Environmental impact assessment of tofu production process: case study in SME Sugihmanik, Grobogan

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Abstract. Tofu contains various substances that are very good when consumed to improve people's nutrition. In addition, tofu also has good taste. The problem is that the tofu production process produces products and non-product outputs in the form of waste that is very dangerous if directly disposed of in the environment. The BOD5 content of tofu small and medium-sized enterprises (SMEs) in Sugihmanik Village ranged from 3,667 – 4,933 mg/L and COD 7,668 – 9,736 mg/L. At the same time, the TSS values ranged from 701–1,189 mg/L. The BOD5 value in the river water content is 367 mg/L. It greatly exceeds the set Threshold Value. This study aims to measure the environmental impact using Life Cycle Assessment (LCA). LCA can identify the impact of each activity based on the impact category to identify the processes that contribute significantly to damaging the environment. This study found that the cooking and frying process had the highest impact, where the climate change category was the largest. Wastewater treatment plants, biogas from the biodigester as a substitute for electricity for water pumps, rice husks, and corn cobs are expected to reduce environmental impacts. The first section in your paper

1. Introduction

Tofu is a highly nutritious food from China that is produced from soybean extract [1]. According to the Directorate General of Public Health in 2018, 100 grams of tofu contains 80 kcal of energy, 10.90 grams of protein, 4.70 grams of fat, 0.80 grams of carbohydrates, 223 mg of calcium, 183 mg of phosphorus, 0.1 mg of vitamin B3. and 82.20 grams of water. Tofu is an essential and valuable nutrient because of its relatively large protein content, minerals, vitamins, lipids, and isoflavones [2]. The various substances contained in tofu are excellent when consumed to improve people's nutrition. The public has realized it as seen from the increase in the average consumption of tofu in Indonesia in 2017 by 0.157 kg/capita/week and 2018 to 0.158 kg/capita/week [3]. The increasing consumption of tofu is followed by the emergence of small businesses that produce tofu in Indonesia, so that it has a positive effect on the economic aspect. However, from the environmental aspect, many negative impacts due to the development of tofu SMEs are not followed by proper waste management.

Tofu production produces emissions, liquid and solid waste. Solid waste has been widely used as "tempe gembus," animal feed, and processed into crackers, shredded, and dry bread [4]. Meanwhile, solid waste from burning husks and firewood can be used as organic fertilizer [4]. Tofu liquid waste contains BOD (Biochemical Oxygen Demand), COD (Chemical Oxygen Demand), TSS (Total Suspended Solid), and high pH (acidity) [5]. The content of these organic compounds can produce...
biogas when processed through an aerobic process [4]. However, tofu waste that is disposed of without being processed will cause negative impacts such as unpleasant odors, water pollution, sources of disease, and lowering the aesthetics of the surrounding environment. Some of the limitations that SMEs have to treat wastewater, for example, are limited funds, technology, and land ownership. To minimize these limitations, clean production practices should reduce the pollutant load to a certain extent [6].

Sugihmanik Village, Tanggungharjo, Grobogan has more than 30 SMEs that produce traditional tofu. The average production capacity is around 150 kg of soybeans per day for one SME. It means that the daily soybean requirement for Sugihmanik village is equivalent to 4 tons. Solid waste from tofu production has been used as animal feed and material for making "tempe gembus," while liquid waste is directly discharged into the river through pipes. This study has tested wastewater in some of these SMEs and river water. The BOD5 content of tofu SMEs ranged from 3,667 – 4,933 mg/L, COD 7,668 – 9,736 mg/L, and TSS values in the range 701-1,189 mg/L. While the BOD of river water is 367 mg/L and COD is 738 mg/L. This value exceeds the threshold value stipulated by Central Java Provincial Regulation No. 5 of 2012. The high organic load content creates anaerobic conditions that produce decomposition products in ammonia, carbon dioxide, acetic acid, and methane. These compounds cause a pungent, black river odor, damage the quality of healthy water around the river, and become one of the factors in decreasing agricultural productivity. This condition reflects the cottage industry as an industry with low energy efficiency and a high level of environmental pollution due to pollution [7].

