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LIFE CYCLE ASSESSMENT OF CANNED CRAB PRODUCTS INDUSTRY IN PT. X MAKASSAR, SOUTH SULAWESI

ANALISIS PENILAIAN DAUR HIDUP PRODUK INDUSTRI PENGALENGAN RAJUNGAN DI PT. X MAKASSAR, SULAWESI SELATAN

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ABSTRAK

Pengalengan rajungan merupakan salah satu produk laut di Indonesia yang memiliki nilai ekonomi tinggi. Pengalengan rajungan mempunyai dampak terhadap lingkungan yang perlu dikaji. Penelitian ini bertujuan untuk mengidentifikasi siklus hidup proses produksi pengalengan rajungan dan mengkaji dampak lingkungan yang ditimbulkan sepanjang siklus hidup produk. Pengalengan rajungan dimulai dari proses pengukusan, pengolahan, dan pengangkutan (ekspor) rajungan. Penelitian ini menggunakan metode Life Cycle Assessment (LCA) dengan pendekatan baseline CML-IA, yang berfokus pada dampak potensi pemanasan Global (GWP), Asidifikasi (AP), dan Eutrofikasi (EP) dengan satuan fungsional 0,454 kg per kemasan. Life Cycle Assessment (LCA) menggunakan metode CML-IA baseline dengan tujuan untuk menghitung dampak global industri pengalengan rajungan di Makassar dengan dampak GWP sebesar sebesar 13.04317 kg CO_2 eq, dampak EP sebesar 3.02x10-2 kg PO_4 eq, dan dampak AP sebesar 6,78x10-2 kg SO_2 eq. Dampak atau hotspot terbesar adalah dampak GWP dengan kontribusi proses produksi terbesar dari penggunaan kemasan kaleng rajungan. Skenario perbaikan yang dilakukan untuk mengurangi dampak tersebut adalah dengan mengganti kemasan kaleng dengan plastik, mengganti LPG dengan gas alam, efisiensi penggunaan air, dan efisiensi penggunaan solar. Hasil simulasi menunjukkan bahwa skenario ini secara signifikan mengurangi dampak lingkungan, khususnya dampak GWP dengan pengurangan sebesar 86%, diikuti oleh dampak EP sebesar 88% dan AP sebesar 75%. Penelitian selanjutnya perlu dikaji ulang skenario perbaikan terkait perhitungan ekonomi serta pengujian kualitas dan daya tahan rajungan dalam kemasan plastik cup.

Kata kunci : CML-IA baseline, LCA, pengalengan rajungan, Simapro

ABSTRACT

Canning crab is one of Indonesia's marine products that has high economic value. Canning crab has an impact on the environment that needs to be studied. This research aims to identify the life cycle of the crab canning production process and examine the environmental impacts caused throughout the product life cycle. Canning crabs start with steaming, processing, and transporting (exporting) the crabs and pushing the Life Cycle Assessment (LCA) method with the CML-IA baseline approach, which focuses on the impact of Global Warming Potential (GWP), Acidification (AP), and Eutrophication (EP) with a functional unit of 0.454 kg per packaging. Life Cycle Assessment (LCA) uses the CML-IA baseline method to calculate the global impact of the crab canning industry in Makassar with a GWP impact of 13.04317 kg CO_2 eq, an EP impact of $3.02x10^{-2}$ kg PO_4 eq, and an AP impact of $6.78x10^{-2}$ kg SO_2 eq. The most significant impact or hotspot is the impact of GWP, which has the most significant production process contribution from using crab can packaging. Improvement scenarios to reduce this impact are replacing can packaging with plastic, replacing LPG with natural gas, efficient water use, and efficient use of diesel. Simulation results show that this scenario significantly reduces environmental impacts, especially GWP impacts, with a reduction of 86%, followed by EP impacts of 88% and AP of 75%. Future research needs to review improvement scenarios related to economic calculations as well as testing the quality and durability of crab in plastic cup packaging.

