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Analysis of Potential GHG Emissions from Tofu Industry and Its Mitigation in Indonesia

Analisis Potensi Emisi Gas Rumah Kaca dari Industri Tahu dan Mitigasinya di Indonesia

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ABSTRAK

Tahu merupakan salah satu sumber protein dengan permintaan yang tinggi di Indonesia. Saat ini beberapa industri tahu telah menggunakan peralatan-peralatan berbahan dasar stainless steel. Kondisi ini menunjukkan keseriusan industri tahu untuk membuat produk tahu yang higienis. Namun, produk tahu yang higienis saja tidaklah cukup. Persaingan pasar global menuntut sebuah produk tidak hanya memperhatikan kualitas, namun juga menjadi produk yang ramah lingkungan dengan ditandai oleh nilai emisi CO_2 yang rendah. Sejalan dengan kondisi tersebut, maka studi terkait dengan perhitungan emisi CO_2 yang dihasilkan oleh sebuah produk menjadi hal yang perlu diutamakan. Pada studi ini dilakukan penelitian estimasi emisi CO_2 yang dihasilkan dari 1 kg tahu dengan menggunakan metode LCA dan menerapkan batasan sistem from cradle to gate, yakni penghitungan emisi Gas Rumah Kaca (GRK) dihitung dari penanaman kedelai hingga menjadi 1 kg produk tahu. Studi kasus dilakukan pada 3 industri tahu dan diketahui bahwa emisi GRK yang dihasilkan per 1 kg tahu berada pada rentang 0,35–0,5 kg CO_2 eq. Faktor utama penyumbang emisi CO_2 berasal dari air limbah hasil dari proses produksi, diikuti budidaya kedelai dan transportasi bahan baku kedelai dari perkebunan menuju ke industri. Hasil penelitian ini memberikan rekomendasi kepada industri tahu untuk mengurangi emisi CO_2 yang dihasilkan dari limbah cair proses produksi tahu. Alternatif pengolahan limbah cair yakni dengan mengolah air limbah menggunakan sistem anaerobik guna menghasilkan biogas yang digunakan untuk kebutuhan memasak.

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ABSTRACT

Tofu is one of the protein sources with high demand in Indonesia. Currently, several tofu industries have used stainless steel-based equipment. This condition shows the seriousness of the tofu industry to make hygienic tofu products. However, hygienic tofu products are not enough. The global market competition required the products to take notice not only of their quality but also of environmentally-friendly products characterized by a low value of CO_2 emission. In accordance with the condition, studies related to calculating CO_2 emissions resulting from a product are necessary. In this study, we conducted research on the estimation of CO_2 emissions resulting from 1 kg of tofu using the LCA method and applying the system boundary from cradle to gate, in which greenhouse gas (GHG) emissions were calculated from soybeans plantation to 1 kg of tofu products. Case studies were conducted on three tofu industries, and it was found that the GHG emissions produced per 1 kg of tofu were in the range of 0.35–0.5 kg CO_2 eq. Three main factors contribute to CO_2 emissions, i.e., wastewater, soybean cultivation, and soybean transportation from plantation area to industry. Therefore, this study recommends the tofu industry reduce CO_2 emissions resulting from wastewater. The alternative is to treat wastewater using an anaerobic system to produce biogas for cooking purposes.

1. INTRODUCTION

1.1 Background

Soybean (*Glycine sp.*) is the world's main source of vegetable protein and vegetable oil. Soybeans based-products popular in Indonesia were tofu and tempeh. Tofu has a high protein content with the most complete of amino acid composition and high digestibility, which was around 85–98% (Indrawijaya et al., 2017; Sitanggang, 2017; Fitriani, 2019). A cheap price and good nutritional ingredients made this soybeans-based products very attractive to be consumed when those were compared to the beef and chicken consumptions (Table 1).

Table 1. Tofu and tempeh consumption (in kg) in average daily per capita for 2015–2019

Year	Tofu	Tempeh	Chicken	Meat
2015	0.144	0.134	0.103	0.008
2016	0.151	0.141	0.111	0.008
2017	0.157	0.147	0.124	0.009
2018	0.158	0.146	0.121	0.009
2019	0.152	0.139	0.124	0.009

Source: Center Bureau of Statistics Republic of Indonesia, 2021

Indonesian residents were preferring to consume the tofu product than to tempeh (Table 1). The total of tofu industries in Indonesia reached 84,000 units with the production was more than 2.56 million tons per day. Based on the location of the tofu industries there was 80% of the industries located on the Java (Sally et al., 2019).

