Global Warming Impact and Energy Analysis of Tempeh Made from Local and Imported Soybean

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Abstract

Indonesia is a country with the largest number of tempeh producers in the world. However, the practice of tempeh production by most entrepreneurs has not paid enough attention to environmental aspects. The objective of this study is to determine the extent of environmental impacts throughout the life cycle of tempeh in the form of GHG emissions and energy efficiency, analyze and propose several improvement scenarios. Life Cycle Assessment (LCA) was used as a method to assess the environmental impact of tempeh labeled as hygienic, produced by Rumah Tempeh Indonesia (RTI) located in Bogor, West Java. The hygienic tempeh consists of two types, namely one made of local soybean (Tempeh Sehat) and the other made of imported soybean (Tempeh Kita). The life cycle of tempeh is limited to soybean cultivation, raw material transportation and tempeh processing at RTI. The results show that Tempeh Sehat generates GHG emissions of 0.323 kg CO_2-eq, while Tempeh Kita is 0.555 kg CO_2-eq per kg of product. The hotspots that contribute to GHG impacts are identified as originating from the stages of soybeans transportation and tempeh processing. Energy efficiency is indicated by the Net Energy Value (NEV) and the Net Energy Ratio (NER) of both types of products. Tempeh Sehat has NEV of 2.064 MJ, while Tempeh Kita is 0.318 MJ. Both types of products show the value of NER>1. Further analysis of existing production practices has led to several scenarios of improvement and their environmental effects have been discussed.

Keywords: *Tempeh; LCA; GHG emission; energy efficiency*

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1. INTRODUCTION

Tempeh is a typical Indonesian food that has been known for centuries [1]. Statistical data shows an increase in consumption of tempeh by the Indonesian people at 3.48% from 2014-2017 [2]. In terms of production, Indonesia is the country with the highest number of producers in the world, namely 81,000 business units, with a total production of 2.4 million tons of tempeh per year [1]. Unfortunately, this is not supported by the availability of soybeans in the country, so it is often a problem for business units in their production activities.

Soybeans used by tempeh producers in Indonesia today are generally yellow soybeans. Tempeh producers prefer yellow soybeans compared to black soybeans because the volume of the tempeh produced is larger and the color is brighter [3]. However, the productivity of yellow soybeans in Indonesia is still lower than that in the United States, which is the highest soybean-producing country in the world. This is due to climate differences between the two countries. The ideal growth of soybean plants requires short sunlight exposure, which approximately less than 12 hours per day, while the sunlight exposure in Indonesia is relatively constant at 12 hours per day [4].

In general, soybeans in Indonesia flower at the age of 25-40 days when the height of the new plant reaches 40-50 cm. In the sub-tropical region where the daylight is 14-16 hours in the spring-summer, the new soybean plants will flower after 50-70 days, or when the height of the plant reaches 70-80 cm and the plant forms many branches. The maturity of soybeans in Indonesia is also very early, ranging from 75-95 days, while soybeans in subtropical regions reach 150-160 days. This climate difference is one of the causes of differences in soybean productivity in Indonesia compared to sub-tropical regions [5].

Agricultural Research and Development Agency of the Ministry of Agriculture has developed and released 34 varieties of superior soybean plants such as Anjasmoro, Burangrang, Bromo, Grobogan and Argomulyo that can produce tempeh with the same weight, volume and sensory properties as imported soybeans and even have a higher protein content [6]. However, the cultivation of these superior varieties has not been able to be adopted quickly by farmers. This has become one of the factors causing Indonesian soybean production from various provinces in 2017 to have a negative growth of -36% in average compared to 2016 [7]. Therefore the import policy becomes the government's temporary choice to meet the domestic demand for soybeans. Throughout national socioeconomic survey of Indonesia or SUSENAS in 2015, Indonesia has recorded import of soybeans at 1.96 million tons or 67% of the total domestic soybean needs [8].

Most tempeh are produced by household-scale industries or also called micro, small and medium enterprises (MSMEs). This industrial group generally does not have sufficient awareness and attention to environmental aspects, whether in terms of material selection, production process, transportation, or waste management. This will certainly have a bad impact on the environment. Therefore, a comprehensive study with a product life cycle approach on the negative impact of the tempeh industry on the environment will be very useful for improving the performance of the tempeh industry.