Keywords: CML-IA baseline, Canning crab, LCA, Simapro

INTRODUCTION

Indonesia has coastal resou rce species with high economic value, including the crab (Portunus pelagicus). Crabs' economic value increases yearly, and export demand is high (Safira *et al.*, 2019). One of the main challenges in managing crab is that it is easily damaged or perishable, which causes the quality of crab meat to decrease. The presence of bacteria and enzyme activity causes this. Therefore,

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handling and processing crab meat is necessary, which can ensure excellent and hygienic handling during processing (Supriadi *et al*., 2019). In Indonesia, crabs are widely used in the pasteurized crab industry and then exported to packaging. One of Indonesia's crab canning product industries is in Makassar, South Sulawesi. The crab canning product industry in Makassar is proliferating because of its location close to the coast, allowing easy access to abundant crab resources (Iswoyo *et al*., 2023). The crab processing industry is an economic sector that generates significant profits. Based on data from the Ministry of Maritime Affairs and Fisheries (KKP), in 2020, crab production in Indonesia was 27,616 tonnes, US$367 million (KKP, 2022).

High amounts of crab production can cause environmental impacts that must be calculated. Almeida *et al*. (2015) research on the sardine processing industry with a functional unit of 1 kg sardine can packaging resulted in total GWP emissions of 0.9 kg CO_2 eq, A.P. impact of 0.038 kg SO_2 eq, and E.P. impact of 0.012 kg PO_4^{3-} eq. Assessment of the life cycle of hake (Merluccius *et al*.) by Varquez-Rowe *et al*. (2011) with a functional unit of 500 grams of fresh fillet fish produced a GWP impact of 0.012 kg CO_2 eq, an A.P. impact of 0.000148 kg SO_2 eq, and an E.P. impact of 0.0000272 kg PO_4^{3-}eq. Other research on the anchovy industry, according to (Laso *et al*., 2007), with a functional unit of 1 kg of raw anchovies, produced a GWP impact of 0.91 kg CO_2 eq, an A.P. impact of 0.003 kg SO_2 eq, and an E.P. impact of 0.00012 kg PO_4^{3-} eq. It is essential to consider environmental impacts to create a sustainable agro-industry. Environmental impact assessment involves observing pollutant sources as assessment indicators by looking for alternative, more efficient processes to reduce environmental impacts.

Life Cycle Assessment (LCA) is often used to assess the environmental impacts produced throughout the life cycle of a product. This method can evaluate and measure the environmental impact of a product at each stage in its life cycle. This assessment covers preparing raw materials, manufacturing processes, distribution and transportation, and product disposal (ISO 14040:2006). LCA analysis plays a vital role in identifying a process that has the potential to be improved and serves to minimize environmental impacts and achieve production optimization. The results of the LCA analysis can be used as a basis for product development that benefits the industrial sector and contributes positively to environmental preservation (Zuhria *et al*., 2021). Previous research mainly discussed fishery products in the form of fish or packaged fish products, while this research focuses on analyzing the environmental impacts of the crab processing process. By using three leading indicators, namely Global Warming Potential (GWP), Acidification Potential (AP), and Eutrophication Potential (EP). According to the IPCC report (2014), Global Warming Potential (GWP) is used to measure the impact of greenhouse gases on climate change. This GWP is applied in Life Cycle Assessment (LCA) to calculate the contribution of gas emissions such as CO_2, CH_4, and N_2O to global warming, thereby accurately calculating the product or process life cycle.

This research aims to identify the stages of the process of steaming, transporting, and canning crab, calculate the environmental impact produced throughout the crab canning life cycle, and determine improvement scenarios to minimize the environmental impact resulting from the crab canning product industry.

MATERIAL AND METHODS

Data collection methods were carried out using literature studies, field observations, and interviews with stakeholders involved in the production process. Literature studies can be carried out using secondary data from books, research related to LCA, journals, and related literature. Data from literature studies is needed for modeling emission calculations and as a reference in determining recommendations for improvement. Furthermore, field observations can be obtained from primary data, which is not available in secondary data resulting from literature studies. Field observations were carried out at every stage of the crab canning industry process. Observation of steaming crabs involves using LPG gas and distributing crabs using refrigerated box cars. Upon arrival at the industry, steamed crabs are immediately processed, enabling the collection of necessary input and output data.

