LIFE CYCLE ASSESSMENT OF CANNED FISH PRODUCTION IN THAILAND

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A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Science in Hazardous Substance and
Environmental Management (Interdisciplinary Program)
Inter-Department of Environmental Management
GRADUATE SCHOOL
Chulalongkorn University
Academic Year 2022

การประเมินวัฏจักรสิ่งแวดล้อมของกระบวนการผลิตปลากระป๋องในประเทศไทย

น.ส.ชัญญา ไกรเวด

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
สาขาวิชาการจัดการสารอันตรายและสิ่งแวดล้อม (สหสาขาวิชา) สหสาขาวิชาการจัดการสิ่งแวดล้อม
บัณฑิตวิทยาลัย จุฬาลงกรณ์มหาวิทยาลัย
ปีการศึกษา 2565

Thesis Title	LIFE CYCLE ASSESSMENT OF CANNED FISH PRODUCTION IN THAILAND
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Field of Study	Hazardous Substance and Environmental Management (Interdisciplinary Program)
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ชัญญา ไกรเวด : การประเมินวัฏจักรสิ่งแวดล้อมของกระบวนการผลิตปลากระป๋องในประเทศไทย. (LIFE CYCLE ASSESSMENT OF CANNED FISH PRODUCTION IN THAILAND) อ.ที่ปรึกษาหลัก : รศ.ดร.มนัสกร ราชากรกิจ

อุตสาหกรรมปลากระป๋องเป็นอุตสาหกรรมที่มีความสำคัญมากในประเทศไทยและเป็นอุตสาหกรรมที่มีการใช้พลังงานเป็นอันดับ4 เมื่อเทียบกับกลุ่มอุตสาหกรรมอื่นๆ (Wiriyatangsakul, 2021) ดังนั้น กลุ่มอุตสาหกรรมปลากระป๋องในไทยควรมีการพัฒนาในทุกๆด้านเพื่อการแข่งขันในตลาดโลก งานวิจัยนี้จึงทำการประเมิณวัฏจักรชีวิตสิ่งแวดล้อมโรงงานปลากระป๋องในจังหวัดสมุทรสาคร ประเทศไทย ทำการประเมินโดยมีขอบเขตในการทำวิจัยแบบ Gare to Gate และมีหน่วยการทำงาน (Functional Unit) เท่ากับ 1 ตันปลาสดเข้าระบบ โดยประเมินวัฏจักรสิ่งแวดล้อมด้วยโปรแกรม Simapro ด้วยวิธี CML 2 baseline 2000 ครอบคลุมทั้ง 10 ผลกระทบ ผลการประเมินพบว่า ความเป็นพิษต่อมนุษย์มีค่าเท่ากับ 3,800 kg 1,4-DB eq/ FU, การทำให้โลกร้อน มีค่าเท่ากับ 2,470 kg CO_2 eq/ FU, ความเป็นพิษต่อสิ่งมีชีวิตในน้ำเค็มมีค่าเท่ากับ 24,100 kg 1,4-DB eq/ FU, การก่อให้เกิดความเป็นพิษต่อสิ่งมีชีวิตในน้ำจืดมีค่าเท่ากับ 22.5 kg 1,4-DB eq/ FU และความเป็นพิษต่อระบบนิเวศน์ทางบกมีค่าเท่ากับ 2.72 kg 1,4-DB eq/ FU ผลกระทบดังกล่าวเกิดจากการใช้บรรจุภัณฑ์ 49 % และการใช้ไอน้ำ 48% ดังนั้น จึงนำหลักการเทคโนโลยีสะอาดทำการประเมินทั้งเทคนิค เศรษฐศาสตร์ และสิ่งแวดล้อม เพื่อจัดลำดับปัญหาในการลดการใช้ทรัพยากรและหาแนวทางแก้ไข ผลการศึกษาพบว่าการใช้บรรจุภัณฑ์ การใช้น้ำ และการใช้ไอน้ำ ซึ่งสอดคล้องกับผลการประเมินวัฏจักรสิ่งแวดล้อม ยกเว้นการใช้น้ำ โดยแนวทางการปรับปรุงการในการใช้บรรจุภัณฑ์คือใช้บรรจุภัณฑ์รีไซเคิลแทน ซึ่งสามารถลดผลกระทบทางสิ่งแวดล้อมได้ แนวทางการแก้ปัญหาด้านไอน้ำคือการลดปริมาณไม้จากการผลิตไอน้ำสามารถทำได้โดยนำถ่านไม้มาผสมกับชานอ้อยและกากน้ำตาล ซึ่งทำให้สามารถลดก๊าซคาร์บอนไดออกไซด์ถึง 38,308 kg CO2 eq ต่อปี การใช้เชื้อเพลิงอัดเม็ดที่มีค่าความชื้นต่ำแทนการใช้ไม้ยางพาราท่อน สามารถลดก๊าซคาร์บอนไดออกไซด์ถึง 33,311 kg CO_2 eq ต่อปี และการติดตั้งเครื่องวัดออกซิเจนเพื่อควบคุมการเผาไหม้สมบูรณ์ของเชื้อเพลิง ลดก๊าซคาร์บอนไดออกไซด์ถึง 19,149 kg CO_2 eq ต่อปี แนวทางการแก้ปัญหาการใช้น้ำคือนำน้ำจากกระบวนการล้างกระป๋องมาใช้ใหม่ในกระบวนการสามารถลดก๊าซคาร์บอนไดออกไซด์ถึง 2,003 kg CO_2 eq ต่อปี และการติดตั้งที่ฉีดน้ำแรงดันสูงเพื่อล้างทำความสะอาดไลน์การผลิตสามารถลดก๊าซคาร์บอนไดออกไซด์ถึง 1,698 kg CO_2 eq ต่อปี

สาขาวิชา	การจัดการสารอันตรายและสิ่งแวดล้อม (สหสาขาวิชา)	ลายมือชื่อนิสิต ....
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6388040920 : MAJOR HAZARDOUS SUBSTANCE AND ENVIRONMENTAL MANAGEMENT (INTERDISCIPLINARY PROGRAM)
KEYWORD: Life Cycle Assessment, Clean Technology
Chanya Kraiwed : LIFE CYCLE ASSESSMENT OF CANNED FISH PRODUCTION IN THAILAND. Advisor: Assoc. Prof. MANASKORN RACHAKARAKIJ, Ph.D.

The canned fish industry is one of the world's most popular exports in Thailand. Moreover, the canned seafood industry ranks fourth in terms of energy consumption, which compares to all industry group (Wiriyatangsakul, 2021). Commercial competitiveness, on the other hand, must be improved because of the competitive conditions in the global market. Thus, this study evaluates the environmental performance of a factory in Samut Sakhon, Thailand, using Life Cycle Assessment (LCA) with Gate-to-Gate approach and setting functional unit by 1 ton fresh fish entering to process. The study used the SimaPro LCA application with the CML 2 baseline 2000 method, which covers ten impact categories. The result of LCA showed that human toxicity (3,800 kg 1,4-DB eq/ FU), global warming (2,470 kg CO_2 eq/ FU), marine aquatic ecotoxicity (24,100 kg 1,4-DB eq/ FU), freshwater aquatic ecotoxicity (22.5 kg 1,4-DB eq/ FU), and terrestrial ecotoxicity (2.72 kg 1,4-DB eq/ FU) were found to have the greatest environmental impacts from 10 categories. Those categories are caused by packaging and steam consumption by 49% and 48%, respectively. Therefore, this study utilized clean technology to assess technical, economic, and environmental feasibility in order to prioritize resource consumption and propose options. The result showed that packaging, steam and water consumption were prioritized in the top three of CT, which was consistent with the LCA results except for water consumption. The following are some options for reducing packaging, water, and steam consumption: Use of packaging as primary packaging (glass, plastic, and recycled material) has the potential to reduce the environmental border to air by approximately 95% and the environmental border to water by 40 to 50%. (J. Laso, 2016). Steam consumption options are using biomass residue as a secondary combustion material in the production of steam could reduce CO2 eq by 38,308 kg CO2 eq/year, using wood pellet biomass could reduce CO2 eq by up to 33,311 kg CO2 eq/year, and improving boiler combustion by installing oxygen detectors could reduce CO2 eq by up to 19,149 kg CO2 eq/year. Water consumption options are reusing water in washing can packaging could reduce CO_2 eq up to 2,003 kg CO_2 eq/year, and Installing water high-pressure cleaner for washing floor could reduce CO_2 eq up to 1,698 kg CO_2 eq/year.

Field of Study:	Hazardous Substance and Environmental Management (Interdisciplinary Program)	Student's Signature ....
Academic Year:	2022	Advisor's Signature ....

ACKNOWLEDGEMENTS

This study was funded by the International Program in Hazardous Substance and Environmental Management, H.M. King Bhumibhol Adulyadej's 72nd Birthday Anniversary Scholarship at Graduate School, Chulalongkorn University. I would like to acknowledge the Technology and Informatics Institute for Sustainability (TIIS) and the Center of Excellence on Hazardous Substance Management, who have supported in providing the database and software used in this research and helped made this research possible.

I would like to express my appreciation to my supervisor, Assoc.Prof. Manaskorn Rachakarakij, PhD, for his expertise and patience, which greatly enhanced my study experience. I am greatful to the chairman of my thesis, Assoc. Prof. Dao Suwansang Janjaroen, PhD., as well as my thesis committee members, Dr. Nattapong Tuntiwiwattanapun, Dr. Vacharaporn Soonsin and Dr. Supreeda Homklin, for sharing their expertise and direction.

I would like to express my gratitude to a company in Samut Sakhon for their assistance and support with the data. Furthermore, I would like to thank Dr. Thantip Punmatharith, all of the IP-HSM program lecturers and staff for their assistance and support during my study.

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CHAPTER 1

Introduction

1.1 Background

In 2018, the food industry group was a controlled industry group that consumes the second-highest amount of energy in production after power plants. The canned seafood industry ranked fourth in terms of energy consumption within the food industry (Wiriyatangsakul, 2021). Material preparation is one of the most important stages in the generation of solid waste, with fish residue weighing up to 250-300 kg/ton frozen fish. In the sterilization step, proportion of steam consumed can reach 290 kg/ton of frozen fish (United Nations Environment Programme, 2000). Furthermore, the stages of washing raw materials and cleaning packaging produce the most wastewater (*Best Practices in Pollution Prevention and Reduction Seafood Processing Industry: Types of Fish*, 2005). The canned fish industry is very important to the Thai economy because of its high quality, ASEAN's best safety standards, and global recognition. In addition, canned food products are among popular exports because of consumer trust, and the location is ideal for the seafood industry (Nguangphan, 2022). Commercial competitiveness, on the other hand, must be improved because of the competitive conditions in the global market.

Thailand has 105 canned fish factories (FIC, 2020). The study was conducted by collecting data from a major manufacture in Samut Sakhon province because it is a professional producer of frozen surimi and canned fish for both export and domestic sales, with the most popular products being Sardine & Mackerel in tomato sauce with productivity volume of up to 37,889,422 cans/year. However, due to high productivity, the company consumes many resources entering the process and generates a large amount of wastewater and solid waste. This study begins with a review of processes. The company has four main processes, which are as follows.

1. Raw material preparation
2. Packaging in container
3. Sterilization
4. Labelling

This study assesses the environmental impacts of canned fish production by first defining the goal and scope, and then conducting an inventory analysis using Simapro version 9.0.0.35 and the CML 2 baseline 2000 method, which covers ten impact categories, including acidification potential (AP), ozone layer depletion potential (ODP), abiotic depletion potential (ADP), global warming potential (GWP), eutrophication potential (EP), photo-chemical oxidant formation potential (POFP), freshwater aquatic ecotoxicity potential (FETP), marine aquatic ecotoxicity potential (METP), terrestrial ecotoxicity potential (TETP), and human toxicity potential (HTP). Furthermore, options based on Clean Technology are being proposed to reduce resource consumption. Thus, The Life Cycle Assessment (LCA) and Clean

Technology (CT) are comprehensive ways to cover and improve all impacts, which lead to pollution control from the production, as well as the quality of life of people in the workplace and surrounding communities, creating economic, social, and environmental business operations, also known as Sustainable development.

1.2 Objective

1.2.1 To assess environmental impacts from canned fish production.

1.2.2 To improve and prioritize resource consumption based on Clean Technology

1.2.3 To make suggestions for reducing consumption of resources in production

1.3 Hypothesis

1.3.1 Global warming has the greatest environmental impact of any category in Life Cycle Assessment.

1.3.2 Water consumption is the greatest consumption of any resource in Clean Technology.

1.4 Scope of Study

1.4.1 Content

- Study process by collecting only input-output data in the canned fish production
- Study Product Category Rules for Prepared and Ready to Eat Products from Thailand Greenhouse Gas Management organization (TGO)
- Study Simapro database manual

1.4.2 Data collection

Collect canned fish production data (primary data and secondary data), which cover raw material reception until packing in box during January to December in 2021

1.4.3 Study Peroid

August 2020 to August 2023

1.4.4 Study Site

Company xxx Address xxx Thasai, Mueang District, Samut Sakhon Province 74000

The factory has produced 2 products consisting of

- Canned food 84.93%
- Dried fish 15.07%

1.4.5 Analysis Tools

- Input-output questionnaire of canned fish production
- Step of Life Cycle Assessment (Goal and scope, Life Cycle Inventory, Life Cycle Impact Assessment and Interpretation)
- Simapro program version 9.0.0.35
- Ecoinvent database
- Thai National Life Cycle Inventory Database
- CML 2 baseline 2000 method version 2.05

1.5 Research plan

Detail	Duration											
	1	2	3	4	5	6	7	8	9	10	11	12
1.Literature review												
2.Writing a research proposal												
3.Proposal defense												
4.Collection data												
5.Assess of the impacts and propose options												
6.Analyze, conclude, and do dissertation												
7. Thesis defense												

1.6 Expected Outcome

1.4.1 This study could reduce the quantity of resources consumed in canned fish production.

1.4.2 This study could serve as a benchmark for other manufacturers of similar products.

CHAPTER 2

Literature Review

2.1 Fish species suiTable for canning

Sardinella is the common name for a variety of sea fish species used in the production of canned fish, as shown in Figure 1. The common name Goldstripe Sardinella belongs to a large species of Clupeidae, which is a shoal in the larger group. It can be found all over the world and is mostly used to make canned fish. Codex 2001 specifies canned sardines or sardine-type products, as well as products produced from fresh or frozen fish, which are classified into 21 types, including S. gibbose. Because of their delicious taste, canned sardines have been popular for a long time. The price is reasonable and rich in Omega-3, with 100 grams of Sardine containing more than 200 mg of Omega-3, which is sufficient to meet the needs of the body. Additionally, sardine have twice as much as calcium as milk and high amounts of essential nutrients such as iron, magnesium, zinc, copper, manganese, lycopene, and vitamin B. However, whether or not canned sardine provides proper nutrition depends on the aquaculture of sardine preservation as well as processing because there is an immediate deterioration in quality after the fish is killed.

Figure 1 Sardine fish from Evimare fish

Mackerel (Scomber spp.) is a pelagic fish in the Scombridae family, as illustrated in Figure 2. Scomber scombrus (Atlantic), Scomber japonicus (Atlantic & Pacific), and Scomber australasicus (South Pacific) are the most important and widely fished species (Evimarefish.nl., 2020). Mackerel contains high levels of vitamin B12, selenium, niacin, and phosphorus, as well as a variety of other essential vitamins and minerals. It strengthens the bones and promotes weight loss, which are two of its benefits (Rachael Link, 2018).