One of the relevant environmental performance parameters for the tempeh industry is greenhouse gases (GHG) which are defined as gases that can trigger an increased heat on the earth's surface (global warming). The potential GHGs for global warming are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). The Intergovernmental Panel on Climate Change (IPCC) states that every GHG has global warming potential (GWP) which is measured relative to CO_2 emissions. The greater the GWP value, the more destructive it will be.

At present a variety of environmental impact assessment methods can be used by industry. One of them is the Life Cycle Assessment (LCA) method which is increasingly in demand by academics and practitioners to determine the environmental impact produced by a product throughout its life cycle. The product life cycle can be started from the supply of raw materials, the transportation, the production process, until the product returns to the environment (disposal). This LCA method can be used as a tool or a basis for policy makers such as government, producers, or consumers in determining products and processes that are suistainable.

This research work is carried out at Rumah Tempeh Indonesia (RTI) located in Cilendek area, Bogor, West Java, which is claimed as a hygienic tempeh processing plant. This claim is made because the applied production process technology has ensured hygienic conditions. In this study, only 2 types of tempeh products from RTI will be studied, namely Tempe Kita which is made of imported GMO soybeans, and Tempeh Sehat which uses local soybean varieties.

The objective of this study is to determine the level of environmental impact of tempeh products in the form of GHG emissions and energy efficiency, by identifying and analyzing the input-output flow of material throughout the tempeh life cycle and evaluating the impact of the material flow into the environment. The results of the analysis and evaluation were then used as a basis for recommending several improvements in aspects of the use of materials and energy to improve environmental performance from existing tempeh production practices.

2. METHODS

This study uses a product life cycle assessment (LCA) approach with reference to ISO 14040. The LCA framework consists of 4 stages, namely goal and scoping, inventory analysis, impact assessment, and interpretation [9].

As already mentioned, RTI produces two types of tempeh, namely Tempeh Kita which is made of imported GMO soybeans and Tempeh Sehat which uses local varieties of soybeans. Imported GMO soybeans come from soybean plantations in Chicago, United States; while local varieties of soybeans come from soybean plantations in the Gunung Kidul area, Yogyakarta.

The scope of this study is limited to the life cycle of tempeh which starts from the process of nursery and plantation, transportation, to processing tempeh at RTI (cradle to gate). The functional unit used is 1 kg of tempeh. The scope of this study is indicated in the system boundary presented in Figure 1

Inventory analysis was carried out by conducting an inventory of all input and output flows involved, in units of mass and energy per kg of tempeh produced, against GHG contributors from the predetermined boundary system. Inventory analysis of the life cycle of tempeh begins with soybean plantations. According to a personal communication with Ridha 2018 (RTI management), the soybeans used by RTI actually consist of three types, namely local soybeans, imported GMO soybeans and imported non-GMO soybeans, but this study only focused on tempeh made from local soybeans and imported GMOs. Data on plantation inputs for imported soybeans were obtained from the results of studies in the United States [10], while those for local soybean plantations referred to the results of the study in Gunung Kidul area [11], and thus representing the typical inputs of each plantation source. Summary of plantation input data from which the calculation of the impact of emissions made is given in *Supplementary Materials 1*.

Next is the inventory at the transportation stage. RTI does not collect the data of the fuel consumption for transportation, and some transportation needs are carried out by involving outside parties. Therefore, fuel consumption was calculated based on typical specific fuel consumption for every distance traveled by the vehicle used in the period of 2017. The map (google maps) was used to estimate the distance traveled by the transport vehicle. This approach was excluded for the vessel transportation system, where fuel consumption was calculated based on the amount of specific fuel consumption from every full day power that it takes. To estimate the length of the vessel cruise, the Netpas Distance application was used. Detailed fuel consumption calculations and assumptions used are presented in *Supplementary Materials 2*.

Inventory analysis in the stages of tempeh processing and waste treatment is based on primary data, measured and collected during plant observations. This phase of LCA is aimed at evaluating the significance of potential environmental impacts based on the LCI flow results.

Impact assessment is aimed at evaluating the significance of potential environmental impacts for every 1 kg of tempeh produced based on the previous inventory flow results. The chosen environmental impact category is the amount of GHG emissions with additional energy efficiency measurements throughout the life cycle of tempeh. The output of CO_2 emissions will be represented by Global Warming Potential (GWP 100), which is a relative measure of the amount of heat trapped in greenhouse gases. The amount of heat trapped in certain gases is compared to CO_2 with the same mass in a period of 100 years.

