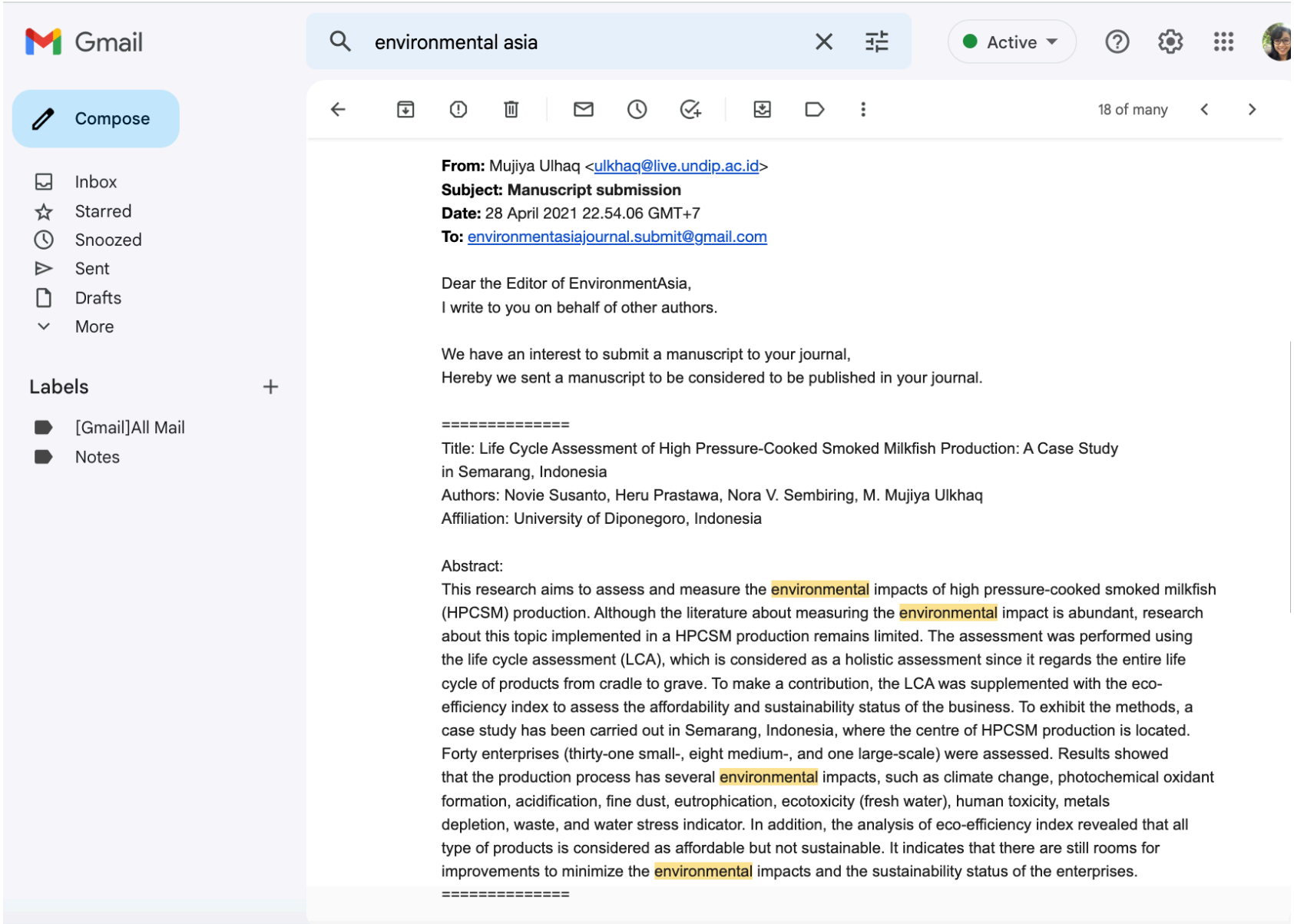
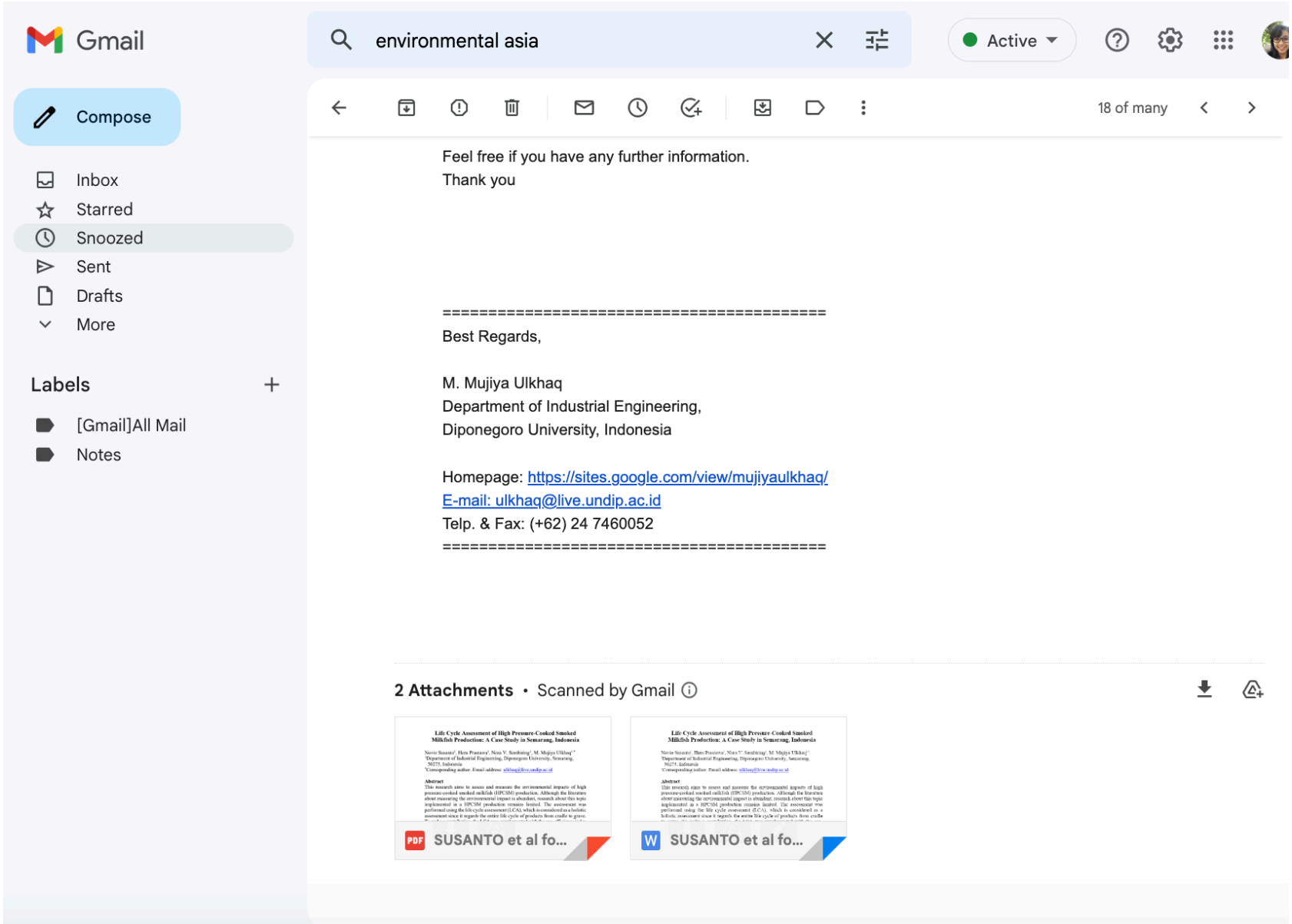
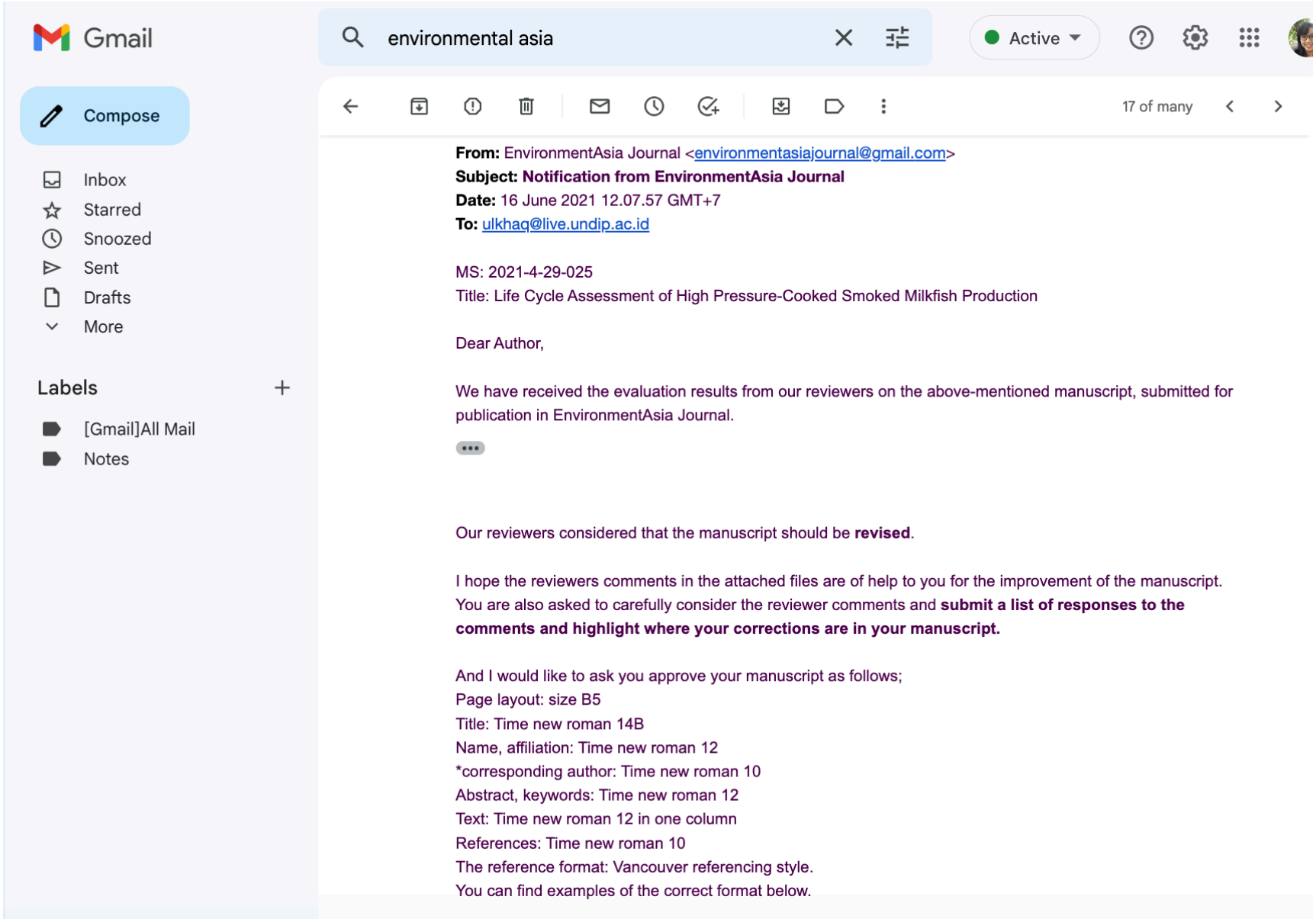
**DAFTAR ISI KORESPONDENSI**