Figure 2 Mackerel fish from Evimare Fish

2.2 Machine in production

2.2.1 Boiler: A boiler is a hot water tank used in the process of boiling or scalding raw materials before packaging them in a container. This is accomplished by passing the raw materials through hot water or directly heating them through steaming. The energy characteristics of the boiling tank are only used by steam heat and the tank size is determined by the quantity. Type of boiling product is classified into two types (Institute, 2005):

- A boiling tank that heats directly with steam uses a small hole in the steam pipe underneath that controls the temperature with valves to fit the desired temperature. However, if the steam pressure is too high, the pipe size is too small, or the valve adjustment is inaccurate, the steam will not provide heat effectively or the system will lose heat.
- A boiling tank that heats through a double tank using steam via heat exchange. The steam will be sent to heat the surrounding area, or steam may be used via a steam pipe coil. A steam trap will act as an automatic valve to release water generated by condensation in the tank during the stream heating exchange. The pressure is adjusted to suit the application to control the temperature. The disadvantage is that it takes longer to heat than a boiling tank that heats directly with steam.

2.2.2 Streamer

2.2.3 Exhausting unit: It is the main equipment used in canning processes for air repellent, which has several processes such as vacuum, but in most production processes it is steam exhausting directly in long box designed cabinets or air repellent cabinets, where steam is injected into the cabinet through a steam pipe placed in the air repellent can be about 5-10 meters long depending on the quantity and type of product. The product is then continuously operated as it moves through the conveyor. The stream temperature ranges between 100°C and 120°C depending on the product, and the exhausting unit's energy consumption is heated by steam and electricity from the conveyor.

2.2.4 Retorts: It takes a lot of energy in the sterilization process to preserve the food that is in the closed can; therefore, it is necessary to know the optimum operating temperature for each product. Retort is divided into two types based on the heating characteristics:

- Steam sterilization, which uses steam to heat itself, is the most common method used today. Initially, the sterilization pot must be pelted with air. Steam replaces the air in retorts to keep the product at the desired temperature and to prevent product damage. After the sterilization, a quick cooling procedure is required to avoid heat accumulation, which diminishes the color, taste, or quality of the product. Circulated cold water is injected into retorts, and the water is cooled by a streaming tower for reuse, as well as electricity is used in pumps and fan motor.
- Disinfection with hot water temperatures ranging from 90°C to 120°C employs steam in both direct heating and heat exchange. The device's characteristics can include a hot water tank or a hot water trough. According to the quantity and type of product, the size resembles that of a standard boiler.

2.2.5 Continuous flash cooker

In addition to steam-powered equipment in the production process, the main equipment in the canned fish production process, which is electrically powered, is as follows

2.2.6 Belt conveyor
2.2.7 Pumps
2.2.8 Air compressor
2.2.9 Refrigeration
2.2.10 Can seamer machine
2.2.11 Automatic labeling machine

2.3 Process of canned fish

Figure 3 depicts the input and output of the processes for canned fish production, which include raw material preparation, packaging in containers, sterilization, and labeling.

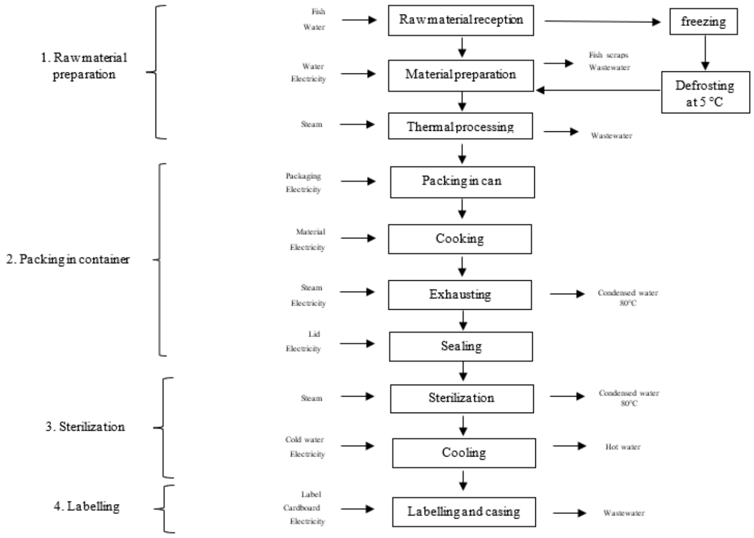

Figure 3 Canned fish processes
Reference: (DIW, 2004)

2.3.1 Raw material preparation

- Raw material reception: The physical quality of the fish is monitored during the process to ensure that it is of good quality and meets the standards. Some factories use frozen raw material, and the facility should be able to keep the fish at -18 °C or lower with minimal temperature fluctuations (World Health Organization, 2001). It must then be defrosted for the fish meat to reach a temperature of 5°C. Electricity is used in the conveyor belt.
- Material preparation: After removing unwanted fish fillets such as the head, tail, and offal, the desired fish fillets are thoroughly washed to reduce the number of microorganisms and weighed to achieve the required weight. When the intestinal tract and internal organs have been removed, gutting is considered complete (World Health Organization, 2001). Water and electricity are used in this input step. The byproducts are fish scraps and wastewater.
- Thermal process: After filling the can with fish meat, it is recommended to steam the fish to give it a sticky texture until it reaches a temperature of 40-60 °C. The length of heating time is determined by the type and size of the fish. This procedure necessitates the separation of the stream process water, resulting in condensed water.

2.3.2 Packaging in container

- Pack in can: Packed thawed fish into a washed metal can, this procedure is packaged from other factories, or some factories have produced their own cans, and electricity is used at this stage. However, the finished product's packaging integrity should be inspected at regular intervals by appropriately trained personnel to ensure the effectiveness of the seal and the proper operation of the packaging machine (World Health Organization, 2001).

- Cooking: Using machinery or labor, fill a can with ingredients such as ketchup or chili sauce. Putting seasoning in a can necessitates the use of electricity.
- Exhausting: Before sealing the can, air must be evicted by spraying steam into the gaps and allowing it to condense. Vacuum capable of inhibiting aerobic microorganism growth. In vacuum conditions, microorganisms from the heating process cannot grow, and anaerobic microorganisms are destroyed. (Dalbandalchok, 2021).
- Sealing: Close the cans with steam to prevent external contaminants such as microorganisms, chemicals, and so on. This process makes use of a lid and electricity.

2.3.3 Sterilization

- Sterilization: Heat is used to kill microorganisms, which are divided into three types: thermophilic facultative anaerobic spores, thermophilic and anaerobic spores, and mesophilic and anaerobic spores. Furthermore, heat can also maintain the quality of colored canned foods, smell, taste, and nutritional values.
- Cooling: This method of preventing heating causes the meat to fluff, which affects the taste, color, and nutritional value, as well as the growth of microorganisms that grow at high temperatures caused by sterilization. As a result, the temperature must be rapidly reduced to prevent such microorganisms. Vacuum conditions during colling can cause canned fish to break. To kill germs, clean water is required to reduce the temperature by adding chlorine to the water. Reduce the temperature of the can to 34-35 °C by using 5 ppm chlorine or by blowing it in the air.

2.3.4 Labelling

- Labelling and casing: After the temperature of the can has dropped to room temperature, the packaging is labeled and packed into the box for further transport.

2.4 Life Cycle Assessment (LCA)

Life Cycle Assessment (LCA) is a tool for assessing environmental impact that includes raw material, process, transportation, consumption, disposal and reuse, reduce and recycle, and consumption of input, output, and pollution data to assess a comprehensive environmental impact. This is to bring the information to ways of improving the product or process so that it has minimal environmental impact as possible (Nattanee Vorayot, 2010).

There are numerous methods for performing LCA, but by now, LCA based on ISO 14000 is widely used as an Environmental Management Standard, closely followed by

(1) ISO 14040: Principles and framework - standard that discusses the Life Cycle Assessment principles, definitions, terminology, and framework.

(2) ISO 14041: Goal and Scope Definition and Life Cycle Inventory Analysis (LCI) - a standard that describes the objectives, scope, analysis, and preparation of a product environmental inventory.

(3) ISO 14042: Life Cycle Impact Assessment (LCIA) - the standard mentioned Environmental Impact Assessment Throughout Product Life Cycle

(5) ISO 14044: Requirements and Guidelines - a standard that addresses the interpretation of data obtained from the Life Cycle Inventory Analysis process, including goal and scope, Life Cycle Inventory (LCI), Life Cycle Impact Assessment (LCIA), Interpretation, Improvement Analysis, as well as the significance of LCA steps, limitations, and data quality.

2.4.1 Step of LCA

2.4.1.1 Goal and scope definition

- **Goal** is the most important step in a life cycle assessment study because it influences the guidelines and scope of the study, and the goal must be clear.
- **Scope** specifies what needs to be assessed and what is inside the system. The method of assessment must be comprehensive, including function, functional unit, product to be studied, the scope of product, inventory, required data, assumptions, limitations, preliminary data quality, and the determination of the scope of the study. Some research must focus on specific geographical areas, such as local, ethnic, regional, continental, or global, and period (Lohsomboon & Jirajariyavech, 2004). The purpose of the study's scope was to identify and define what needed to be assessed and scheduled, as well as gather information relevant to the LCA study's goals.
- **Function** of the product should be clearly stated in the scope of the LCA study because a single product can perform multiple functions. To investigate the LCA of a product that performs both primary and secondary functions, making such studies more complex and difficult. As a result, the function chosen for the LCA study must be consistent with the study's goals and scope (Lohsomboon & Jirajariyavech, 2004).
- **Functional Unit** is used as the basis for storing incoming and outgoing substances in the system, which is important to compare the results of

life cycle assessments in different systems between products or multiple products on the same basis. However, the functional unit can take a variety of forms.

2.4.1.2 Life Cycle Inventory (LCI)

It is an examination of inputs such as raw materials, water, energy, and outputs such as pollution or wastewater. LCI is the most important step in Life Cycle Assessment, and it must be following the goal and scope. The basic principle of LCI is data collection and analysis of input, output, and energy in each unit process. The clear LCI directs correct data analysis to improve production, supply chain, resource planning, decision making, policymaking, and requesting environmental labels such as Carbon Footprint, among other things (Mungkalasiri, 2020).

2.4.1.3 Life Cycle Impact Assessment (LCIA)

The aim of Life Cycle Impact Assessment (LCIA) is to convert the inventory data collected from product input and output from Life Cycle Inventory (LCI) into the form of environmental impact indicators to indicate competence in causing environmental impacts, which is then followed by (Ruesaiwong, 2005)

- **Classification** The input and output of LCI are classified into a categorized selection of impact groups, e.g., Carbon Dioxide (CO_2) and Methane (CH_4) are classified as Climate Change. An impact group can have more than one input and output. For example, nitrogen dioxide (NO_2) is classified both as eutrophication and acidification. This step aims to find relevant information among inventory lists and impact categories (Midpoint).
- **Characterization** is a step to use the quantity of data obtained from the Inventory to evaluate quantitative impacts according to impact categories because each substance has the potential to cause varying levels of environmental impact. As a result, it must be compared to the baseline by considering Potential Environmental Impact multiplied by characterization factor to convert weight quantity to indicative value of impact and combining all values of each impact.
- **Normalization** The procedure for expressing the size of the environmental impact of products or services is viewed as a whole scale, comparing the environmental impact of a product or service over its lifetime and the proportion of the environmental impact on a person or per year. The result of this process determines the impacts of a process or product on a national or regional scale, depending on the area of study.

For example, studying CO2 emissions generated by products and comparing them to CO_2 emissions on a continental scale.

2.4.1.4 Interpretation and Improvement Analysis

It is a step toward reducing environmental impacts. It is known what process has the greatest impact that leads to the identification of solutions. Interpretation, on the other hand, should be based on boundaries.

2.4.2 LCA Program

(Olagunju & Olanrewaju, 2020) compared 45 LCA programs on the market that covered six features, resulting in only four most suiTable tools remaining consisting of GaBi, OpenLCA, SimaPro and Umberto. The result shows that Umberto's distinguishing characteristics are not as strong as those of the others. It is not user-friendly, and it does not always provide enough innovations when compared to SimaPro and GaBi, despite their similar prices. GaBi, which appears to be more robust in its characteristics, is too complex to work with. SimaPro, with its robust characteristic features, meets all the requirements of LCA software, and it supports a wide range of databases that focus on energy, electricity generation, and related processes such as transportation, processing, and waste treatment, including 1200-unit processes and 1200 system processes. Furthermore, inexperienced users quickly learn how to use SimaPro, and there are hundreds of users in more than 45 countries (Boureima, 2007).

2.4.3 LCA Related Research

Table 1 summarizes Life Cycle Assessment literatures covered author, title, functional unit, scope of study, and result.

Table 1 Life Cycle Assessment related research

Author	Title	Function Unit	Scope	Result
(Abdou K, 2017)	Environmental life cycle assessment of seafood production: A case study of trawler catches in Tunisia	1 ton of landed seafood by demersal trawlers in the Gulf of Gabes	Cradle-to-gate approach covered fish production, fuel and lubricating oil production, paint and antifouling production, trawler and trawl net construction and maintenance and transport	Fuel and lubricating oil contributed mainly 97% of ozone depletion. Fish production contributed 84% of acidification and global warming. Trawlers and trawling net construction mainly contributed 84% of terrestrial toxicity. Paint and antifouling production mainly contributed 14% to marine toxicity. Transportation contributed slightly to all impact categories. Furthermore, Onboard vessel activities and the specialization chosen are the main causes of environmental impacts.
(Perez-Martinez et al., 2018)	Evaluation of environmental impact of two ready-to-eat canned meat products using Life Cycle Assessment	a unit of canned food product	Cradle-to-grave approach covered meat production, Production elaboration, the distribution to the final consumer, the consumption and final disposal	The meat production and product elaboration of both products have the same impact categories, while distribution, consumption, and disposal all have negative effects due to recycling. The main process of canned pork leans 220 g that has the greatest impacts is from sterilization process, while dosing and canning, sterilization and the preparation of additional ingredient are the main environmental impact of canned meatballs with peas of 430 g. Using recycled aluminum packaging instead of tin can and reusing water are considered as alternative scenario.

(Iribarren et al., 2009)	Revisiting the Life Cycle Assessment of mussels from a sectorial perspective	100 kg of mussels cultivated in rafts and processed within the Spanish mussel sector according to the market share of sub-sectors	Cover all the main sub-sectors of the mussel cooking plants consisted of Mussel culture, mussel shell management and mussel cooking	Culture was the main contributor to impacts due to energy demand for capital goods, diesel consumption in boats, and iron demand for capital goods. However, the process of canned and frozen mussels contributes to TETP due to sludge management and electricity production.
(Laso et al., 2016)	When product diversification influences life cycle impact assessment: A case study of canned anchovy	1 kg of raw anchovy entering the factory	Cradle-to- grave covered raw material production, packaging, transportation, canned manufacture, waste management and final product to wholesale and retail market	The type of oil and packaging had a significant influence on the environmental performance of the products. Sunflower oil presented the greatest value in all environmental impact categories and aluminum is more eco-friendly product than others.
(Zufia & Arana, 2008)	Life cycle assessment to eco-design food products: industrial cooked dish case study	2 kg tray of pasteurized tuna with tomato	Raw material extraction and farming to final disposal covered fishing, product elaboration, distribution and use and elimination	The tuna ingredient has the greatest impact because it is transported by airplane at freezing temperatures from the South Atlantic Ocean to Spain. Plastic packaging, natural gas, and electrical consumption have a significant impact in the majority of categories, whereas waste management has no effect on the overall environmental impact.
(Iribarren et al., 2010)	Life Cycle Assessment of fresh and canned mussel processing and consumption in Galicia (NW Spain)	1 kg of commercial canned mussel flesh for consumption	Mussel culture, mussel transformation in canning factories covered initial operations, processing, final operation, ancillary operations as well as canned mussel consumption	The canned mussel production contributed the greatest of fresh water aquatic ecotoxicity potential (FETP) and terrestrial ecotoxicity potential (TETP), while the ancillary operations subsystem contributed ozone layer depletion potential (ODP) and terrestrial ecotoxicity potential (TETP) and the final operations subsystem was the main contributed to marine aquatic ecotoxicity potential (METP) and fresh water aquatic ecotoxicity potential (FETP).
(Avadí et al., 2015)	Life cycle assessment of Ecuadorian processed tuna	1 ton of tuna product	Cradle-to-gate	The processing should focus on fuel performance and container technology, which would increase the use of larger tinplate cans, aluminum cans, or other non-metal container technologies and reduce tuna processing's environmental impact.
(Hospido et al., 2006)	Environmental assessment of canned tuna manufacture with a life-cycle perspective	1 ton of raw frozen tuna entering the factory	Cradle-to-grave approach covered the factory process to disposal of the wastes generated during the production and the consumption stages, which consist of reception, thawing and cutting, cooking, manual cleaning, liquid dosage and filling and sterilization	Both acidification and global warming are impact categories where efforts must be directed in order to reduce the overall impact of canned tuna manufacturing processing. Processing contributes the most to both categories, with nearly 85 and 95 percent, respectively.
(Almeida et al., 2015)	Environmental Life Cycle Assessment of a Canned Sardine Product from Portugal	1 kg of edible product of canned sardines	Cradle-to-gate covered the production of supply materials, transportation to the factory and the canning process	Can manufacturing and olive oil production are the two processes with the highest contributions in six categories: CED, GWP, POP, METP, ADP, and AP, while olive oil adds ODP and EP. A potential improvement is to replace the aluminum can with plastic, which is a significant improvement option.