According to SNI 01-3142-1998, tofu was defined as a food product in the form of soft solids made through the processing of soybeans by precipitation of protein from soybeans, with or not added other permitted ingredients (*Badan Standardisasi Nasional*, 1998). The basic ingredients in tofu production include soybeans, coagulant, and turmeric dye (if needed). Hence, the quality of tofu products was strongly affected by the quality of soybeans, process production, and the coagulants used for the process (Andarwulan et al., 2018; Wang et al., 2020). Soybeans as a raw material must be good quality, i.e., its nutritional content meets the standards and its condition was undamaged and free of all impurities. The coagulant commonly used for the production were calcium sulfate ($CaSO_4$), vinegar, and tofu, but for the dye was a turmeric (Cao et al., 2017; Darmawan & Rahim, 2018; Arii et al., 2021). In general, the process of tofu production consisted of two main steps, namely (1) production of tofu slurry, and (2) coagulation process of tofu slurry to form a white precipitate, then it was pressed to be a tofu product. For more details the tofu production process consisted of soaking the soybeans, peeling the soybeans, milling the soybeans, filtrating the soybeans, cooking the soybeans, coagulation of tofu pulp, molding the tofu, and cutting the tofu (Zheng et al., 2010; Dey et al., 2017; Wang et al., 2020).

Tofu is one of Indonesia's traditional foods mostly produced by small and medium enterprises (SMEs) industries. SMEs industry is characterized as industry with low levels of energy efficiency, inefficient use of energy, and low use of human resources and technology (OECD, 2018; Maksum et al., 2020; Surya et al., 2021). SMEs plays an important role in generating waste and pollutants. Environmental impacts can be caused by waste and pollutants during the preparation, production, and distribution of the product to the market. Solid waste and wastewater during the process can damage the environment due to the carbon dioxide gas emission resulted from the production contributing as an air pollutant.

The wastewater generated during the tofu production process, which were directly discharged into the environment without being processed, have the potency to generate greenhouse gas (GHG) emissions. The tofu wastewater has a high number of BOD and COD value, i.e., 6,000–8,000 mg/L and 7,500–14,000 mg/L, respectively (Zheng et al., 2010; Faisal et al., 2016; Karamah et al., 2018; Wang et al., 2018; Sabarudin & Kartohardjono, 2020). Besides that, the untreated wastewater from the tofu production has an economic value due to the organic compounds and several types of gases contained in the wastewater, i.e., oxygen (O_2), hydrogen sulfide (H_2S), ammonia (NH_3), carbon dioxide (CO_2) and methane (CH_4) (Faisal et al., 2016; Anggraini et al., 2020). The organic compounds in the wastewater can be in the form of protein (40–60%), carbohydrate (25–50%), oil and fat (10%), and nutrients i.e., nitrogen (N), phosphorus (P), and potassium (K) (Wang et al., 2018; Chua & Liu, 2019; Anggraini et al., 2020; Chaorlina et al., 2020). A high value of N, P, and K in the wastewater has a potency to damage environment due to the eutrophication caused by the organic compounds (Lin, et al., 2020; Potter & Röös, 2021). In addition to wastewater generated during the tofu production process, the high energy consumption during the production process also has the potential to produce greenhouse gas emissions due to the use of fuel during the boiling process. Therefore, it is necessary to evaluate the use of resources in the production of tofu and the environmental impacts to gain the sustainable production activities.

Rosyidah et al. (2018) conducted a study to identify the environmental impact of tofu production process. The boundary system used in the study limited to the production process, namely a boundary system from gate to gate. Other LCA studies used this boundary system to calculate the impact of GHG emissions from tofu production have been carried out by Kurniawati et al. (2019) and Sukmana et al. (2019). There is no paper discussed the GHG emission from tofu production in Indonesia using more extensive system boundary for the LCA methodology. In this study we conducted research on the potential of GHG emissions from tofu production using boundary system, which was not limited only for the tofu production, but the production and transportation of soybeans were included, namely boundary system from cradle to gate. This study was conducted on three tofu industries in three different cities, namely, tofu A industry located in South Tangerang city, tofu B industry located in Tangerang city, and tofu C industry located in Jakarta city.