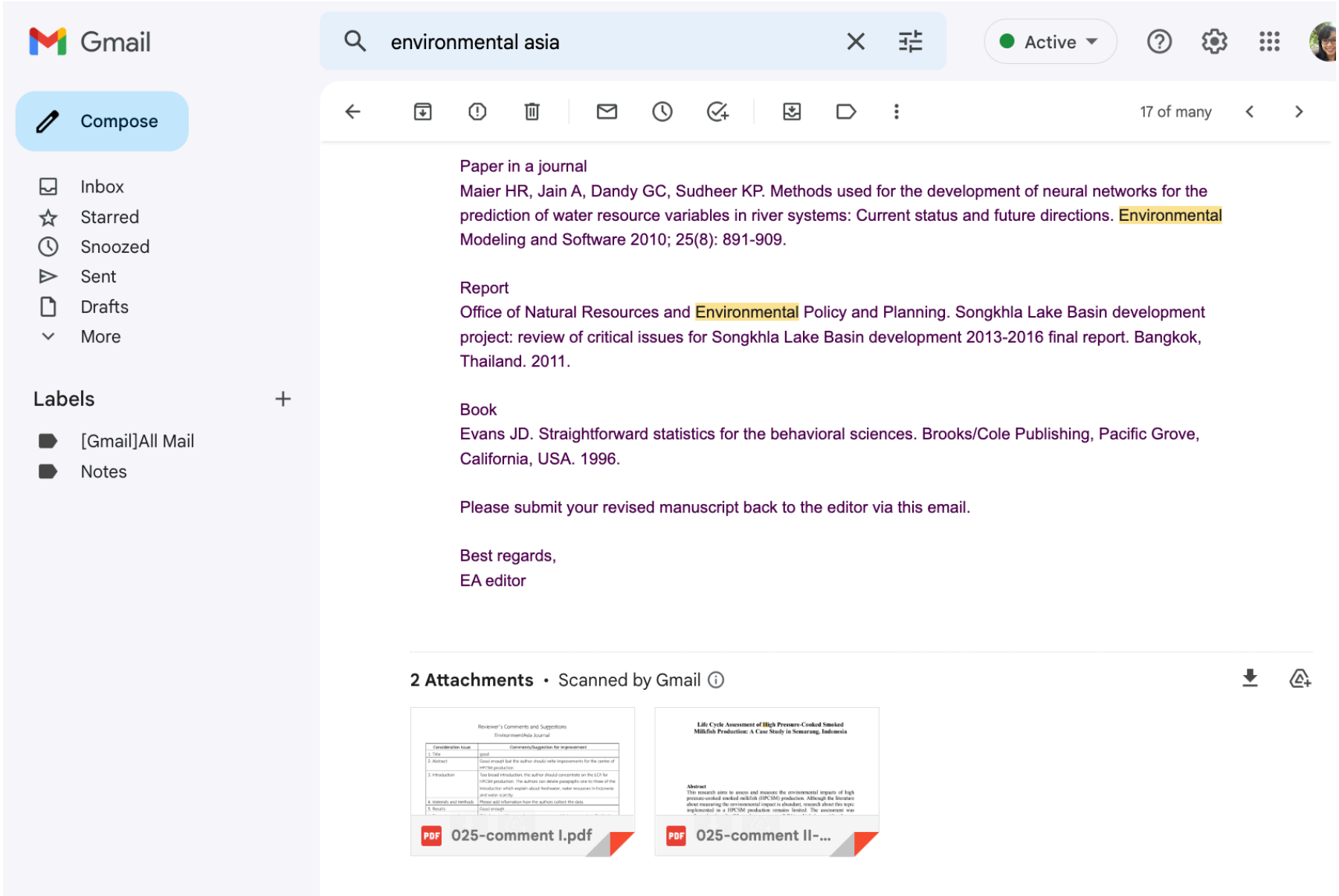
JUDUL Life Cycle Assessment of High Pressure-Cooked Smoked Milkfish
ARTIKEL Production: A Case Study in Semarang, Indonesia

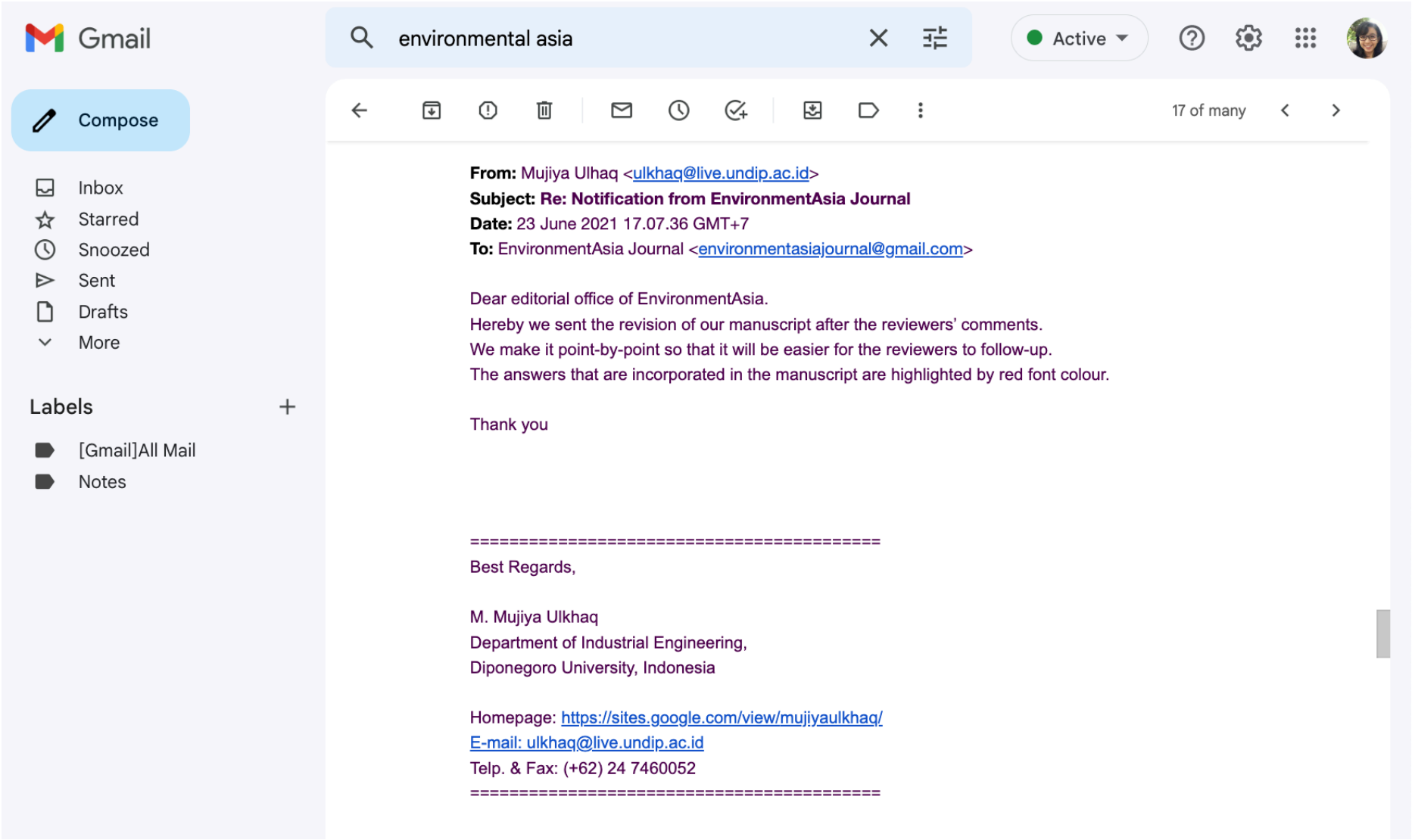

| Nr. | Keterangan | Hal |
|---|---|---|
| 1 | Manuscript submission (email) | 1 |
| 2 | Result of review 1 (email) | 3 |
| 3 | Submission of revised manuscript (email) | 6 |
| 4 | Response to reviewer 1 | 7 |
| 5 | Revised article 1 | 9 |
| 6 | Result of review 2 (email) | 23 |
| 7 | Response to reviewer 2 | 24 |
| 8 | Revised article 2 | 26 |
| 9 | Result of review 3 (email) | 41 |
| 10 | Response to reviewer 3 (email) | 42 |
| 11 | Revised article 3 | 43 |
| 12 | Acceptance notification (email) | 58 |