2.5 Clean Technology

Strategies for continuously improving products, services, and processes in order to manage resources more efficiently. At the same time, the environmental and production costs are being reduced (Lohsomboon & Jirajariyavech, 2004).

2.5.1 Principles of Clean Technology

2.5.1.1 Reducing pollution at source

- Product modifications: Design products to have a low environmental impact or to last longer, for example, by reducing unnecessary packaging.

- Manufacturing procedure modifications
  - Input Material Change: It is the use of high-quality or pure raw materials, as well as the reduction or elimination of hazardous raw materials consumption to avoid introducing contaminants into the manufacturing process.
  - Technology Improvement: It is to reduce waste and pollution, redesign production systems or adopt modern technology. The conditions for technological innovation include the 5 M: Material, Machine, Man, Measurement, and Method.
  - Operational Management**:** It improves existing production methods by employing techniques that simplify production flows, resulting in less production waste.

2.5.1.2 Reuse

- Utilization of renewable resources: It utilizes low-quality raw materials or finds a way to take full advantage of substances, materials found in waste by reusing them in the original manufacturing process and other manufacturing processes.
- Utilization of renewable technology: It puts waste through processes that allow it to be reused or turned into a byproduct.

2.5.2 Step of Clean Technology

2.5.2.1 CT Planning & Organization: Planning and teaming are intended to demonstrate cooperation in setting goals for the development of clean technologies (Industries, 2021).

- **Pre-assessment:** It determines the initial scope of consideration and evaluation of which issues have an impact and can be improved.
- **Detail assessment:** It balances the mass and energy input-output to determine the source of waste and the causes of loss, and then analyzes the solutions.
- **Feasibility study:** It is intended to prioritize the choice derived from step 3 (Detail assessment) by carefully considering three aspects: technical, economic, and environmental.
- **Implementation & evaluation:** It defines a detailed roadmap, including target area procedures, duration, and responsibility. When the steps are completed, evaluations should be performed to ensure that the practice adheres to the defined plan.

2.5.2 Clean technology Related Research

Table 2 summarizes Clean Technology literature covering author, title and result.

Table 2 Clean technology-related research

Author	Title	Result
(Tangjitpornchai, 2008)	The assessment of the potential use of clean technology for the canned pickles production of the peace canning (1958) Co., Ltd.	Employee used hands rather than machines, and the machine channel transporting the pickles were too small, resulting in pickle loss. Installing taller borders on the Table to reduce waste was one of the improvements.
(Sumransub, 2006)	Application of cleaner technology in the canning of sweet corn kernel	Sorting corn size before entering the production process, increasing the number of blade sharpening times to two per shift, and reducing furnace oil loss were accomplished by insulating the steam pipeline to reduce heat loss and proposed. The plant installed an airborne oxygen meter to optimize the pot combustion system of the stream.
(Thepphan & Rattana, 2008)	Application of clean technology in the environmental quality management of the industrial factory in Tha Chin Watershed	The problems with applying clean technology were that administrators believed that clean technology was expensive and that employees lacked knowledge.
(Chaiwong, 2003)	Application of clean technology on production of frozen fresh soybean	The loss of water consumption was the most crisis-related. The washing water from the individual quick freezing belt conveyor was reused in the pre-washing of fresh raw material.
(Phuttirat, 2008)	Implementation of Clean technology of Thai Vermicelli Factory	The most critical resource that needed to be improved was the loss of water. The loss was caused by practice and technology.
(Kanchanwong, 2011)	Cost Reduction in Canned Food Production Processing Using Cleaner Technology	The most critical loss of water consumption and steam were sterilization and cooling. The improvements included reusing used water from washing can packaging, insulating the retort to reduce steam, and installing the control machine at the retort.
(Uttamangkabovorn, 2001)	Cleaner Production in the Seafood Canning Industry	Installing pressure spraying nozzles at the spray cooling process reduced 45 degrees to open water valve, using hot water and releasing every 4 hours for can washing (after seaming) process, and educating plant personnel on water conservation in equipment and floor washing process were all options for reducing water consumption. The improvement of solid waste was sold at a low cost.

CHAPTER 3

Methodology

3.1 Life Cycle Assessment

3.1.1 Goal and Scope Definition

The goal is to evaluate the environmental impact of canned fish production using 1 ton of frozen fish (excluded residue) from the canned fish production using Life Cycle Assessment (LCA). The methodology shown in Figure 4 included goal and scope definition, collecting data, assessment of the environmental impacts, clean technology, suggestion and conclusion.

- Scope of the study: Environmental impact assessment based on Life Cycle Assessment (LCA), which evaluates all resources used in canned fish production.
- Goal: Manufacturers can implement suggestions to improve production to reduce environmental impacts and improve resource consumption.
- Function: Canned fish, which is a ready-to-eat product, is used in this study.
- Functional Unit: Raw material input of frozen fish 1 ton (excluded residue) in the canned fish production

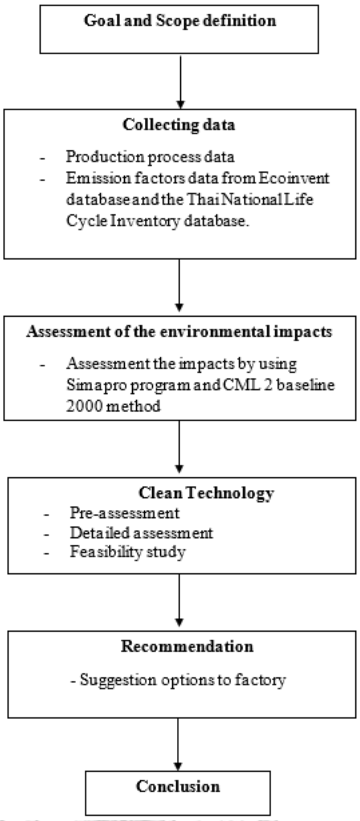

Figure 4 Diagram of Methodology

3.1.2 Life Cycle Inventory (LCI)

3.1.2.1 Collecting data

➢ Production data: The data were obtained from manufacture, such as the inventory input-output survey of canned fish production.

➢ Emission factor: The Ecoinvent database and the Thai National Life Cycle Inventory database were used to compile emission factors.

3.1.2.2 Lists of the data

➢ Primary data: It should collect data at least 50% of raw material samples entering the factory, which collects production data at least 12 months in 2021 with XXX Company in Samut Sakhon province (*TGO, 2020*).

- Total product volume obtained in 2021
- Total amount of output produced (e.g., Wastewater, air emission or stream)
- The number of raw materials consumed in the entire production
- The total amount of energy consumed during the entire production

- The amount of energy consumed, which includes the input and output of the support system, such as a steam system, canning production or seasoning production.
- The total amount of water consumed in each manufacturing process
- The quantity of water consumed in the support process, such as the steam system

➢ Secondary data: The data from the Ecoinvent database, Thai National Life Cycle Inventory Database and Technology and Informatics Institute for Sustainability (TIIS)
  - Emission factor of rubber wood
  - Emission factor of electricity
  - Emission factor of water consumption
  - Emission factor of stream consumption
  - Emission factor of packaging
  - Emission factor of chemical
  - Emission factor of solid waste

3.1.3 Life Cycle Impact Assessment (LCIA)

3.1.3.1 Characterization: Using the CML 2 baseline 2000 method that is very common in LCA for seafood (Pelletier et al., 2007). and widely used in previous LCA of seafood products (Avadí et al., 2014). The ten impact categories consist of acidification potential (AP), ozone layer depletion potential (ODP), abiotic depletion potential (ADP), global warming potential (GWP), eutrophication potential (EP), photo- chemical oxidant formation potential (POFP), freshwater aquatic ecotoxicity potential (FETP), marine aquatic ecotoxicity potential (METP), terrestrial ecotoxicity potential (TETP), and human toxicity potential (HTP). The characterization is used to calculate by equation (Punpaphatporn Bunprom, 2013)

$$\boxed{EP_j = \sum(Q_j x EF_{ij})}$$

EP_j (potential environmental impacts) = potential environmental impacts of J Impacts

Q_j (Quantity of substance) = Quantity of substance J that was emitted (kg of substance j)

EF_{ij} (Equivalency factor) = Equivalency factor of substance i that causes environmental impact j (kg Substance Equivalent/kg Substance j)

3.1.3.2 Normalization: This step is calculated by equation (Punpaphatporn Bunprom, 2013)

$$NP_j(product) = \frac{EP_j}{TxER_j}$$

NP_j (Product) = Normalized Environment Impact Potential of product j (Person)

T = Lifetime of Product (Year)

ER_j = Normalization Reference of environmental impact at J per person, per year (kg Substance Equivalent/ Person/ Year)

3.1.4 Interpretation

It is a step toward reducing environmental impacts. It is known what process has the greatest impact that leads to the identification of solutions. Interpretation, on the other hand, should be based on boundaries.

3.2 Clean Technology

The Clean Technology steps are suggested by Department of Industrial Works, which are as follows (Kitti, 2017).

3.2.1 Pre-assessment: The goal of the pre-assessment is to provide information about the factory's production and related environmental issues. The team can use important tools, such as the production process plan, to explain the production process, and this production process plan will be used for mass balance in the next step to do a detailed assessment.

3.2.2 Detailed assessment: This step involves developing pollution prevention methods or clean technology alternatives that can be implemented right away. This step yields the input-output balance, mass balance, and energy balance.

3.2.3 Feasibility study: The objective of this step is to prioritize resources from mass balance by concern Technical, Economic and Environmental feasibility.

3.2.3.1 Technical feasibility uses International Benchmarking to compare each resource production factor with the final product using the following equations (Jaritantiwet, 2017):

$$\text{Technical feasibility}(\%) = \frac{\text{Average index value} - \text{The best index}}{\text{The best index}} \text{x100}$$

$$\text{Index} = \frac{\text{Resource consumption}}{\text{Product capacity}}$$

3.2.3.2 Economic feasibility compares each resource cost by using the following equations (Jaritantiwet, 2017):

$$Economic\ \text{feasibility}\ (\%) = \frac{\text{feasibility value}}{\text{Sum of feasibility value}} \text{x100}$$

$$\text{Economic feasibility} = \frac{\text{Average index value} - \text{The best index}}{\text{Sum of feasibility}} \text{x Product average x expenses per unit}$$

3.2.3.3 Environmental feasibility considers pollution quality (Q), effect (E), and distribution (D) to evaluate environmental feasibility using a weighted score from the index (Jaritantiwet, 2017).

Index = Q x E x D

3.2.4 Weighted scoring based on the feasibility

Combine all calculated feasibilities to prioritize the use of resource using the following equations (Jaritantiwet, 2017):

$$\text{Sum of the feasibility} = (S1 + \text{W1}) + (S2 + W2) + (S3 + W3)$$

S1 = Technical feasibility score

S2 = Economic feasibility score

S3 = Environmental feasibility score

The weight value of the score, which ranges from 1-3, is determined by the priorities provided by the team that can improve the use of resources accurately.

W1 = Weighted value of technique

W2 = Weighted value of economy

W3 = Weighted value of environment

3.3 Suggestions

The suggestion for improvement is to reduce the use of resource inputs, which leads to pollution control from the production, as well as the quality of life of people in the workplace and surrounding communities, thereby creating economy, social, and environmental business operations. Furthermore, the manufacturer can apply the improvement to all processes, resulting in increased production efficiency as well as lower environmental impacts.

CHAPTER 4

Results and Discussions

4.1 Life Cycle Assessment of canned fish product

The Life Cycle Assessment scope is gate-to-gate consideration that collects only type and quantity of inventory data (secondary data) because the factory could provide some primary data. The process includes raw material preparation, packaging in container, sterilization, and labeling by considering direct environmental impact from processes such as emitted pollution from the production process resulting from the activity of resource consumption. However, it does not consider wastewater and solid waste in all categories acceptep in global warming category due to data limitation. Following an environmental impact assessment, there are five significant environmental impacts consisting of human toxicity, global warming, marine aquatic ecotoxicity, freshwater aquatic ecotoxicity, and terrestrial ecotoxicity, respectively.

4.2 Life Cycle Inventory (LCI)

Input-output inventory is the process of listing all resource consumption of main processes as well as waste from the processes leading to a life cycle assessment of one product that can be compared to similar products by setting functional unit in 1 ton of fresh frozen (excluded residue) as shown in Table 3. This study, however, excludes calculation from the support system, such as softened water. Every input-output inventory is applied with cut off 0.1% of all inventories and mass allocation (MTEC, 2012), which is typically used when all products derived from a system have a unit value that does not differ significantly and are not energy products (All calculation of mass allocation and cut off are shown in appendix B).

4.3 Characterization

Life Cycle Assessment considers 10 environmental impacts following CML 2 baseline 2000 method and uses emission factors from Thai National LCI Database, Eco-invent database and Food Intelligence Center, which result of characterization shows in Table 4 and Figure 5.

