EnvironmentAsia
The international journal by the Thai Society of Higher Education Institutes on Environment

EnvironmentAsia 14(3) 2021 124-135
DOI 10.14456/ea.2021.29
ISSN 1906-1714; ONLINE ISSN: 2586-8861

Life Cycle Assessment of High Pressure-Cooked Smoked Milkfish Production: A Case Study in Semarang, Indonesia

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Received: April 29, 2021; Revised: June 16, 2021; Received: June 30, 2021

Abstract

This research aims to assess and measure the environmental impacts of high pressure-cooked smoked milkfish (HPCSM) production. Although the literature about measuring the environmental impact is abundant, research about this topic implemented in a HPCSM production remains limited. The assessment was performed using the life cycle assessment (LCA), which is considered as a holistic assessment since it regards the entire life cycle of products from cradle to grave. To make a contribution, the LCA was supplemented with the eco-efficiency index to assess the affordability and sustainability status of the business. To exhibit the methods, a case study has been carried out in Semarang, Indonesia, where the centre of HPCSM production is located. Forty enterprises (thirty-one small-, eight medium-, and one large-scale) were assessed. Results showed that the production process has several environmental impacts, such as climate change, photochemical oxidant formation, acidification, fine dust, eutrophication, ecotoxicity (fresh water), human toxicity, metals depletion, waste, and water stress indicator. In addition, the analysis of eco-efficiency index revealed that all type of products is considered as affordable but not sustainable. The recommendations for the improvement to minimize the environmental impacts and the sustainability status of the enterprises are also provided.

Keywords: Eco-efficiency index; Life cycle assessment; Water scarcity; High pressure-cooked smoked milkfish.

1. Introduction

Life cycle assessment (LCA) is a measurement method which quantifies numerous environmental impacts related to the whole life cycle (i.e., from cradle to grave) of particular products, processes, or activities (Finnveden *et al.,* 2009). Especially in manufacturing and construction, LCA has been broadly applied; for example, in iron and steel industries (Olmez *et al.,* 2016; Ma *et al.,* 2018; Rossi *et al.,* 2017), in building analysis (Fay *et al.,* 2000; Ramesh *et al.,* 2020), and food productions (Andersson *et al.,* 1998; Cederberg and Stadig, 2003; Beauchemin *et al.,* 2020). However, to the best of our knowledge, there is limited—or even no—study analysing the environmental impacts using LCA in high pressure-cooked smoked milkfish (HPCSM) production.

Milkfish *(Chanos chanos)*, which is the sole living species in the Chanidae family (Nelson, 2006), is a big toothless silver fish which exists in warm parts of the Indian and Pacific oceans. The species is called "bandeng" in Bahasa. It has many bones that makes it difficult to eat. As the technology and demand of more nutritional consumption are increasing, processing milkfish with high pressure cooker is made. This makes the bones of the fish get softened so that it is easier to be consumed—it is usually called soft-boned or boneless milkfish, or "bandeng presto" in Bahasa Indonesia—while the nutritional value is not being affected and decreased.

A case study to assess the environmental impacts of HPCSM production was carried out in Semarang, the capital city of Central Java Province, Indonesia, where the centre of HPCSM production is located. The HPCSM is also well-known as a local culinary souvenir for tourists who visited Semarang. Although the industry is considered as one of major industries to support the economy of the city, the activities produce what we called “non-product output (NPO)” that has negative impacts for the environment since it contains dissolved and suspended solids in the form of organic and nonorganic substances. The waste water is inevitable because the production needs a large scale of freshwater; it amounts about 100 to 400 litres of freshwater for one production cycle—depending on the production scale (personal interview with Industry and Trade Office of Semarang). This freshwater is used in production process of HPCSM, such as washing, seasoning, and steaming the milkfish. Therefore, such a holistic assessment (i.e., the LCA) is necessary. This research is expected to give a valuable insight towards the environmental impacts generated by the activities at the HPCSM production in Semarang.