Gmail
environmental asia
Active
Compose
Inbox
Starred
Snoozed
Sent
Drafts
More
Labels
[Gmail]All Mail
Notes
18 of many
From: Mujiya Ulhaq <ulkhaq@live.undip.ac.id>
Subject: Manuscript submission
Date: 28 April 2021 22.54.06 GMT+7
To: environmentasiajournal.submit@gmail.com
Dear the Editor of EnvironmentAsia,
I write to you on behalf of other authors.
We have an interest to submit a manuscript to your journal,
Hereby we sent a manuscript to be considered to be published in your journal.
==========
Title: Life Cycle Assessment of High Pressure-Cooked Smoked Milkfish Production: A Case Study in Semarang, Indonesia
Authors: Novie Susanto, Heru Prastawa, Nora V. Sembiring, M. Mujiya Ulkhaq
Affiliation: University of Diponegoro, Indonesia
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. It indicates that there are still rooms for improvements to minimize the environmental impacts and the sustainability status of the enterprises.
==========


Gmail
environmental asia
Active
Compose
Inbox
Starred
Snoozed
Sent
Drafts
More
Labels
[Gmail]All Mail
Notes
18 of many
Feel free if you have any further information.
Thank you
==========
Best Regards,
M. Mujiya Ulkhaq
Department of Industrial Engineering,
Diponegoro University, Indonesia
Homepage: https://sites.google.com/view/mujiyaulkhaq/
E-mail: ulkhaq@live.undip.ac.id
Telp. & Fax: (+62) 24 7460052
==========
2 Attachments • Scanned by Gmail
SUSANTO et al fo...
SUSANTO et al fo...


Gmail
environmental asia
Active
Compose
Inbox
Starred
Snoozed
Sent
Drafts
More
Labels
[Gmail]All Mail
Notes
17 of many
From: EnvironmentAsia Journal <environmentasiajournal@gmail.com>
Subject: Notification from EnvironmentAsia Journal
Date: 16 June 2021 12.07.57 GMT+7
To: ulkhaq@live.undip.ac.id
MS: 2021-4-29-025
Title: Life Cycle Assessment of High Pressure-Cooked Smoked Milkfish Production
Dear Author,
We have received the evaluation results from our reviewers on the above-mentioned manuscript, submitted for publication in EnvironmentAsia Journal.
Our reviewers considered that the manuscript should be revised.
I hope the reviewers comments in the attached files are of help to you for the improvement of the manuscript. You are also asked to carefully consider the reviewer comments and submit a list of responses to the comments and highlight where your corrections are in your manuscript.
And I would like to ask you approve your manuscript as follows;
Page layout: size B5
Title: Time new roman 14B
Name, affiliation: Time new roman 12
*corresponding author: Time new roman 10
Abstract, keywords: Time new roman 12
Text: Time new roman 12 in one column
References: Time new roman 10
The reference format: Vancouver referencing style.
You can find examples of the correct format below.


Gmail
environmental asia
Active
Compose
Inbox
Starred
Snoozed
Sent
Drafts
More
Labels
[Gmail]All Mail
Notes
17 of many
Paper in a journal
Maier HR, Jain A, Dandy GC, Sudheer KP. Methods used for the development of neural networks for the prediction of water resource variables in river systems: Current status and future directions. Environmental Modeling and Software 2010; 25(8): 891-909.
Report
Office of Natural Resources and Environmental Policy and Planning. Songkhla Lake Basin development project: review of critical issues for Songkhla Lake Basin development 2013-2016 final report. Bangkok, Thailand. 2011.
Book
Evans JD. Straightforward statistics for the behavioral sciences. Brooks/Cole Publishing, Pacific Grove, California, USA. 1996.
Please submit your revised manuscript back to the editor via this email.
Best regards,
EA editor
2 Attachments • Scanned by Gmail
025-comment I.pdf
025-comment II-...




**From:** Mujiya Ulhaq <ulkhaq@live.undip.ac.id>
**Subject:** **Re: Notification from EnvironmentAsia Journal**
**Date:** 23 June 2021 17.07.36 GMT+7
**To:** EnvironmentAsia Journal <environmentasiajournal@gmail.com>

Dear editorial office of EnvironmentAsia.
Hereby we sent the revision of our manuscript after the reviewers' comments.
We make it point-by-point so that it will be easier for the reviewers to follow-up.
The answers that are incorporated in the manuscript are highlighted by red font colour.

Thank you

==========
Best Regards,

M. Mujiya Ulkhaq
Department of Industrial Engineering,
Diponegoro University, Indonesia

Homepage: https://sites.google.com/view/mujiyaulkhaq/
E-mail: ulkhaq@live.undip.ac.id
Telp. & Fax: (+62) 24 7460052
==========

Dear Reviewers,

Thank you for your thorough and detailed comments regarding our manuscript. We believe that your comments will improve the quality and readability of our manuscript.

The following is the answers of your comments; we make it point-by-point so that it will be easier for you to follow-up. The answers that are incorporated in the manuscript will be highlighted by red font colour.

1. **Comment**:
   *Title*: Good
   **Answer**: Thank you!

2. **Comment**:
   *Abstract*: Good enough but the author should write improvements for the centre of HPCSM production
   **Answer**: Thank you for this comment. We have added several recommendations for the improvement to minimize the environmental impacts and put them in the new Subsection 3.3. In the manuscript, it is written in the red font colour.

3. **Comment**:
   *Introduction*: Too broad introduction, the author should concentrate on the LCA for HPCSM production. The authors can delete paragraphs one to three of the introduction which explain about freshwater, water resources in Indonesia and water scarcity.
   **Answer**:
   Thank you for this comment. We have deleted paragraph one to three in the introduction section.

4. **Comment:**
   *Materials and Methods*: Please add information how the authors collect the data.
   **Answer**: Thank you for this comment. We have added one subsection as 2.1 Data collection, providing how we collected the data. Also, we have changed a little bit in Subsection 3.1: (i) moving Figure 2 to the new Subsection 2.1 as suggested by the reviewers; and (ii) rewrite the sentences to improve the readability. In the manuscript, it is written in the red font colour.

5. **Comment:**
   *Results*: Good enough
   **Answer**: Thank you!

6. **Comment:**
   *Discussion and conclusion*: “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." What do the authors suggest so that the products are not damaged?
**Answer**: Thank you for this comment. We have added the recommendation for this issue in the new Subsection 3.3, specifically in paragraph 5. In the manuscript, it is written in the red font colour

7. **Comment:**
   *References and citations*: Enough
   **Answer**: Thank you!

8. **Comment:** Please change to USD
   **Answer**: We are sorry to keep the values in Euro. The output of the software was in Euro and we cannot change it! If we change it manually, we are afraid that this change would affect the calculation as well as the analysis. Furthermore, we do not think that the readers would have difficulties in the interpretation since Euro also considered as a global currency.

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

Novie Susanto[1], Heru Prastawa[1], Nora V. Sembiring[1], M. Mujiya Ulkhaq[1,*]
[1]Department of Industrial Engineering, Diponegoro University, Semarang, 50275, Indonesia
[*]Corresponding author. E-mail address: ulkhaq@live.undip.ac.id

**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 liquid waste that has negative impacts for the environment since it contains dissolved and suspended solids in the form of organic and nonorganic substances. The liquid waste 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 non-product output (NPO), such as liquid waste (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 a salty atmosphere 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±1)°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.

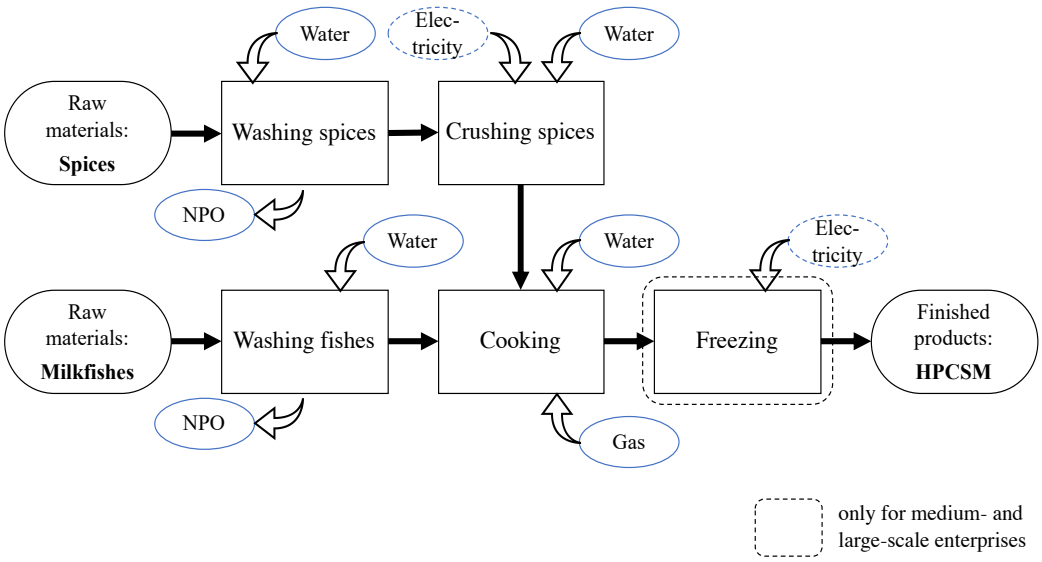



**Figure 1 Production process of high pressure-cooked smoked milkfish**

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.

**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 |
| Purcha-se 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.