Table 3 Input-output inventory of processes

Inventory	Detail	Quantity in 2021	Quantity per 1-ton fish production (without residue)	Unit
Input	Water	58,010	22.51	m^3
	Electricity	2,088,974	688.61	kWh
	Steam	2,532,529	834.82	kg
	Printed label	74,526.58	28.93	kg
	Tin plate	1,140,842.66	442.80	kg
	Board box	338,075.80	131.22	kg
	Fish	4,155,572.47	1612.90	kg
	Ice	831,114.49	200	kg
	Tomato Sause	231,019.11	89.67	kg
	Flour	158,843.39	61.65	kg
	Salt	76,633.98	29.74	kg
	Sugar	85,575.36	33.21	kg
Output	Canned fish	37,889,422	14,706	can
	Wastewater	168,181.70	65.28	m3
	Fish residue*	977,839.11	612.90	kg
	Plastic waste	64,675	25.10	kg
	Can waste	4,160	1.61	kg
	Sack waste	420	0.16	kg

* Fish residue is recycled, which is not considered in the assessment, and the emission factor is assumed to be zero (TGO, 2020)

Table 4 Characterization of 1-ton frozen fish production

		Water kg	Electricity	Stream kg	Printed paper kg	Tin plate m2	board box	Fish	ice	Salt	Tomato sauce	flour	sugar	Wastewater	Plastic waste	Can waste	Sack waste
Quantity		2.25E+04 kg	6.89E+02 kWh	8.35E+02 kg	2.87E+01 kg	9.06E+02	1.31E+02 kg	1.61E+03 kg	2.00E+02 kg	2.97E+0 kg	8.97E+01 kg	6.17E+01 kg	3.32E+01 kg	6.53E+01 m3	2.50E-02 ton	1.60E-03 ton	1.60E-01 kg
Impact categories	Unit																
Abiotic depletion	kg Sb eq	6.35E-06	2.08E-04	4.62E-02	3.39E-05	3.59E-02	3.40E-05	4.95E-04	1.39E-03	1.86E-06	7.78E-06	2.05E-05	8.80E-06	-	-	-	-
Acidification	kg SO2 eq	4.73E-06	1.54E-04	1.76E-01	2.20E-05	2.98E-02	2.64E-05	2.00E-04	8.94E-04	2.27E-06	8.22E-06	2.72E-05	1.18E-05	-	-	-	-
Eutrophication	kg PO4 eq	2.36E-06	3.06E-02	4.88E-02	8.84E-06	9.96E-03	2.64E-05	8.27E-05	2.26E-03	1.11E-07	4.70E-06	2.04E-05	1.87E-05	-	-	-	-
Global warming	kg CO2 eq	6.94E+00*	4.12E+02	1.56E+03	4.69E+01	5.47E+00	5.05E-03	3.34E+02	1.05E+02	3.33E-04	1.43E-03	4.13E-03	1.76E-03	8.42E+00	-1.04E+01	-1.78E-02	3.20E-01
Ozone layer depletion	kg CFC-11 eq	9.05E-10	4.23E-10	6.07E-05	2.96E-10	2.93E-07	8.61E-10	1.71E-09	4.34E-08	0.00E+00	2.01E-10	1.69E-10	2.61E-11	-	-	-	-
Human toxicity	kg 1,4-DB eq	1.06E-03	2.53E-12	3.71E+03	3.99E-03	8.06E+01	2.30E-02	3.78E-02	1.68E-01	2.15E-06	1.24E-03	2.58E-04	5.71E-04	-	-	-	-
Fresh water aquatic ecotox	kg 1,4-DB eq	6.10E-04	7.57E-03	7.51E+00	1.77E-03	1.49E+01	4.99E-03	1.65E-02	9.30E-02	1.75E-06	3.87E-04	1.23E-03	2.37E-03	-	-	-	-
Marine aquatic ecotox	kg 1,4-DB eq	1.08E+00	1.63E+01	9.18E+03	3.78E+00	1.47E+04	1.68E+01	3.34E+01	1.65E+02	1.18E-03	5.93E-01	3.01E-02	2.40E-02	-	-	-	-
Terrestrial ecotoxicity	kg 1,4-DB eq	1.08E-05	4.56E-05	2.61E+00	1.76E-05	1.07E-01	6.62E-05	1.37E-04	1.49E-03	5.89E-07	4.90E-06	3.21E-04	7.27E-06	-	-	-	-
Photochemical oxidation	kg C2H4 eq	2.52E-07	5.80E-06	2.33E-02	1.09E-06	1.75E-03	1.85E-06	9.42E-06	4.86E-05	1.12E-07	3.02E-07	5.29E-07	1.99E-06	-	-	-	-

*Calculated emission factors at 0.2840 kg CO_2 eq per m^3

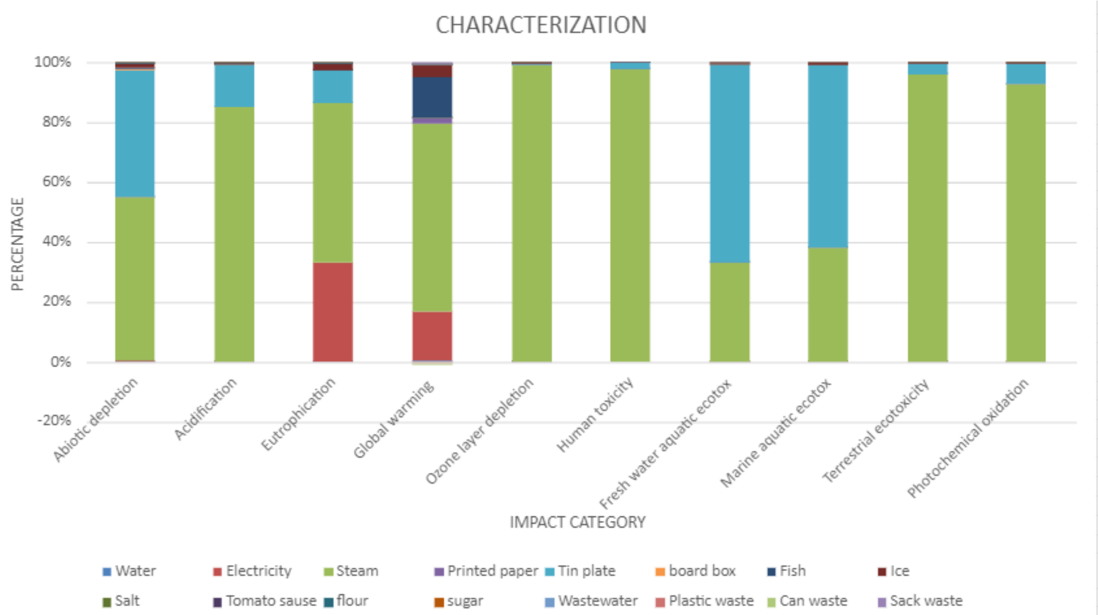

Figure 5 Result of characterization

4.3.1 Global Warming

It is a calculation of the Global Warming Potential (GWP) caused by increased greenhouse gas emissions, based on Carbon Dioxide Equivalent. Greenhouse gas (GHG) emissions are the primary cause of global warming, which are CO_2, CH_4, CO, and N_2O. Environmental assessment concerning frozen fish preparation until packing to box shows that global warming category emitted 2,470 kg CO_2 eq/ FU compared to all categories. The top three causes of the category are resource consumption in steam (63%) followed by electricity consumption (17%) and fish consumption (13%), respectively as shown in Figure 6.

To generate steam, wood is burned in the process. Burning wood emits methane and black carbon particles, both of which have been proposed as significant contributors to global warming. (Savolahti et al., 2019). The global warming category was the main impact category of provincial electricity production (Greadmeta, 2016) because of machines in production, especially from froze fish before entering the processes.

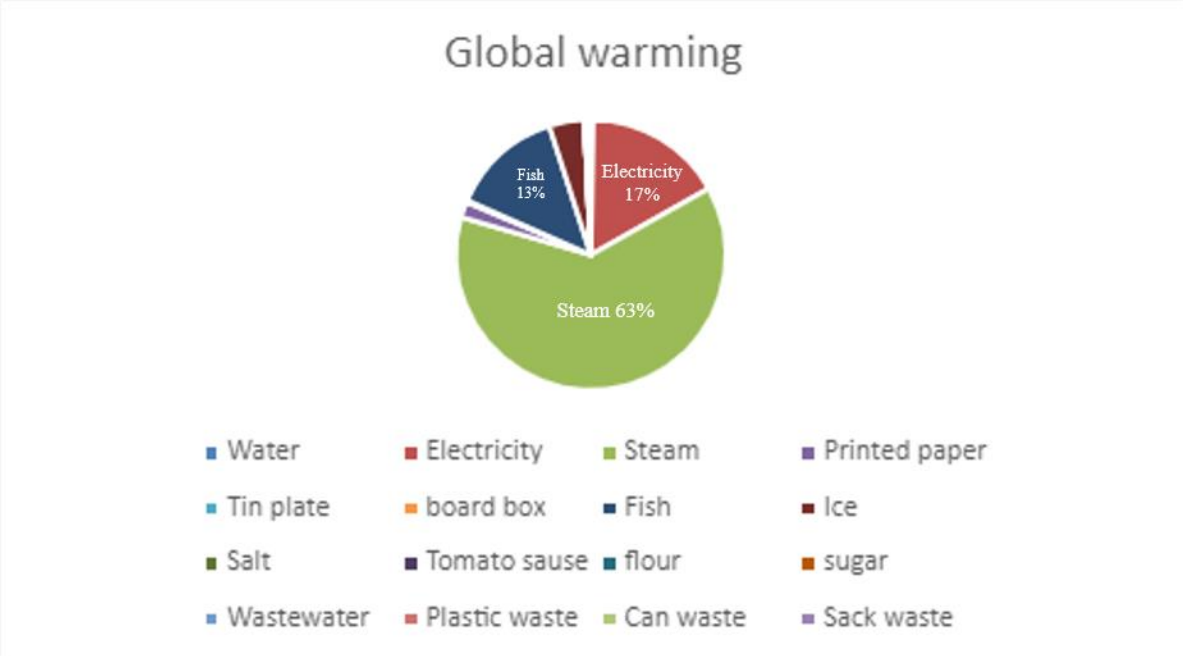

Figure 6 Global Warming characterization

4.3.2 Human Toxicity

This category is concerned with the effects of toxic substances on human health. The health risks of exposure in the workplace are not included. The HTP is based on 1,4-Dichlotobenzene (Yan, 2005), which is the cause of cancer, respiratory diseases, non-cancerous diseases, and diseases that cause ionizing radiation effects. Environmental assessment concerning frozen fish preparation until packing to box shows that human toxicity category emitted 3,800 kg 1,4-DB eq/ FU compared to all categories. The consumption of steam is significantly higher at 98%, followed by tin plate consumption in can production at 2% as shown in Figure 7.

The primary cause of human toxicity was incomplete combustion of para wood in steam and fly ash dumping, both of which caused respiratory system problems (Yamsorn, 2017). The characterization results suggest emissions to atmosphere are the major contribution to human toxicity.

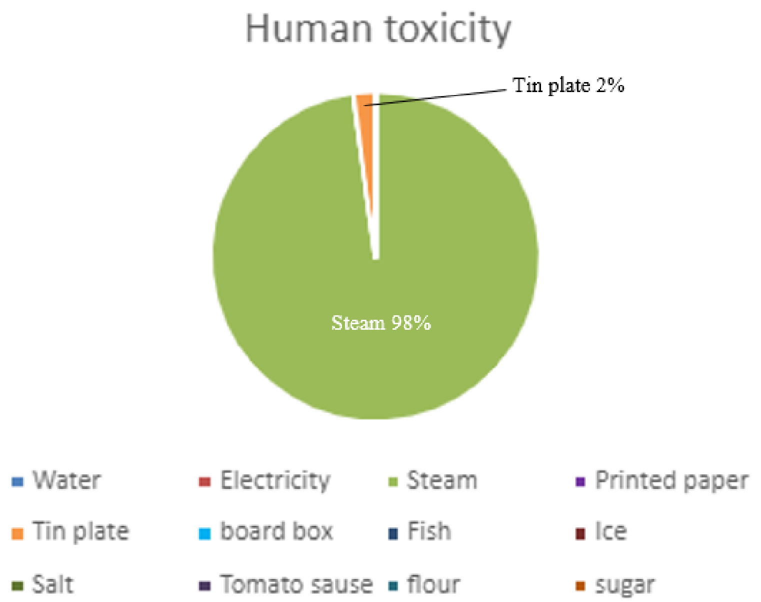

Figure 7 Human Toxicity characterization

4.3.3 Freshwater aquatic ecotoxicity

The Eco-toxicity Potential (FAETP) of toxic substances describes the fate, exposure, and effects of toxic substances. Characterization factors are measured in 1,4-dichlorobenzene equivalents per kilogram of emission. Environmental assessment concerning frozen fish preparation until packing to box shows that freshwater aquatic ecotoxicity category emitted 22.5 kg 1,4-DB eq/ FU compared to all categories. The consumption of tin plate in packaging consumption is significantly higher at 66 %, followed by consumption of steam at 33% as shown in Figure 8.

High metal concentrations, even of essential metals, can have a negative impact on freshwater ecotoxicity due to consumption tinplate packaging ("Environmental Toxicity of Metals in Freshwater," 2020). Steam production, moreover, emitted air pollution, soil pollution, as well as water pollution on freshwater ecosystem due to flying ash and incomplete combustion.

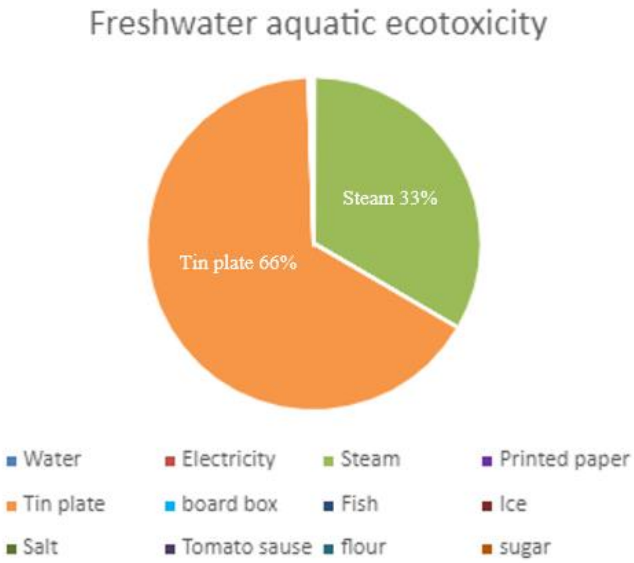

Figure 8 Freshwater aquatic ecotoxicity characterization

4.3.4 Marine aquatic ecotoxicity

Characterization factors are measured in 1,4-dichlorobenzene equivalents per kilogram of emission. Environmental assessment concerning frozen fish preparation until packing to box shows that marine aquatic ecotoxicity emitted up to 24,100 kg 1,4-DB eq/ FU compared to all categories. The consumption of tin plate in packaging production is significantly higher at 61%, followed by consumption of steam at 38% as shown in Figure 9.

Tinplate was used in canned fish containers in the factory, which is essentially a steel product because it is light gauge steel strip coated with tin on both surfaces and as an agent to remove carbon-based contamination from metal. Metals can be transported in dissolved form or as particulate matter in streams and rivers. They travel through the atmosphere as particulate matter, aerosols, and, in the case of some metals (for example, Hg), as vapor (D.Álvarez-Muñoz, 2016). Another significant cause of marine aquatic ecotoxicity is the combustion of wood to generate steam, which produces polycyclic aromatic hydrocarbons (PAHs), one of the most significant environmental pollutants. They are commonly produced as byproducts of combustion processes (Julián Blasco, 2016).

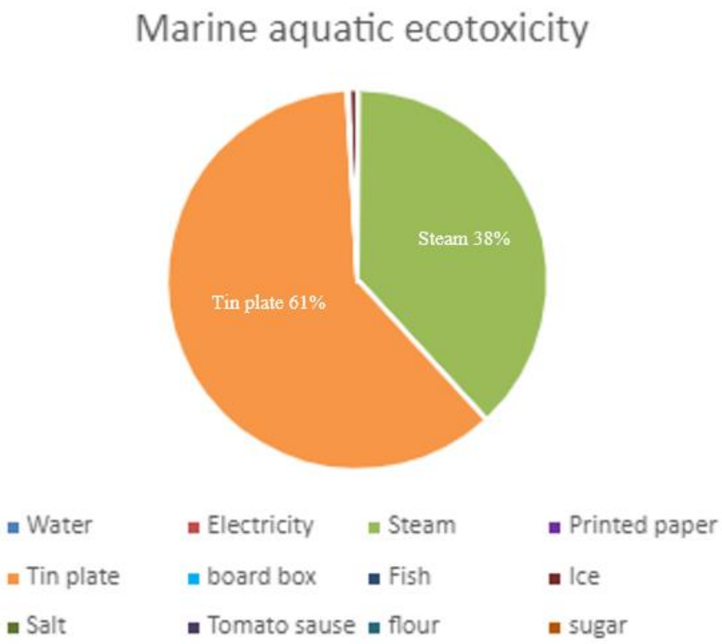

Figure 9 Marine aquatic ecotoxicity characterization

4.3.5 Terrestrial ecotoxicity

Terrestrial Ecotoxicity is the analysis of the potential for ecosystems to degrade because of toxins, which characterization factors are measured in 1,4-dichlorobenzene equivalents per kilogram of emission. Environmental assessment concerning frozen fish preparation until packing to box shows that terrestrial ecotoxicity emitted 2.72 kg 1,4-DB eq/ FU compared to all categories. Steam consumption is significantly higher at 96.0% followed by tin plate in packaging production at 4% as shown in Figure 10.

Due to burning wood in steam production, burning process produces polycyclic aromatic hydrocarbons (PAHs). Moreover, terrestrial ecotoxicity is dominated by steam during the conversion process (Aiduan Li Borrion, 2012). The factory also dumps fly ash in landfill. Fly-ash also has an impact on soil physicochemical properties because it is generally very basic, rich in various essential and non-essential elements, but low in nitrogen and available phosphorus (Dharmendra K. Gupta, 2022). Therefore, to avoid the possibility of causing harm to human health or the environment, fly ash must be stabilized, encapsulated, and made hygienic by removing pollutants (Takayuki Shimaoka, 1997).