The final method is interviews. To obtain direct information, interviews were conducted with stakeholders involved in each stage of the production process. Data were collected at the fishing and production stages of the crab canning life cycle using prepared questions. The interview process involves crab suppliers to obtain information about the initial processing of crab. Next, interviews were conducted with industrial managers at PT. X, who have in-depth knowledge of the crab processing process from suppliers to canned products.

The LCA method is carried out based on the LCA framework in SNI ISO 14040:2016, namely by determining the objectives and scope, analyzing life cycle inventory, analyzing life cycle environmental impacts, and providing interpretation of the results as a basis for formulating improvement scenarios (BSN, 2016). LCA research in the fisheries processing sector aims to evaluate greenhouse gas (GHG) emissions from processing activities. This process includes identifying the inputs used and outputs produced, calculating the life cycle of the fishing industry, and implementing corrective actions to minimize environmental impacts (Sofiah, 2018).

The objectives and scope are determined based on literature studies, interviews, and observations in the crab canning product industry. The scope includes determining the product to be studied, system boundaries, functional units, and impact categories (BSN, 2016). Inventory analysis includes the process of collecting data and calculating data. Impact analysis using SimaPro 9.4.0.2 software with calculation methods using the Center of Environmental Science of Leiden University Impact Assessment (CML-2001-IA baseline). Environmental impact analysis will analyze environmental impacts such as Global Warming Potential (GWP), Acidification (AP), and Eutrophication (EP). Next, a further stage was carried out in the form of normalization to determine the magnitude of the influence of each impact produced in the same units (Puspaningrum *et al*., 2022).

The final stage is the interpretation of the results, which contains evaluations and reports or reports from the results of the impact assessment that has been carried out, as well as determining the hotspots or most significant impact contributors. Based on SNI 14044:2017, the life cycle interpretation stage of an LCA study consists of several elements, namely, identification of essential issues based on the results at the inventory analysis and environmental impact analysis stages, an evaluation that considers checks for completeness, sensitivity, and consistency, and conclusions. Evaluation at the interpretation stage will look at the contribution of each process unit that produces an impact. The impact contribution will be based on the material and energy input to the process units involved.

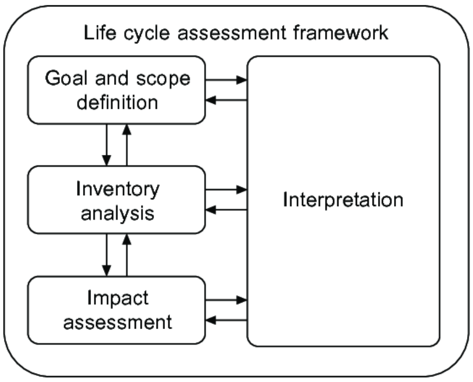

Figure 1. Life cycle assessment framework

RESULTS AND DISCUSSION

Industry Overview

The Life Cycle Assessment (LCA) study in this research was carried out at the PT X seaweed industry in Makassar, South Sulawesi. Location of PT. X is in a strategic industrial area with adequate transportation access for containers and trucks carrying raw and production support materials. Apart from that, this location also makes it easy to obtain water sources and is affordable for the State Power Plant (PLN) as a source of electricity to support production processes and various other industrial activities.

PT Crab (Portunus pelagicus) is processed into crab meat. Raw materials are obtained from crab suppliers and processed into canned products according to the flow diagram of the crab canning process. Canning crab production process at PT. X uses various equipment such as air conditioning, seamer machines, coding machines, boilers, and cold storage. After pasteurization, the crab is packaged. The entire processing process is carried out in one room, while the crab storage is in cold storage at a temperature of 0°C. The amount of crab production in the last four years can be seen in Figure 2.