Calculation of the amount of CO_2-eq emissions per kg of tempeh refers to the IPCC 2006 guide [12] as shown in Equation 1 below:

$$E = AD * EF \quad (1)$$

where,
E = emission
AD = activity data
EF = emission factor (kg CO_2-eq/AD)

The values of emission factors (EF) used in this study are presented in *Supplementary Materials 3.*

The estimated energy consumption is calculated through energy conversion in the form of standard energy units Joules (J) using Equation 2 below:

$$En = n * CV \quad (2)$$

where,
En = energy
n = inventory volume
CV = calorific value (energy conversion value)

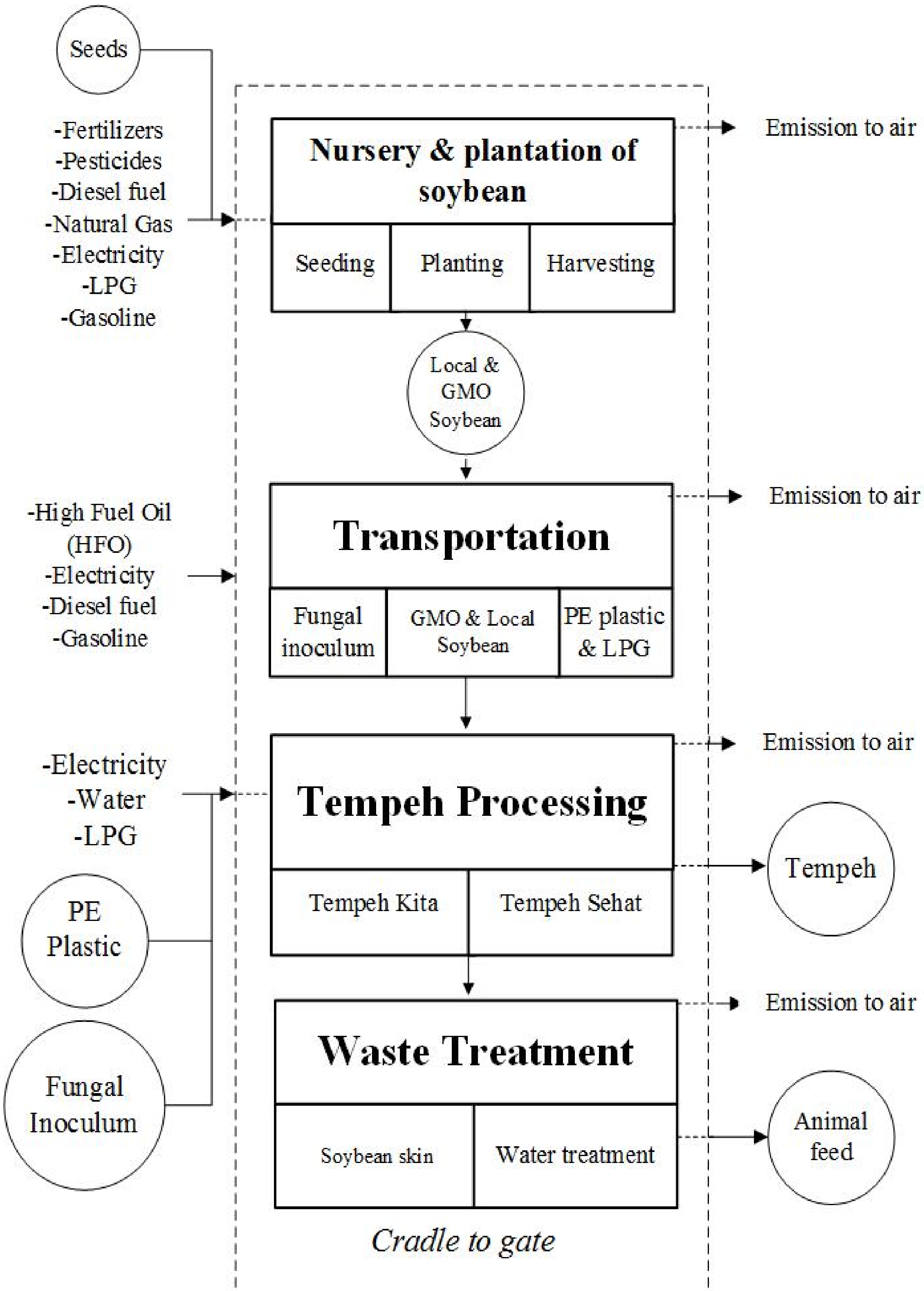

Fig. 1. System boundary of hygienic tempeh

The caloric values (CV) used in this study are presented in *Supplementary Materials 4*. Energy efficiency is expressed in terms of Net Energy Value (NEV) and Net Energy Ratio (NER). NER and NEV calculations are given in Equations 3 and 4, respectively.