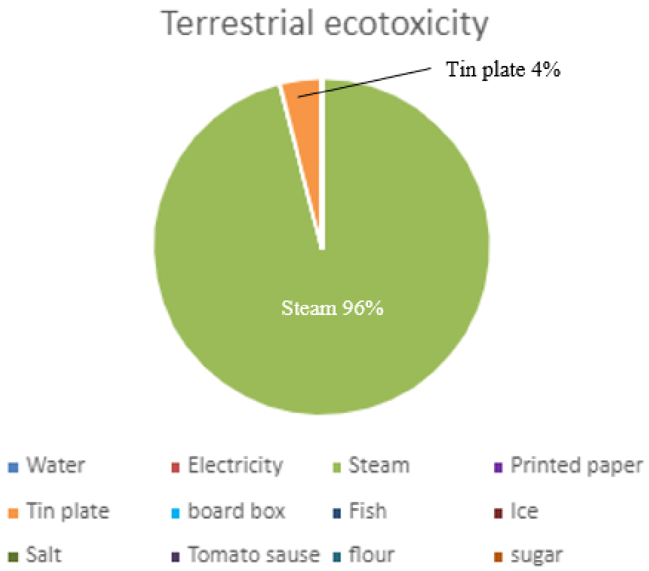

Figure 10 Terrestrial ecotoxicity characterization

4.4 Normalization

There are five significant impact assessments in canned fish production followed by human toxicity (6.65E-11 Pt or 33.9%), global warming (5.95E-11 Pt or 30.3%), marine aquatic ecotoxicity (4.7E-11 Pt or 23.9%), freshwater aquatic ecotoxicity (1.10E-11 Pt or 5.16%) and terrestrial ecotoxicity (1.01E-11 Pt or 5.15%), respectively as shown in Figure 11. (Detail of calculation was shown in Appendix A)

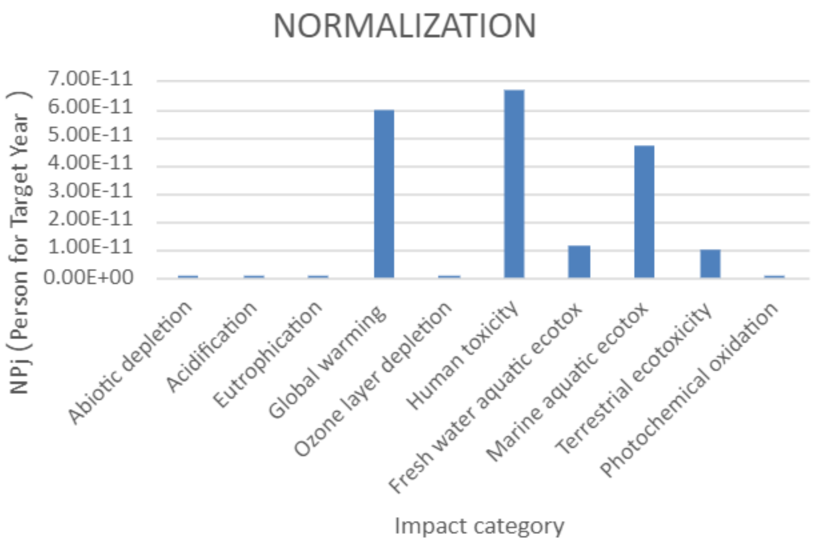

Figure 11 Normalization

Note: Pt = Person for Target Year

4.5 Hotspot specification

The identification of hotspots in five impact categories will assist in minimizing the most effective and significant environmental impact, which should be improved in production. Steam consumption is the highest hotspot in human toxicity, global warming, and terrestrial ecotoxicity. Packaging consumption is the highest hotspot in freshwater aquatic ecotoxicity and marine ecotoxicity. Figure 12 depicts these hotspots.

Based on input and output data, the results show that packaging and steam consumptions are the most significant in all hotspots, accounting for 49% and 48%, respectively, followed by ingredient and electricity consumptions, as shown in Figure 13. However, ingredients and solid waste were not included in Clean Technology to prioritize resources consumption and provide options due to a lack of data and a lower environmental impact.

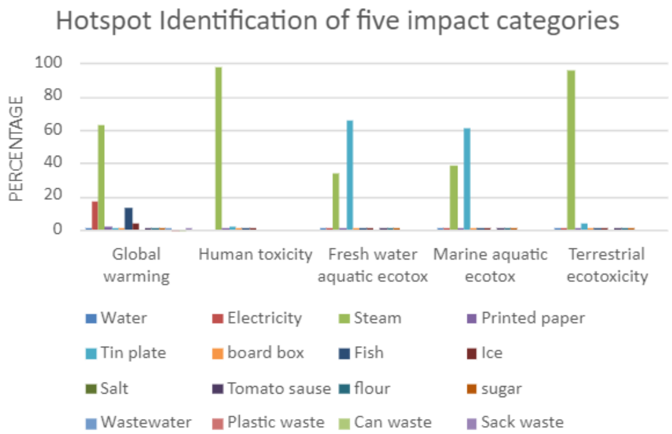

Figure 12 Hotspot identification of five impact categories

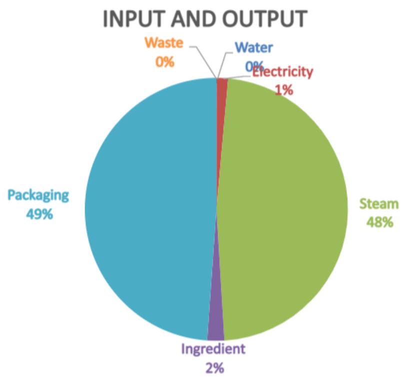

Figure 13 Percent of input-output consumption

4.6 Clean Technology (CT)

4.6.1 Pre-assessment

Details of canned fish production identify input and output in the main processes of raw material preparation, container packaging, sterilization, and labeling, as illustrated in Figure 14 and Appendix D.

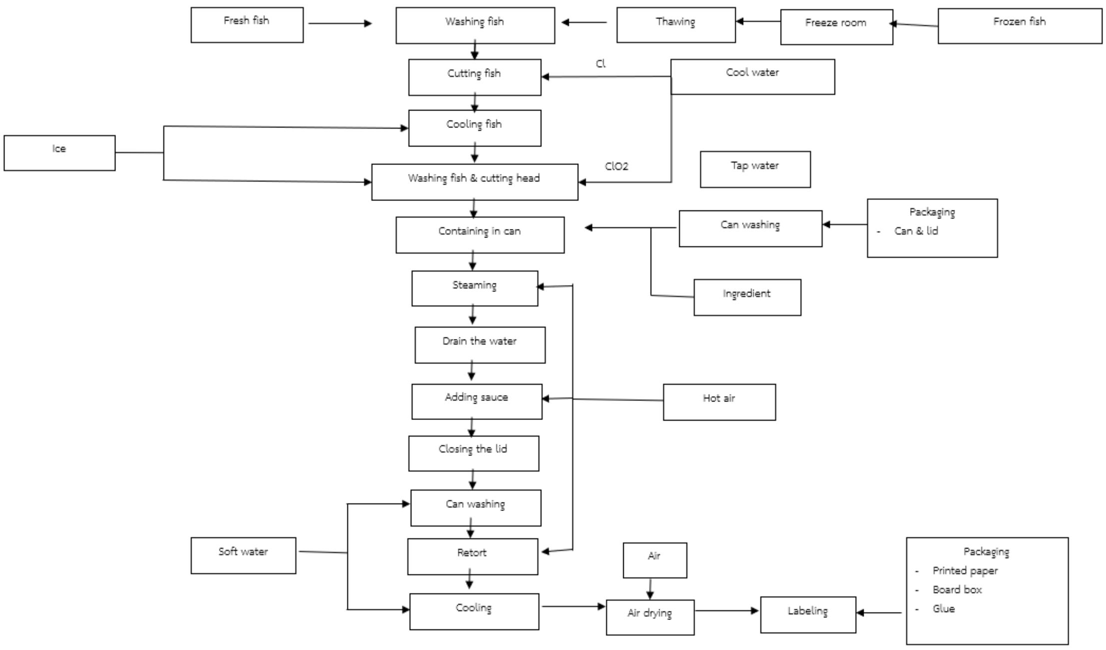

Figure 14 Canned fish process
Reference: A factory in Samut Sakorn, 2021

4.6.2 Detailed assessment

The mass balance entering the factory in 2021 consists of resource input, packaging, chemicals, ingredients, main products, secondary products, solid waste and wastewater, as illustrated in Figure 15.

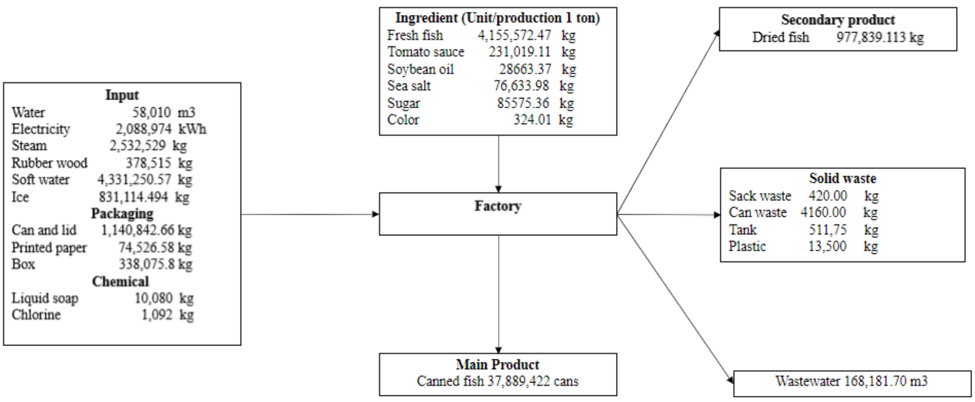

Figure 15 Mass balance

4.6.3 Feasibility study

As part of the pre-assessment step, a detailed assessment of canned fish processing was conducted, focusing on the main processes and verifying the mapping and mass balance. Afterward, by feasibility study step, prioritize all resources entering the factory in technical feasibility, economic feasibility, and environmental feasibility (accepted ingredients and waste consumption due to lack of data and a lower environmental impacts). The Table 5 depicts the product, energy, and resources consumption in the production in 2021.

4.6.3.1 Basic assessment

Table 5 Inventory of canned fish production in 2021

Detail	Unit	Expense (baht/unit)	Quantity												Average	The best key factor	Total
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec			
Product	kg		280,865	250,212	56,541.25	148,103	574,406.19	502,715	306,356	691,737	771,385.50	519,333.45	610,223.80	510,690	435,214.02		5,222,568.1900
Electricity	kWh	3.31	181,584	139,661	188,111	229,825	154,943	143,907	102,728	188,642	182,849	220,960	218,683	137,081			2,088,974
Key factor of electricity			0.6465	0.5582	3.3270	1.5518	0.2697	0.2863	0.3353	0.2727	0.2370	0.4255	0.3584	0.2684	0.7114	0.2370	
Water	kg	0.023	5,474,000	3,836,000	4,436,000	3,358,000	5,391,000	4,935,000	3,196,000	5,558,000	4,306,000	5,852,000	6,329,000	5,066,000			58,010,000
Key factor of water			20.4618	15.3310	78.4560	22.6734	9.3853	9.8167	10.3997	8.0348	5.5822	11.2683	10.3761	9.9199	17.6417	5.5822	
Steam	kg	1.35	127,812	125,957	168,449	59,847	241,589	212,642	194,295	309,602	327,883	286,390	275,934	202,129			2,532,529
Key factor of steam			0.4551	0.5034	2.9792	0.4041	0.4206	0.4230	0.6342	0.4476	0.4251	0.5515	0.4522	0.3958	0.6743	0.3958	
Can+lid	kg	102	58,110	51,768	67,849.50	30,642	118,842.66	104,010	63,384	143,118	159,597	107,448.30	126,253.20	105,660			1,136,682.66
Key factor of can and lid			0.2069	0.2069	1.2000	0.2069	0.2069	0.2069	0.2069	0.2069	0.2069	0.2069	0.2069	0.2069	0.2897	0.2069	
Label	kg	75.38	2,518.20	2,243.28	2,940.15	1,327.82	5,149.85	4507.10	27,466.40	6,201.78	6,915.87	4,656.09	5,470.97	4,578.60			73,976.11
Key factor of label			0.0090	0.0090	0.0520	0.0090	0.0090	0.0090	0.0090	0.0090	0.0090	0.0090	0.0090	0.0090	0.0193	0.0090	
box	kg	2.04	3,874	34,512	45,233	20,428	79,228.40	69,340	42,256	9,541.20	10,639.80	7,163.20	8,416.80	7,044			337,676.40
Key factor of box			0.0138	0.1379	0.8000	0.1379	0.1379	0.1379	0.1379	0.0138	0.0138	0.0138	0.0138	0.0138	0.1310	0.0138	

Note: $Key\ factor = \frac{Resource\ quantity}{Productivity}$

$$Average\ key\ factor = \frac{Sum\ of\ key\ factors}{Number\ of\ key\ factors}$$

The best key factor is the lowest value of each resource.

4.6.3.1.1 Technical feasibility

The feasibility of each resource is determined by identifying the potential or opportunities for technical improvement as shown in Table 6.

Table 6 Result of technical feasibility

Resource	Average key factor	The best key factor	Technical feasibility	Score S1 (1-3)
Electricity	0.7114	0.2370	200.1688	1
Water	17.6417	5.5822	210.0350	1
Steam	0.6743	0.3958	70.3638	1
Can and lid	0.2897	0.2069	40.0193	1
label	0.0193	0.0090	114.4440	1
box	0.1310	0.0138	849.2754	3

Note $Technical feasibility = \frac{Average\ key\ factor - The\ best\ key\ factor}{The\ best\ key\ factor} x100$

Score = $\frac{Max - Min}{3}$

$= \frac{849.2754 - 40.0193}{3} \approx 270$

Scoring criteria: 0 – 270 = 1 score

271 - 539 = 2 score

More than 540 = 3 score

4.6.3.1.2 Economic feasibility

The feasibility is determined by comparing the saved expenses by concern cost, average key factor, and best factor as shown in Figure 7.

Table 7 Result of economic feasibility

Resource	Unit	Expense (baht/unit)	Average key factor	The best key factor	Feasibility	Economic feasibility %	Score S2 (1-3)
Electricity	kWh	3.31	0.7114	0.2370	683,400.91	13.4386	1
Water	kg	0.023	17.6417	5.5822	120,714.66	2.3738	1
Steam	kg	1.35	0.6743	0.3958	163,629.59	3.2177	1
Can and lid	kg	102	0.2897	0.2069	3,675,643.49	72.2791	3
label	kg	75.38	0.0193	0.0090	337,906.25	6.6447	1
box	kg	2.04	0.1310	0.0138	104,054.45	2.0462	1
					5,085,349.35		

Note

$Feasibility = (Average\ key\ factor - The\ best\ key\ factor)\ x\ Average\ productivity\ x\ expense$

$$Economic\ feasibility = \frac{Feasibility}{Sum\ of\ feasibility} x100$$

$$\text{Score} = \frac{Max - Min}{3}$$

$$= \frac{72.2791 - 2.0462}{3} \approx 23$$

Scoring criteria: 0 – 22 = 1 score

23 - 45 = 2 score

More than 45 = 3 score

4.6.3.1.3 Environmental feasibility

The feasibility is to determine which resource has the greatest environmental impact based on Quantity (Q), Effect (E), and Dispersion (D) as shown in Figure 8.