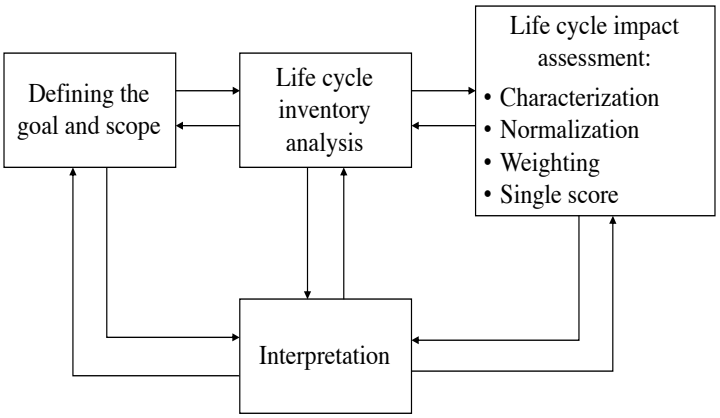



**Figure 2 Stages in life cycle assessment**

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"). 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):

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

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):

$$\text{EER} = (1 - \text{EVR}) \times 100\%, \quad (2)$$

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.

**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.<br>• This study is conducted in Semarang, Indonesia.<br>• 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. |

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 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 |

| Scale of the enterprise | Activity | Input | Output | Unit | Average Quantity |
|---|---|---|---|---|---|
| | | 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 | $3.46 \times 10^{-8}$ | $1.10 \times 10^{-7}$ | $2.14 \times 10^{-7}$ |
| 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) | € $5.54 \times 10^{-6}$ / 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 |

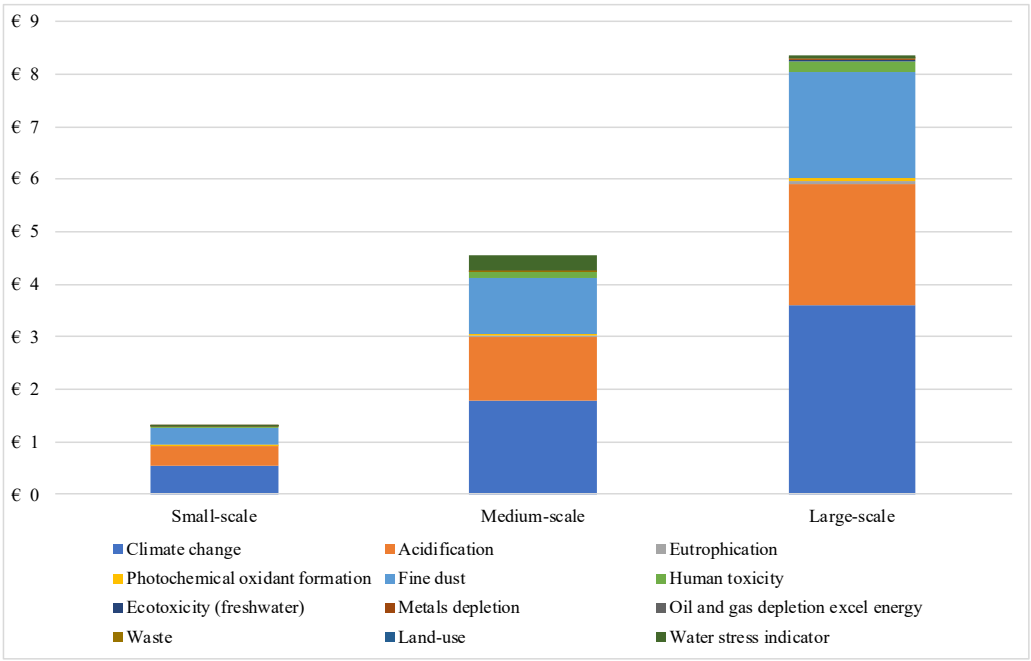



**Figure 3. Life cycle assessment result**

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. Liquid waste 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).

**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 |

| Variables | Small-scale | Medium-scale | Large-scale |
|---|---|---|---|
| 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% |

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 liquid waste 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.

### *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 liquid waste 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 liquid waste 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 liquid waste 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).

## 5. References

Andersson K, Ohlsson T, Olsson P. Screening life cycle assessment (LCA) of tomato ketchup: A case study. J. Cleaner Prod. 1998;3-4:277-288.

Beauchemin KA, Janzen HH, Little SM, McAllister TA, McGinn SM. Life cycle assessment of greenhouse gas emissions from beef production in western Canada: A case study. Agr. Syst. 2020;103:371-379.

Cederberg C, Stadig M. System expansion and allocation in life cycle assessment of milk and beef production. Int. J. Life Cycle Assess. 2003;8:350-356..

De Simone L, Popoff F. Eco-efficiency: The Business Link to Sustainable Development. Cambridge: MIT Press; 1997.

Fay R, Treloar G, Iyer-Raniga U. Life-cycle energy analysis of buildings: a case study. Building Res. Inf. 2000;28:31-41.

Filina-Dawidowicz L, Filin S. Innovative energy-saving technology in refrigerated containers transportation. Energy Efficiency. 2019;12:1151–1165.

Finnveden G, Hauschild MZ, Ekvall T, Guinée J, Heijungs R, Hellweg S, Koehler A, Pennington D, Suh S. Recent developments in life cycle assessment. J. Env. Manage. 2009;91:1-21.

Hur T, Lim ST, Lee HJ. A study on the eco-efficiencies for recycling methods of plastics wastes. Konkuk University; 2003.

Husni A, Santosa U, Heriyadi D, Sidik, Hernaman I. The effect of utilization of ginger (zingiber officinale) waste meal in sheep ration on rumen microbe. Jurnal Ilmu Ternak. 2015;15(1):1-4.

IPCC. Climate change 2001: the scientific basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change (Houghton JT, Ding Y, Griggs DJ, Noguer M, van der Linden PJ, Dai X, Maskell K, Johnson CA (Eds.)). Cambridge: Cambridge University Press; 2001.

ISO. ISO 14040–Environmental Management –Life Cycle Assessment: Principles and Framework. Paris: International Standard Organization; 1997.

ISO. ISO 14044-Environmental Management –Life Cycle Assessment: Requirements and Guidelines. Paris: International Standard Organization; 2006.

Karim M, Salman D, Genisa J, Rahmadanih. Competitiveness and SMEs production sustainability through the cleaner production (case study: SMEs of fish processing unit in Pinrang Regency, Indonesia). IOP Conf. Series: Earth and Environmental Science. 2020;473:012019.

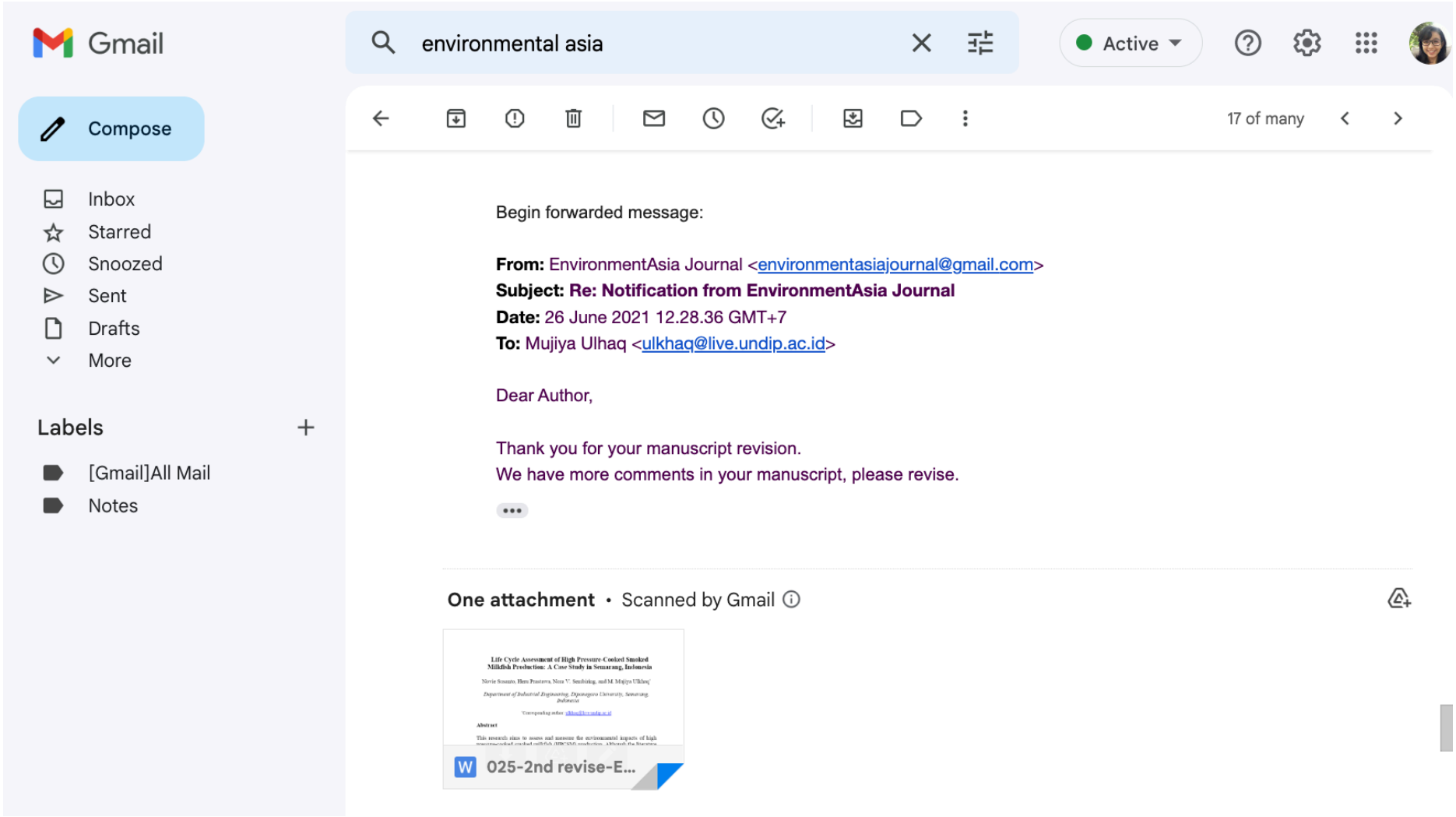
Kim TH, Chae CU. Environmental impact analysis of acidification and eutrophication due to emissions from the production of concrete. Sustainability. 2016;8:578.