1.2 Objectives

The purpose of this study is to represent the potential GHG emissions of the tofu industry using boundary system, which was not limited only for the tofu production, but also included the production and transportation of soybeans. The results of this analysis can be input for the central government to build Indonesian tofu products that ready for export and can compete with the global market.

2. METHODS

2.1 Data source for tofu production process

We collected tofu production data in three different locations. The calculation of the GHG emissions value in the three tofu industries was carried out using the LCA method and the boundary system from cradle to gate. Therefore, the result of this study will obtain a quantitative description of the environmental impact values produced by the tofu industry.

The data collection process took place from March to August in 2018. The data collection technique was carried out through a combined method, namely direct observation and measurement in the field, as well as in-deep interview with workers in the tofu industry.

2.2 The Life Cycle Assessment

The Life Cycle Assessment (LCA) is one method that can be used in calculating the impact of greenhouse gas emissions produced by a process or product (Sharma et al., 2018; Potter & Röös, 2021). LCA is carried out by quantifying the use of resources involved and carbon dioxide emissions produced by a system that is limited by a system boundary (*Badan Standardisasi Nasional*, 2016; *Badan Standardisasi Nasional*, 2017). The LCA method has been used among others to quantitatively calculate environmental impacts on the agricultural sector and a number of food products (Daalgard et al., 2008; Heller & Keoleian, 2011; Venkat, 2012; Vidergar et al., 2020; Odey et al., 2021). Of the several methods available in calculating the Life Cycle Impact Assessment (LCIA), in this study we used the CML-IA baseline V3.01/World 2000 method. This method was implemented in PC-tool SimaPro 8 (Pre 2016). SimaPro 8 (Pre 2016) is an LCA tool (software) that are able to calculate the number of emissions generated from material and energy inputs from the life cycle of a product and convert these emission values into several environmental impact parameters, in this case the impact parameter was greenhouse gas (GHG) emissions. The inventory data of tofu industry was entered into the SimaPro software as an input to calculate the emission value (GHG emissions), using an algorithm that has been programmed in the SimaPro software with a period of 100 years. The characterization factors used in the calculation are 1 kg of carbon dioxide is equals to 1 kg of carbon dioxide equivalent (CO_2 eq); 1 kg of methane is equals to 25 kg of CO_2 eq; and 1 kg of nitrous oxide is equal to 298 kg of CO_2 eq (Putri et al., 2018).

2.3 Choice of assumptions and methodologies

Attributional LCA was used in this study. The attributional LCA method is able to provide the right level of accuracy and clear information about the inputs, outputs, and impacts of the production, consumption, and disposal processes of a product (Brander, 2016; Sala et al., 2018). Inventory data for all material inputs, energy, soybeans, transportation, and tofu industrial processes were entered into SimaPro 8 to calculate the value of GHG emissions resulting from the production process of 1 kg of tofu. Soybean is the main raw material in the process of tofu production. When we did data collection, we got information that the soybeans used by the industry were imported soybeans (Genetically Modified Organisms/GMOs) from the USA. Therefore, we use U.S. soybean production data from U.S. databases Life Cycle Inventory available in SIMAPro 8 EcoInvent database. Soybean transportation from the plantation area to the industrial site is also part of the boundary system. Based on the literature study, it is known that the largest soybean production in the US is concentrated in the Midwest, which includes Illinois, Iowa, Minnesota, Indiana, Nebraska, and Ohio. About 45% of the total US soybean production is exported to other countries and Indonesia is the third largest soybean export destination after China and Mexico. About 60% of soybean exports are shipped via the Mississippi Bay and about 24% via the Pacific Northwest, and the remainder via other ports (Putri et al., 2018). In this study, it was assumed that soybean production was in the Illinois area and soybeans exported to Asia were shipped from plantations to the Mississippi Bay port using land transportation (railway). Furthermore, soybeans were shipped by sea (ship) from the port of the Mississippi Bay to the port of Cigading, Indonesia.

Input for soybeans plantation in the SimaPro 8 database does not include potential carbon emissions from the soil or carbon trapped by soil. Soybean plantation land in the SimaPro 8 database has been around for a long time, so the potency of lost carbon associated with land conversion from forest to soybean plantation land is not included in the boundary system. Nitrous oxide (N_2O) produced from the use of nitrogen fertilizers is not included in our boundary system due to the process of growing soybeans that do not use nitrogen fertilizer in the SimaPro 8 database.