Table 8 Result of environmental feasibility

Resource	Unit	Quantity per year	weight score			QxExD	Score S3 (1-3)
			Quantity (Q)	Effect (E)	Dispersion (D)		
Electricity	kWh	2,088,974.00	1	1	1	1	1
Water	kg	58,010,000.00	3	1	2	6	3
Steam	kg	2,532,529.00	1	3	3	9	3
Can and lid	kg	1,136,682.66	1	3	1	3	2
label	kg	73,976.11	1	1	1	1	1
box	kg	337,676.40	1	1	1	1	1

$$\text{Score} = \frac{Max - Min}{3}$$

$$= \frac{9-1}{3} \approx 3$$

Scoring criteria: 0 – 2 = 1 score

3 - 5 = 2 score

More than 5 = 3 score

Table 9 Criteria score of environmental feasibility

	1 score	2 score	3 score
Quantity (Q)	Less consumption (Quantity between 0 – 19,999,999 Unit)	Medium in consumption (Quantity between 20,000,000 – 39,999,999 Unit)	High in consumption (Quantity more than 39,999,999 Unit)
Effect (E)	Percentage of total environmental impacts from LCA Water 0.03% Electricity 1.44% Steam 48.6% Can 49.7% Label 0.17% Box 0.06% Score = $\frac{Max-Min}{3}$ = $\frac{49.7-0.03}{3}$ ≈17		
	0 – 17	18 - 37	More than 37
Dispersion (D)*	Solid	Liquid	Gas

*Reference: (Suthinprapha, 2010)

4.6.3.1.4 Weighting score based on the feasibility

Table 10 Weighted scoring to prioritize resource consumption in 2021

Resource	Technic		Economics		Environment		total score	Rank
	*F1=2		*F2=3		*F3=1			
	S1	S1xF1	S2	S2xF2	S3	S3xF3		
Electricity	1	2	1	3	1	1	6	4
Water	1	2	1	3	3	3	8	3
Steam	1	2	1	3	3	3	8	3
Can and lid	1	2	3	9	2	2	13	1
label	1	2	1	3	1	1	6	4
box	3	6	1	3	1	1	10	2

*The F1, F2 and F3 are the weighting score that could be intra-agency agreement (Kittirong, 2017)

According to Table 10, the results of clean technology in canned fish production show that packaging, water, and steam are the top three priorities that should be recommended. Water consumption has a minor environmental impact in neither LCA nor CT, however it was recommended in this study because the factory consumes a lot of tap water. Therefore, water consumption should be analyzed to solve problems.

4.6.3.2 Analysis of consumption problem-solving

The result of resource prioritization in basic assessment are packaging, water and steam consumption, respectively by using Ishikawa diagram, which is a graphical technique to show the several causes of a specific event or phenomenon (Coccia, 2017) as shown below in Figure 16, 17 and 18, which lead to suggestions.

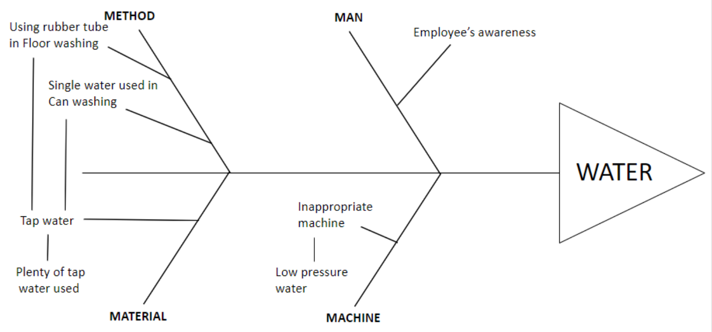

Figure 16 Ishikawa diagram to find problem in water consumption

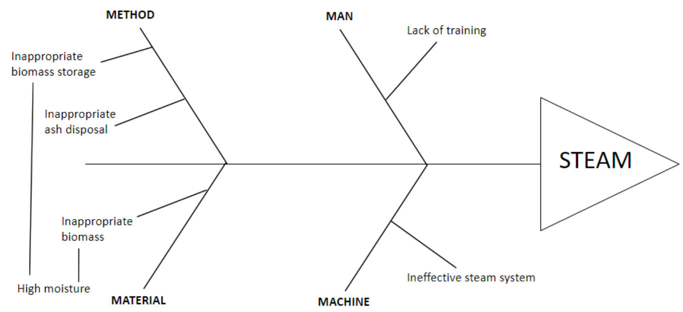

Figure 17 Ishikawa diagram to find problem in steam consumption

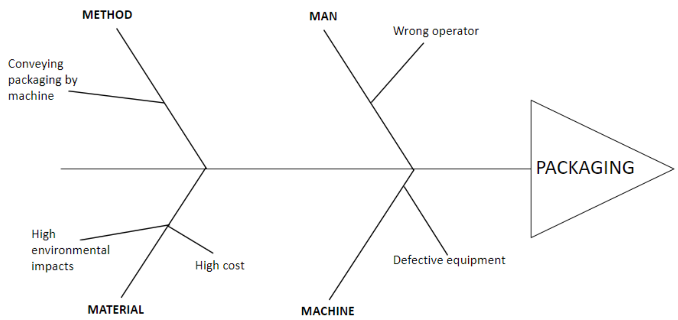

Figure 18 Ishikawa diagram to find problem in packaging consumption

4.6.3.3 Suggestions

There are two types of environmental impact assessments of resource consumption: life cycle assessment (based on environmental feasibility) and clean technology assessment (based on environmental, economic, and technical feasibility). Both tools' results indicate that packaging and steam consumption have the most significant in inventory consumption, while water was the main contributor in CT. Those of which should have been considered during production.

As a result, the suggestion to reduce resource consumption will concentrate on packaging, steam and water consumption. To make the choice approach practical in packaging, steam and water consumption, which will be used to reduce environmental impact significantly.

4.6.3.3.1 Suggestion for packaging consumption

Option 1: Using secondary packaging instead of primary packaging

The direct environmental impacts of packaging material and its end-of-life come primarily from material production and waste management, respectively (Cheila Almeida, 2022). Cardboard boxes, labels and tinplate are used in the factory for packaging, and it had the highest environmental impact in both LCA and CT because it had the most material per functional unit, tinplate generated the most non-hazardous waste (J. Laso, 2016). Replacing tinplate with aluminum for canned tuna, as proposed by (Avadí et al., 2015), would have a lower environmental impact. (Almeida et al., 2015) proposed the same replacement for canned sardine products, which resulted in a 56% reduction in climate change. According to (Hospido et al., 2006), an increase in the percentage of recycled tinplate used and the substitution of tinplate with another packaging material. Both proposals would reduce the negative environmental effects and using plastic bags instead of tinplate cans reduced global warming and acidification potential by more than half. The consumption of glass and plastic bags would improve the environmental performance of the product (J. Laso, 2016). Because it is resealable, transparent, and available in a variety of appealing shapes, sizes, and colors, glass has many appealing properties as a packaging material. It can also be heat-treated. However, it is a heavy material (which raises transportation costs), prone to breakage (a potential safety hazard if clear glass is used), and requires a well-sealed closure to prevent recontamination after processing (Hall, 2011). Plastic, on the other hand, degrades the quality of canned fish and may result in product rejection. As a result, there must be a balance struck between eco-design and consumer perception (J. Laso, 2016).

According to (J. Laso, 2016), using substitution of packaging (glass, plastic and recycled material) as primary packaging could reduce the environmental border to air by approximately 95% and the environmental border to water by 40 to 50%. Result of applying the option in this study is shown in Figure 19. Changing both primary and recycled packaging, according to (Ferrao P., 2003), would be the best way to reduce the impact assessment of the final product within various food preservation technologies. (Guillermo Pardo, 2012) proposed that the best opportunity to reduce the impact assessment of the final product within different food preservation technologies is to modify both primary and secondary packaging. However, the cost of producing recycled material is 80% higher than that of using fresh products (Oloyede & Lignou, 2021). Switching from traditional to eco-friendly packaging can be costly for many businesses (Gofersnational, 2021).

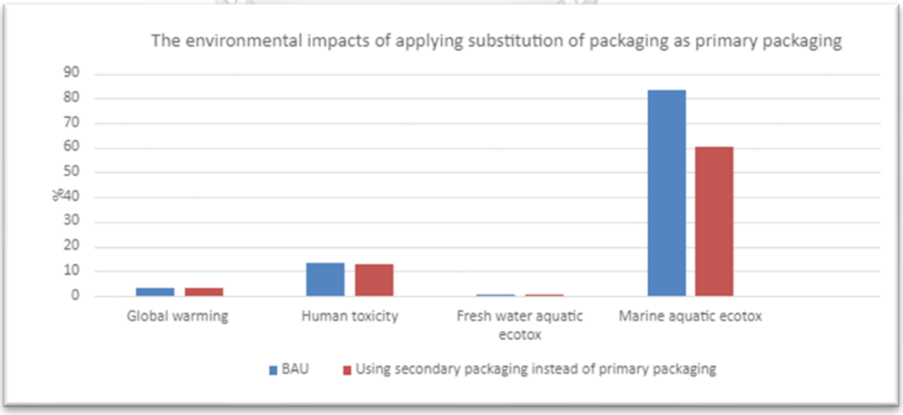

Figure 19 Result of the environmental impacts applied substitution of packaging as primary packaging in characterization

4.6.3.3.2 Suggestion for steam consumption

Option 1: Using combustible residue as a secondary combustion material in the production of steam

The factory consumes a lot of steam in comparison to other inputs and outputs. Para wood is combusted in steam production by 3,536,204.93 kg/year 2021 or 1,616.04 kg/FU, and 50 kg of biomass ash is dumped to landfill per day without reuse incompletely combustible residue, which has the greatest in human toxicity and ecotoxicity. Similar findings were obtained in other studies, such as (Lorenzo Tosti, 2019), in which the leaching of Cr from pure biomass fly ash landfilling had the greatest impact on human toxicity, carcinogenicity, and ecotoxicity. Reusing biomass residue as secondary materials benefits the majority of the impact categories while posing no unaccepTable leaching risks.

According to (Nuntawut Kongchin, 2015), the best way to reduce biomass ash and parawood consumption is to combine incompletely combustible residue with waste grease and molasses in the ratios 7.5: 4: 1 and 7.5: 4.7: 0.3 into re-charcoal product, which has 2.3 kg of incompletely combustible residue per parawood combustion in boiler 10 kg. Therefore, using combustible residue as a secondary material has the potential to reduce carbon footprint while maintaining technical and environmental (LorenzoTostia, 2018). However, the cost of molasses and machinery such as a hammer mill, mixing machine, incubator, and so on must be factored into the investment. The comparison result of kg CO_2 between unimproved and improved option 1 is shown in Figure 20. The results of option 1 are as follows

The reduction of wood consumption is 813,327 kg/year

The saving cost is = 479,863 baht/year (0.59 baht/kg x 813,327.13 kg/year)

The reduction in CO_2 from wood consumption is 38,308 kg CO_2 eq/year (0.0471 kg CO_2eq/kg x 813,327.13 kg/ year).

If a factory applies combustible residue as a secondary combustion material in the production of steam, they could save approximately 479,863 baht per year and reduce 38,308 kg CO2 eq per year.

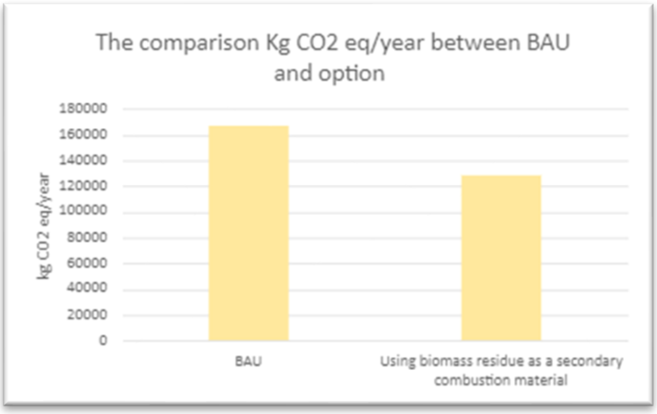

Figure 20 Result of Kg CO_2 equivalent reduction in using biomass residue as a secondary combustion material in the production of steam

Option 2: Using wood pellet biomass

Rubber wood, which burns for a longer period of time, is used to heat the factory's boiler by 3,536,204.93 kg/year. However, because of the high humidity up to 12% (Kitti, 2017) and the need for a lot of storage space, this type of biomass will have a disadvantage because the factory storage area is not suiTable for it, and it is difficult to maintain moisture. As a result, effective combustion is low when the wood is unsTable.

The boiler combustion of biomass should be optimized by improving or changing the biomass introduced for the boiler. The biomass fuel should be pellet biomass with a low moisture content assumed at 100% after improving (Kitti, 2017) and a sTable heat value (All calculations are shown in Apendic C). The comparison result of kg CO_2 between unimproved and improved option 2 is shown in Figure 21. The results are as follows

The reduction of wood is 707,241 kg/year

The saving wood cost is 417,272 baht/year

The investment value is 0 baht

Payback Period is immediate.

The reduction in CO_2 from wood consumption is 33,311 kg CO_2 eq/year.

If a factory applies using wood pellet biomass in the production of steam, they could save approximately 417,272 baht/year and reduce 33,311 kg CO2 eq per year.

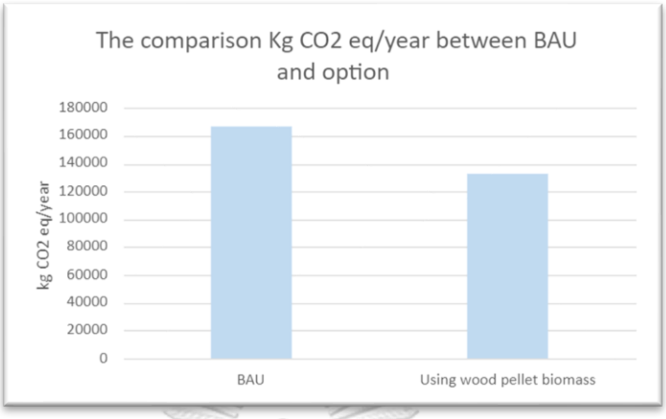

Figure 21 Result of Kg CO_2 equivalent reduction in using wood pellet biomass

Option 3: Improving the combustion of boiler

A good combustion, also known as a complete combustion, is one in which the previously occurring combustion can provide the same amount of heat as the calorific value of the fuel and has a good combustion composition. The end result of combustion will be carbon dioxide and water. The ratio of fuel to oxygen must be reasonable. The appropriate value is determined for radiators that use coal as fuel. The waste air released through the crater contains 20 - 50% excess air by weight (Pattarasathapornkul, 2005) or 4 - 7% oxygen.

Because of factors such as the condition of the air used for combustion and unsTable fuel properties, combustion cannot always be complete. The combustion control system, for example, requires us to add combustion air in order for the fuel to completely burn. However, if it adds too much air, it will lose too much heat through the chimney.

Due to exploring the factory, wood is used by 3,536,204.93 kg/year and time worker of boiler is 2200 hr/year. The 15 ton/hr boiler is used in canned food products, and the effluent oxygen content exceeded 12%, resulting in heat loss (Kitti, 2017). Therefore, installation of oxygen detectors should be used in the combustion process. The comparison result of kg CO_2 between unimproved and improved option 3 is shown in Figure 22. The results of option 3 are as follows (All calculation are shown in Apendix C).

The reduction of wood is 406,571 kg/year

The saving wood cost is 239,877 baht/year

The investment value is 300,000 baht (Kitti, 2017).

Playback Period is around 1.3 year

The reduction in CO_2 from wood consumption is 19,149 kg CO_2 eq/year.

If a factory applies improving the combustion of boiler in the production of steam, they could save approximately 239,877 baht/year and reduce 19,149 kg CO2 eq per year.