Ma X, Ye L, Qi C, Yang D, Shen X, Hong J. Life cycle assessment and water footprint evaluation of crude steel production: A case study in China. J. Env. Manage. 2018;224:10-18.

Nelson JS. Fishes of the World (4th ed.). Hoboken: John Wiley & Sons; 2006.

Olmez GM, Dilek FB, Karanfil T, Yetis U. The environmental impacts of iron and steel industry: A life cycle assessment study. J. Cleaner Prod. 2016;130:195-201.

Pizzol M, Laurent A, Sala S, Weidema BP, Verones F, Koffler C. Normalisation and weighting in life cycle assessment: quo vadis? Int. J. Life Cycle Assess. 2017;22:853-866.
Ramesh T, Prakash R, Shukla KK. Life cycle energy analysis of buildings: An overview. Energy Build. 2020;42:1592-1600.
Rosenbaum RK, Bachmann TM, Gold LS, Huijbregts MA, Jolliet O, Juraske R, ... McKone TE. USEtox—the UNEP-SETAC toxicity model: recommended characterisation factors for human toxicity and freshwater ecotoxicity in life cycle impact assessment. Int. J. Life Cycle Assess. 2008;13:532.
Rossi R, Marquart S, Rossi G. Comparative life cycle cost assessment of painted and hot-dip galvanized bridges. J. Env. Manage. 2017;197:41-49.
Saling P, Kicherer A, Dittrich-Krämer B, Wittlinger R, Zombik W, Schmidt I, Schrott W, Schmidt S. Eco-efficiency analysis by BASF: the method. Int. J. Life Cycle Assess. 2002;7:203-218.
UNEP. UN Environment's Freshwater Strategy 2017-2021; 2017.
Vogtlander JG. LCA-based Assessment of Sustainability: The Eco-costs/value Ratio (EVR). VSSD; 2007.
World Economic Forum. The Global Risks Report 2019 (14th Ed.). Geneva: World Economic Forum; 2019.


Gmail
environmental asia
Active
Compose
Inbox
Starred
Snoozed
Sent
Drafts
More
Labels
[Gmail]All Mail
Notes
17 of many
Begin forwarded message:
From: EnvironmentAsia Journal <environmentasiajournal@gmail.com>
Subject: Re: Notification from EnvironmentAsia Journal
Date: 26 June 2021 12.28.36 GMT+7
To: Mujiya Ulhaq <ulkhaq@live.undip.ac.id>
Dear Author,
Thank you for your manuscript revision.
We have more comments in your manuscript, please revise.
One attachment • Scanned by Gmail
Life Cycle Assessment of High Pressure-Cooked Smoked Milkfish Production: A Case Study in Semarang, Indonesia
Abstract
025-2nd revise-E...

Dear Reviewers,

Thank you for your thorough and detailed comments regarding our manuscript. We believe that your comments will improve the quality and readability of our manuscript.

The following is the answers of your comments; we make it point-by-point so that it will be easier for you to follow-up.

1. **Comment**: about "liquid waste"
   **Answer**: Thank you for this comment, we have changed the word "liquid waste" to "waste water". In the manuscript, we highlighted the changed word by red font colour.

2. **Comment**: why are them [refer to liquid waste or has been changed into waste water] no impact? really?
   **Answer**: In the manuscript we have stated that the liquid waste [has been changed into waste water] has negative impact for the environment. It is written in 15$^{th}$ to 16$^{th}$ line of third paragraph of Introduction section. To make it clearer, we have highlighted the statement by yellow background colour and red font colour.

3. **Comment**: in "a salty atmosphere" means boiled in brine water or steam with brine water?
   **Answer**:
   Thank you for clarifying this. "in a salty atmosphere" means "boiled in brine water". We have changed the phrase and written it by red font colour.

4. **Comment:** What does it mean? [refer to the equation of EEI]
   **Answer**: We have described EEI and the equation in the manuscript in Subsection 2.3

   "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."
   …
   "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" … "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."

   To make it clearer, we have highlighted the statement by yellow background colour and red font colour.

5. **Comment:** What's activity? [refer to Table 5]
   **Answer**: It is washing spices activity. We think that the reviewers did not see this information clearly because Table 5 is "cut" (it is written in a different page). To make it clearer, we made Table 5 not to be cut by page.

6. **Comment:** Use full name of journal [refer to the References section]
   **Answer**: Thank you for this comment. We have changed the journal's name to be full name instead of abbreviation. In the manuscript, we highlighted the changed word by red font colour.

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

Novie Susanto[1], Heru Prastawa[1], Nora V. Sembiring[1], M. Mujiya Ulkhaq[1,*]
[1]Department of Industrial Engineering, Diponegoro University, Semarang, 50275, Indonesia
[*]Corresponding author. E-mail address: ulkhaq@live.undip.ac.id

**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 waste water 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 non-product output (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±1)°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.

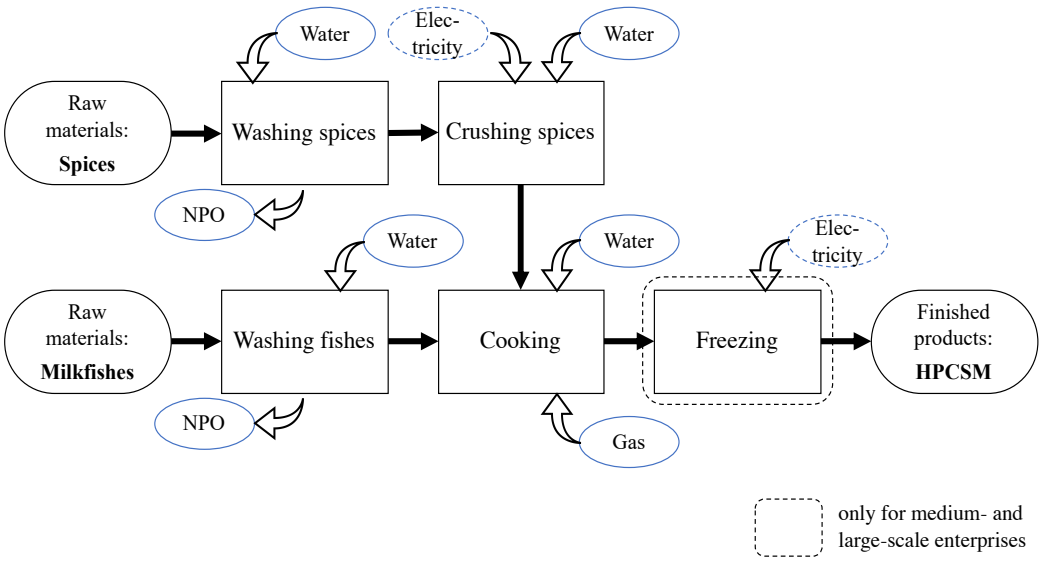



**Figure 1 Production process of high pressure-cooked smoked milkfish**

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.

**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 |
| Purcha-se 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.

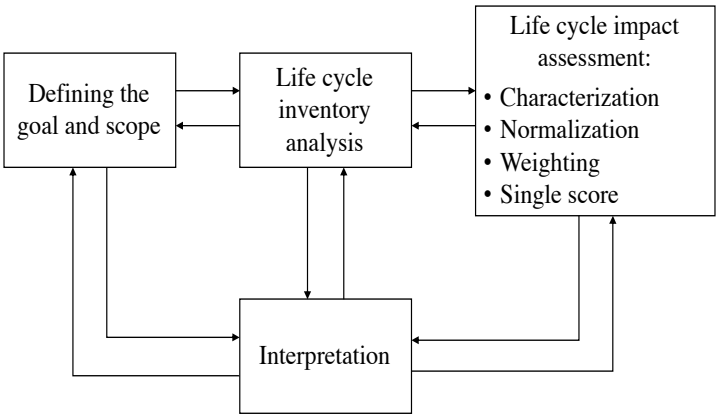



**Figure 2 Stages in life cycle assessment**

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"). 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):

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

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):

$$\text{EER} = (1 - \text{EVR}) \times 100\%, \quad (2)$$

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.

**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.<br>• This study is conducted in Semarang, Indonesia.<br>• There are forty enterprises analysed in this study, categorised as small-scale (31 enterprises), medium-scale (8 enterprises), and large-scale (1 enterprise).<br>• 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. |

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 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 | $3.46 \times 10^{-8}$ | $1.10 \times 10^{-7}$ | $2.14 \times 10^{-7}$ |
| 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) | € $5.54 \times 10^{-6}$ / 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 |

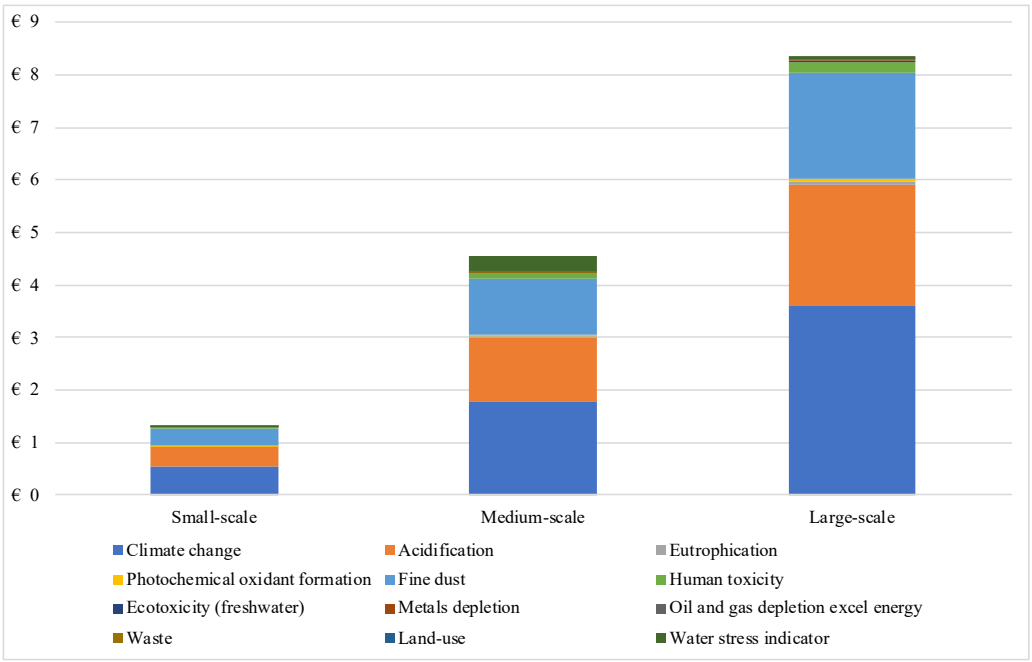



**Figure 3. Life cycle assessment result**

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).

