Life cycle assessment on a small scale tofu industry in Baturetno village, Bantu district Yogyakarta

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Abstract. Tofu is one of Indonesian traditional foods that is produced mostly by small medium scale industry. It is indicated by low production scale, inefficient in using production material and energy during the process. Baturetno village in Bantul district is center of tofu industries in Yogyakarta Province and is facing common problem such as lack of knowledge, inefficient using energy, using human labour, and no appropriate technology applied. This study is aimed to apply Life Cycle Assessment (LCA) for evaluating the process, waste and emission released to environment and is focused on Global Warming Potential (GWP). The LCA gate-to-gate was applied in a small-scale tofu industry, which had one worker, a production capacity 50 kg soybean/day, 6 working stations and used wood and electricity. For producing 1 kg fresh tofu it was needed energy from human, fuel, wood and electricity were needed for producing 1 kg fresh tofu 1.5269 MJ/kg and produced pollutant contributed as global warming potential of CO₂, NOₓ, CO and CH₄ totally 0.1766 kg CO₂-equivalent.

1. Introduction

Tofu is one of Indonesian traditional foods that is produced mostly by small medium scale industry. A small medium enterprise (SME) is characterized as an industry with a low level of energy efficiency, then lack of knowledge, inefficient energy use, human resources and low technology use. It is facing problems with management, finance and human labour. The SMEs sometimes play important role in producing waste and pollutants. Green House Gases is increasing due to the use of huge energy resources at the SME activities such as production, preservation and distribution of products. It leads to Global Warming Potential (GWP), so it is necessary to evaluate the environmental impact and utilization of resources in tofu production and its distribution system for achieving sustainable consumption.

Tofu is originating from China and has high-protein content, is processed foods from soybean and has affordable price. The environmental impact could be caused by waste and pollutant during preparation, production and distribution of product to market. Solid and liquid waste during the process could contaminate the product itself and environment and the gases contribute as pollutant to the air.

Based on Office of Industry and Trade (Disperindag) Yogyakarta in 2015 [1], tempeh and tofu producers in this province were approximately 1011 producers and were divided into some regions namely Sleman (207), Bantul (485), Kulon Progo (282) and Gunung Kidul (67). Both foods are high
protein content and become most favourite foods in this province, so that the producers are spread in all regions. Other reasons is, tofu is fresh product and processed without any preservative agent, so its shelf life is very limited and easily decay. The producers try to minimize its distribution distance, so their products were still fresh, when tofu was sold in the market.

Small and medium enterprises are characterized as industry with low energy efficiency and high level of pollution [2]. Tofu industry is chosen as object of study because it is one of traditional Indonesian foods and is easily found in most of regions. It is easily produced with simple process although it is needed to be controlled and it has affordable price that it can be bought by society level.

Life Cycle Assessment (LCA) is a tool for evaluating environmental effects of a product, process or activity throughout its life cycle or life time. The LCA is conducted by assessing a product from an initial production process to the end and knowing the use of resources and emissions issued will potentially damage the surrounding environment [3].

Life Cycle Cost (LCC) is defined as total cost of a product, process or activities, including acquisition process, operation, maintenance, transformation and including worker firing [4]. LCC and life cycle approach are methods for predicting cost for all supply chain system, production, preparation and consumption. The LCC is very useful for cost analysis on product life cycle, with boundary system and unit same with LCA [5].

Baturetno village is one of villages in Bantul, where tofu industries are clustered and one industry was selected for sample in applying Life Cycle Assessment and focusing on Global Warming Potential (GWP). It produced tofu usually with excess of water usage for each production step and low energy efficiency. It uses normally 50 kg fresh soybean per day as raw material.

This study was aimed to evaluate the application of LCA in a small scale tofu industry, to calculate Life Cycle Cost (LCC) and to assess its contribution to Global Warming Potential (GWP).

2. Materials and Methods

2.1. Samples
The sample of this study was a small scale tofu industry at Baturetno village, Banguntapan sub district, Bantul Region at Special Province of Yogyakarta. It uses everyday 50 kg fresh soybean as raw material and has 1 worker who does all activities from preparation until cutting tofu for marketing. It has 8 working hours, from 05.00 am to 01:00 pm and its distribution distance is around 4.1 km at a traditional market (Pasar Pleret).

2.2. Methods
In this study the analysis of the environmental impacts of a tofu company located in small scale tofu industry at Baturetno village. LCA is methodology used for analyzing and assessing the environmental loads and potential environmental impacts of a material, product or service throughout its entire life cycle, from raw materials extraction and processing, through manufacturing, transport, use and final disposal [6].

2.2.1. Goal Definition and Scope
Goal and scope definition is an integral part of conducting an LCA and relates to any of the others phases. The structure of the LCA methodology has been well established by the International Standard Organization 14040 [7]. This step probably the most important component of LCA, because the study is carried out according to the statement made in this phase, which defines the purposes of the study, the expected product of the study, system boundaries, functional unit and assumptions.

2.2.1.1. Goal Definition
The objective of this study is to analyze the environmental impacts (global warming potential) of tofu production. This paper also aims to support technicians in evaluating of the environmental load of tofu production with the application of LCA method.