Based on our observations, the tofu industries have no wastewater treatment system. The location of the industry, which is not far from the river, caused the waste is directly discharged into the river. Therefore, in this study, we conducted an LCA analysis using a scenario of disposing of waste directly into the river without going through a treatment process.

2.4 Data inventory of tofu production

The data collection process was carried out using two methods, namely direct measurements in the field, and in-deep interviews. Data collection lasted for five months, from March to July 2018.

Industry A

The production process of tofu industry A required soybeans as a raw material with a quantity of 150 kg of soybeans per day with a total tofu product produced by the industry reached 3,000 pieces of tofu per day. The tofu solid wastes produced from the production were used for consumption of privately managed pig feed. Currently, there was no direct wastewater treatment in the industry, so the wastewater was discharged directly into the river and it required 40 pieces of parallel pipe connections for the disposal of tofu wastewater.

Figure 1. Product of tofu from industry A

The characteristics of this tofu industry was the factory condition was clean and the tofu production process was carried out hygienically, and all of the used equipment were made of stainless steel. It was not surprising that the price of tofu from industry A was three times higher than the current average price of tofu. The process of tofu production was no different from the general process, such as the boiling process, in which it still used firewood as a fuel. However, the condition of the industry was very comfortable, not messy, and clean (Fig. 2). Production quality and hygiene were top priorities in the process of tofu production. However, the management for tofu wastewater has not been found in this industry, possibly due to the lack of management funds and technology.

(a) (b)

Figure 2. Process of tofu production in industry A. Firewood for boiling process (a), Stamping of tofu (b).

Industry B

Based on our observation it was known the total of equipment used in this industry was smaller than tofu industry A (Fig. 3). However, some of the used equipment were made of stainless steel, such as for filtration and coagulation tanks. Industry B produced pong and Sumedang tofu. This tofu product was marketed to consumers, which was most of them were owner of small-scale fritter industries who live near the factory. Tofu production required about 80 kg of soybeans as raw material per day. There was no disposal system for the wastewater produced by the industry. Meanwhile, solid waste produced by the industry was treated as animal feed.

(a) (b)

Figure 3. Tofu process production in industry B. Boiling process (a), Grinding machine (b).

Industry C

Industry C was located in tofu-tempeh industrial center in Jakarta city (Fig. 4). The tofu products in this industry consisted of white tofu and yellow tofu. The total soybeans needed for the production reached 300 kg per day. The industry used 18 equipment consisting of 3 milling machines, 3 boiling tanks, 6 filtration tanks, 3 drums, and 3 tables for stamping the tofu. Most of the equipment used for the production process were made of stainless steel, except for the immersion drum and drum starter, which are made of plastic, as well as a permanent boiling tank made of a mixture of brick and cement.

(a) (b)

Figure 4. Tofu Industry C. Boiling tank (a), Coagulation tank (b).

2.5 System boundary

In conducting LCA modeling, we assumed the calculation of environmental impacts was assessed using boundary system from cradle to gate, namely from soybean plantation and followed by transportation of soybeans from the plantation location to the industry (Fig. 5). We applied 1 kg of tofu as functional unit in this study.

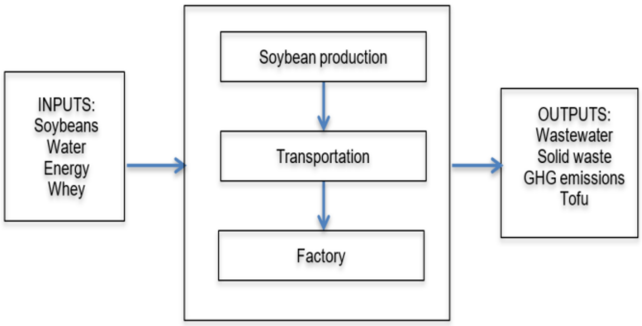

Figure 5. Boundary system of Life Cycle Assessment (LCA) of tofu

The difference of process production and equipment used in each of industry will affect the GHG emissions value. Other components that also affected the value are the consumption of fuel and energy used during the production process. Each of tofu industry has its own characteristics, so the value of GHG emissions produced may not be the same from one industry to others. The focus in this study was compare the value of GHG emissions derived from 1 kg of tofu of several industries as a basis data. We assumed the functional unit in this study was 1 kg of tofu product. Inventory data sources that include types of input materials, energy, transportation, and SimaPro databases (EcoInvent 3.1 and U.S. Life Cycle Inventory Database) were used in the calculation of environmental impact analysis. The sources of data related to input and output as well as a series of tofu production processes were obtained from direct observation and data collection in several tofu industries. Transportation data was a part of the boundary system. Transportation in this study included the delivery of soybeans from the plantation area to the industries. The choice of land and sea transportation modes also contributed to the emission of environmental impacts. The material and age of the building where the production process taken place were not included in the boundary system.

