Environmental impact of tofu production in West Jakarta using a life cycle assessment approach

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Abstract. Tofu is one of the processed soybean foods that are very popular with Indonesian society. Despite the popularity of Tofu, Tofu production in Indonesia is generally small and medium, reaching 500 kg per day, as in the tofu factory in Semanan, West Jakarta. The purpose of this study is to analyze the environmental impact of tofu production in West Jakarta. The life cycle assessment (LCA) approach was used to achieve this goal with SimaPro software for impact calculations. This research applies the LCA cradle to gate, which consists of soybean cultivation, transportation, and tofu production processes. The environmental impacts of tofu production analyzed in this study include global warming, ozone depletion, acidification, and eutrophication. The impact analysis showed that the acquisition of soybeans, which consisted of soybean cultivation and transportation, had the most significant environmental impact with a global warming potential value of 0.882 kg CO$_2$ eq out of a total of 0.978 CO$_2$ eq for the whole process.

1. Introduction

Soy processed foods such as tofu and tempeh are very popular in Indonesia. Primarily, soybeans in Indonesia are used to produce tempeh (50%), tofu (40%), and other processed soybean products [1]. Semanan is one of the largest tofu production areas in West Jakarta. Each tofu factory in Semanan usually produces 500 kg of tofu per day. Tofu is made in this area using the traditional method of using electricity and firewood as fuel. So with the amount of tofu produced every day, it is necessary to analyze the environmental impact of this tofu production activity.

Tofu products can be analyzed for their impact on the environment using a life cycle assessment (LCA) approach. Life cycle assessment is an approach used to analyze energy and material consumption and the environmental impact of a product. This approach is based on the cradle to the grave, a product of the life cycle analysis process starting from preparing raw materials until the product is consumed by consumers [2]. LCA needs to be applied in various industries as an effort towards a sustainable industry. LCA consists of four stages: determination of objectives and scope, inventory analysis, impact analysis, and interpretation. By using LCA to analyze the life cycle of tofu products, the impact of tofu production on the environment will be known. Thus, the results of this LCA can be used to determine what improvements must be made by tofu producers so that the tofu production process can be categorized as a sustainable industry.

In Indonesia, studies on LCA are still quite limited and are still being developed. LCA in Indonesia has been applied to cement products PT. Holcim [3], mining industry [4], milk product [5], electricity production [6] [7], bottled beverage packaging [8], and waste management [9]. In addition, there are
also LCAs in agriculture, such as LCA for rubber production [10], herbal turmeric acid products [11], and oil palm plantations [12]. LCA studies on tofu products have been carried out by several researchers from Indonesia and other countries. However, most of the LCA for tofu products still adopt a "gate-to-gate" boundary system that only focuses on making tofu. Sukmana et al. [13] have implemented a "cradle to gate" on tofu products but have not included the equipment used to calculate environmental impacts. So it is necessary to do development research to analyze the environmental impact of tofu production thoroughly. This study uses an LCA approach with a "cradle to gate" system boundary where the soybean cultivation process, soybean transportation, and equipment used during the tofu production process are also considered in calculating environmental impacts.

2. Methodology
The environmental impact of the tofu production process is determined and analyzed using the LCA approach, which consists of four main stages as explained below.

2.1. Goal and scope definition
This study uses an LCA approach to analyze the life cycle impact of tofu products. Calculation of the environmental impact of tofu production uses Simapro 9.2 software, and the CML-IA baseline method was used as an impact analysis method. The input data used primary data obtained at one of the tofu factories in Semanan. In addition, the ecoinvent 3 database and data from the literature have conditions that match the actual production of tofu. The functional unit defined in this study is 1 kg of tofu product. The "cradle to gate" system boundary (figure 1) was used to evaluate the environmental impact of tofu production. The soybean cultivation process, soybean transportation from America to the tofu factory, and all stages in tofu production were evaluated in this study. The stages of tofu production consist of washing and soaking soybeans, grinding soybeans, boiling soybean curd, filtering to separate the soymilk from tofu dregs, forming tofu lumps, and pressing tofu.

2.2. Inventory analysis
Primary and secondary data were used in this study. Primary data were obtained through direct observation during tofu production activities and interviews with tofu producers. The data used in this study is the average tofu production data per day, which is 500 kg of tofu. Secondary data were obtained.
from the ecoinvent 3 database and various literature. The input data considered is the amount of energy, raw materials, equipment, and other materials such as water used for tofu production. At the same time, the output data are the top products, by-products, and emissions to water resulting from production activities.

2.3. Impact Assessment
The categories of impacts that could arise due to tofu production activities were determined based on the inventory analysis. The potential environmental impacts evaluated are the potential for global warming, ozone depletion, eutrophication, and acidification. In this study, normalization and weighting were not carried out.

3. Result and discussion
3.1. Inventory analysis result
This study analyzes the use of materials and energy in tofu production using the LCA approach. The environmental impact assessed in this study represents 1 kg of tofu product. Tofu production inventory data is shown in table 1, where the data provided is tofu production data per day which produces 500 kg of tofu. Soybean cultivation data was obtained from the ecoinvent database. Meanwhile, soybean transportation is estimated based on the location of soybean cultivation in America. The modes of transportation used are trains for shipping soybeans from Chicago (cultivation site) to the port, ships for

Table 1. Inventory data of tofu production.