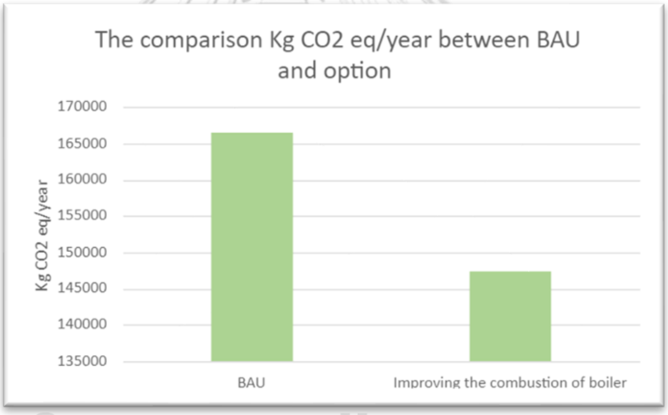

Figure 22 Result of Kg CO_2 equivalent reduction in Improving the combustion of boiler

4.6.3.3.3 Suggestion for water consumption

Option 1: Reusing washing water in can washing

Because the factory does not reuse water for processing, water consumption was prioritized first in the CT step. Returning the last water batch to the first water batch (counter current washing) can save 66.67% of the water consumed during the preparation process without any investment (Institute, 2005). The factory used up to 21,145 m3/year in the can washing process, which could reduce wastewater treatment if option 1 is applied (All calculations are shown in Appendix C). The comparison result of kg CO_2 between unimproved and improved option 1 is shown in Figure 23. The results are as follows

The reduction of water is 14,097 m^3/year

The saving water cost is 162,096 baht/year

The investment value is 0 baht.

The reduction in CO_2 from water consumption is 2,003 kg CO_2 eq/year.

If a factory applies reusing washing water in can washing, they could save approximately 162,096 baht/year and reduce 2,003 kg CO2 eq per year.

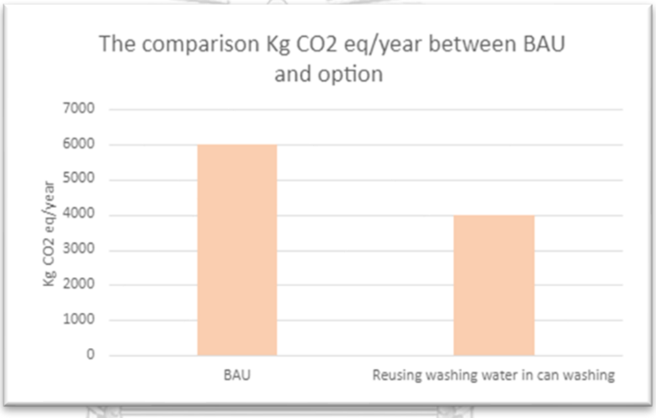

Figure 23 Result of Kg CO_2 equivalent reduction in reusing washing water in can washing

Option 2: Installing water high-pressure cleaner for washing floor

The water consumption in process is mainly caused by washing, which they use rubber tube. The quantity of washing floor is 14,933.80 m^3/year. Therefore, Installing water high-pressure cleaner for washing floor could reduce water consumption by 60% of water consumption in washing (Prathumsee, 2017) (All calculations are shown in Appendix C). The comparison result of kg CO_2 between unimproved and improved option 2 is shown in Figure 24. The results are as follows

The reduction of water is 8,960 m^3/year

The saving water cost is 138,311 baht/year

The investment value is 15,900 baht.

Payback Period is 0.08 year or 1 month.

The reduction in CO_2 from water consumption is 1,698 kg CO_2 eq/year.

If a factory applies installing water high-pressure cleaner for washing floor, they could save approximately 138,311 baht/year and reduce 1,698 kg CO2 eq per year.

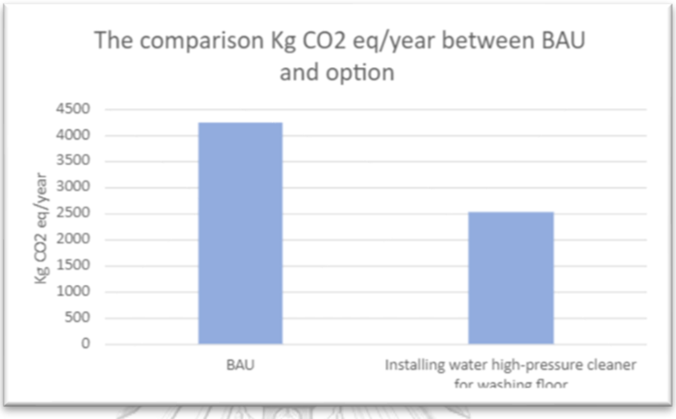

Figure 24 Result of Kg CO_2 equivalent reduction in installing water high-pressure cleaner for washing floor

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The primary goal of this paper is to assess the environmental impacts of canned fish production using data from a canning plant in Samut Sakhon, Thailand, by defining a functional unit of 1 ton of frozen fresh fish (excluding residues) entering processes that included 10 impact categories covering raw material preparation, packaging in container, sterilization, and labeling. Human toxicity, global warming, marine aquatic ecotoxicity, freshwater aquatic ecotoxicity, and terrestrial ecotoxicity are the top five environmental impacts, in that order. Tinplate and steam consumption were the highest compared to overall input and output consumption.

Using Clean Technology to prioritize and solve environmental impact problems and putting them into practice in the factory by pre-assessment and detailed assessment, which assess a three-part evaluation of environmental, economic, and technological feasibility. Packaging, water and steam consumption were the highest when compared to total input and output consumption, which was consistent with the LCA results accepted water consumption.

The following are some options for reducing packaging, water, and steam consumption: The use of packaging as primary packaging (glass, plastic, and recycled material) has the potential to reduce the environmental border to air by approximately 95% and the environmental border to water by 40 to 50%. (J. Laso, 2016). Steam consumption options are using biomass ash as a secondary combustion material in the production of steam could reduce CO2 eq by 38,308 kg CO2 eq/year, using wood pellet biomass could reduce CO2 eq by up to 33,311 kg CO2 eq/year, and improving boiler combustion by installing oxygen detectors could reduce CO2 eq by up to 19,149 kg CO2 eq/year. Water consumption options are reusing water in washing can packaging could reduce CO_2 eq up to 4004 kg CO_2 eq/year, and Installing water high-pressure cleaner for washing floor could reduce CO_2 eq up to 2,547 kg CO_2 eq/year.

5.2 Future study

- This study is simply a life cycle assessment guideline that focuses mainly on canned fish production only in one factory (Gate to Gate). Therefore, the impact assessment should include considerations for raw material extraction, material manufacturing, product manufacturing, use stage, and end-of-life (Cradle to Grave).
- This study makes extensive application of Ecoinvent databases, which based on international database, and it is country-specific data. Therefore, Thailand requires a research study to develop a database to support LCA data.

5.3 Recommendations

- According to some literature, coolant data was excluded from the calculation of the ice emission factor, which is the most important factor in ice production.
- The LCA grouping step was overlooked, which can be easily summarized to factory.
- Because of the insufficient electricity data used in this study, primary data, such as solar cell system should be collected.
- Instead of LCA, water footprint should be used to assess water consumption.

Appendix A
Calculation of environmental impact assessment and Normalization, and Emission Factors

Table A-1 All emission factors

Impact categories	Unit	Water	Electricity	Stream	Printed paper	Tin plate	board box	Fish	Ice	Salt	Tomato sauce	Flour	sugar	Wastewater	Plastic waste	Can waste	Sack waste
Abiotic depletion	kg Sb eq	2.82E-10	3.02E-07	5.53E-05	1.18E-06	3.96E-05	2.59E-07	3.07E-07	6.96E-06	6.25E-08	8.68E-08	3.33E-07	2.65E-07	-	-	-	-
Acidification	kg SO2 eq	2.10E-10	2.23E-07	2.11E-04	7.66E-07	3.29E-05	2.01E-07	1.24E-07	4.47E-06	7.63E-08	9.17E-08	4.41E-07	3.54E-07	-	-	-	-
Eutrophication	kg PO4 eq	1.05E-10	4.45E-05	5.58E-05	3.08E-07	1.10E-05	2.01E-07	5.13E-08	1.13E-05	3.74E-09	5.24E-08	3.31E-07	5.63E-07	-	-	-	-
Global warming	kg CO2 eq	2.84E-01	5.99E-01	1.87E+00	1.63E+00	6.04E-03	3.85E-05	2.07E-01	5.25E-01	1.12E-05	1.59E-05	6.70E-05	5.30E-05	1.29E-01	-4.14E+02**	-1.11E+01**	2.00E+00
Ozone layer depletion	kg CFC-11 eq	4.02E-14	6.14E-13	7.27E-08	1.03E-11	3.23E-10	6.56E-12	1.06E-12	2.17E-10	0.00E+00	2.24E-12	2.74E-12	7.87E-13	-	-	-	-
Human toxicity	kg 1,4-DB eq	4.73E-08	3.67E-15	4.45E+00	1.39E-04	8.90E-02	1.75E-04	2.34E-05	8.38E-04	7.23E-08	1.38E-05	4.19E-06	1.72E-05	-	-	-	-
Fresh water aquatic ecotox	kg 1,4-DB eq	2.71E-08	1.10E-05	9.00E-03	6.15E-05	1.64E-02	3.80E-05	1.02E-05	4.65E-04	5.90E-08	4.32E-06	1.99E-05	7.15E-05	-	-	-	-
Marine aquatic ecotox	kg 1,4-DB eq	4.80E-05	2.37E-02	1.10E+01	1.32E-01	1.62E+01	1.28E-01	2.07E-02	8.24E-01	3.97E-05	6.61E-03	4.89E-04	7.22E-04	-	-	-	-
Terrestrial ecotoxicity	kg 1,4-DB eq	4.78E-10	6.62E-08	3.13E-03	6.13E-07	1.18E-04	5.05E-07	8.49E-08	7.47E-06	1.98E-08	5.47E-08	5.21E-06	2.19E-07	-	-	-	-
Photochemical oxidation	kg C2H4 eq	1.12E-11	8.42E-09	2.79E-05	3.80E-08	1.93E-06	1.41E-08	5.84E-09	2.43E-07	3.77E-09	3.37E-09	8.58E-09	6.00E-08	-	-	-	-

Thai National LCI Database, TIIS-MTEC-NSTDA, 2019

Ecoinvent database CML 2 baseline 2000 V.2.05

Calculation

Literature (Sulistyaningsih, 2020)**

Table A-2 Emission factor of ice

Impact categories	Unit	Water (kg/ 1kg ice)	EF water	Water x EF	Electricity (kWh/ 1 kg ice)	EF electricity	Electricity x EF	EF water + EF electricity
		Characterization						EF of ice
Global warming	kg CO2 eq	1.40E+00	2.84E-01	3.98E-01	2.12E-01	5.98E-01	1.27E-01	5.25E-01
Human toxicity	kg 1,4-DB eq		5.99E-04	8.38E-04		3.67E-15	7.77E-16	8.38E-04
Freshwater aquatic ecotoxicity	kg 1,4-DB eq		3.31E-04	4.63E-04		1.10E-05	2.33E-06	4.65E-04
Marine aquatic ecotoxicity	kg 1,4-DB eq		5.85E-01	8.19E-01		2.37E-02	5.02E-03	8.24E-01
Terrestrial ecotoxicity	kg 1,4-DB eq		5.33E-06	7.46E-06		6.62E-08	1.40E-08	7.47E-06

Table A-3 Emission factors calculation of steam

Impact categories	Unit	Softed water (kg/ 1kg steam)	EF softed water	Softed water x EF	Electricity (kWh/ 1 kg steam)	EF electricity	Electricity x EF	Wood (kg/ 1 kg steam)	EF wood	Wood x EF	EF water + EF electricity + EF wood
		Characterization									EF of ice
Global warming	kg CO2 eq	1.87	9.70E-01	1.81E+00	7.74E-02	5.99E-01	4.63E-02	1.50E-01	4.71E-02	7.04E-03	1.87E+00
Human toxicity	kg 1,4-DB eq		8.82E-05	5.23E-11		3.67E-15	2.84E-16		2.98E+01	4.45E+00	4.45E+00
Freshwater aquatic ecotoxicity	kg 1,4-DB eq		2.01E-05	1.19E-11		1.10E-05	8.51E-07		5.99E-02	8.96E-03	8.96E-03
Marine aquatic ecotoxicity	kg 1,4-DB eq		2.72E-02	1.61E-08		2.37E-02	1.83E-03		7.29E+01	1.09E+01	1.09E+01
Terrestrial ecotoxicity	kg 1,4-DB eq		3.79E-07	2.25E-13		6.62E-08	5.12E-09		2.09E-02	3.13E-03	3.13E-03

Reference: (Prathumsee, 2017)

Normalization

Normalization (similar to weighting) is an optional step in Life Cycle Impact Assessment, according to ISO 14044 (ISO 2006 or LCIA). The normalization factors represent the total impact of a reference region each year for a specific impact category (SALA Serenella, 2017). Normalization factors, therefore, are a value that each country must create for itself, which is no such thing as universal value (Sachakamol, 2013). Normalization formular is as follows:

$$\text{NPj (Product)} = \frac{EPj}{TxERj}$$

NPj = Normalized Environmental Impact Potentials (Person for Target Year)

T = Lifetime of Product (Year)

EPj = Environmentaal OImpact Potential (kg Substance Equivalent eg. Climate change = 5 kgCO2e, etc.)

ERj = Normalization Reference (kg Substance Equivalent/ person/ year)

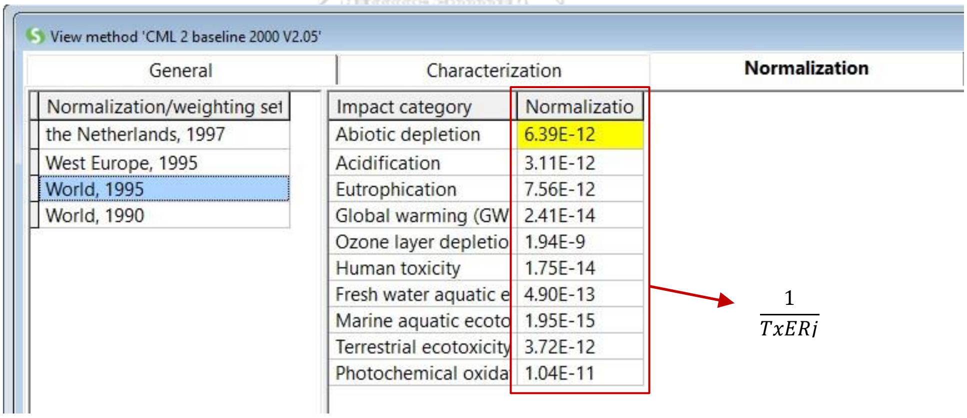

Figure A-1 Normalization factor of method CML 2 baseline 2000 V2.05, 2007

Table A-4 Calculation of normalization following World, 1995 method

Impact categories	1/TxERj	Unit (ERj)	EPj	Unit (EPj)	NPj (Pt)
Abiotic depletion	6.39E-12	kg Sb eq/kg/person /year	8.42E-02	kg Sb eq	5.38E-13
Acidification	3.11E-12	kg SO2 eq/kg/person /year	2.07E-01	kg SO2 eq	6.44E-13
Eutrophication	7.56E-12	kg PO4 eq/kg/person /year	9.19E-02	kg PO4 eq	6.95E-13
Global warming	2.41E-14	kg CO2 eq/kg/person /year	2.47E+03	kg CO2 eq	5.95E-11
Ozone layer depletion	1.94E-09	kg CFC-11 eq/kg/person /year	6.10E-05	kg CFC-11 eq	1.18E-13
Human toxicity	1.75E-14	kg 1,4-DB eq/kg/person /year	3.80E+03	kg 1,4-DB eq	6.65E-11
Fresh water aquatic ecotox	4.90E-13	kg 1,4-DB eq/kg/person /year	2.25E+01	kg 1,4-DB eq	1.10E-11
Marine aquatic ecotox	1.95E-15	kg 1,4-DB eq/kg/person /year	2.41E+04	kg 1,4-DB eq	4.70E-11
Terrestrial ecotoxicity	3.72E-12	kg 1,4-DB eq/kg/person /year	2.72E+00	kg 1,4-DB eq	1.01E-11
Photochemical oxidation	1.04E-11	kg C2H4 eq/kg/person /year	2.51E-02	kg C2H4 eq	2.61E-13

Appendix B

Cut off & Mass allocation

Cut off

Table B-1 Cut off

List	Unit/FU	% Cut off < 0.1*
Water	14375.9	77.25
Electricity	688.61	3.70
Steam	834.82	4.49
Ice	200	1.07
Tin plate	441.18	2.37
Printed paper	28.71	0.15
Board box	196.59	1.06
Soap	3.91	0.02
Chlorine	0.42	0.002
Fish	1612.9	8.67
Tomato sauce	89.67	0.48
Soybean oil	11.13	0.06
Flour	61.65	0.33
Sugar	33.21	0.18
Sea salt	29.74	0.16
Color	0.13	0.0007
Sum of resource quantity	18608.57	100

*(*Establishment of Thai National Life Inventory Database*, 2012)

$$\text{Cut off} = \frac{Quantity\ of\ resource\ (Unit/FU)}{Sum\ of\ resource\ quantity\ (Unit/FU)} x100$$

Mass Allocation (*Establishment of Thai National Life Inventory Database*, 2012)

The factory manufactures two products: canned fish and fish meal. This research only looks at canned fish. The canned fish and fish meal manufacturing processes use both electricity and steam. As a result, mass allocation is as follows.