3. RESULT AND DISCUSSION

3.1 Diagram process of tofu production

The data collection process in the field was carried out up to 3 times for each of tofu industries. In general, the process of tofu production in industries A, B, and C, has similarities, but there are differences in the total time required for each section of the process and the equipment that were used by the industries. Diagram of the tofu production process from three industries can be seen in Figure 6. Each section of the total process in the tofu industry was inseparable based on the equipment and machines used by them (see Table 2).

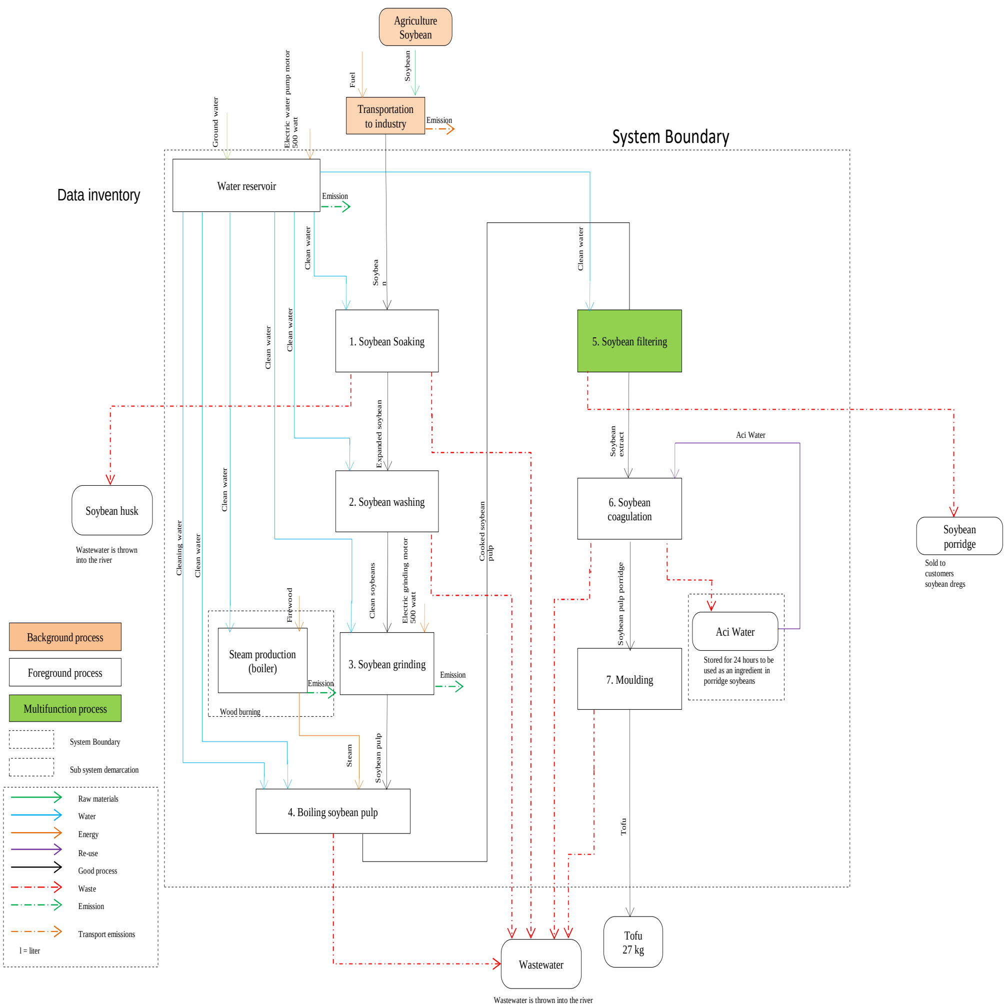

Figure 6. Tofu process production in the tofu industries

Table 2. Comparison of used equipment and machines in the tofu A, B, and C industries