2. Materials and Methods

2.1 Data collection

In Semarang, there are forty enterprises that involve in HPCSM production; where most of them are located in Krobokan village, District of Semarang Barat (27%) and Tambakrejo village, District of Gayamsari (22%). They are divided into three categories, i.e., large-scale production, producing 100 to 200 kg per day (only one enterprise); medium scale, producing 30 to 75 kg per day (eight enterprises); and small scale that produces 10 to 25 kg per day (thirty-one enterprises). Data were collected through direct observation and interviews with the owners and the employees of all those forty enterprises. We collected data and information about the production process, raw materials used, as well as waste generated from the production of HPCSM.

Generally, there are five activities in the production process of HPCSM–see Figure 1. Slightly difference exists according to the scale of the enterprises. The first activity is washing the raw materials, i.e., fresh milkfishes and raw spices. Before processing further, the fishes have to be cleaned to reduce the smell of the fish; also, washing is useful to remove the offal and feces of the fish. The spices, for instance, turmeric and ginger, also have to be cleaned before going to be used. These activities will produce NPO, such as waste water (after-washing water), scales, offal, and feces of the fish, waste of spices, etc. The spices then would be crushed (by adding minor water) before being applied to the fish. After applying clean and crushed spices to the fishes, the next activity is cooking. For small-scale enterprises, they use traditional cooking process called “pemindangan”. In this traditional cooking process, the fishes which are arranged in a box (e.g., bamboo basket) are boiled in brine water for a certain period of time in a waterproof container. It is performed under normal pressure and without any further preservation process to reduce the water content to a certain level. For medium- and large-scale enterprises, they use high pressure cooker in the production process. It is a pot (or pan) which is made of strong metal with a tight cover; it can be used to cook food quickly with high pressure steaming process. After being cooked, the bones will get softened; thus, it is called “boneless”. The boneless milkfish then will be kept in cold storage in order to maintain the freshness of the fish and to prevent from contamination. In addition, freezing process will not alter the original texture, smell, and taste of the fish. According to the Indonesian National Standard (SNI) of boneless milkfish (SNI 7316.3:2009), the recommended temperature in the cold storage is $(-20 \pm 1)\,^{0}$C. Note that for small-scale enterprises, they do not store the finished products in the cold storage, instead, they directly sell them to their consumers.

The raw materials used in the production process are milkfish and spices (turmeric, ginger, and salt). The descriptive statistics of raw materials used per day, including the quantity and the purchase price in the small-scale, medium-scale, and large-scale enterprises are depicted in Table 1, Table 2, and Table 3, respectively. Notice that because there is only one enterprise categorized as large-scale enterprise, there is only one single value shown in Table 3. Also, the owner of the enterprise did not want to reveal the purchase prices of the raw materials used. However, these missing data will not affect the calculation and further analysis in this study.

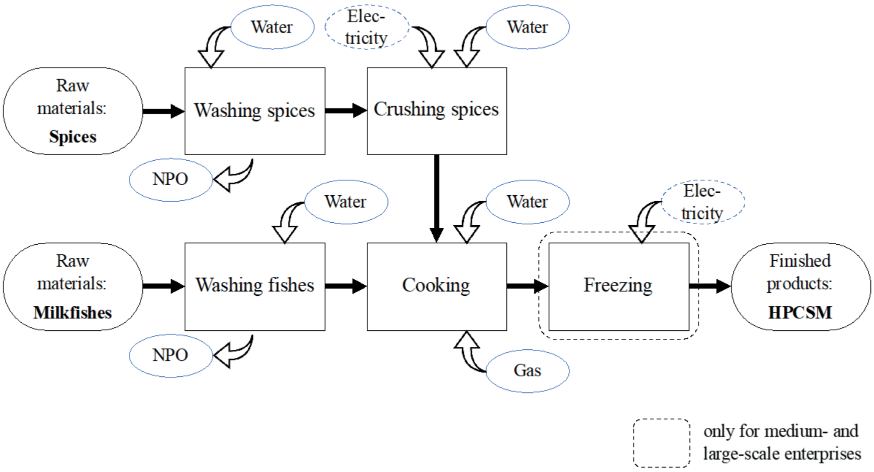

Figure 1. Production process of high pressure-cooked smoked milkfish

Table 1. Descriptive statistics of raw materials used (per day) in the small-scale enterprises