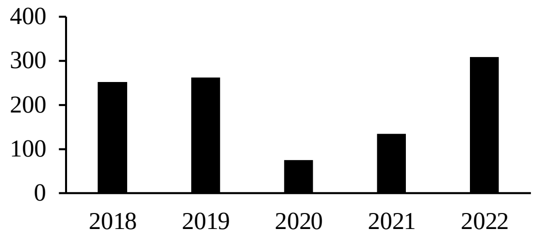

Figure 2. Number of crab production PT. X for the last four years (in tons)

Canned crab production at PT. X shows an increasing trend every year. This increase was caused by fulfilling demand from buyers and the abundant availability of crab. However, there was a decline in production in 2020 and 2021 due to the COVID-19 pandemic, which forced many workers to Work From Home (WFH) and decreased demand from buyers-average monthly crab production at PT. X is 763.5 kg. In 2023, production will increase significantly to 308 tons per year, driven by high demand after export difficulties in 2021, especially in the United States, due to lockdown policies and restrictions on export permits. With the high crab production each year, a method is needed to measure the emissions released into the environment. One method that can be used in LCA.

The Process of Canning Crab

The life cycle of crab canning is divided into four subsystems: steaming crab, transporting crab, and processing steamed crab in the industry, which will later be ready for export. The life cycle of crab canning is presented in Figure 3. Processing of crab products starts with the crabs caught and collected by fishermen and then proceeds to the following process: weighing and steaming the crabs.

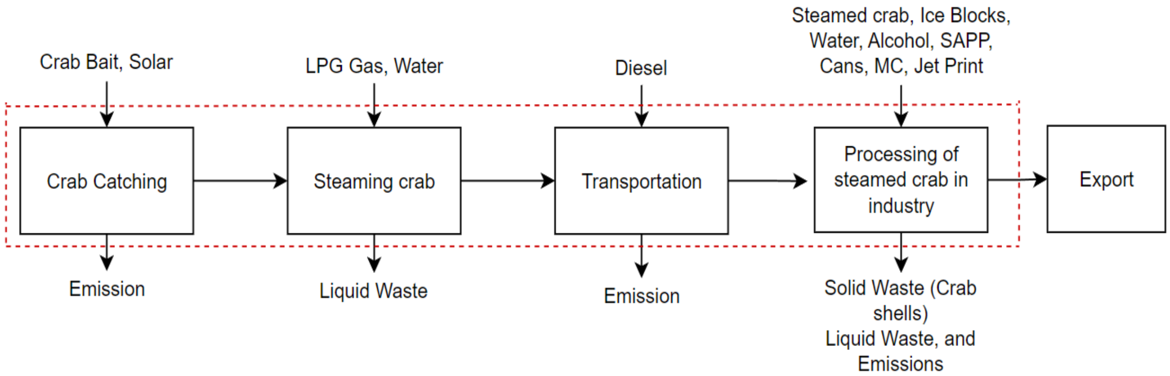

Figure 3. The life cycle of crab canning

The steaming process for crabs uses Liquefied Petroleum Gas (LPG) as the primary energy source. Steaming crab produces liquid waste, which is discharged directly into the environment. This was also explained by Wiloso *et al*. (2022), who stated that the amount of wastewater at the pre-processing site is discharged without any treatment. The next subsystem is transporting the crabs to the industry using box cars with steamed crabs.

The steamed crab that arrives at the industry will undergo a manual peeling process followed by weighing. The yield of crab that has been steamed and will be peeled is 23-25% (Wiloso *et al.*, 2022). After the crabs are peeled, the following process involves sorting and checking the quality of the crabs using water, alcohol, and ice cubes. At this stage, the quality of the crab is checked using gloves that have been added with alcohol. This antiseptic kills viruses and bacteria (Lusiana *et al*., 2020). Large and small crab meat is mixed in one package and then rinsed with water. Next, canning is carried out using 2 mm cans, followed by coding using jet printing according to industry standards. The following important stage is the pasteurization of the crab, carried out at a temperature of around 183ºF ±1 for 2 hours by immersing in a pasteurization bath with a capacity of 72 lbs per batch, using 1500 liters of water per batch. The final stage involves packaging using a Master Carton (MC), making the product ready for storage and export.

