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THE GREENHOUSE GAS ANALYSIS USING LIFE CYCLE ASSESSMENT (LCA) IN SMALL SCALE TOFU INDUSTRY

ANALISIS GAS RUMAH KACA (GRK) DENGAN METODA LIFE CYCLE ASSESSMENT (LCA) PADA INDUSTRI TAHU SKALA KECIL

Aditya Wahyu Nugraha, Dyah Putri Larassati, and Annisa Dwi Wulandari

Agro-industrial Technology Department, Faculty of Industrial Technology, Institut Teknologi Sumatera,
Way Hui, Lampung Selatan, 35365
Email: aditya.wahyu28@gmail.com

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ABSTRAK

Industri tahu merupakan salah satu industri yang banyak tumbuh dan berkembang di Indonesia untuk memenuhi kebutuhan pangan masyarakat. Pada siklus produksi tahu, banyak aktivitas yang berpotensi menghasilkan emisi yang berbahaya bagi lingkungan, salah satunya adalah gas rumah kaca (GRK). Terdapat berbagai kegiatan yang dilakukan industri tahu untuk menghasilkan produk yang siap dijual, mulai dari pengadaan bahan baku, produksi dan distribusi tahu ke pasar. Panjangnya rantai produksi tahu, maka potensi untuk menghasilkan emisi GRK akan semakin besar. Untuk mengetahui jumlah emisi GRK yang dihasilkan maka perlu dilakukan pendekatan siklus daur hidup produk tahu (LCA). Oleh karena itu, penelitian ini bertujuan untuk menghitung emisi GRK yang dihasilkan pada siklus produksi di industri tahu X. Hasil analisis menunjukkan bahwa industri tahu X menghasilkan emisi GRK sebesar 3.373,53 $KgCO_{2eq}$ per 300 kg kedelai yang bersumber dari penggunaan listrik, pertalite, kayu bakar dan air limbah. Setiap aktivitas yang dilakukan juga berkontribusi terhadap munculnya emisi GRK. GRK tertinggi bersumber pada penggunaan kayu bakar sebesar 3.198,81 $KgCO_{2eq}$, sementara itu, tahapan yang paling banyak menghasilkan GRK pada tahapan pemasakan. Alternatif perbaikan yang dapat dilakukan untuk mengurangi emisi yang timbul adalah dengan meminimalisasi penggunaan alat transportasi, meminimalisasi penggunaan air (water reduction), penggunaan kembali air limbah, mengkonversi penggunaan kayu bakar dengan LPG dan memanfaatkan air limbah menjadi biogas untuk proses pemasakan.

Kata Kunci: emisi, gas rumah kaca (GRK), industri tahu, *life cycle assessment (LCA*)

ABSTRACT

The tofu industry is one of the industries that has grown and developed a lot in Indonesia to meet the community's food needs. In the tofu production cycle, many activities have the potential to produce emissions that are harmful to the environment, one of which is greenhouse gases (GHGs). There are various activities carried out by the tofu industry to produce products that are ready for sale, starting from the procurement of raw materials, the production and distribution of tofu to the market. The longer the tofu production chain, the greater the potential to produce GHG emissions. To find out the amount of GHG emissions produced, it is necessary to take a tofu product life cycle (LCA) assessment. Therefore, this study aimed to calculate the GHG emissions produced in the tofu production cycle in the X's tofu industry. The results showed that X's tofu industry produces GHG emissions of 3,373.53 $KgCO_{2eq}$ per 300 kg soybean which originate from the use of electricity, gasoline, firewood, and liquid waste. Every activity carried out also contributes to the emergence of GHG emissions. The highest GHG comes from the use of firewood of 3,198.81 $KgCO_{2eq}$, meanwhile, the stage that generates the most GHG is during the cooking stage. Alternative improvements that can be made to reduce emissions are minimizing the use of transportation equipment, minimizing water usage (water reduction), water reuse, converting the use of firewood to LPG, and utilizing liquid waste into biogas for the cooking process.

Keywords: emission, greenhouse gas (GHG), life cycle assessment (LCA), tofu industry

INTRODUCTION

Tofu is a product that is widely consumed and in demand in Indonesia. This is because the price is affordable, has high nutritional value, and can fulfill the body's protein intake (Lolo *et al*., 2021). Based on data from the Central Statistics Agency (BPS) (2023), the average consumption of tofu in Indonesia reaches 0.15 kg/capita/week. Meanwhile, in Bandar Lampung, total tofu consumption is slightly higher than the national average, namely 0.155 kg/capita/week.