	Activity	Raw Materials	Unit	Min.	Max.	Mean	Std. Dev.
Quantity	Washing fishes	Milkfish	kg	10	25	16.130	5.430
	Washing spices	Turmeric	g	50	125	83.390	24.410
		Ginger	g	50	125	83.390	24.410
		Salt	g	200	550	354.800	123.390
Purchase price	Washing fishes	Milkfish	€/kg	1	1.125	1.063	0.036
	Washing spices	Turmeric	€/kg	0.313	0.375	0.321	0.021
		Ginger	€/kg	0.188	0.250	0.195	0.019
		Salt	€/kg	0.125	0.188	0.154	0.014

Table 2. Descriptive statistics of raw materials used (per day) in the medium-scale enterprises

	Activity	Raw Materials	Unit	Min.	Max.	Mean	Std. Dev.
Quantity	Washing fishes	Milkfish	kg	30	70	50	15.120
	Washing spices	Turmeric	g	240	560	332.500	105.800
		Ginger	g	240	560	332.500	105.800
		Salt	g	750	2,100	1,293.75	456.260
Purchase price	Washing fishes	Milkfish	€/kg	1.188	1.313	1.250	0.033
	Washing spices	Turmeric	€/kg	0.313	0.313	0.313	
		Ginger	€/kg	0.188	0.188	0.188	
		Salt	€/kg	0.156	0.219	0.176	0.029

Table 3. Descriptive statistics of raw materials used (per day) in the large-scale enterprises

Activity	Raw Materials	Unit	Value
Washing fishes	Milkfish	kg	100
Washing spices	Turmeric	g	800
	Ginger	g	800
	Salt	g	2,500

2.2 Life cycle assessment

The objective of LCA is to measure and assess the various environmental impacts, e.g., global warming, climate change, eutrophication, acidification, and others, caused by not only a particular product, but also process and activity (later on it is called "the system"). The boundaries of the systems encompass the whole life cycle phases from cradle to grave, containing extracting and processing raw materials, distribution and transport of materials and/or finished products, production or manufacturing, use or consumption, reuse, recycle, and final disposal. Formally, according to ISO 14040, LCA is defined as "a technique for assessing the potential environmental aspects associated with a product (or service) by compiling an inventory of relevant inputs and outputs, evaluating the potential environmental impacts associated with these inputs and outputs, and interpreting the results of the inventory and impact phases in relation to the objectives of the study" (ISO, 1997).

Basically, there are four stages in LCA, i.e., planning, life cycle inventory (LCI) analysis, life cycle impact assessment (LCIA), and interpretation—see Figure 2. The first stage defines the goals of the LCA including the scope or boundaries, breadth, as well as depth of the research. This stage is very crucial as it determines and guides the other stages of LCA; thus, it is suggested to expend adequate time in this particular stage, defining what is the objective of the research clearly. Formally, ISO 14040 mentioned that the goals should define (ISO, 1997):

- "the intended application and the reason for carrying out the research;
- the intended audience, i.e., to whom the results are intended to be communicated; and
- whether the result is intended to be used in comparative assertions disclosed to the public."

Next, the scope must explain depth and the detail of the research, showing that the goals are able to be accomplished considering several limitations. Once the scope has been defined, some aspects have to be considered, such as: the system, i.e., the product or process or activity; the functions, including the functional unit and reference flow; the boundaries; allocation procedures; the methodology to assess the environmental impacts; data requirements; as well as assumptions and limitations.

The next stage is called LCI analysis. It delivers input and output of the system quantitatively. The input includes raw materials and energy used; while the output includes air emission and waste.

The third stage is LCIA. As the main stage of LCA, it assesses how the environment is affected by the system. In this stage, there are four steps to be conducted, i.e., characterization, normalization, weighting, and single score. In characterization step, LCI analysis results are classified to the environmental effect they might affect, for instance, climate change, global warming, acidification, eutrophication, and so forth (sometimes it is called "classification").