Process	Industry A	Industry B	Industry C
Soaking	Stainless steel tank	Plastic bucket	Plastic bucket
Washing	Stainless steel tank	Plastic bucket	Plastic bucket
Grinding	Disc Mill	Disc Mill	Disc Mill
Boiling	Wood	Wood	Wood
Draining	Filter cloth	Filter cloth	Filter cloth
Coagulation	Stainless steel tank	Stainless steel tank	Stainless steel tank
Molding	Tofu mold with ballast, and using stainless steel for rack of fermentation	Tofu mold with tofu printer (build up), and using wood for rack of fermentation	Tofu mold with the tofu printer (build up), and using wood for rack of fermentation

Based on the measurement of the total mass balance resulted from the production of tofu A, B, and C industries (Table 3) we concluded that the average for 1 kg of soybeans needed for production required 8 kg of fresh water to produce 2.87 kg of tofu and 6.5 kg of untreated wastewater. We calculated each of industry consumed 200 kg of soybeans per day, then the tofu product and wastewater produced by the industry were 573 kg and 1,298 kg, respectively.

Table 3. Total mass balance of tofu A, B, and C industries

Industry	Soybeans (kg)	Fresh water (kg)	Tofu (kg)	Wastewater(kg)
A	85	638.66	178.92	544.74
B	50	358.05	117.82	290.23
C	100	886.25	376.89	690.36

3.2 Analysis of GHG emissions

The results of the calculation of GHG emissions for tofu A, B, and C industries using the CML-IA 2000 baseline method can be seen in Table 4.

Table 4. A result of GHG emissions from 3 industries

	A	B	C
kg CO_2 eq / kg tofu	0.515	0.414	0.35

In general, the value of GHG emissions resulted from the tofu production in industry A derived from the untreated wastewater, cultivation, and transportation of soybeans as a raw material, energy consumption during the production process, i.e., wood as a fuel for the boiling process, electricity and heat of the process (Fig.7). The percentages of the main contributors for GHG emissions, i.e., untreated wastewater (39%), then followed by soybeans cultivation (27%), and soybeans transportation from plantation area to the tofu industry (15%).

The total value of GHG emissions from the production of 1 kg of tofu in industry B was 0.414 kg CO_2 eq (Table 4). The untreated wastewater from the tofu production process, soybean cultivation, as well as soybean transportation from the plantation area to the tofu industry were the main contributors to GHG emissions for 1 kg of tofu products. The percentage of each component of the total value of GHG emissions, was 33.42% from the untreated wastewater resulted from the tofu production process, 30.64% and 18.86% from soybean cultivation and transportation, respectively (Fig. 7).

Low value of GHG emissions was produced by tofu industry C. However, the contributed components to the GHG emissions were produced by the same components as A and B industries (Fig. 7). The percentage of each of these components was the untreated wastewater (26.5%), while the other two components, namely soybeans plantation and transportation resulted in 20 and 22% of total GHG emissions, respectively.

Rosyidah et al. (2018) found that the main source of GHG emissions in the tofu production, study case in Palembang, derived from the utilization of wood for the boiling process, which contributed 26% of the total emissions, and the remains for the untreated wastewater. Based on our result (Fig. 7), we see that heat (thermal energy) and the production process were the dominant contributors to the GHG emissions after the untreated wastewater and the soybeans plantation.