$$NEV = \Sigma En_o - \Sigma En_i \quad (3)$$
$$NER = \Sigma En_o / \Sigma En_i \quad (4)$$

where,
NEV = Net Energy Value
NER = Net Energy Ratio
$\sum En_o$ = Total output energy
$\sum En_i$ = Total input energy

The net energy performance that is considered good from the product life cycle is indicated by a positive NEV value and NER above 1

3. RESULTS AND DISCUSSION

3.1. Inventory analysis

The results of inventory analysis on both types of hygienic tempeh are grouped into 4 stages, namely nursery and plantation, transportation, tempeh processing, and treatment of production waste as shown in Table 1.

Table 1. Inventory analysis of 1 kg of hygienic tempeh

Inventory	Unit	Quantity (per kg tempeh)	
		Local soybeans	Imported GMO soybeans
Nursery and plantation			
Diesel fuel	Liter	-	[a]0.00813
Gasoline	Liter	-	[b]0.00183
LPG	Kg	-	[b]0.00041
Natural gas	Kg	-	[b]0.00048
N-fertilizer	Kg	[a]0.00560	[b]0.00110
P-fertilizer	Kg	[a]0.00560	[b]0.00461
K-fertilizer	Kg	[a]0.00560	[b]0.00768
Pesticide	Kg	[a]0.00078	[b]0.00049
Seeds	Kg	[a]0.02488	[b]0.01670
Electricity	kWh	-	[b]0.00414
Transportation			
Gasoline	Liter	[c]0.00240	[c]0.00021
Diesel Fuel	Liter	[c]0.01306	[c]0.03543
HFO	Liter	-	[c]0.02701
Electric train	ton-km	-	[d]1.94574
Tempeh processing			
Electricity	kWh	[e]0.03102	[e]0.03202
LPG	Kg	[e]0.03750	[e]0.03871
Processing water	m^3	[e]0.01067	[e]0.01101
PE Plastics	Kg	[e]0.00444	[e]0.00444
Fungal inoculum	Kg	[e]0.00125	[e]0.00129
Waste treatment			
Soybean skin	Kg	[e]0.25000	[e]0.25806
Waste water	m^3	[e]0.00986	[e]0.01018

[a]Calculated using weighted average used in soybean agricultural input of Gunung Kidul Area, Indonesia [11]; [b]Calculated using weighted average used in soybean agricultural input of USA [10]; [c]Calculated using total distance of travel area by Google maps and Netpas Distance apps multiplied by the vehicle fuel consumption per km. [d]Calculated using total Rail ton-km distribution soybean from shuttle elevators in US [34]; [e]observations at Rumah Tempe Indonesia in 2018.

The results of the inventory analysis show different input from the plantation sector between local soybeans and imported GMO soybeans. Imported GMO soybean cultivation technology that is more advanced than local soybeans causes differences in the type and amount of inputs in soybean plantations. Local soybean cultivation still uses simple technology both for land processing and harvesting [11].

Soil processing is rarely done because the cultivation generally starts at the beginning of the dry season by using former rice fields. Harvesting is still done manually by cutting the soybean stems using a sickle. The transport of soybeans from fields to soybean threshing places is generally carried, using carts, and some use motorcycles [13]. In this study, it is assumed to use a cart, because in this way it results in the lowest level of loss during transport. For threshing of soybeans, it is still done manually (hit) by using bamboo or coconut leaf midrib which are placed with a tarpaulin [13].

In addition to the differences in soybean cultivation technology, land quality and soybean seeds can also affect the amount of fertilizer and pesticides used. Table 1 shows that the quantity of pesticides required by imported GMO soybeans is lower than that used by local soybeans. This is presumably because genetic engineering treatment on imported GMO soybean produces plants that are more resistant to pest attacks. Imported GMO soybeans also have a higher productivity of 2662 kg of soybeans per hectare [10], while local soybeans are 1827 kg of soybeans per hectare [11].