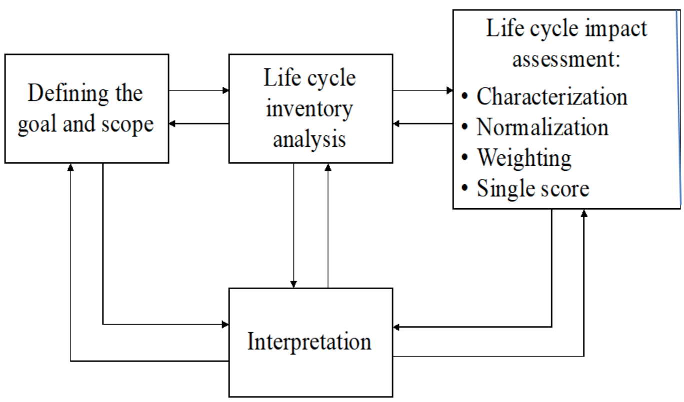

Figure 2. Stages in life cycle assessment

The effects are converted to common units and then aggregated within the category of the impact. Altogether, it will result in a numerical indicator, i.e., the LCIA profile. Normalization and weighting, according to ISO 14044 are defined as “calculating the magnitude of category indicator results relative to reference information” and “converting and possibly aggregating indicator results across impact categories using numerical factors based on value-choices” (ISO, 2006). Normalization can be seen as converting the magnitude of each impact category to the same common scale by associating them to a common reference. It can enable comparisons across category of the impact. Weighting is assigning different weights to the corresponding impact categories that reflects the relative importance for each impact. By weighting, the results might be summed across impact categories to reach at a specific score indicator of LCA. Contrarily from the characterization step, which is mandatory, normalisation and weighting steps are optional because of for instance, value choices and the potential biases they are associated with, as well as the consequent legal and commercial concerns (Pizzol *et al.,* 2017).

The last stage is interpretation, where sensitivity analysis might be performed to interpret the results of LCA according to the goal and scope of the research defined previously. Several recommendations could be suggested to make any improvement so that it can minimize the environmental burdens affected by the system.

2.3 Eco-efficiency index

To assess the environmental impacts, this research not only employ LCA, the eco-efficiency index (EEI) also be applied since this research was applied in the business area. The eco-efficiency concept was introduced in 1992 by World Business Council for Sustainable Development in the course of the United Nations Conference on Environment and Development as a business concept for a sustainable development. It describes how efficient the business is with regard to nature’s products. Simply speaking, it is a sustainability measure combining environmental and economic performances. It is considered as a practical tool for the business to participate to the sustainable development by using efficiently its resources so that it can run in a sustainable manner to generate profit consistently. Since then, this concept has been widely applied in various industrial applications, see for example de Simone and Popoff (1997) and Saling *et al.* (2002).

The EEI can be calculated as follows (Hur *et al.,* 2003):

$$EEI = \frac{\text{Net value}}{\text{Total production cost + Eco-cost}} \quad (1)$$

where net value is obtained by subtracting the total production cost from the sales (selling price times number of goods sold) and eco-cost expresses the amount (in terms of currency) of the environmental burden affected by the product at every step in the chain (Vogtlander, 2007). In other words, eco-cost means the cost that must be paid to bear the environmental impacts and depletion of natural resources that respects the carrying capacity of the earth. Product is said to be affordable and sustainable if the EEI is more than 1 (EEI > 1); while the range is from 0 to 1, the product is said to be affordable but not sustainable; and lastly, the product is said to be not affordable and not sustainable if EEI < 0. Next, the eco-efficiency ratio (EER) of the product can be found by employing the following equation (Vogtlander, 2007):

$$EER = (1 - EVR) \times 100\% \quad (2)$$

where EVR is the eco-cost per value ratio which can be calculated by eco-cost/net value.

3. Case study: Results and discussion

3.1 Life cycle assessment result

LCA was used to evaluate the environmental impacts of the various processes in HPCSM production. Defining the boundary or scope of the system is a necessary stage to do firstly. The goal and scope of this study are shown in Table 4.

The second stage in LCA is LCI analysis. This stage shows input and output involved in the production process. The input consists of raw materials (milkfish and spices), electricity (or power), water, and gas; while the output is NPO. While the flow is depicted in Figure 1, the result of LCI analysis is shown in Table 5. Note that the difference between small- and medium/large-scale lies in electricity consumption. Electricity acts as an input in crushing spices and freezing activities. Small-scale enterprises do not use blender to crush the spices, instead, they use traditional crusher; thus, electricity is not involved in calculation. While for freezing activity, as has been previously mentioned, only medium- and large-scale enterprises keep their finished products in cold storage.