The high demand for tofu in public has led to an increase in the tofu production capacity in Indonesia, one of which is in Lampung. In Bandar Lampung City there are 238 tofu craftsmen, and 115 tofu craftsmen are in Gunung Sulah Village (Shafira *et al*., 2018). The low risk of failure in tofu production

*Coressponding Author

is one of the reasons why there are many tofu craftsmen there, so it is possible to run (Rafi *et al*., 2019).

The tofu production process produces wastewater and solid waste, as much as 2,600 L and 300 Kg, besides tofu products (Lolo *et al*., 2021). Wastewater is generated from the use of water during the production process. According to research by Lolo *et al*. (2021), tofu production wastewater is produced from the washing, soaking, and molding of tofu. In general, tofu wastewater is channeled into the sewer with or without prior treatment.

According to Rahmawati *et al*. (2022), to produce 2,770 kg of tofu, it needs 703 kg of soybeans, 9,389 L of water, 2,173 L of acetic acid used, and generate 8,045 L of wastewater, and 1,450 kg (wb) of solid waste. The results of Setiawan *et al*. (2021) show that tofu wastewater contains COD 19,052 mg/L, BOD 10,327 mg/L, TSS 1,301 mg/L, and pH 5.5-5.6. This value indicate that the quality of tofu wastewater is above the standards, namely pH 6-9, BOD 150 mg/L, COD 300 mg/L, and TSS 200 mg/L (KLHK, 2014). This high value indicates that wastewater contains a high pollutant load (Romli and Suprihatin, 2009). Meanwhile, solid waste is the dregs left over from the extraction of soybeans and materials that are discarded during the production process (Pagoray *et al*., 2021). According to Saputra *et al*. (2018), tofu dregs contain 82.69% water, 0.55% ash, 0.62% fat, 2.42% protein and 13.71% carbohydrates.

According to Jatmiko *et al*. (2019) and Sari *et al*. (2021), the activities carried out in an industry will hurt the environment and sooner or later can cause damage to the environment, like global warming. In the tofu industry, apart from waste, tofu production also produces GHG emissions caused by the use of raw materials and energy as well as activities during production. These emissions are in the form of CO_2, CH_4, and N_2O gases. Based on Lolo *et al*. (2021), the total emissions resulting from burning sawdust, electricity, and tofu wastewater processing are 24.80 kg CO_2, 12 kg CH_4, 0.42 kg NO_2, and 0.59 N_2O in 1 production cycle (350 kg soybeans) or equivalent to 4,026.08 $KgCO_{2eq}$. GHG emissions are very dangerous if they occur continuously and no mitigation efforts are made. The high or low GHG value of an industry is one of the parameters for the level of production efficiency and environmental performance of an industry (Wahyudi, 2017).

GHG emissions in the tofu industry do not only come from the production process but also from the procurement of raw materials and delivery of tofu products. According to Sukmana *et al*. (2019), the GHG produced by 1 kg of tofu production is 3.84 $kgCO_{2eq}$. Meanwhile, according to Sari *et al*. (2021), 1 kg of tofu produces GHG of 0.98 $kgCO_{2eq}$, 90% of these emissions are formed in land processing and soybean transportation.

The GHG impact an industry can be determined by assessing the product life cycle. One method that can be used is the Life Cycle Assessment (LCA) method. LCA is used to calculate the influence of environmental impacts based on inventory analysis starting from the use of raw materials, energy, fuel, water, and others (Parameswari *et al*., 2019). Environmental impact analysis using LCA is carried out by identifying and assessing factors that influence the emergence of environmental impacts, evaluating factors that have the potential to cause environmental impacts, and carrying out treatment analyses to reduce the impacts caused (Nurbaiti *et al*., 2022).

Industry X is a tofu producer in Bandar Lampung and has been operating for 13 years. Industry X has a production capacity of around 300 kg of soybeans a day. The production process is carried out manually by workers, but in the milling process, a grinding machine is used to speed up the grinding of the soybeans. The energy sources used in tofu production in industry X consist of firewood, electricity, and gasoline. The handling of solid waste resulting from the production process is by processing tofu dregs into oncom by oncom producers and animal feed by breeders, while wastewater is discharged into rivers without processing. Tofu production process activities in industry have the potential for GHG emissions from materials usage, energy, transportation, and waste. Therefore, in this research, an assessment of the life cycle of the tofu industry in industry X was carried out to determine the potential GHG arising from tofu production in industry X.

MATERIAL AND METHOD

Research Location

The research was conducted in the X's tofu industry, Way Halim, Bandar Lampung, Lampung Province (Figure 1).