This study aims to measure environmental impacts and provide recommendations for improvements to the tofu production process. The method used is the Life Cycle Assessment (LCA) method. LCA helps decision-makers to measure the environmental impact based on the production process so that they can identify environmental impacts based on their activities [8,9-11]. It is essential as a basis for efforts to reduce environmental impacts. LCA has four stages, namely goal and scope definition, life cycle inventory (LCI) collection, life cycle impact assessment (LCIA), and life cycle interpretation phase [12,13].

2. Methodology

2.1. The production process of tofu in Sugihmanik

The primary raw materials for the tofu production process are soybeans and water. The tofu production process consists of soaking, grinding, cooking, clumping, printing, and frying. The clumping process requires materials to precipitate the protein. Tofu products generally use vinegar, but in tofu production in the SME, Sugihmanik Village uses whey. Whey ferments the remaining water from the clotting process, which is left for 1-2 nights. The bacterial fermentation of wastewater from the clotting process produces lactic acid, which can coagulate protein. The energy used consists of gasoline to fuel soybean grinders, rice husks, and corn cobs for cooking and frying. The final product of SMEs is fried tofu, so it requires cooking oil for the finishing process. The tofu production process also produced non-product output (NPO) in the form of liquid waste, solid waste in tofu dregs, roasted husk ash, roasted corn cobs, and used cooking oil.

2.2. Life Cycle Assessment

Life cycle assessment (LCA) is an internationally recognized standard for estimating the environmental impact of a product, process, or activity [8]. LCA helps decision-makers measure the environmental impact based on the production process to identify environmental impacts based on their activities [9]-[11]. Measurements are interpreted in terms of potential impact and evaluated in categories [14]. It is essential as a basis for efforts to reduce environmental impacts. LCA has four stages, namely goal and scope definition, life cycle inventory (LCI) collection, life cycle impact assessment (LCIA), and life cycle interpretation phase [12-13].
3. Result and discussion

3.1. Input-output diagram of the tofu production process

The tofu production process in Sugihmanik generally has the same process and technology, namely the traditional method. The production process is carried out in small sizes, which is known as cooking. One-time cooking usually uses 5 kg of soybeans which are then processed into two trays of molds. Each SME produces soybeans between 100 - 150 kg or 20 - 30 cooking. The input-output diagram is made based on 30 samples of observations in Sugihmanik Village SMEs. Figure 1 is an input-output diagram of the tofu production process.

![Input-process-output diagram](image)

Figure 1. Input-output diagram of the tofu production process.

3.2. The result of the Life Cycle Assessment

The research goal is to identify environmental impacts and costs arising from the production process of tofu SMEs in Sugihmanik Village. The scope studied is Gate to Gate, which produces tofu from soaking to frying. The system does not review the soybean supply process from the supplier to the supplier and does not evaluate the distribution and marketing process. LCA evaluation is based on material and energy consumption and the resulting output, both in product and non-product output. Material consumption is calculated in units of mass (kg) and volume (litres).

The second stage is the Life Cycle Inventory (LCI) phase which explains the inputs and outputs from the beginning to the end of the tofu production process. Table 1 describes the life cycle inventory for one cooking.
Table 1. Life cycle inventory of tofu production process.