Goals and Scope

The LCA studied was limited to a gate-to-gate scope, starting from the process of steaming the crabs to the canning stage of the crabs. The determination of gate-to-gate limits is based on data limitations and difficulties in obtaining specific data regarding crab catches. This approach was chosen to avoid ambiguity and ensure the validity of the data used in the analysis. According to Peniari *et al.* (2023), the number of crabs caught by fishermen tends to fluctuate every year, so restocking efforts are essential. The crab cultivation process is considered less profitable financially, with a survival rate of only around 36.55%.

Limits are determined in this framework to assess environmental impacts that arise during a complete cycle of fishery product processing. Functional units in this context are used to present structured comparison conditions for the inputs and outputs involved in this evaluation system. (Athirafitri *et al*., 2021). This research used functional unit 1 packaging of canned crab meat totaling 1 lb (0.454 kg). Determination of functional units using one packaging unit was also studied by Almeida *et al.* (2015) and Varquez-Rowe *et al*. (2011); the functional unit uses 1 kg of canned sardines with olive oil and 500 g of fresh fish fillets according to 1 package of product to be sold or marketed.

Inventory Analysis

Inventory analysis in the crab processing product industry uses a functional unit of one can of crab, namely 1 lb (0.454 kg) in one day. Inventory analysis connects data with process units carried out in the form of data input and data output during the crab can production process. In the inventory analysis, there are two significant limitations to steaming crab and industrial processing of crab. The following is a mass balance for the life cycle of steaming crab and industrial processing of crab, presented in Figure 4.

Based on the one-day mass balance, the Inventory mass balance will be used from the material input requirements to produce 0.454 g crab packaging or packages. Inventory input data for the canned crab product industry, 0.454 g/package, can be seen in Table 1.

Impact Analysis

Based on analysis carried out using the CML2001-IA Baseline method in SimaPro software. The impact analysis calculation is based on the results of an inventory of the life cycle of the crab industry with contribution indicators including crab steaming, transportation, and crab can production. The impact categories that will be observed are GWP, AP, and EP. The calculation results can be displayed in Table 2.

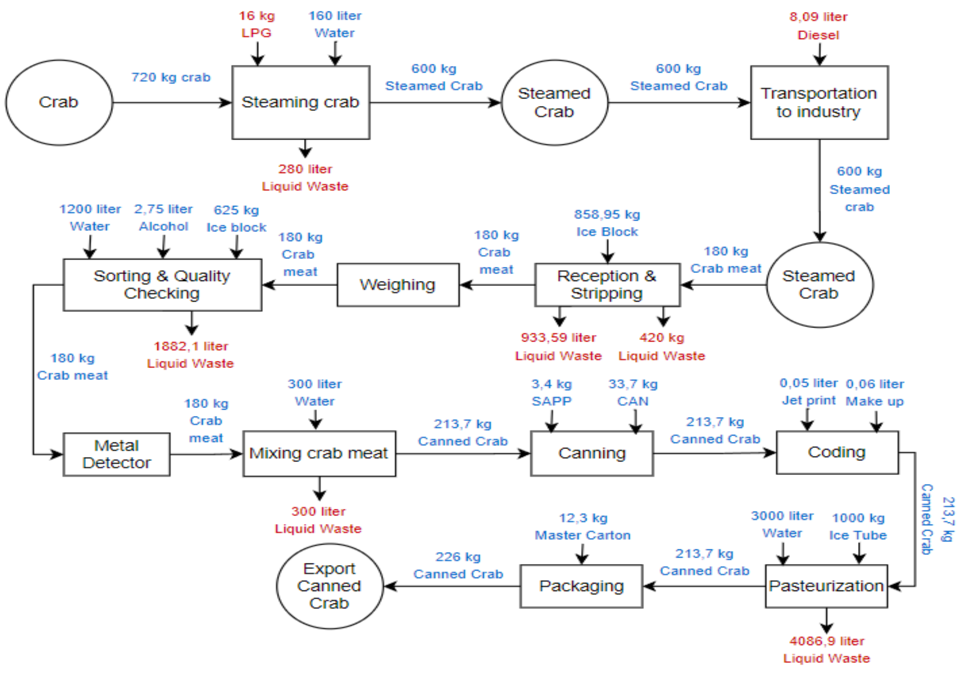

Figure 4. Mass balance of crab industry processing

Table 1. Inventory input and output data for the canned crab industry is 0.454 g/pack