Table 4. The goal and scope of this study

Goal	Assess and measure the environmental impacts through eco-cost of HPCSM production.
Scope	• System to be evaluated is the production process of HPCSM. • This study is conducted in Semarang, Indonesia. • There are forty enterprises analysed in this study, categorised as small-scale (31 enterprises), medium-scale (8 enterprises), and large-scale (1 enterprise). • Software "SimaPro v8.5" was used in the analysis by employing eco-cost 2017 method version 1.1, where the indicators and their values are based on the standard of WBCSD.

Table 5. Input and output involved in HPCSM production per day

Scale of the enterprise	Activity	Input	Output	Unit	Average Quantity
Small-scale	Washing fishes	Milkfish		kg	16.10000
		Water		m^3	0.12968
			NPO	m^3	0.11984
	Washing spices	Turmeric		kg	0.08339
		Ginger		kg	0.08339
		Salt		kg	0.35480
		Water		m^3	0.00184
			NPO	m^3	0.00150
	Crushing spices	Water		m^3	0.00185
	Cooking	Water		m^3	0.00777
		Gas		kg	3.23000
			Water	m^3	0.00388
Medium-scale	Washing fishes	Milkfish		kg	50.00000
		Water		m^3	0.21250
			NPO	m^3	0.20438
	Washing spices	Turmeric		kg	0.33250
		Ginger		kg	0.33250
		Salt		kg	0.00150
		Water		m^3	0.00638
			NPO	m^3	0.00581
	Crushing spices	Water		m^3	0.00725
		Electricity		kWh	0.09400
	Cooking	Water		m^3	0.01775
		Gas		kg	10.10000
			Water	m^3	0.00888
	Freezing	Electricity		kWh	4.72200
Large-scale	Washing fishes	Milkfish		kg	100.00000
		Water		m^3	0.40000
			NPO	m^3	0.39000
	Washing spices	Turmeric		kg	0.80000
		Ginger		kg	0.80000
		Salt		kg	2.50000
		Water		m^3	0.01200
			NPO	m^3	0.01100
	Crushing spices	Water		m^3	0.01500
		Electricity		kWh	0.16500
	Cooking	Water		m^3	0.03500
		Gas		kg	20.00000
			Water	m^3	0.01750
	Freezing	Electricity		kWh	30.00000

The next stage is LCIA. This is the main stage in LCA since in this stage, it will perform analysis towards the environmental impacts—the category and the magnitude—caused by the production process. LCIA will convert the data collected in LCI to the environmental impacts' category. There are four steps in LCIA, namely, characterization, normalization, weighting, and single score. In this research, software "SimaPro v8.5" was used to perform LCIA by employing eco-cost 2017 method version 1.1, where the indicators and their values are based on the standard of WBCSD. In the characterization step, all data collected in LCI are stored into classes based on the effect they might have on the environment. Then, they are multiplied by a factor reflecting their contribution relative to the environmental impact, quantifying how much impact a product has in each impact category. The result of this step is shown in Table 6. Note that the result is different according to the scale of the enterprises. Results from the previous step differ in unit; thus, normalization was performed so that all impact categories would have same unit. This step enables comparisons across impact category. In this research, the unit chosen was Euro (€). The result is shown in Table 7. This research did not conduct weighting step as it is regarded as "not a science-based procedure" due to its subjectivity; therefore, each impact category will be assigned "1" as their weight value. Finally, in the single score step, all impact categories for each scale of the enterprises are summed to get one single value. The single score of LCA for small-scale enterprise is € 1.317, while for medium-scale and large-scale are € 4.540 and € 8.364 respectively. The result of each impact category across type of the enterprise is depicted in Figure 3.

Table 6. Characterization result

Impact Category	Unit	Small-Scale	Medium-Scale	Large-Scale
Climate change	kg CO_2 eq	4.740	15.364	31.103
Acidification	kg SO_2 eq	0.042	0.137	0.260
Eutrophication	kg PO_4 eq	0.003	0.008	0.017
Photochemical oxidant formation	kg C_2H_4 eq	0.001	0.003	0.006
Fine dust	kg $PM_{2.5}$ eq	0.010	0.031	0.059
Human toxicity	Cases	3.46×10^{-8}	1.10×10^{-7}	2.14×10^{-7}
Ecotoxicity (freshwater)	PAF.m^3.day	1,079.570	3,558.824	6,896.188
Metal depletion	Euro	0.001	0.003	0.000
Oil and gas depletion excel energy	kg oil eq	0.000	0.000	0.000
Waste	MJ	0.344	1.131	2.148
Land-use	Bio factor	0.000	0.000	0.000
Water stress indicator	WSI factor	0.008	0.282	0.054