**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% |

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.

*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).

## 5. References

Andersson K, Ohlsson T, Olsson P. Screening life cycle assessment (LCA) of tomato ketchup: A case study. Journal of Cleaner Production 1998;3-4:277-288.

Beauchemin KA, Janzen HH, Little SM, McAllister TA, McGinn SM. Life cycle assessment of greenhouse gas emissions from beef production in western Canada: A case study. Agricultural Systems 2020;103:371-379.

Cederberg C, Stadig M. System expansion and allocation in life cycle assessment of milk and beef production. International Journal of Life Cycle Assessment 2003;8:350-356.

De Simone L, Popoff F. Eco-efficiency: The Business Link to Sustainable Development. Cambridge: MIT Press; 1997.

Fay R, Treloar G, Iyer-Raniga U. Life-cycle energy analysis of buildings: a case study. Building Research & Information 2000;28:31-41.

Filina-Dawidowicz L, Filin S. Innovative energy-saving technology in refrigerated containers transportation. Energy Efficiency 2019;12:1151–1165.

Finnveden G, Hauschild MZ, Ekvall T, Guinée J, Heijungs R, Hellweg S, Koehler A, Pennington D, Suh S. Recent developments in life cycle assessment. Journal of Environmental Management 2009;91:1-21.

Hur T, Lim ST, Lee HJ. A study on the eco-efficiencies for recycling methods of plastics wastes. Konkuk University; 2003.

Husni A, Santosa U, Heriyadi D, Sidik, Hernaman I. The effect of utilization of ginger (zingiber officinale) waste meal in sheep ration on rumen microbe. Jurnal Ilmu Ternak 2015;15(1):1-4.

IPCC. Climate change 2001: the scientific basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change (Houghton JT, Ding Y, Griggs DJ, Noguer M, van der Linden PJ, Dai X, Maskell K, Johnson CA (Eds.)). Cambridge: Cambridge University Press; 2001.

ISO. ISO 14040–Environmental Management –Life Cycle Assessment: Principles and Framework. Paris: International Standard Organization; 1997.

ISO. ISO 14044-Environmental Management –Life Cycle Assessment: Requirements and Guidelines. Paris: International Standard Organization; 2006.

Karim M, Salman D, Genisa J, Rahmadanih. Competitiveness and SMEs production sustainability through the cleaner production (case study: SMEs of fish processing unit in Pinrang Regency, Indonesia). IOP Conference Series: Earth and Environmental Science 2020;473:012019.

Kim TH, Chae CU. Environmental impact analysis of acidification and eutrophication due to emissions from the production of concrete. Sustainability 2016;8:578.

Ma X, Ye L, Qi C, Yang D, Shen X, Hong J. Life cycle assessment and water footprint evaluation of crude steel production: A case study in China. Journal of Environmental Management 2018;224:10-18.

Nelson JS. Fishes of the World (4th ed.). Hoboken: John Wiley & Sons; 2006.

Olmez GM, Dilek FB, Karanfil T, Yetis U. The environmental impacts of iron and steel industry: A life cycle assessment study. J. Cleaner Prod. 2016;130:195-201.

Pizzol M, Laurent A, Sala S, Weidema BP, Verones F, Koffler C. Normalisation and weighting in life cycle assessment: quo vadis? The International Journal of Life Cycle Assessment 2017;22:853-866.

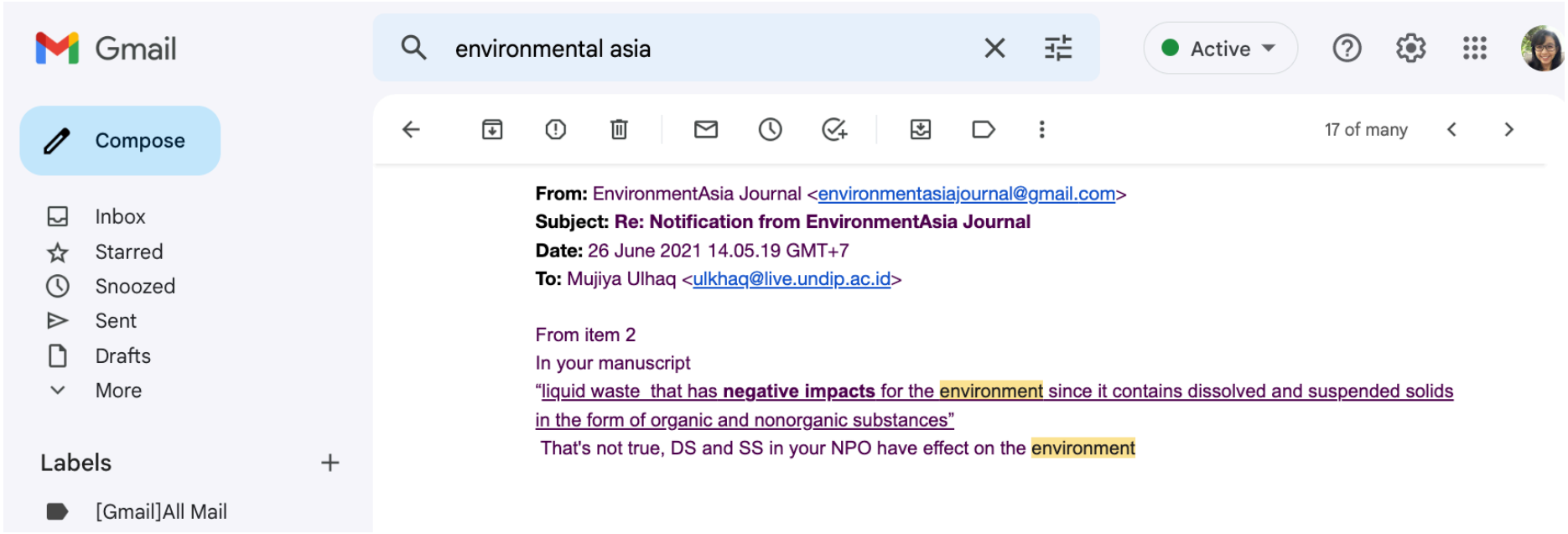
Ramesh T, Prakash R, Shukla KK. Life cycle energy analysis of buildings: An overview. Energy Buildings 2020;42:1592-1600.

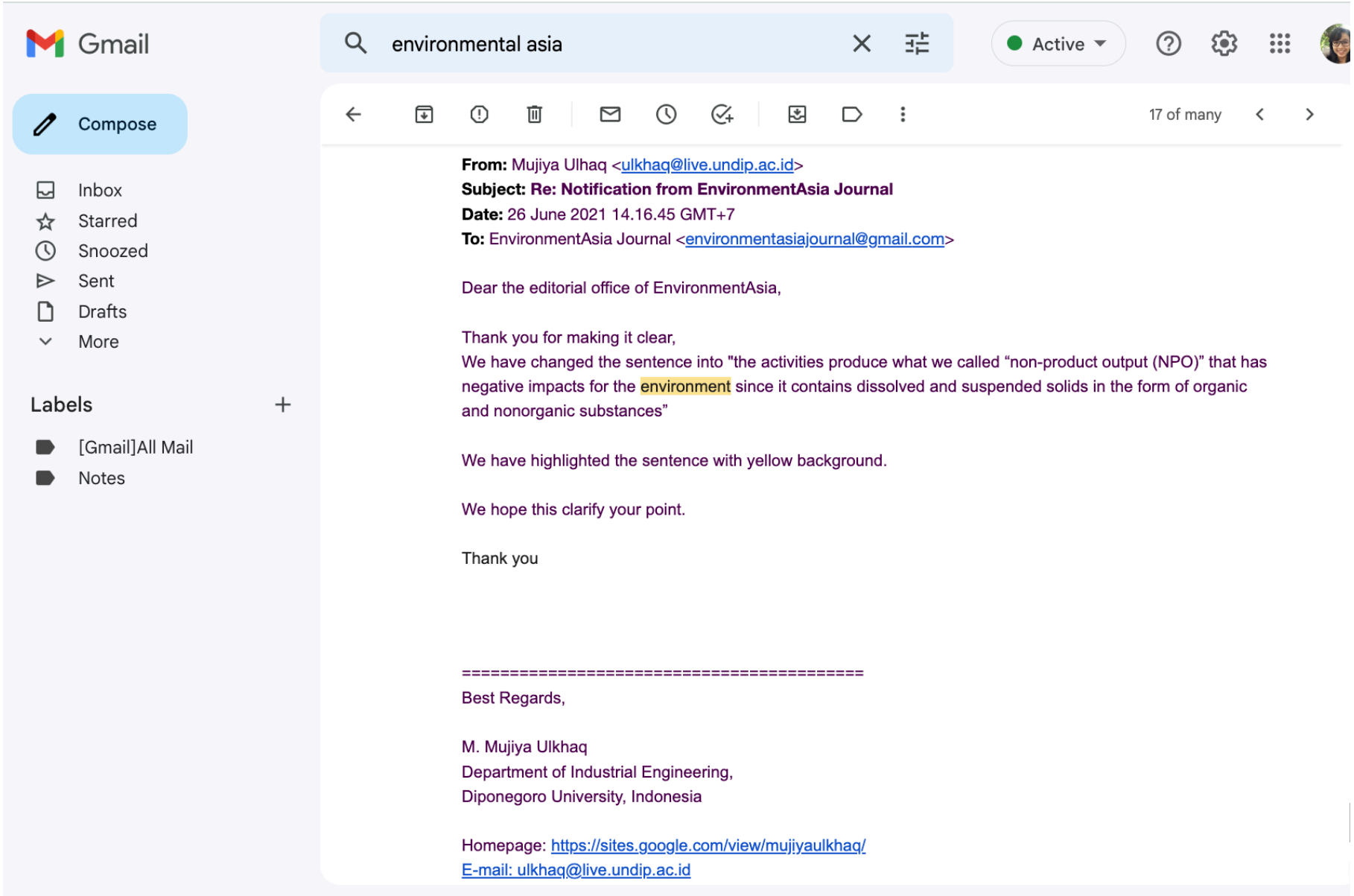
Rosenbaum RK, Bachmann TM, Gold LS, Huijbregts MA, Jolliet O, Juraske R, ... McKone TE. USEtox—the UNEP-SETAC toxicity model: recommended characterisation factors for human toxicity and freshwater ecotoxicity in life cycle impact assessment. The International Journal of Life Cycle Assessment 2008;13:532.