Subsystem	Input Data	Unit	Total	Output Data	Unit	Total
Crab Industry	Crab	kg	1,816	Liquid waste	liter	17,4
	Box Car	tkm	0,0454	Solid Waste	kg	6,53
	Diesel	liter	0,695			
	Steamed Crab	kg	1,5133			
	Ice Block	kg	3,7429			
	Water	liter	11,35			
	Alcohol	liter	0,0069			
	CAN	kg	0,085			
	SAPP	kg	0,0086			
	Jet Print	liter	0,000126			
	Make Up	liter	0,000151			
	Master Carton	kg	0,031			
	Electricity	kwh	2,0607			
	Diesel	liter	0,5044			

Table 2. Calculation results of the impact of the crab can industry

Impact Category	Unit	Total
MAP	kg 1,4-DB eq	42182,59
ADP FF	MJ	228,832
HTP	kg 1,4-DB eq	149,6762
FAP	kg 1,4-DB eq	29,40145
GWP100	kg CO_2 eq	13,04317
TEP	kg 1,4-DB eq	4,737744
AP	kg SO_2 eq	6,78E-02
EP	kg PO_4 eq	3,02E-02
POP	kg C_2H_4 eq	4,01E-03
ADP	kg Sb eq	2,85E-04
ODP	kg CFC^{-11} eq	1,40E-07

Based on Table 2, the impact of the crab canning industry is the largest on MAP, with an emission value of 42182.59 kg 1.4-DB eq. MAP tends to be high because most crab canning activities are related to activities in marine waters (Marine Aquatic), following recent research by Wiloso *et al*. (2022) confirms that steaming crab is carried out around marine waters.

The GWP impact has a value of 13,043 kg CO_2 eq. GWP arises from human activities, especially from high emissions of carbon compounds released into the air through natural energy. This contribution has potentially impacted global warming over a hundred years. (Ahmad *et al*., 2019). The use of can packaging produces high levels of emissions because the manufacturing process requires high temperatures. However, packaging can be recycled to prevent corrosion and reduce environmental impacts (Anggraini *et al*., 2018). Using fossil fuels, such as diesel fuel, can produce CO_2 and CH_4 emissions, which increase global warming (Sulistiyono, 2012). The use of diesel fuel in crab transportation also contributes to the GWP impact. The impact of GWP on the crab canning process is also caused by fishermen's activities and the operations of the crab processing industry.

The following most enormous impact occurred in AP with a value of 6.78x10-2 kg SO_2 eq. Acidification is the impact of environmental pollution due to increased acidity levels caused by pollutants such as SO_2, NOx, and NH_3 in the atmosphere. The primary sources of pollutants that cause acidification, especially those containing SO_2, are activities such as fuel use, electricity generation, and sulfur combustion—the most significant impact of AP on crab processing results from crab packaging. Following research (Laso *et al*., 2007), canned product packaging has a significant environmental impact. The use of cans can also cause increased acidification because the fuel used in the can pasteurization process produces SO_2 emissions (Almeida *et al*., 2015).

The EP impact is 3.02x10-2 kg PO_4 eq. Eutrophication occurs when nutrient levels increase in surface waters, triggering plant growth, which decreases oxygen and light levels reaching the waters. These impacts decreasing biota populations in water ecosystems (Simbolon, 2016). Amann *et al*. (2018) stated that water system pollution comes from industrial waste. Liquid waste plays a significant role in increasing eutrophication because waste directly enriches nutrients in the water. NO_x pollution comes from using electricity and fuel, while NO_3^- and PO_4^{3-} are produced from liquid waste management. The pollutants that have the most influence on eutrophication are PO_4^{3-} and NO_{3-}. The can packaging production process also significantly impacts the production process by producing ammonia, nitrogen, phosphate, PO_4^{3-}, and COD emissions (Laso *et al*., 2007).