2.2.1.2. Functional Unit
3. Result and discussion

3.1. Tofu Production Process

Actually the tofu production process consists of six main processing in separated working stations as follow:

a. Soaking process

This soaking process of soybean is first step before soybean is prepared as raw material. The soaking time was approximately 5 hours at ambient temperature. Goals of soaking soybean were to reduce soybean hardness, so it would be easily ground and become thick soybean porridge, and it would reduce anti-trypsin content in soybean. Anti-trypsin is anti-nutritive agent that should be reduced in human body.

b. Washing

The soybean from soaking process were put in the buckets then washed manually with fresh and clean water. This process was aimed to remove the beans from dirt, which had to be discarded for avoiding them in the soy porridge. By soaking the, the soybean were not contaminated by microbes and they have brighter color. Then the beans were drained before they come to next process.

c. Grinding

Functional unit itself is a functional measure used when reviewing the environmental impact of several product systems. The purpose of functional unit is to provide a reference unit to which the inventory data are normalized. The functional unit is often based on mass of the product under the study [8]. The functional units used in study was 1 kg of soybean.

2.2.1.3. System Boundaries

A system boundary is often illustrated by a general input and output flow diagram. All operations that contribute to the life cycle of the product, process, or activity fall within the system boundaries. The tool was developed for a gate to gate analysis and the system boundary is on one system, tofu production processing.

2.3. Inventory Analysis

In this phase most of intensive work and time consuming – in data collection - than other phase is conducted. The data should include all inputs and outputs from the processes. Inputs are energy, water, raw material, etc. Outputs are the products and co-products, emissions (CO$_2$, CH$_4$, SO$_2$, NO$_2$, and CO) to air, water and soil. The inventory analysis included in the tool was developed based on the inputs and the outputs for all the production stages. The main part of the data and information related to the inputs and to the outputs had to be collected directly on the tofu production with a dedicated check-list.

2.4. Impact Assessment

The impact assessment aims to understand and to evaluate environmental impacts based on the inventory analysis, within the framework of the goal and scope of the study. The results of inventory analysis are grouped into different impact categories according to the kind of environmental problem to which they contribute - classification; contributions to all environmental impact categories are individually quantified - characterization; the environmental categories to which each process contributes are compared.

2.5. Interpretation

The purpose of LCA is to draw conclusion that can support a decision or can provide understandable of LCA. The results are interpreted and translated into opportunities to reduce the environmental impacts of the product system. The qualitative and quantitative measurements in the impact assessment could lead to some improvement like changes in production specification, processing, design of activities, raw material use, consumer use, waste management and energy efficiency.
In this process all soybeans were grinded until thick soybean porridge were produced. The grinding was better conducted if the hot water was used for making soybean easily reduced, and probably more protein and other nutritive agents were extracted in the porridge.

d. Boiling of soybean porridge.
The boiling process should be conducted approximately 3-10 minutes at 100 – 110°C. This process was for cooking the porridge, protein denaturation and removing beany flavor.

e. Filtering and coagulating
After boiling process, the porridge was filtered to separate liquid and solid ones. The liquid or soy milk was added with coagulant agent for forming coagulant of protein as basic material of tofu or curd. The solid content will influence on tofu texture.

f. Forming tofu
The curd or protein coagulant was placed into boxes then pressed with hand-turned screw or normal press. Firmness/texture of tofu was regulated by press force to the protein coagulant (curd), because some excess of water were run out the curd and the tofu become firm. It is cut in certain size and dimension then put into the bucket with water for soaking tofu to maintain its shelf life and to make its transportation easier.

3.2. Input and output
In this study the LCA was applied gate-to-gate on small scale tofu enterprises, and it was focused on size reduction and boiling of the soybean. Both processes were predicted as pollutant contributors to the air. The overview of tofu production and its mass balance was depicted at figure 1.

Figure 1. System boundary of tofu production

To produce tofu this industry used 9 kg wood for one batch as energy source for cooking soybean milk and one day they utilized 27 kg wood for three batches. Other source was electricity for running a
grinder (2000watt) for producing soybean milk. It was used for 18 minutes per process or 54 minutes per day. The water pump (650watt) was operated by electricity, and usually it operated for 8 hours per day. The transportation from the industry to market place was motorcycle, that used gasoline, and the distance was approximately 4 km. Based on the energy usage, LCA for this tofu industry was calculated and the result was shown in table 1.

Table 1. LCA of tofu industry at Baturetno Village for 1 kg tofu

| Energy Resources | Value (MJ) |
|------------------|------------|
| Human (MJ)       | 0.0729     |
| Fuel (MJ)        | 1.404      |
| Electricity (MJ) | 0.35       |
| Wood (MJ)        | 0.0636     |
| Total (MJ)       | **1.5269** |

It was shown that transportation gave highest contribution on energy usage, because they used motorcycle, which could only carry only half of production, so transportation was conducted 2 times per day and fuel consumption became higher. All energy source gave contribution on pollutant and emission to the environment and resume of the emission was shown at table 2.

Table 2. Emission for producing 1 kg tofu at this small-size industry

| Emission | Value (kg) | Conversion | kg CO2-eq |
|----------|------------|------------|-----------|
| CO2      | 0.0063     | 1          | 0.0063    |
| NOx      | 0.0007     | 30         | 0.0021    |
| CO       | 0.0052     | 1.57       | 0.0082    |
| CH4      | 0.0064     | 25         | 0.16      |
|          | Total kg CO2-eq |           | **0.1766** |

Based on table 2 the process for producing 1 kg tofu produced 0.1766 kg CO2-eq, that released to the environment and led to global warming potential (GWP). Actually the value was still low, but if the tofu producer cluster produced tofu in huge amount, it contributed to global warming.

4. Conclusion

The conclusion of this research was as follow:

a. Due to the life cycle assessment of this small-scale tofu industry, the energy from human, fuel, wood and electricity were needed for producing 1 kg fresh tofu 1.5269 MJ/kg. It produced pollutant of CO2, NOx, CO and CH4 totally 0.1766 kg CO2-equivalent.

b. These gases could contribute to global warming potential (GWP).

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