Rossi R, Marquart S, Rossi G. Comparative life cycle cost assessment of painted and hot-dip galvanized bridges. Journal of Environmental Management 2017;197:41-49.

Saling P, Kicherer A, Dittrich-Krämer B, Wittlinger R, Zombik W, Schmidt I, Schrott W, Schmidt S. Eco-efficiency analysis by BASF: the method. The International Journal of Life Cycle Assessment 2002;7:203-218.

UNEP. UN Environment's Freshwater Strategy 2017-2021; 2017.
Vogtlander JG. LCA-based Assessment of Sustainability: The Eco-costs/value Ratio (EVR). VSSD; 2007.
World Economic Forum. The Global Risks Report 2019 (14th Ed.). Geneva: World Economic Forum; 2019.


Gmail
environmental asia
Active
Compose
Inbox
Starred
Snoozed
Sent
Drafts
More
Labels
[Gmail]All Mail
17 of many
From: EnvironmentAsia Journal <environmentasiajournal@gmail.com>
Subject: Re: Notification from EnvironmentAsia Journal
Date: 26 June 2021 14.05.19 GMT+7
To: Mujiya Ulhaq <ulkhaq@live.undip.ac.id>
From item 2
In your manuscript
"liquid waste that has negative impacts for the environment since it contains dissolved and suspended solids in the form of organic and nonorganic substances"
That's not true, DS and SS in your NPO have effect on the environment


Gmail
environmental asia
Active
Compose
Inbox
Starred
Snoozed
Sent
Drafts
More
Labels
[Gmail]All Mail
Notes
17 of many
From: Mujiya Ulhaq <ulkhaq@live.undip.ac.id>
Subject: Re: Notification from EnvironmentAsia Journal
Date: 26 June 2021 14.16.45 GMT+7
To: EnvironmentAsia Journal <environmentasiajournal@gmail.com>
Dear the editorial office of EnvironmentAsia,
Thank you for making it clear,
We have changed the sentence into "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”
We have highlighted the sentence with yellow background.
We hope this clarify your point.
Thank you
==========
Best Regards,
M. Mujiya Ulkhaq
Department of Industrial Engineering,
Diponegoro University, Indonesia
Homepage: https://sites.google.com/view/mujiyaulkhaq/
E-mail: ulkhaq@live.undip.ac.id

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

Novie Susanto[1], Heru Prastawa[1], Nora V. Sembiring[1], M. Mujiya Ulkhaq[1,*]
[1]Department of Industrial Engineering, Diponegoro University, Semarang, 50275, Indonesia
[*]Corresponding author. E-mail address: ulkhaq@live.undip.ac.id

**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±1)°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.

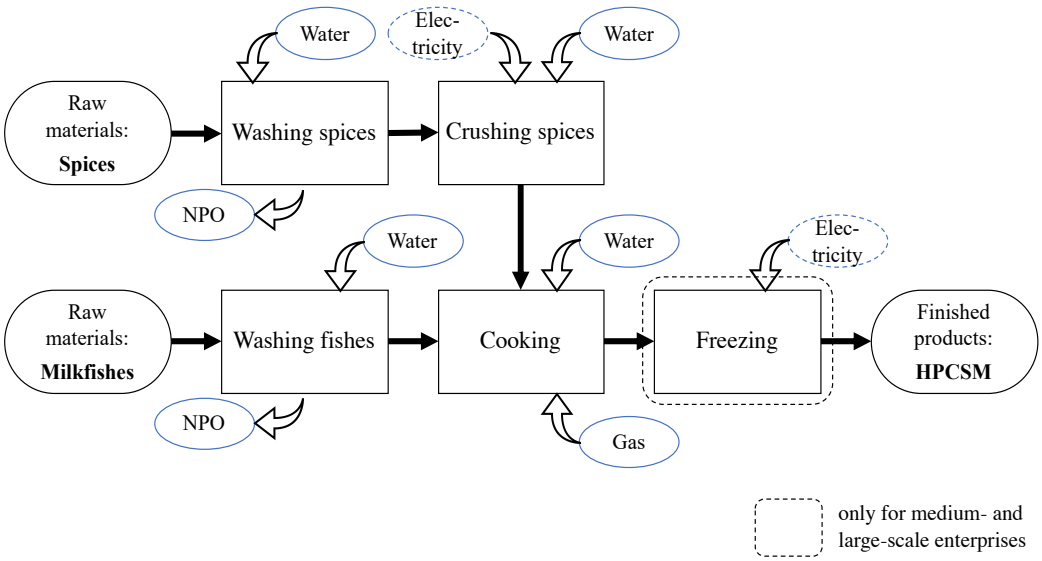



**Figure 1 Production process of high pressure-cooked smoked milkfish**

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.

**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 |
| Purcha-se 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.

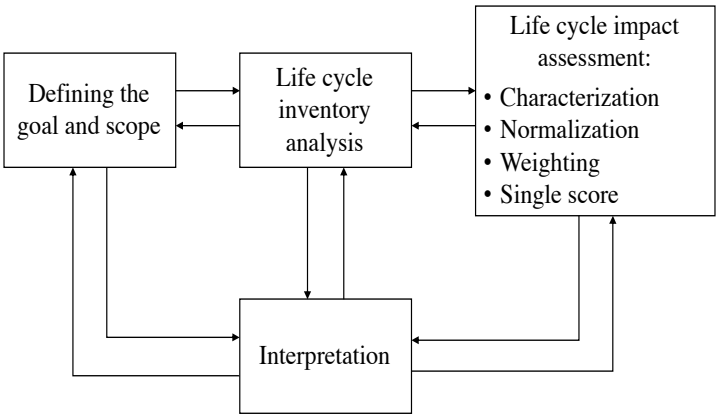



**Figure 2 Stages in life cycle assessment**

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"). 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):

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

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):

$$\text{EER} = (1 - \text{EVR}) \times 100\%, \quad (2)$$

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.

**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.<br>• This study is conducted in Semarang, Indonesia.<br>• There are forty enterprises analysed in this study, categorised as small-scale (31 enterprises), medium-scale (8 enterprises), and large-scale (1 enterprise).<br>• 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. |

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 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 | $3.46 \times 10^{-8}$ | $1.10 \times 10^{-7}$ | $2.14 \times 10^{-7}$ |
| 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) | € $5.54 \times 10^{-6}$ / 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 |

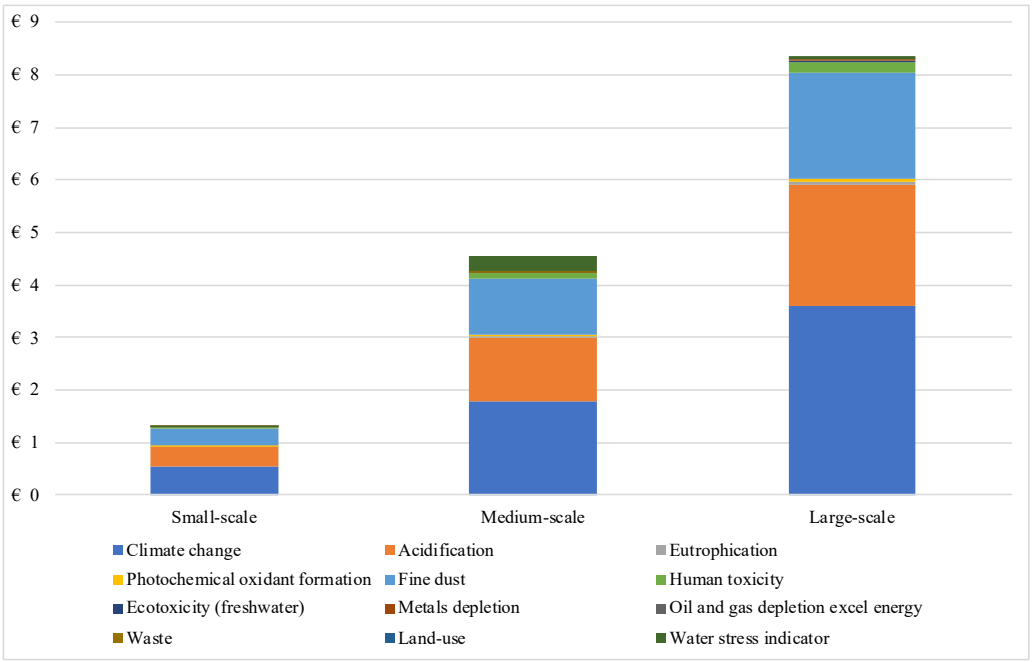



**Figure 3. Life cycle assessment result**

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).