| Process                                | Input          | Total   | Unit |
|----------------------------------------|----------------|---------|------|
| Raw materials acquisition              |                |         |      |
| Soybeans cultivation                    | Soybean seeds  | 175     | kg   |
| Soybeans transportation:                |                |         |      |
| Chicago to Portland Maine              | Train          | 304.5   | tkm  |
| Portland Maine to Cigading             | Shipping       | 2419.08 | tkm  |
| Cigading to West Jakarta (factory)     | Trucking       | 17.6925 | tkm  |
| Soybeans washing                       | Soybeans       | 175     | kg   |
|                                        | Water          | 400     | kg   |
|                                        | HDPE equipment | 0.062   | kg   |
| Soybeans soaking                       | Washed soybeans| 175     | kg   |
|                                        | Water          | 400     | kg   |
|                                        | HDPE equipment | 0.062   | kg   |
| Soybeans grinding                      | Soaked soybeans| 210     | kg   |
|                                        | Electricity    | 45.02   | kWh  |
|                                        | Water          | 540     | kg   |
| Soybeans curd boiling                  | Soybeans curd  | 750     | kg   |
|                                        | Water          | 800     | kg   |
|                                        | Electricity / heat | 940.43  | MJ   |
|                                        | Stainless steel equipment | 0.015 | kg |
|                                        | Transportation | 5.25    | tkm  |
| Soymilk filtering                      | Cooking curd   | 1500    | kg   |
|                                        | Water          | 435     | kg   |
|                                        | Fibre equipment| 0.039   | kg   |
|                                        | Stainless equipment | 0.015 | kg |
| Tofu lumps formation                   | soymilk        | 1658.5  | kg   |
|                                        | coagulant      | 497.5   | kg   |
|                                        | Stainless stainless | 0.029 | kg |
| Pressing / tofu formation              | Tofu lumps     | 630     | kg   |
|                                        | Wood equipment | 0.049   | kg   |
transporting soybeans from ports in America to Cigading port and trucks for shipping soybeans from Cigading to the tofu factory. The distance of each route is determined using Google Maps for land transportation modes and Sea Distance for ships.

The energy used in the production of tofu is electrical energy and heat. Electricity is used by water pumping machines and soybean grinding machines. Meanwhile, the heat is obtained from burning firewood for boiling soybean curd. The equipment used was calculated based on the mass, number and service life of the equipment. For example, the service life of HDPE equipment is one year, so in the calculation, the total mass of equipment is divided by 365 days and other equipment. The coagulant used to coagulate tofu is a by-product of the coagulation process where the uncoagulated soymilk will be left for one day and then used as a coagulant for the production of tofu the next day.

3.2. Impact assessment

Figure 2 shows the impact of global warming from the production process of 1 kg of tofu. The analysis results show that 1 kg of tofu production process produces a global warming impact with a value of 0.978 kg CO$_2$-eq, as shown in table 2 and figure 2. Soybean acquisition consisting of soybean cultivation and transportation from Chicago to tofu factory resulted in the highest emission of 0.882 kg CO$_2$-eq. Similar study results are shown by Meija [14], which produced 0.982 kg CO$_2$-eq. However, Meija did a study up to the tofu packaging stage. The value of global warming impact is comparable due to differences in distance and transportation used. The results of this study are also comparable with the existing tofu product database on Ecoinvent.

The total impact of global warming shown is different from the results of the LCA research on tofu products conducted in Indonesia, including by Kurniawati [15], which produces a minimal value of 0.1766 kg CO$_2$-eq. Kurniawati uses a “gate to gate” boundary system that does not include soybean cultivation and soybean transportation to the tofu factory. In addition, there is also no calculation of the impact of the equipment used, such as stainless and HDPE equipment. Different results were also shown by research conducted by Sukmana [13], which produced 3.84 kg CO$_2$-eq.

### Table 2. Environmental impact of 1 kg tofu production.

| Impact category                        | Unit     | Total   |
|----------------------------------------|----------|---------|
| Global warming (GWP100a)               | kg CO$_2$ eq | 0.978   |
| Ozone layer depletion (ODP)            | kg CFC-11eq | 1.55x10$^{-8}$ |
| Acidification                          | kg SO$_2$ eq | 0.00157 |
| Eutrophication                         | kg PO$_4$-eq | 0.00157 |

In addition to the impact of global warming, other impacts such as ozone layer depletion, acidification and eutrophication are also analyzed, as shown in table 2. The impact of ozone layer depletion shows a value of 1.55x10$^{-8}$, where the most significant contributor is the soybean acquisition process which consists of soybean cultivation and soybean transportation, with a percentage of 77.8%. In addition, ozone layer depletion is also obtained from the process of using firewood to boil soybeans. Burning firewood produces monochloromethane, which contributes to the depletion of the ozone layer [16]. The resulting acidification and eutrophication impact values are different from the study conducted by Situmorang [17], which obtained an acidification value of 0.005 kg SO$_2$ eq and eutrophication value of 6.1 kg PO$_4$-eq for the production of 25 kg of tofu. This difference is due to differences in the system boundary set in this study using a cradle to gate system, while the Situmorang study uses a gate to gate system boundary. The potential environmental impacts of acidification and eutrophication result from wastewater from tofu production, which is released into the waters without going through waste treatment [17].
Figure 2. Global warming impact of tofu production.
4. Conclusion

This study analyzes the environmental impact of 1 kg of tofu products. The results of the calculation of the impact with the Simapro software and the CML-Ia method show that the global warming impact is 0.978 kg CO\textsubscript{2} eq, 1.55E-8 ozone layer depletion, 0.00157 kg SO\textsubscript{2} eq acidification, and 0.00157 kg PO\textsubscript{4}-eq eutrophication.

This research needs to be developed by providing alternative improvements and analyzing the environmental impact of each improvement scenario so that a smaller environmental impact value is obtained.

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