| Process           | Input Material       | Input Unit | Input Massa | Output Material | Output Unit | Output Massa |
|-------------------|----------------------|------------|-------------|-----------------|-------------|--------------|
| Soaking           | Raw soybean          | kg         | 5           | Soybean         | kg          | 9            |
|                   | Water                | kg         | 12          | Wastewater      | kg          | 8            |
| Grinding of       | Water                | kg         | 14          | Soybean         | kg          | 23           |
| Soybean           | Fuel                 | Litres     | 0.13        | Emission        |             |              |
|                   | Soybean              | kg         | 9           |                 |             |              |
| Heating of        | Rice Husk            | kg         | 6.5         | Burnt husk      | kg          | 1.6          |
| Soymilk           |                      |            |             | Water vapor     | kg          | 4            |
|                   |                      |            |             | Emission        |             |              |
|                   | Water                | kg         | 30          | Soy sauce       | kg          | 99           |
| Filtering         | Cooked soymilk       | kg         | 79          | Tofu dregs      | kg          | 10           |
| Clumping          | Whey                 | kg         | 23          | Tofu            | kg          | 23           |
|                   | Soy sauce            | kg         | 99          | Wastewater      | kg          | 99           |
| Forming           | Tofu                 | kg         | 23          | Formed tofu     | kg          | 9            |
|                   |                      |            |             | Wastewater      | kg          | 14           |
| Frying            | Cooking oil          | kg         | 0.9         | Waste cooking   | kg          | 0.3          |
|                   | Corn Cob             | kg         | 3.7         | Roasted corn    | kg          | 0.9          |
|                   |                      |            |             | cob             |             |              |
|                   | Formed tofu          | kg         | 9           | Fried tofu      | kg          | 9            |

The next stage is the Life Cycle Impact Assessment (LCIA) phase. This phase aims to evaluate the environmental impact resulting from the tofu production system. The LCIA phase in this study uses the Eco-Cost 2017 v1.5 method on the SimaPro software with 12 impact categories. Eco-costs is a measure to state the amount of environmental impact of a product based on the costs incurred to reduce the pollution it causes. Environmental costs should be considered as a hidden obligation or 'external costs' in environmental economics [15]. This phase has several stages consisting of characterization, normalization, weighting, and a single score. The characterization stage identifies production factors and groups them into several categories of environmental impacts based on the method used. Table 2 shows the impact characterization values at the stages of the production process using SimaPro software.

The normalization stage aims to assess an activity that contributes to environmental impacts. The normalization value is the multiplication between the characterization and normalization values so that the impact categories have the same units—normalization factor for each impact category using Eco-Cost 2017 v1.5 method. The weighting stage is a stage of assigning weights to each category of environmental impact. The weighting factor has different values depending on the method used and the level of importance of the impact category. In this study, the weighting factor using the Eco-Cost 2017 v1.5 method, where all impact categories have a weight value of 1. Thus, the normalization and weighting stages have the same impact category value. The single score stage aims to classify the value of the impact category of each process or activity. Based on the value of this stage, it can be seen which process contributes the most to the environmental impact and damage. Table 3 is the result of a single score after the normalization and weighting stages in euro, and Table 4 is the result of a single score in IDR. Figure 2 is the result of a single score in a bar chart. The biggest impact category is on climate change and acidification. Climate change is a change in the earth's climatic conditions that are becoming hotter. Global warming is caused by increasing greenhouse gases, namely CO₂, CH₄, N₂O, in the
troposphere. These gases are like the greenhouse effect, which reflects radiation from the earth back to the earth. Sources of greenhouse gases are produced from burning fuel, burning biomass, piles of garbage, draining peatlands, cement, ethanol, and even from the plants themselves. At tofu SMEs in Sugihmanik, CO$_2$ is produced from the cooking and frying process wherein the process uses rice husks, corn cobs, and electrical energy for water pumping machines and cooking oil which produces CO$_2$ gas. From the results of the characteristics, it is known that the value of the impact of climate change on the tofu production process is 47.93 kg CO$_2$ equivalent per batch.