RTI produces a lot more of Tempeh Kita compared to Tempeh Sehat. This is due to the very limited amount of local soybean supply for RTI compared to imported soybeans which are available almost every day. RTI itself has an average production of around 250 kg of soybeans per day. As much as 97% of the total soybeans processed in 2017 are imported soybeans and the rest is local soybeans. The average amount of tempeh produced per day is around 1000 packs with a net weight of 450 grams per pack. In other words, for each weight unit of soybeans processed, tempeh weighing 1.5 to 1.6 times will be produced.

From the observations at the factory, local soybeans produced 160% tempeh yield while imported soybeans produced only 155% for each soybean weight unit used. This difference in yield caused the difference in the amount of tempeh produced. These yield values are in accordance with a study which concluded that local soybean varieties such as agromulyo, anjasmara, and grobogan produced higher tempeh yields than imported GMO soybeans [14].

3.1. Impact Assessment

3.1.1. Energy efficiency

This energy efficiency is actually not included in the impact category contained in ISO 14040 in 2006, but only an additional measurement to determine the amount of energy efficiency in producing 1 kg of tempeh. The amount of energy input and energy efficiency throughout the life cycle of hygienic tempeh is presented in Tables 2 and 3.

The amount of energy is calculated using equation 2. The calorific value of the input used is presented in *Supplementary Material 4*.

Table 2 and 3 show that the energy input from Tempeh Kita is greater than that of Tempeh Sehat. The efficiency of both types of tempeh can be seen from the NER and NEV values. Tempeh Kita has a greater NEV value than Tempeh Kita, because of the large difference in energy input, which is 1.746 MJ per kg of tempeh. The difference in the energy input is caused by the greater fuel required for importing GMO soybeans.

For NER, it can be seen that Tempeh Sehat is of greater value than Tempeh Kita. In addition to the low energy input, Tempeh Sehat also has a higher yield than Tempeh Kita. For every 1 kg of soybeans processed from local varieties Grobogan can produce 1.6 kg of tempeh; while for imported GMO soybeans only produces 1.55 kg of tempeh.

The calculation of NEV and NER values of the two types of tempeh at RTI have shown good energy efficiency. This is indicated by the positive value of NEV and the NER value above 1 (one).

In addition to transportation, the production process also consumes a considerable amount of energy from the use of LPG for soybean cooking and boiling washing water which reaches 33-46% of the total energy needed. In fact, the use of LPG at RTI for cooking soybeans is more efficient than the use of firewood in other tempeh industries in general. The combustion efficiency of firewood is approximately 16%, while combustion of LPG may reach an efficiency of 60% [15].

3.1.2. GHG emission

In this study the impact of greenhouse gas emissions is expressed in kilograms of CO_2-eq/kg of tempeh. Figure 2 presents a comparison of the impact of emissions for Tempeh Sehat and Tempeh Kita.

Table 2. Comparison of energy inputs in the product life cycle of Tempeh Sehat and Tempeh Kita

Energy Input	Tempeh Sehat	Tempeh Kita
	(MJ/kg tempeh)	(MJ/kg tempeh)
Nursery and plantation	1.468	1.290
-Diesel fuel	-	0.293
-Gasoline	-	0.060
-LPG	-	0.021
-Natural gas	-	0.023
-N-fertilizer	0.260	0.051
-P-fertilizer	0.060	0.050
-K-fertilizer	0.028	0.038
-Pesticide	0.287	0.180
-Seeds	0.832	0.559
-Electricity	-	0.015
Transportation	0.529	2.374
-Gasoline	0.087	0.007
-Diesel fuel	0.431	1.169
-HFO	-	1.080
-Electricity	-	0.117
Tempeh processing	2.208	2.275
-Electricity	0.112	0.115
-LPG	1.950	2.013
-Plastics	0.147	0.147
Waste treatment	-	-
Total energy	4.194	5.940

Table 3. Total energy of input, output, NER, dan NEV per 1 kg tempeh

Energy	Tempeh Sehat	Tempeh Kita
Input energy (MJ)	4.194	5.940
Output energy (MJ)	6.258	6.258
Net Energy Ratio	1.492	1.054
Net Energy Value (MJ)	2.064	0.318