Interpretation of Results

Interpretation of the results showing the contribution to the total environmental impact of crab canning industry production is shown in Figure 5. The impact value is displayed based on the normalization results of environmental impacts assessed in person equivalent units. The most significant total impact on GWP contributed 36%, followed by the AP impact at 33% and the EP impact at 31%. The GWP impact is the most significant, so it is the hotspot of the crab canning process in production, with the highest GWP impact on water use. The impact of AP is relatively high on steaming crab. Meanwhile, the impact of EP is relatively high on electricity use and crab packaging.

Improvement Scenario

Substitute Tin Packaging With Plastic Cup Packaging.

Tin packaging is the packaging used for packaging crab. Canned materials significantly contribute to most environmental impacts in the canned crab products industry. Hospido *et al*. (2006) and Avadi *et al*. (2015) proposed recycling cans to reduce the environmental impact of using other alternative packaging materials. The processing of crabs in plastic cups has been carried out well, according to the specified specifications, and the process has complied with SNI 6929:2016 standards. Plastic cup packaging has carried out organoleptic tests on raw materials, and the final product meets the standards set out in SNI (Maurina and Sipahutar, 2021). This can significantly reduce GWP, AP, and EP by 97%, 95%, 92%, and 93%, respectively.

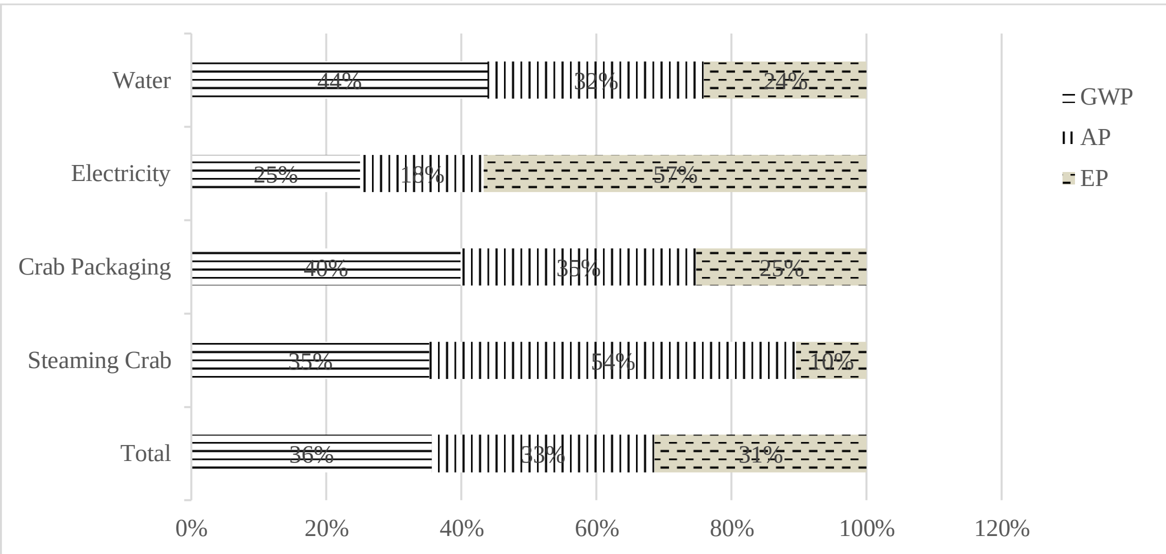

Figure 5. Total impact of canning crab

Substitution of LPG with Natural Gas

One improvement solution that can be implemented is replacing LPG (Liquefied Petroleum Gas) with natural gas. Natural gas supplied by PT. PGN (State Gas Company) offers higher energy efficiency than LPG. Natural gas energy is available in Makassar, South Sulawesi. Natural gas energy is located in two sub-districts, Biringkanaya District and Tamalanrea District, Makassar, South Sulawesi, with a natural gas energy of 550 MW (Pratama *et al*., 2019). The research results show that using natural gas can reduce the GWP, and AP EP emission values by 3%, 25%, 23%, and 15%, respectively.