**Table 2.** The result of the characterization stage.

| Impact Category | Unit                  | Soaking | Grinding | Heating | Filtering | Clumping | Forming | Frying |
|-----------------|-----------------------|---------|----------|---------|-----------|----------|---------|--------|
| Climate Change  | kg CO$_2$ eq           | 5.04    | 3.63     | 1.57x10$^1$ | 7.60      | 2.78     | 0.00    | 1.32x10$^3$ |
| Acidification   | kg SO$_2$ eq           | 2.05x10$^{-2}$ | 2.00x10$^{-2}$ | 1.00x10$^{-1}$ | 3.28x10$^{-2}$ | 1.26x10$^{-2}$ | 0.00     | 6.00x10$^{-2}$ |
| Eutrophication  | kg PO$_4$ eq           | 3.00x10$^{-3}$ | 8.40x10$^{-4}$ | 5.42x10$^{-3}$ | 1.73x10$^{-3}$ | 2.72x10$^{-2}$ | 3.04x10$^{-3}$ | 3.00x10$^{-2}$ |
| Photochemical Oxidant | kg C$_2$H$_4$ eq     | 2.00x10$^{-4}$ | 1.40x10$^{-4}$ | 6.40x10$^{-4}$ | 2.92x10$^{-4}$ | 1.32x10$^{-4}$ | 0.00     | 3.10x10$^{-4}$ |
| Fine Dust       | kg PM$_2.5$ eq         | 9.00x10$^{-4}$ | 8.50x10$^{-4}$ | 3.57x10$^{-3}$ | 1.77x10$^{-3}$ | 4.36x10$^{-3}$ | 0.00     | 4.40x10$^{-4}$ |
| Human Toxity    | Cases                 | 5.00x10$^{-8}$ | 5.00x10$^{-8}$ | 2.00x10$^{-7}$ | 9.83x10$^{-8}$ | 1.52x10$^{-8}$ | 0.00     | 9.00x10$^{-9}$ |
| Ecotoxicity (Freshwater) Metals Scarcity | PAF.m$^3$.day  | 1.16x10$^{-1}$ | 1.13x10$^{-1}$ | 4.84x10$^{-1}$ | 2.38x10$^{-1}$ | 3.28x10$^{-1}$ | 0.00     | 4.75x10$^{-1}$ |
| Oil & Gas Depletion excl Waste | Euro  | 1.25x10$^{-1}$ | 5.00x10$^{-2}$ | 2.00x10$^{-1}$ | 1.05x10$^{-1}$ | 1.68x10$^{-1}$ | 0.00     | 1.90x10$^{-3}$ |
| Land-Use        | Bio factor            | 0.00    | 0.00     | 0.00    | 0.00      | 0.00     | 0.00    | 0.00 |
| Water Stress Indicator | WSI factor  | 2.58x10$^{-2}$ | 1.00x10$^{-2}$ | 1.00x10$^{-1}$ | 1.60x10$^{-2}$ | 8.70x10$^{-2}$ | 0.00     | 2.00x10$^{-4}$ |

Acidification occurs due to air pollution, which causes a decrease in the pH of the water and makes the water acidic. This acidification can cause acidification of water in both the sea and rivers, damage forests, and health problems for humans. Acidification also causes an increase in SO$_2$ (sulfur dioxide) in the earth's atmosphere, so that it can cause acid rain. A small portion of SO$_2$ is caused by nature, such as volcanoes, and most of it is caused by burning fossil fuels to generate electricity, vehicles, manufacturing processes, oil refineries, and other industries. In these tofu SMEs, the most significant impact of acidification is generated from the cooking process due to electricity to pump water generated from burning fossil fuels. Burning corn cobs in the tofu frying process also has an enormous impact. The total value of the environmental impact of the acidification category from the tofu production in Eko Budi enterprise is 0.21 Kg SO$_2$ equivalent.

**Table 3.** The result of a single score in euro.

| Impact Category | Unit | Soaking | Grinding | Heating | Filtering | Clumping | Forming | Frying | Total |
|-----------------|------|---------|----------|---------|-----------|----------|---------|--------|-------|
| Climate Change  | Euro | 0.584   | 0.421    | 1.80    | 0.882     | 0.322    | 1.528   | 5.537  |
| Acidification   | Euro | 0.179   | 0.141    | 0.600   | 0.287     | 0.110    | 0.500   | 1.817  |
| Eutrophication  | Euro | 0.013   | 0.004    | 0.020   | 0.007     | 0.113    | 0.013   | 0.112  | 0.282 |
This study obtained an eco-cost value of €9,7076 to produce one batch of tofu with a yield of 9 kg. Based on the Euro to Rupiah exchange rate on August 2, 2021, it is known that it is IDR 17,066.87, which is equivalent to IDR 165,679. SMEs produce an average of about 20 batches of tofu, so it has an eco-cost value of around IDR 3,313,580/day/SME.