Table 7. Normalization result

Impact Category	Unit	Small-Scale	Medium-Scale	Large-Scale
Climate change	€ 0.116 / kg CO_2 eq	0.550	1.782	3.608
Acidification	€ 8.83 / kg SO_2 eq	0.371	1.207	2.300
Eutrophication	€ 4.17 / kg PO_4 eq	0.011	0.035	0.070
Photochemical oxidant formation	€ 10.38 / kg C_2H_4 eq	0.009	0.029	0.057
Fine dust	€ 34 / kg $PM_{2.5}$ eq	0.326	1.067	2.010
Human toxicity	€ 920.000 per cases	0.032	0.102	0.197
Ecotoxicity (freshwater)	€ 5.54×10^{-6} / PAF.m^3.day	0.006	0.020	0.038
Metal depletion	€ 1	0.001	0.003	0.007
Oil and gas depletion excel energy	€ 0.8 / kg oil eq	0.000	0.000	0.000
Waste	€ 0.01125 / MJ	0.004	0.012	0.023
Land-use	Bio factor	0.000	0.000	0.000
Water stress indicator	€ 1 per WSI factor	0.008	0.282	0.054

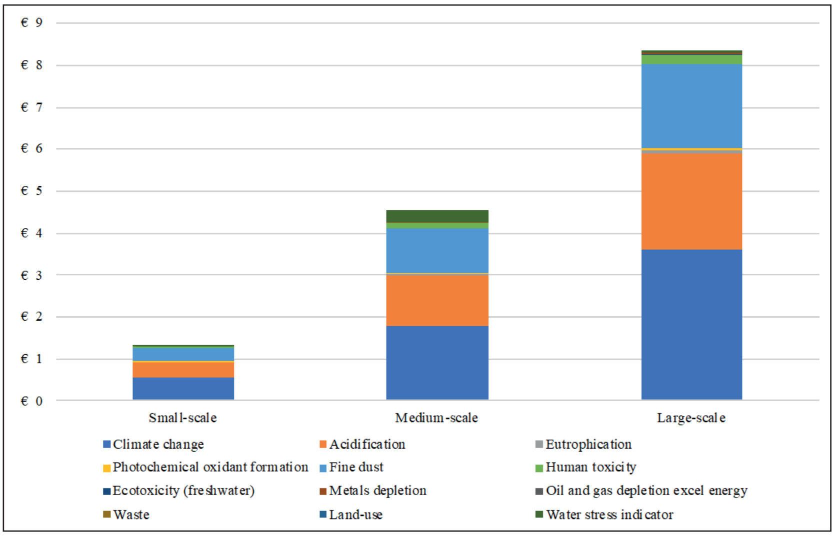

Figure 3. Life cycle assessment result

As has been shown in Figure 3, small-scale enterprises have smaller environmental impacts compared to medium- and large-scale enterprises. Medium- and large-scale enterprises use cold storage to store finished products before selling them to the consumers. The cold storage does warm the planet as it contributes to the global warming. Not only it sucks in electricity which was usually made by burning fossil fuels, but also it contains various toxic and hazardous components, such as chlorofluorocarbons (CFCs) or hydrochlorofluorocarbons (HCFCs), greenhouse gases (GHGs), and ozone-depleting substances (ODSs) (IPCC, 2005). The gases have a foremost impact on warming the atmosphere when they are not demolished. The gases block heat escaping from the earth, they also deplete the ozone layer which filters the sun's rays, and thus, accelerate the climate change. This climate change could affect natural conditions which causes natural disasters, such as drought, wildfire, and flood. In addition, it also affects human physical health. The effect of global warming, but also on eutrophication and acidification. This is due to the usage of gas in cooking activity which releases sulphuric uncontrolled rainfall would cause flood so that the supply of clean water is insufficient resulting in diseases such as dengue fever, malaria, and other diseases.