Increasing Water Use Efficiency

The process of processing crab meat requires significant water because it can reduce liquid waste, which has the potential to pollute the environment (Rukmana *et al*., 2022). A flow meter can be used to measure water discharge to increase water use efficiency. A flow meter function will be installed to monitor company water use. This action is part of an effort to determine potential water loss as a first step in water conservation practices. This water conservation effort refers to limiting or modifying human water use to prevent fluctuations in water quantity and quality in natural cycles, which can be caused by natural events on the time scale of human history (Sturman, 2004 in Krisnawati *et al*., 2015). Apart from installing flow meters, companies can use high-pressure water. High-water-pressure jet technology can increase the pressure on the water, thereby converting significant water pressure into a strong impact. It can reduce water use over a particular time (Wang 2020). Reducing water use can reduce GWP, AP, and EP impacts by 38%

Three improvement solutions can be applied: substitution of can packaging for plastic cup packaging, substitution of LPG gas for natural gas, and efficient water use. Of these three solutions, the highest emissions come from using canned packaging for crab. Therefore, replacing can packaging with plastic cup packaging is P.T.'s best and easiest solution. X. Previously, the company had used plastic cup packaging made from polypropylene, which had lower emissions than can packaging, although the shelf life of crab products was shorter. The second solution most likely to be implemented is water use efficiency. The most significant use of water is for cleaning equipment, washing hands, and cleaning the floor in the crab processing room. The amount of water used can be minimized using a high-pressure water device to increase water use efficiency. The third solution is substituting LPG gas with natural gas for the crab steaming process. Using LPG gas causes high environmental emissions, so using natural gas is expected to reduce these emissions. The proposal to replace LPG with natural gas can be submitted to village heads and the regional government of South Sulawesi Province to enable the installation of natural gas pipelines, which will reduce environmental emissions

Table 3. Percentage reduction with improvement scenario

Hotspot	Impact	Before	After	%
Water	GWP	5,05E-16	3,11E-16	38%
	AP	3,68E-16	2,27E-16	38%
	EP	2,76E-16	1,71E-16	38%
Packaging Crab	GWP	1,62E-12	7,64E-14	95%
	EP	1,42E-12	1,09E-13	92%
	AP	1,02E-12	6,90E-14	93%
Steaming Crab	GWP	1,71E-13	1,28E-13	25%
	EP	2,64E-13	2,03E-13	23%
	AP	5,07E-14	4,31E-14	15%
Total	GWP	1,86E-12	2,66E-13	96%
	AP	1,86E-12	4,60E-13	93%
	EP	1,10E-12	1,33E-13	93%

CONCLUSIONS AND RECOMMENDATION

Conclusions

The environmental impact assessment was taken from data on crab steaming, crab transportation, and crab processing. The input data was obtained as crab, LPG, water, box cars, diesel, CAN, SAPP, jet print, alcohol, electricity, and cardboard packaging. As well as output data in the form of solid waste and liquid waste. The canning crab with the SimaPro application using the CML-2001 IA Baseline method produces GWP, AP, and EP impacts with a functional unit of 0.454 kg/pack of crab. The canning industry produces a GWP impact of 13.04317 kg CO_2 eq, EP impact of 3.02E-02 kg PO_4 eq, and AP 6.78E-02 kg SO_2 eq.

Interpretation produces a hotspot where the most influential impact lies in GWP100 on water use and crab packaging. The crab packaging substitution scenario reduces GWP100, AP, and EP emissions by 95%, 92%, and 93%. The LPG gas substitution scenario can reduce GWP100 by 25%, AP by 23%, and EP by 15%. Increasing water use efficiency can reduce the impact of GWP100, AP, and EP by 38%. The efficiency scenario that has been implemented can reduce 96% of the GWP impact, 93% of the AP impact, and 93% of the EP impact.

Recomendation

The repair scenarios that have been carried out need to be reviewed regarding calculations from an economic perspective, as well as testing the quality and durability of the crab

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