Ratio canned fish per fish meal = 620 kg : 110 kg

$$\text{Canned fish} = \frac{620}{620+110} x100 = \frac{620}{730} x100 = 84.93\%$$

$$\text{Fish meal} = \frac{110}{620+110} x100 = \frac{110}{730} x100 = 15.07\%$$

- Mass allocation of electricity = $\frac{810.79 \frac{\text{kWh}}{\text{FU}} \text{x } 84.93}{100} = 668.61\ kWh/FU$
- Mass allocation of steam = $\frac{982.95 \frac{\text{kg}}{\text{FU}} \text{x } 84.93}{100} = 834.82\ kg/FU$
- Mass allocation of wood = $\frac{4{,}163{,}670 \frac{kg}{year} x84.93}{100} = 3{,}536{,}204.93\ kg/year$

Appendix C

Calculation of options

Steam options

Option 2 Calculation

Table C-1 Information of increase boiler efficient

List	Variable	Unit	Value	Reference
Quantity of wood	Wo_1	Kg/year	3,536,204.93	Factory
Efficient of combustion before improving	-	%	80	(Kitti, 2017)
	F_1	-	0.8	(Kitti, 2017)
Efficient of combustion after improving	-	%	100	(Kitti, 2017)
	F_2	-	1	(Kitti, 2017)
Heat value of wood	Cw_o	MJ/kg	6.57	(DEDE, 2013)
Cost of wood	Wo_c	Baht/kg	0.59	Factory

<u>Before improvement</u>

The quantity of wood consumption is 3,536,204.93 kg/year used in combustion without reducing moisture, resulting of wood combustion efficient lower than 80% (Kitti, 2017).

Heat value $(Q_{80\%}) = Wo_1 \times Cw_o \times F_1$

$= 3{,}536{,}204.93$ kg/year x 6.57 MJ/kg x 0.8

$= 18{,}586{,}293.11$ MJ/year

<u>After improvement</u>

Drying the wood in the sun and storing it in an enclosed space could increase the full wood combustion efficiency by 100% (assuming the wood has a moisture content of 12% at the begin (Kitti, 2017)).

Quantity of wood $(Wo_2) = Q/Cw_o/1$

$$= \frac{18{,}586{,}293.11\frac{MJ}{year}}{6.57\frac{MJ}{kg}x1}$$

$= 2{,}828{,}963$ kg/year

The decreasing of wood consumption $(Wo_s) = 3{,}536{,}204.93 - 2{,}828{,}963$kg/year

$= 707{,}240.99$ kg/year

Cost savings $(B_{save}) = Wo_s \times Woc$

$= 707{,}240.99$ kg/year x 0.59 baht/kg

$= 417{,}272.18$ baht/year

There is no playback period because of changing the wood changed to pallet wood with low moisture.

Payback period = immediate

CO_2 eq reduction = 707,240.99 kg/year x 0.0471 kg CO_2 eq/kg

= 33,311.05 kg CO_2 eq/year

Option 3 Calculation

Table C-2 Information of combusted effective calculation

List	Variable	Unit	Value	Reference
Boiler size	-	Ton/hr	15	(Kitti, 2017)
Time work of boiler	T_w	Ton/hr	2,200	Factory
Quantity of wood	F	Kg/hr	1,607	Factory
Feed water	FW	Kg/hr	6,500	(Kitti, 2017)
Temp Feed water	-	C°	60	(Kitti, 2017)
Low heating value of wood	LH	Kcal/kg	6,934.02	(TISTR, 2007)
Specific heat value of wood	H_s	Kcal/kg-C	0.55	(instruments, 2018)
Ambient air Temperature	T_a	C°	30	(Kitti, 2017)
Air Pollution Temperature	T_g	C°	220	(Kitti, 2017)
Blowdown value	B	%	1	(Kitti, 2017)
Blowdown Temperature	-	C°	170.70	(Kitti, 2017)
Steam pressure	P_w	Bar	7.0	(Kitti, 2017)
Specific Enthalpy of Water	H_f	Kcal/kg	172.22	Saturated team Table (Sarco, 2023)
Specific Enthalpy of Evaporation	H_{fg}	Kcal/kg	488.77	Saturated team Table (Sarco, 2023)
Specific Enthalpy of Steam	H_g	Kcal/kg	661.34	Saturated team Table (Sarco, 2023)
Temperature of combustion	-	C°	35	(Kitti, 2017)
Enthalpy of feeding water	$H_{f,w}$	Kcal/kg	60	Saturated team Table (Sarco, 2023)
Specific Enthalpy of 30 C° water	$H_{f,30}$	Kcal/kg	30	Saturated team Table (Sarco, 2023)
Specific Enthalpy of blowdown	$H_{f,b}$	Kcal/kg	172.92	Saturated team Table (Sarco, 2023)
Heat loss at boiler surface	H_l	%	3	(Kitti, 2017)
Oxygen in air	O_2	%	21	(Kitti, 2017)
Oxygen in air pollution before improvement	$O_{2,bef}$	%	12	(Kitti, 2017)
Oxygen in air pollution after improvement	$O_{2,af}$	%	7	(Kitti, 2017)
Cost of wood	F_w	Baht/kg	0.59	Factory
Sensible Heat of feeding water	Q_w	Kcal/hr	195,000	(Kitti, 2017)
Air ratio before improvement	M_{be}	%	2.33	(Kitti, 2017)
Air ratio after improvement	M_{af}	%	1.50	(Kitti, 2017)
Steam production	S	Kg/hr	6,305	(Kitti, 2017)

<u>Before improvement</u>

Oxygen in air pollution before improvement ($O_{2,bef}$) = 12 %

Heat Influent

Heat of wood (Q_c) = $FxLH$

$$= 1{,}607\frac{kg}{hr}x6{,}934.02\frac{kcal}{kg}$$

= 11,142,970.14 kcal/hr

Heat Effluent

The actual air content of theoretical air pollution (Go) = $\frac{(0.89\ x\ LH)}{1{,}000} + 1.65$

$$= \frac{(0.89\ x\ 6{,}934.02)\ kcal/kg}{1{,}000 kcal/m3} + 1.65$$

= 7.82 m^3/kg

The air content of theoretical (Ao) = $\frac{(1.01\ x\ LH\ )}{1{,}000}$+0.5

$$= \frac{(1.01\ x\ 6{,}934.02)}{1{,}000} + 0.5$$

= 7.50 m^3/kg

The actual of air content (G_{be}) = Go + (Ao x (M_{be}-1))

= 7.82 m^3/kg + (7.50 m^3/kg x (2.33-1))

= 17.80 m^3/kg

Heat loss in air pollution (Qe_{be}) = F x G_{be} x H_s x (T_g-T_a)

$$= 1{,}607\frac{kg}{hr}x\ 17.80\frac{m3}{kg}\ x\frac{0.55kcal}{kg}\ x\ (220 - 30)C°$$

= 2,989,180.7 kcal/hr

Heat loss in blowdown (Q_b) = B x FW x ($H_{f,b}$-$H_{f,w}$)

$$= \frac{\frac{1\ x\ 6{,}500\ kg}{hr}x(172.92-60)}{100}$$

= 7,339.8 kcal/hr

Heat loss in boiler surface (Q_r) = (Q_c+Q_w) x H_l

$$= \frac{11{,}142{,}970.14\frac{\text{kcal}}{\text{hr}}+195{,}000\frac{kcal}{hr}}{100}x3$$

= 340,139.10 kcal/hr

Heat of steam (QST_{be}) = Q_c+Q_w- Qe_{be}- Q_b- Q_r

= 11,142,970.14 kcal/hr + 195,000 kcal/hr – 2,989,180.7kcal/hr - 7,339.8 kcal/hr – 340,139.10 kcal/hr

= 8,001,310.54 kcal/hr

Effective of steam ($\%Eff_{be}$) = (QST_{be}/(Q_c+Q_w))x100

$$= \frac{8{,}001{,}310.54\ \frac{kcal}{hr}}{11{,}142{,}970.14+195{,}000\frac{kcal}{hr}}x100$$

= 70.57 %

<u>After improvement</u>

Oxygen in air pollution after improvement ($O_{2,af}$) = 7 %

The actual of air content (G_{af}) = Go + (Ao x (M_{af}-1))

= 7.82 m^3/kg + (7.50 m^3/kg x (1.50-1))

= 11.57 m^3/kg

Heat loss in air pollution (Qe_{af}) = F x G_{af} x H_s x (T_g-T_a)

= 1,607 kg/hr x 11.57 m^3/kg x 0.55 kcal/kg x (220-30)c°

= 1,942,967.46 kcal/hr

Heat of steam (QST_{af}) = Q_c+Q_w- Qe_{af}- Q_b- Q_r

= 11,142,970.14 kcal/hr + 195,000 kcal/hr - 1,942,967.46kcal/hr - 7,339.8 kcal/hr – 340,139.10 kcal/hr

= 9,047,523.78 kcal/hr

Effective of steam ($\%Eff_{af}$) = (QST_{af}/(Q_c+Q_w))x100

$$= \frac{9{,}047{,}523.78\ \ kcal/hr}{11{,}142{,}970.14\frac{\mathrm{kcal}}{\mathrm{hr}}+195{,}000\frac{\mathrm{kcal}}{\mathrm{hr}}}x100$$

= 79.80 %

Increase of boiler efficient ($\%Eff_{inc}$) = ($\%Eff_{af}$ - $\%Eff_{bf}$)/ $\%Eff_{af}$ x 100

$$= \frac{79.80 - 70.57}{79.80}x100$$

= 11.56 %

Wood consumption (W) = F x T_w

= 1,607 kg/hr x 2,200 hr/year

= 3,535,400 kg/year

Wood reduction (F_s) = %Eff_{inc} x W

= 11.56 % x 3,535,400 kg/year

= 406,571 kg/year

Saving cost (B_{save}) = F_s x F_w

= 406,571 kg/year x 0.59 baht/kg

= 23,987.89 baht/year

<u>Investment cost</u>

Cost = 300,000 baht

Payback Period = 300,000 baht/23,987.89 baht/year

= 12 year

CO_2 eq reduction = 406,571 kg/year x 0.0471 kg CO_2 eq/kg

= 19,149.49 kg CO_2 eq/year

Water option

Option 1 Calculation

<u>Before improvement</u>

The factory consumed water in can washing by 21,145 m^3/year

<u>After improvement</u>

Returning the last water batch to the first water batch can save 66.67% of the water consumed during the preparation process without any investment (Best Practices in Pollution Prevention and Reduction Seafood Processing Industry: Types of Fish, 2005).

The reduction of water = 21,145 m^3/year x 66.67%

= 14,097.37 m^3/year

The saving water cost = (21,145 - 14097.37 m^3/year) x 23 baht/m^3

= 162,096 baht/year

The investment value is 0 baht.

The reduction in CO_2 from water consumption = 0.2843 kg CO_2 eq/m^3 x 7,047.63 m^3/year = 2,003 kg CO_2 eq/year

Option 2 Calculation

<u>Before improvement</u>

The quantity of water consumption in cleaning floor is 14,933.8 m^3/year.

<u>After improvement</u>

<u>Investment cost</u>

Installation of water high-pressure cleaner brand SUMO160 Bar = 15,900 baht

Electricity consumed per day (Pump motor 2500W, 0.5hr/day) = 1.25 kWh/day

Electricity consumed per year = 1.25 kWh/day x 275 worked day/ year = 343.75 kWh/year

Electricity cost (3.31 baht/kWh x 343.75 kWh/year) = 1137.81 baht/year

<u>Water reduction</u>

The saving of water consumption = 14,933.8 m^3/year x 60%

= 8,960.28 m^3/year

The saving water cost = (14,933.8 - 8,920.28 m^3/year) x 23 baht/m^3

= 138,311 baht/year

Net saving cost (The saving water cost – Electricity cost in pump – Water high-pressure cleaner) = 138,311 – 1137.81 – 15,900 = 121,273 baht/year

Payback period = (15,900 baht + 1,137.81 baht/year)/121,273 baht/year

= 0.1 year or 1 month

The reduction in CO_2 from water consumption = 0.2843 kg CO_2 eq/m^3 x 5,973.72 m^3/year = 1,698.27 kg CO_2 eq/year

Appendix D

Processes

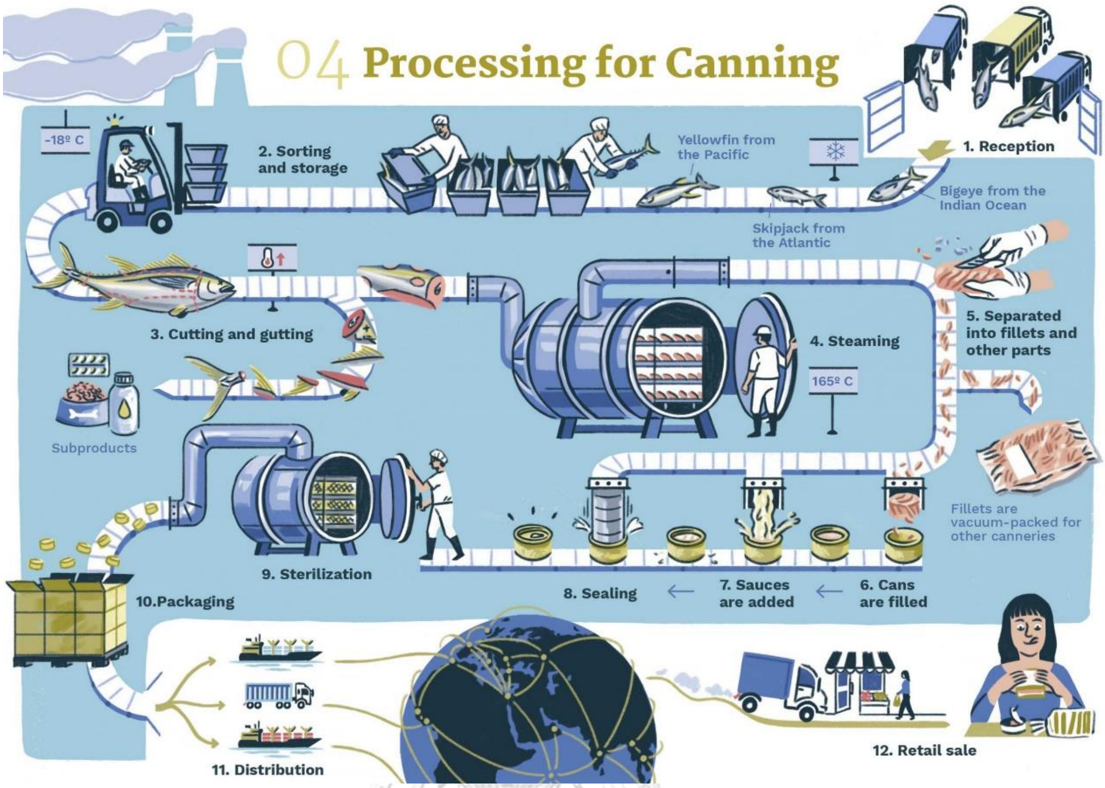

Figure 25 Processing of canned fish

Reference: (Planettuna, 2022)

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