It is shown that the values of the impact of Tempeh Sehat and Tempeh emissions are 0.323 and 0.555 kg CO_2-eq/kg, respectively. Tempeh made from local soybean have a lower level of emission impact compared to tempeh made from imported GMO soybeans. The length of the transportation path for imported GMO soybean raw materials causes higher transportation fuel consumption than that of local soybeans. This is indicated by the emission of GMO soybeans transportation which reaches 6 times that of local soybean transportation, i.e. 0.2800 and 0.0467 kg CO_2-eq/kg tempeh, respectively. The high emissions impact of imported GMO soybeans transportation is due to the use of diesel fuel in trucks (20.06%), the use of High Fuel Oil (HFO) by soybean carriers (16.65%), and the use of electricity by train transportation (14.03%).

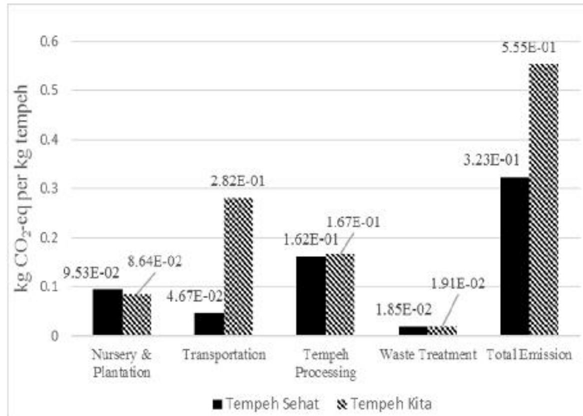

Fig. 2. Comparison of the impact of GHG emissions on two types of hygienic tempeh

The value of GHG emissions generated from the plantation sector for local soybeans and imported GMO soybeans is 0.0953 and 0.0864 kg CO_2-eq/kg tempeh, respectively. Although the input of GMO soybean cultivation is higher than that of local soybeans, the impact of emissions per kg of soybeans is lower than that of local soybeans. This is due to the higher productivity of imported GMO soybeans (kg of soybean/hectare) compared to local soybeans.

This should be a concern for the government and farmers to always improve the local soybean cultivation system for an increased productivity. The productivity of some local soybean varieties that have been developed exceeds 2 tons per hectare, but the adoption rate of these varieties by farmers is still slow [16].

Table 2 shows that the contribution of emissions from the tempeh production process is quite significant. For tempeh from local soybeans, the impact value of the production process stage reached 50.29% of the total emissions and 30.15% for tempeh from imported GMO soybeans. The biggest contribution in the production process of both types of tempeh comes from the use of LPG gas. The impact of emissions resulting from the use of LPG itself is 0.12315 kg CO_2-eq/kg Tempeh Sehat and 0.12712 kg CO_2-eq/kg Tempeh Kita.

From the impact of emission viewpoint, the use of LPG in RTI generally gave a lower impact than the use of firewood in the process of cooking soybeans in other tempeh industries. Physically, wood burning also produces more smoke and soot. As an illustration, in tofu industry, 98% of CO_2-eq emissions generated come from firewood burning during the cooking process of the soybeans [15]. Several studies on the impact of emissions on similar products made from soybean have also been carried out, as presented in Table 4.

3.2. Interpretation and improvement analysis

This stage is the final step, aiming at reducing the environmental impact caused by tempeh. In this study, the focus is on reducing GHG emissions. The followings are some improvement scenarios to reduce GHG which can be recommended in the hygienic tempeh life cycle.

3.2.1. Utilization of biogas from effluent of tempeh processing

GHG emissions can be caused by anaerobic microbial decomposition of organic matter in tempeh processing effluent, either resulted from uncontrolled decomposition or the biological waste treatment systems that do not utilize the generated biogas. The GHG is mainly in the form of methane. Methane has a GWP level 25 times greater than CO_2 [19]. RTI currently uses septic tanks as a method of treating liquid waste. This system will certainly contribute to GHG emissions because the methane gas produced will be directly discharged into the atmosphere. Therefore, it is necessary to use methane for energy sources, if it is considered economical; or flare it completely to eliminate methane emission.

Biogas generally contains 60-70% methane (CH_4), 30-40% carbon dioxide (CO_2), and traces of other compounds, including hydrogen sulfide (H_2S), ammonia (NH_3), and hydrogen (H_2). The quality of biogas for energy sources is determined by the content of methane; the higher the methane in the biogas the greater the energy produced [20].