**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% |

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.

*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).

## 5. References

Andersson K, Ohlsson T, Olsson P. Screening life cycle assessment (LCA) of tomato ketchup: A case study. Journal of Cleaner Production 1998;3-4:277-288.

Beauchemin KA, Janzen HH, Little SM, McAllister TA, McGinn SM. Life cycle assessment of greenhouse gas emissions from beef production in western Canada: A case study. Agricultural Systems 2020;103:371-379.

Cederberg C, Stadig M. System expansion and allocation in life cycle assessment of milk and beef production. International Journal of Life Cycle Assessment 2003;8:350-356.

De Simone L, Popoff F. Eco-efficiency: The Business Link to Sustainable Development. Cambridge: MIT Press; 1997.

Fay R, Treloar G, Iyer-Raniga U. Life-cycle energy analysis of buildings: a case study. Building Research & Information 2000;28:31-41.

Filina-Dawidowicz L, Filin S. Innovative energy-saving technology in refrigerated containers transportation. Energy Efficiency 2019;12:1151–1165.

Finnveden G, Hauschild MZ, Ekvall T, Guinée J, Heijungs R, Hellweg S, Koehler A, Pennington D, Suh S. Recent developments in life cycle assessment. Journal of Environmental Management 2009;91:1-21.

Hur T, Lim ST, Lee HJ. A study on the eco-efficiencies for recycling methods of plastics wastes. Konkuk University; 2003.

Husni A, Santosa U, Heriyadi D, Sidik, Hernaman I. The effect of utilization of ginger (zingiber officinale) waste meal in sheep ration on rumen microbe. Jurnal Ilmu Ternak 2015;15(1):1-4.

IPCC. Climate change 2001: the scientific basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change (Houghton JT, Ding Y, Griggs DJ, Noguer M, van der Linden PJ, Dai X, Maskell K, Johnson CA (Eds.)). Cambridge: Cambridge University Press; 2001.

ISO. ISO 14040–Environmental Management –Life Cycle Assessment: Principles and Framework. Paris: International Standard Organization; 1997.

ISO. ISO 14044-Environmental Management –Life Cycle Assessment: Requirements and Guidelines. Paris: International Standard Organization; 2006.

Karim M, Salman D, Genisa J, Rahmadanih. Competitiveness and SMEs production sustainability through the cleaner production (case study: SMEs of fish processing unit in Pinrang Regency, Indonesia). IOP Conference Series: Earth and Environmental Science 2020;473:012019.

Kim TH, Chae CU. Environmental impact analysis of acidification and eutrophication due to emissions from the production of concrete. Sustainability 2016;8:578.

Ma X, Ye L, Qi C, Yang D, Shen X, Hong J. Life cycle assessment and water footprint evaluation of crude steel production: A case study in China. Journal of Environmental Management 2018;224:10-18.

Nelson JS. Fishes of the World (4th ed.). Hoboken: John Wiley & Sons; 2006.

Olmez GM, Dilek FB, Karanfil T, Yetis U. The environmental impacts of iron and steel industry: A life cycle assessment study. J. Cleaner Prod. 2016;130:195-201.

Pizzol M, Laurent A, Sala S, Weidema BP, Verones F, Koffler C. Normalisation and weighting in life cycle assessment: quo vadis? The International Journal of Life Cycle Assessment 2017;22:853-866.

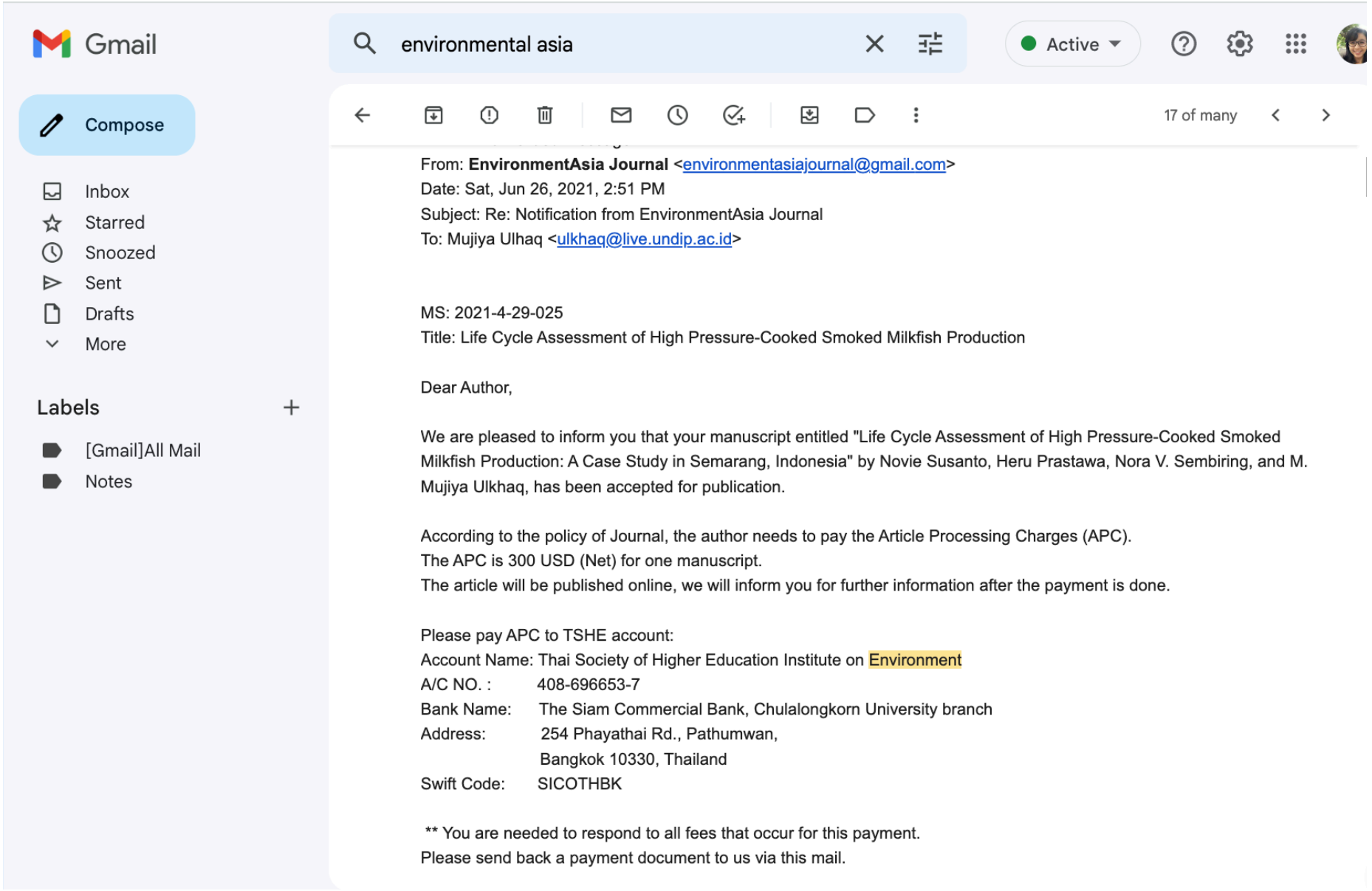
Ramesh T, Prakash R, Shukla KK. Life cycle energy analysis of buildings: An overview. Energy Buildings 2020;42:1592-1600.

Rosenbaum RK, Bachmann TM, Gold LS, Huijbregts MA, Jolliet O, Juraske R, ... McKone TE. USEtox—the UNEP-SETAC toxicity model: recommended characterisation factors for human toxicity and freshwater ecotoxicity in life cycle impact assessment. The International Journal of Life Cycle Assessment 2008;13:532.

Rossi R, Marquart S, Rossi G. Comparative life cycle cost assessment of painted and hot-dip galvanized bridges. Journal of Environmental Management 2017;197:41-49.

Saling P, Kicherer A, Dittrich-Krämer B, Wittlinger R, Zombik W, Schmidt I, Schrott W, Schmidt S. Eco-efficiency analysis by BASF: the method. The International Journal of Life Cycle Assessment 2002;7:203-218.

UNEP. UN Environment's Freshwater Strategy 2017-2021; 2017.
Vogtlander JG. LCA-based Assessment of Sustainability: The Eco-costs/value Ratio (EVR). VSSD; 2007.
World Economic Forum. The Global Risks Report 2019 (14th Ed.). Geneva: World Economic Forum; 2019.


Gmail
environmental asia
Active
Compose
Inbox
Starred
Snoozed
Sent
Drafts
More
Labels
[Gmail]All Mail
Notes
17 of many
From: **EnvironmentAsia Journal** <environmentasiajournal@gmail.com>
Date: Sat, Jun 26, 2021, 2:51 PM
Subject: Re: Notification from EnvironmentAsia Journal
To: Mujiya Ulhaq <ulkhaq@live.undip.ac.id>
MS: 2021-4-29-025
Title: Life Cycle Assessment of High Pressure-Cooked Smoked Milkfish Production
Dear Author,
We are pleased to inform you that your manuscript entitled "Life Cycle Assessment of High Pressure-Cooked Smoked Milkfish Production: A Case Study in Semarang, Indonesia" by Novie Susanto, Heru Prastawa, Nora V. Sembiring, and M. Mujiya Ulkhaq, has been accepted for publication.
According to the policy of Journal, the author needs to pay the Article Processing Charges (APC).
The APC is 300 USD (Net) for one manuscript.
The article will be published online, we will inform you for further information after the payment is done.
Please pay APC to TSHE account:
Account Name: Thai Society of Higher Education Institute on Environment
A/C NO. : 408-696653-7
Bank Name: The Siam Commercial Bank, Chulalongkorn University branch
Address: 254 Phayathai Rd., Pathumwan,
Bangkok 10330, Thailand
Swift Code: SICOTHBK
** You are needed to respond to all fees that occur for this payment.
Please send back a payment document to us via this mail.