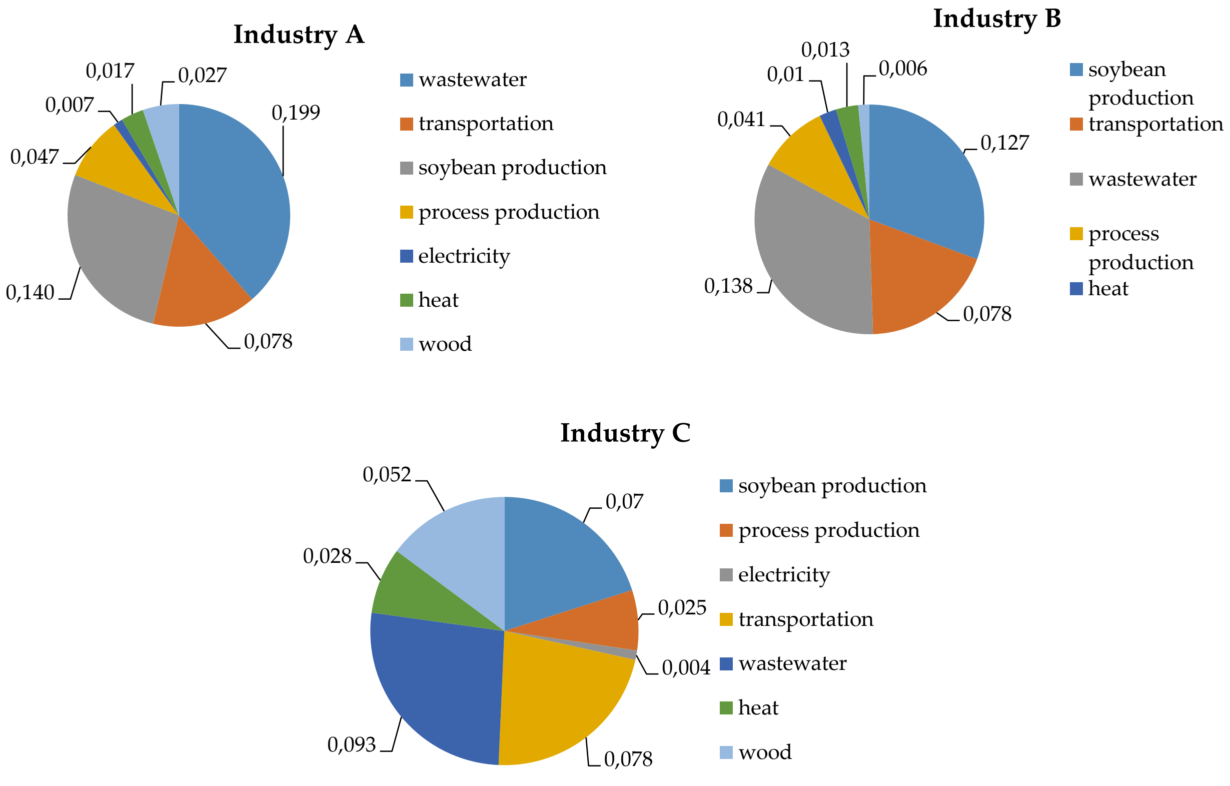

Figure 7. Distribution of GHG emissions resulted from the production of 1 kg of tofu from three industries

From the previous studies related to GHG emissions from two tofu industries, which was located in Palembang and Jakarta cities, using system boundary gate to gate, the value of GHG emissions was obtained 0.177 and 3.84 kg CO_2 eq. It means the average of GHG emissions of 1 kg tofu from two previous study was 2 kg CO_2 eq. Meanwhile, the GHG emissions produced in this study with a wider system boundary, namely from cradle to gate, the obtained GHG emissions were around 0.35–0.51 kg CO_2 eq and its average was 0.43 kg CO_2 eq. Mejia et al. (2017) has calculated the GHG emissions generated from 1 kg of tofu in using LCA methodology and cradle to gate boundary system, using a study case based in United States. The value of GHG emissions resulted from 1 kg of tofu was 0.982 kg CO_2 eq. Compared to our analysis, the GHG emissions from 1 kg of tofu in Indonesia are lower than the GHG emissions generated from 1 kg of tofu in study case in United States, which based on Mejia et al. analysis. Hamerschlag et al. (2011) estimated that the full life cycle (including soybean production, processing, transportation, cooking, and waste disposal) of tofu resulted in 2 kg CO_2 eq per kilogram of product. Blonk et al. (2008) conducted an LCA of tofu produced in The Netherlands and estimated that the soybean production, processing, transportation, and tofu production amounted to 1.9 kg CO_2 eq per kg of product. Both of these estimates are around 4 times higher in comparison to our analysis. This could be partly a result of using assumptions in system boundary, such as transportation to the industry, boiling process, and waste disposal; and also due to differences in the technology used and prevailing climatic conditions. It is also possible that the soybeans were transported greater distances and/or by more fuel-intensive transport modes from the plantation area to the industry. Another factor to consider is the level of variation in terms of GHG emissions factors for soybean production, which can impact the overall level of GHG emissions associated with tofu production.