From Figure 3, it is known that the most significant single score is in the cooking and frying process. The cooking process is caused by the extensive use of electricity for water pumps that use fossil fuels (conventional) as a producer of electrical energy and rice husk fuel for boiler engines. In the frying process, the environmental impact becomes large due to the use of corn cob as fuel. This study recommends energy conservation efforts in the production process of tofu using biogas as a substitute for rice husks and corn husks.
Table 5. The comparison of environmental impact between existing conditions and proposed.

| Impact Category                      | Characterization | Single score (euro) | Single score ( IDR) |
|--------------------------------------|------------------|---------------------|---------------------|
|                                      |                  | Existing | Proposed | Existing | Proposed | Existing | Proposed |
| Climate Change                        | kg CO2 eq        | 47.93     | 41.90    | 5.56     | 4.86     | 94875.38 | 82939.24 |
| Acidification                         | kg SO2 eq        | 0.21      | 0.16     | 1.84     | 1.43     | 31316.44 | 24369.62 |
| Eutrophication                        | kg PO4 eq        | 0.07      | 0.05     | 0.28     | 0.12     | 4852.44  | 2026.17  |
| Photochemical Oxidant Formation       | kg C2H4 eq       | 0.00      | 0.00     | 0.02     | 0.02     | 309.15   | 318.49   |
| Fine Dust                             | kg PM2.5 eq      | 0.01      | 0.01     | 0.27     | 0.26     | 4637.30  | 4483.69  |
| Human Toxicity                        | Cases            | 0.00      | 0.00     | 0.38     | 0.38     | 6526.90  | 6525.96  |
| Ecotoxicity (Freshwater)              | PAF.m³.day       | 10,326.43 | 10,219.39| 0.06     | 0.06     | 976.38   | 966.26   |
| Metals Scarcity                       | Euro             | 0.51      | 0.55     | 0.51     | 0.55     | 86.67    | 9391.97  |
| Oil & Gas Depletion excl Energy       | kg Oil eq        | 0.35      | 0.35     | 0.28     | 0.28     | 4722.83  | 4781.14  |
| Waste                                 | MJ               | 27.32     | 0.10     | 0.30     | 0.00     | 5032.87  | 18.43    |
| Land-Use                              | Bio factor       | 0.00      | 0.00     | 0.00     | 0.00     | 0.00     | 0.00     |
| Water Stress Indicator                | WSI factor       | 0.22      | 0.25     | 0.22     | 0.25     | 3761.38  | 4328.98  |
| Total                                 |                  | 9.71      | 8.22     | 165678.64| 140149.96|

Suparni [16] stated that biogas could be alternative energy to replace firewood in the cooking process. The use of biogas can result in a cleaner cooking process because it does not produce smoke and reduces greenhouse gas emissions due to wood fuel. Biogas itself can be produced from the processing of tofu liquid waste which is produced in large quantities. To see the effect of biogas, this study has recalculated if energy conservation has been carried out. For the amount of biogas used, the equation for the conversion of biogas with rice husks and corn cobs is carried out. 1 kg of corn cobs is equivalent to 0.21675 m³ biogas [17]. Meanwhile, 1 kg of rice husk is equivalent to 0.25 m³ of biogas [18].
Furthermore, the processing is carried out with SimaPro replacing the energy of rice husks and corn cobs with biogas. From Table 1, it can be seen that if the energy source of corn husks and cormcobs is changed to biogas, the eco-cost value from IDR 165,679 to IDR 140,150 per batch so will decrease by around IDR 25,529 per batch. If SMEs cook 20 batches per day, the eco-cost will be reduced by around IDR 510,574 per day. Sugihmanik Village has around 30 tofu SMEs, so switching energy sources to biogas will reduce the eco-cost by around IDR 15,317,208 per day or around IDR 459,516,240 per month.