The substances released into the water and air during the production process affect not only on emissions. Acidification can be defined as an environmental impact affected by acidified streams or rivers as well as soil because of anthropogenic air pollutants, for instance, NH_3, SO_2, and NO_x. It upsurges mobilization and leaching behaviour of heavy metals in soil and exerts awful impacts on terrestrial and aquatic plants and animals by intruding the food web. On the other side, eutrophication is "a phenomenon in which inland waters are heavily loaded with excess nutrients due to chemical fertilizers or discharged wastewater, triggering rapid algal growth and red tides" (Kim and Chae, 2017).

The usage of low-density polyethylene (LDPC) as a product packaging would cause the fine dust, which has an impact on human body as well as the environment. The use of LDPC is considered as a very serious environmental problem since it is categorized as waste which is difficult to be degraded by nature. Waste water produced in the production process would cause ecotoxicity (freshwater) because it contains dissolved and suspended solids in the form of organic and nonorganic substances. These substances can affect the health of living things if it is found in aquatic ecosystems (Rosenbaum *et al.,* 2008).

3.2 Eco-efficiency index result

The EEI of the HPCSM is then carried out to identify whether the sustainability and affordability status of HPCSM. It is considered as an important concept for enterprises to reach sustainability by considering not only the added value aspect but also the environmental impacts. According to Equation (1), there are three terms that must be investigated to obtain EEI, i.e., net value, total production cost, and eco-cost. In this research, net value is calculated using cost benefit analysis by subtracting the total production cost from the sales. The total production cost comprises of the direct production cost, overhead cost, and personnel cost. The direct production cost consists of cost of raw materials (i.e., milkfish, spices), packaging, and gas used. The overhead cost is calculated by summing the electricity and maintenance cost. The personnel cost is the salary of the worker per day. On the other side, the sales are found by multiplying the selling price to the number of products sold. Selling price of the HPCSM ranges from € 2.6 to € 6.6 per kilogram. The EEI for each type of the enterprise are shown in Table 8. Note that the eco-cost represents the single score of LCA (see Subsection 3.1).

The results show that all products sold from all types of enterprises are considered as affordable but not sustainable (i.e., EEI < 1). Affordable means that the products are already economically efficient and provide benefits to the enterprises because the selling price is greater than the total production cost. However, the products are considered as not sustainable. This unsustainability condition can be caused by several things, such as the disposal of waste water which harms the environment; and the use of cold storage which causes emissions that are released into the open air and water. From the assessment that has been carried out, the environmental impacts include acidification, global warming, metals depletion, fine dust, eutrophication, photochemical oxidant formation, human toxicity, waste, water stress indicator, and ecotoxicity (freshwater). The impacts trigger the emergence of the environmental impact costs (eco-cost) that must be spent by enterprises to cope with the impacts that occur in the environment. In addition, since the production cost is high, it indicates that the process is not efficient, and it can lead to unsustainable products.

The EER for this research is 67.74% for small-scale enterprises, 92.83% for medium-scale enterprises, and 96.67% for large-scale enterprise. It is the ratio between product sales and the impacts on the environment. The rate of efficiency of a production activity signifies the impacts on the environment. The low rate is directly proportional to the negative impacts caused. In this research, small-scale enterprises have lower negative impacts compared to medium- and large-scale enterprises.

Table 8. Eco-efficiency index result

Variables	Small-scale	Medium-scale	Large-scale
Total Production cost per day	€ 42.30	€ 115.18	€ 408.34
Raw materials cost	€ 23.08	€ 72.51	€ 183.76
Overhead cost	€ 13.92	€ 32.03	€ 51.37
Personnel cost	€ 5.30	€ 10.64	€ 173.21
Sales per day	€ 46.37	€ 178.49	€ 660.00
Net value per day	€ 4.07	€ 63.31	€ 251.66
Eco-cost per day	€ 1.317	€ 4.540	€ 8.364
EEI	0.09	0.53	0.60
EVR	0.32	0.07	0.03
EER	67.74%	92.83%	96.67%

3.3 Recommendations for improvement

The previous calculations show that the production process has several environmental impacts, such as climate change, photochemical oxidant formation, acidification, fine dust, eutrophication, ecotoxicity (fresh water), human toxicity, metals depletion, waste, and water stress indicator. In addition, the analysis of eco-efficiency index revealed that even though all products are affordable, but they are not sustainable. It is inevitable for the following reasons. Mostly, the production process is conducted in an open space under the house. It could invite wild animals such as flies, dogs, and chickens to swarm around the production place. Most of the enterprises have not applied the principle of sanitation and hygiene yet. It is possible that they dispose the waste water into open sewers that can flow into rivers or rice fields. Also for solid waste, the enterprises have not managed well the waste optimally so that it is wasted. The recommendations for the improvement to minimize the environmental impacts and the sustainability status of the enterprises are given as following.