The boiling process has a high contributor in producing the emissions when it compared to other processes in tofu process production. The use of wood for boiling process produced higher CO_2 emissions than the use of LPG as a fuel (Acharya & Marhold, 2018; Thoday et al., 2018; Borisade et al., 2020). When we suggested the tofu industries to utilize LPG as a substitute for wood, it seems impossible, because the boiling process for tofu takes a long time, then the substitution of wood to LPG fuel would increase the production cost, and certainly it would have an impact on the high price of the product. Although the boiling process is one of the components producing the emissions, however, when it compared to the other components i.e., untreated wastewater and soybean production, the CO_2 emissions from the boiling process were not too significant.

The untreated wastewater as the largest component of CO_2 emission has a potency to be processed to be renewable energy (Lay et al., 2013). The untreated wastewater was an organic waste that easy to decompose by microorganisms naturally. Tofu wastewater contained a high of protein, fat, and carbohydrates as well as organic compounds. If these organic compounds were decomposed both aerobically and anaerobically, they will produce methane (CH_4) and carbon dioxide (CO_2). The mixture of these two gases, which is commonly called a biogas, was the result of fermentation of anaerobic bacteria. By utilization the biogas that generated from treated tofu wastewater for cooking purpose, it will reduce the impact of GHG emissions. CO_2 emissions that should be released into the air were captured in a biogas reactor and piped to the tofu industry for cooking purpose. Therefore, processing tofu wastewater into biogas will have a positive impact on reducing CO_2 emissions.

3.3 Management strategy of tofu wastewater

The characteristics of tofu wastewater have a low pH (4–5) and contained a large amount of biodegradable organic matter, such as reduced sugar, sucrose, starch, protein, and flying fatty acids. COD levels in tofu wastewater reached of 7,500–14,000 mg/L and total BOD value of 6,000–8,000 mg/L (Zhu et al., 1999; Karamah et al., 2018). Based on those characteristics, we need to do an efficient and effective treatment process in order to obtain output water that was secure to be disposed of into the environment or recycled in such a way as to be reused in the tofu manufacturing. Anaerobic waste treatment technology was an alternative to treat the wastewater to be biogas as a by-product that can be used directly by the community or by the tofu industry (Fukushima and Tan, 2014). It assumed 1 kg of soybeans was able to produce 9.5 liters of tofu wastewater, then the potential for biogas produced about 15 liters per 1 kg soybeans. If we assumed the total energy required for cooking for 4–5 persons were 1.5 m^3 of biogas, then 100 kg of soybeans were needed to generate biogas in order to meet the needs of cooking for 1 family that consists of 4–5 persons (Sriharti et al., 2018).

Currently, our government is pay attention to apply a carbon tax for the industry. The carbon tax rate is set at a minimum of IDR 75.– per kg CO_2 eq resulted by the industry (Republika News, 2021). If we consider the generated CO_2 emissions of 1 kg of tofu product ranged from 0.35–0.5 kg, then the tax range that must be paid by each industry was around IDR 26.25–37.5 per kg of tofu. If each of the industry needed 200 kg of soybeans, then the tofu products produced were around 573 kg per day, thus the total generated emissions will be 200.5–286.5 kg CO_2 eq. The carbon tax that must be paid by tofu industry reached IDR 15,000–21,000 per day or IDR 450,000–630,000 per month. The importance of a carbon tax that must be paid by the tofu industry, in which it will have a direct impact on increasing of the production cost, the tofu industry is necessary to manage the untreated wastewater in order to reduce the potential value of GHG emissions.

4. CONCLUSION

LCA study of tofu product has been conducted in three tofu industries using boundary system from cradle to gate. The value of GHG emissions produced from the each of industries were 0.52 kg CO_2 eq, 0.41 kg CO_2 eq, and 0.35 kg CO_2 eq per kg of tofu. The main components of GHG emission generated from the industry were the untreated wastewater resulted from the production process, then followed by soybeans cultivation, and then soybeans transportation from the plantation area to the industry. The untreated wastewater as the largest component of CO_2 emission has a potency to be processed to be renewable energy. By utilization the biogas that generated from treated tofu wastewater for cooking purpose, it will reduce the impact of GHG emissions. CO_2 emissions that should be released into the air are captured in a biogas reactor and piped to the tofu industry for cooking purpose. Therefore, processing tofu wastewater into biogas will have a positive impact on reducing CO_2 emissions.

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