Increasing energy efficiency in the form of NEV and NER in the tempeh industry can be done by utilizing waste organic materials from the production process of tempeh, either liquid or solid to be converted into biogas, as additional energy for the boiling process.

3.2.2. Use of solar water heater

The use of LPG for soybean cooking has been better compared to firewood. However, there are other technologies that can be used as alternatives for cooking water, namely solar water heater. This hot water is used in the final stage of soybean washing before draining and fermentation. This hot water washing function for material sterilization.

Table 4. Comparison of the impact of emissions from some products made from soybeans

Product	kg CO_2-eq/kg product	System boundary	Case
Tofu	2.0	cradle to gate to retail	Netherland [17]
Tofu	0.982	Cradle to gate	USA [18]
Tempeh	1.1	cradle to gate to retail	Netherland [17]
Tempeh Sehat	0.323	Cradle to gate	This study
Tempeh Kita	0.555	Cradle to gate	This study

Nowadays, water heating technology is very diverse. There are three types of water heater according to the type of energy used, namely electricity-based, LPG-based, and solar energy-based. Each technology has its own advantages and disadvantages. Solar water heater (SWH) can be chosen as a water heater for washing soybeans because it is more environmentally friendly compared to LPG-based heater which still produces greenhouse gas emissions. Solar water heater does not produce emissions because the energy is obtained directly from solar energy, except for the use of additional electricity when the solar energy captured in SWH is insufficient.

3.2.3. Use of boiler in soybeans cooking

Boiler is a steam-producing vessel that has been commonly used by some tofu and tempeh industries for the cooking process of soybeans. Boilers are considered to have higher energy efficiency than furnace for the cooking process in various food processing factories. The use of steam boiler in soybeans cooking can save fuel by 33% and save cooking time by up to 50% [21]. From the calculations it is estimated that there will be a potential saving of 2.82 kg LPG per day or an increase in cooking fuel efficiency from 70% to 92% with the use of small-size boilers from KOPTI Bogor.

3.2.4. Replacement with gas fuel in the transportation system

The use of natural gas for motor vehicles is one of the government's scenarios to reduce emissions from the transportation sector. The advantage of gas fuel is that it has a higher combustion efficiency and more environmentally friendly properties than the use of oil fuel so far. Gas fuel itself has a heating value of 48 MJ per kg, while oil fuel is 33 MJ per liter for gasoline and 36 MJ for diesel. In Indonesia the use of gas fuel in the transportation sector is still limited to Trans-Jakarta buses, reconditioned bajaj and several other public transport vehicles.

It is, in fact, possible to utilize natural gas in the transportation sector. With large natural gas potential, efficient combustion, and environmental friendliness, the use of natural gas for the transportation should be considered by the community and, especially, the government. The use of natural gas products, such as compressed natural gas (CNG) and liquifed natural gas (LNG), for transportation in the life cycle of tempeh will reduce GHG emissions.

4. CONCLUSIONS

The total impact of GHG emissions throughout the product life cycle of Tempeh Sehat and Tempeh Kita is 0.323 and 0.555 kg CO_2-eq/kg tempeh, respectively. The difference in the emission value of the two products is caused mainly by differences in the value of input inventory at the plantation and the transportation stages of both products. The long distance of transportation of imported GMO soybean is the main cause of the high value of the impact of emissions on Tempeh Kita compared to Tempeh Sehat.

According to the collected data, the energy input needed to produce 1 kg of Tempeh Sehat is 4.194 MJ, and for Tempeh Kita is 5.940 MJ, while both products have the same energy output of 6.258 MJ per kg of tempeh. The calculation results in the NER and NEV values for Tempeh Sehat, namely 1.492 and 2.064 MJ respectively, and 1.054 and 0.318 MJ, respectively for Tempeh Kita. Since the value of NER is above one and that of NEV is positive, it can be concluded that the efficiency of both products is good.

This study has identified that the highest hotspot occurrence of GHG and energy use in tempeh production is at the stages of soybean transportation and tempeh processing, so it is necessary to make improvements in both. The proposed scenario for the transportation phase is to substitute oil fuel with gas fuel for transportation by trucks, buses, pick-ups and motorbikes. In the tempeh processing stage, the proposed scenario includes the utilization of organic wastes from tempeh production process to biogas, the use of solar water heater, and the replacement of the fuel furnace with a boiler.

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