Tofu SMEs already know the importance of tofu wastewater treatment so as not to damage the environment. Tofu SMEs who are members of an association have purchased land planned to build a wastewater treatment plant. However, in reality, they have not treated the waste and immediately dumped it into the river. The main problem lies in the limited cost of constructing WWTPs, which are high and do not understand the technology. It requires the participation of universities and local governments. The pattern of collaboration needs to be applied in overcoming environmental problems that are considered disturbing to the surrounding community.

4. Conclusion
This study has found that the highest impact categories occur in the climate change and acidification categories. The most impactful activities are the cooking and frying processes. Due to the very high level of water consumption where the extraction uses an electric pump, the process requires energy from rice husks and corn cobs. To reduce the environmental impact, it is necessary to conserve water and energy by building WWTPs and biodigesters. This study also evaluates the environmental impact of energy conversion using biogas. This study has not yet designed an appropriate WWTP design for water conservation. Further studies need to be carried out appropriate WWTP design and evaluation of BOD/COD level after the WWTP and environmental impact measurement with life cycle assessment if the WWTP has been built.

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References
[1] Zheng L, Regenstein J M, Teng F and Li Y 2020 Comprehensive Reviews in Food Science and Food Safety 19(6) 3683–3714
[2] Yang Y et al 2021 Food Chemistry 346 no October 2020
[3] BPS 2018 Perkembangan Data Usaha Mikro, Kecil, Menengah dan Usaha Besar. In www.Dekpok.Go.Id (Vol. 2000, Issue 1)
[4] Faisal M, Gani A, Mulana F and Daimon H 2016 Asian J Chem 28(3) 501–507
[5] Suryoko S, Hadi S P and Purwanto 2019 E3S Web of Conferences 125(201) 9
[6] Carucci G, Carrasco F, Trifoni K, Majone M and Beccari M 2005 Journal of Environmental Engineering 131(7) 1037–1045
[7] Kurniawati S D, Supartono W and Suyantohadi A 2019 IOP Conf Ser Earth Environ Sci 365(1)
[8] Bessou C, Cynthia L, Alice V, Hadrien H, Henri V, Jean-Pierre C 2016 International Journal of Life Cycle Assessment 21(3) 297–310
[9] Hartini S, Sari D, Aisy N and Widharto Y 2020 E3S Web of Conferences 202 10004 p 1–9
[10] Hartini S, Wicaksono P A, Prastawa H, Hadyan A F and Sriyanto 2019 IOP Conference Series: Materials Science and Engineering 598(1)
[11] Prastawa H and Hartini S 2019 The influence of product design on environmental impacts using life cycle assessment 030015 no June p 030015
[12] International Organization for Standardization 2006 Environmental management -- Life cycle assessment - Principles and framework p 20 [Online]
[13] Ramos A and Rouboa A 2020 Environmental Impact Assessment Review 85 no April p 106469
[14] N Duarte da Silva Lima, I de Alencar Nääs, Garcia R G and D Jorge de Moura 2019 *Journal of Cleaner Production* **237**

[15] Vogtlander J G, Scheepens A E, Bocken N M P and Peck D 2017 *Journal of Remanufacturing* 7(1) p 1–17

[16] Rahayu S S, Budiyono B and Purwanto P 2018 *E3S Web of Conferences* 31 p 2017–2019

[17] Li W et al 2015 *Bioresource Technology* **194** p 276–282

[18] Djoeffie B and Nastiti D M 2019 *Pencegahan, Pengendalian, dan Pemanfaatan Limbah Organik*. (PT Penerbit IPB Press)