 3.17 Photonic energy production. *Comprehensive Energy Systems*. 3(5):707–754.

[DPP] Dinas Perikanan dan Pangan Kabupaten Solok. 2023. Data Produksi Ikan Bilih Tahun 2018-2022. Solok (ID): DPP Kabupaten Solok.

Febriani L. 2010. Studi Makanan dan Pertumbuhan Ikan Bilih (Mystacoleucus padangensis) di Danau Singkarak, Sumatera Barat [skripsi]. Bogor (ID): Departemen Manajemen Sumberdaya Perairan, Fakultas Perikanan dan Ilmu Kelautan, Institut Pertanian Bogor.

Gunawan. 2019. Perbaikan Kinerja Proses Produksi dan Lingkungan Pabrik Gula Sistem Tertutup dengan Pendekatan Keseimbangan Massa dan LCA [disertasi]. Bogor (ID): Institut Pertanian Bogor.

Hegerl G, Zwiers F, Braconnot P, Gillent N, Luo Y, Orsini J, Nicholls N, Penner J, Stott P. 2007. *Understanding and Attributing Climate Change.* Volume ke-80. Cambridge University Press.

Hermawan, Marzuki PF, Abduh M, Driejana R. 2013. Peran life cycle analysis (LCA) pada Material Konstruksi dalam Upaya menurunkan dampak emisi karbon dioksida pada efek gas rumah kaca. Surakarta (ID): Universitas Sebelas Maret. P47-52.

Iribarren D, Moreira MT, and Feijoo G. 2010. Life cycle assessment of fresh and canned mussel processing and consumption in Galacia (NW Spain). *Conservation and Recycling*. 55(2):106–117.

[KLHK] Kementerian Lingkungan Hidup dan Kehutanan. 2021. Peraturan Menteri Lingkungan Hidup dan Kehutanan Republik Indonesia No. 1 Tahun 2021 tentang Program Penilaian Peringkat Kinerja Perusahaan (PROPER). Jakarta (ID): Kementerian Lingkungan Hidup.

Kusnadi, Suprihatin, Fahma F, Suparno O, Indrasti NS. 2023. Life cycle assessment of processing crab shells into chitosan, liquid organic fertilizer, and animal feed - a case study in Karawang regency, Indonesia. *Journal of Applied Science and Engineering*. Vol. 27, No. 7.

Laso J, Margallo M, Faullana P, Bala A, Gazulla C, Irabien A, Aldaco R. 2007. When product diversification influences life cycle assessment: a case study of canned anchovy. *Science of the Total Environment*. 581–582:629–639.

Nosita F. 2023. Analisis penilaian daur hidup (Life Cycle Assessment) gula semut aren (Studi Kasus: KUB Mitra Mandala Banten) [tesis]. Bogor (ID): Institut Pertanian Bogor.

Perdana R, Ismayana A, and Yani M. 2024. Analisis perbandingan emisi dari perbedaan metode penggorengan keripik pisang di lampung dengan metode LCA (Life Cycle Assessment). *Jurnal Teknologi Industri Pertanian*. 34(1):87–96.

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.

Rahayu M. 2005. Teknologi proses produksi biodiesel. *Prospek Pengembangan Biofuel sebagai Substitusi Bahan Bakar Minyak*. 1(1):17–28.

Rinaldo R, Suprihatin, and Yani M. 2023. Life cycle assessment produksi crude palm oil (CPO) (studi kasus: PT X provinsi Bengkulu). *Agrointek: Jurnal Teknologi Industri Pertanian*. 17(3):651–659.

Setiadi RT and Miefthawati NP. 2023. Potential analysis of used cooking oil as raw material for biodiesel production in Pekanbaru city. *IJEERE: Indonesian Journal of Electrical Engineering and Renewable Energy*. Vol. 3 Iss. 1 June 2023, pp: 70–79. Journal Homepage: https://journal.irpi.or.id/index.php/ijeere.

Silva LAD, Nunes OA, Piekarski MC, Moris AV, Souza MSL, Rodrigues OT. 2019. Why using different life cycle assessment software tools can generate different results for the same product system? a cause effect analysis problem. *Journal Sustainable Production and Consumption*. 20 (2019):304–315.

Sofiah I, Yani M, and Ismayana A. 2018. Dampak pemanasan global pengolahan hasil perikanan menggunakan metode life cycle assessment (LCA): analisis gate to gate. *Jurnal Teknologi Industri Pertanian*. 28(1):1–11.

Suirta IW. 2009. Preparasi biodiesel dari minyak jelantah kelapa sawit. *Jurnal Kimia*. 3(1):1–6.

Tagliaferri C and Lettieri P. 2019. Methane from waste: thermal and biological technologies compared under a life cycle assessment perspective. *Elsevier Inc*. 275–315.

Usubharatana P and Phungrassami H. 2017. Evaluation of opportunities to reduce the carbon footprint of fresh and canned pineapple processing in central thailand. *Pol J Environ Stud*. 26(4):1725–1735.

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