The solid waste typically found in the HPCSM production process are the middle bone, fine thorns, fish fins, fish scales, fish spines, and fish entrails. The total yield of the edible part is about 77.2%, which is still the largest portion. To minimize the environmental pollution problems due to these solid waste, the enterprises could reuse them. Karim *et al.* (2020) showed some endeavours to utilize the solid waste of HPCSM production process, e.g., the enterprises might make a fish meat ball from leftover meats that cannot enter the production process; the bones can be processed to be stick fish bone; fish spines and fish fins can be a shredded milkfish; fish entrails (i.e., fish intestines) can be sold; the gills and other fish digestive organs can be made as animal feed: for catfish, geese, and ducks.

Apart from solid waste that are coming from the milkfish, the solid waste which are coming from spice are also can be utilized. Husni *et al.* (2015) showed that ginger waste can be utilized as animal feed: for sheep.

The waste water is one source of pollutants for the environment, because if is disposed into the environment without proper management it can disrupt the recipient's water body. The enterprises can perform filtration of waste water before disposal. The filtration process could remove most of the suspended solids and dissolved materials.

Next is about the use of cold storage to store the finished products. It obviously has negative impacts to the environment since it contains halocarbons that could cause global warming, acidification, and eutrophication. The cold storage spends huge electricity cost; but the number of average fish stored in the cold storage is less than 1 ton per day. It is recommended to use freezer storage container which has lower electricity power so that it can reduce energy consumption as well as electricity cost (Filina-Dawidowicz and Filin, 2019). In the end, the impact for the environment also will be reduced.

The last is concerning the use of the water in the production process. It is recommended to minimize the use of water. In the small-scale enterprises, for one day, they use 141.14 litres of water. This number is doubled in the medium-enterprises (i.e., 243.88 litres of water per day), and four folded in the large-enterprise (i.e., 462 litres of water per day). This endeavour can be performed by minimizing the use of water in washing activities. The enterprises usually purchase fresh milkfishes from their suppliers. The enterprises need to wash these fresh fishes before cooking them. In order to save the water use, the enterprises could ask the suppliers to clean the fishes first before distributing them. This endeavour is believed to minimize the risk of water scarcity or lack of freshwater. As we know that water scarcity is listed by the World Economic Forum as one of the major global risks over the next decade (World Economic Forum, 2019). Therefore, managing freshwater well is vital for promoting sustainability and facing the threat of climate change (UNEP, 2017).

4. Conclusion

This research has demonstrated how to measure and assess the environmental impacts of HPCSM production in small-, medium-, and large-scale enterprises in Semarang. Since the production uses large amount of water and releases liquid as well as solid waste to open air and water, such assessment is necessary. LCA was used in this research to accomplish the study's goal. Results showed that the production process contributes to several environmental impacts, such as climate change, eutrophication, acidification, photochemical oxidant formation, fine dust, human toxicity, ecotoxicity (fresh water), metals depletion, waste, and water stress indicator. For small-scale enterprises, the LCA's single score is € 1.317, while for medium-scale and large-scale are € 4.540 and € 8.364 respectively. It indicates the amount of money spent by the enterprises per day to compensate the environmental impacts they caused. The EEI revealed that the products for all type of enterprises are considered as affordable but not sustainable. The unsustainability condition is inevitable as the results of LCA showed several negative environmental impacts. Lastly, the recommendations for the improvement to minimize the environmental impacts and the sustainability status of the enterprises are also provided.

Acknowledgments

This research was financially supported by "Direktorat Riset dan Pengabdian Masyarakat, Direktorat Jenderal Penguatan Riset dan Pengembangan, Kementerian Riset, Teknologi dan Pendidikan Tinggi," Indonesia, in PDUPT scheme (2019).

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