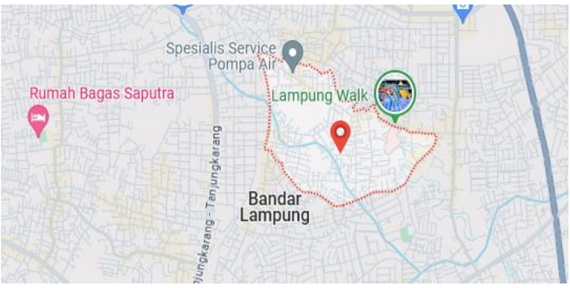

Figure 1. The location of X's tofu industry

Research Data Collection

The data used in this research is categorized into 2, namely primary and secondary data. Primary data was obtained by making direct observations in the industry. Meanwhile, secondary data was obtained by conducting a review of supporting literature, such as through journals, theses, dissertations, and other supporting sources related to research from 2006 - 2023. Further, secondary data was also obtained from calculations that followed the rules of LCA calculations.

Research Stages

The research stages were carried out based on the life cycle assessment (LCA) method according to ISO 14040:2016. The LCA method is carried out by quantitatively calculating all input and output flows in a system. The four stages of LCA include:

Goal and Scope Definition

This stage aims to describe the objectives, systems, boundaries, and assumptions regarding the impacts caused. This research aims to calculate the potential GHG impact on the X's tofu industry. The system boundary used is gate to gate, where the GHG impact is calculated from the transportation of raw material purchases from the supplier until the tofu is distributed to the market (Figure 2). Soybean supplier from around Bandar Lampung region. The tofu production process consists of soaking, grinding, cooking, filtering, coagulating, molding, cutting, and packaging. The functional unit in this research is per 300 kg of soybeans in a batch production.

Life Cycle Inventory Analysis

This stage is conducted to collect and analyze the input and output of each stage and quantify energy, materials, waste, and all outputs that are discharged into the environment. The data needed for this research can be seen in Table 1.

Life Cycle Impact Assessment

GHGs are emissions resulting from every human activity. The high levels of GHG produced can hurt the environment, like climate change and water scarcity. This stage is carried out to analyze the type and high value of environmental impacts arising from each stage based on the objectives and scope. The calculation of GHG emissions is calculated in the form of carbon dioxide equivalent (CO_{2eq}). 1 CO_2 is equivalent to 1 CO_{2eq}, 1 CH_4 is 23 CO_{2eq}, and 1 N_2O is 296 CO_{2eq} (IPCC 2006). The formula used can be seen in Tables 2 and 3.

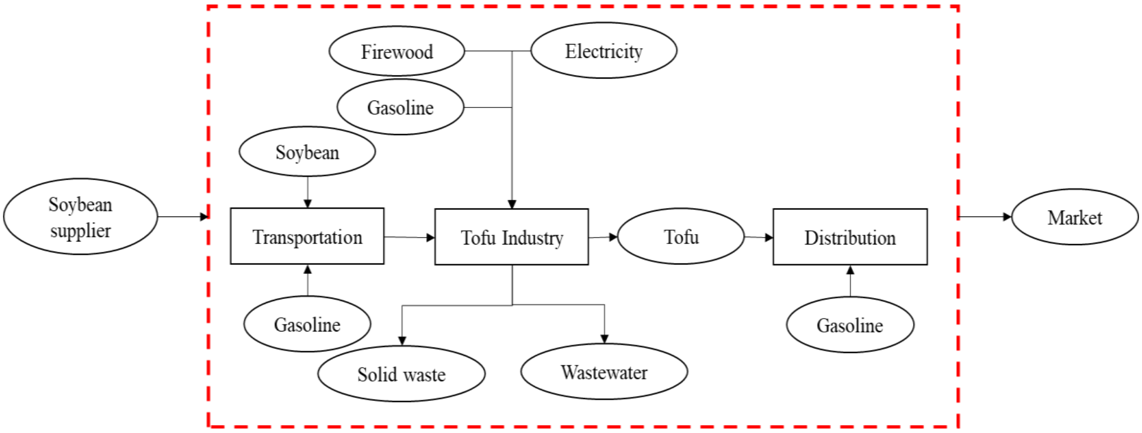

Figure 2. Gate-to-gate research boundary

Table 1. Data needed in LCA studies

Stages	Data type	Unit
Transportation and distribution	Total vehicles	Unit
	Vehicle type	Bike/car/truck
	Fuel type	Gasoline/diesel
	Fuel consumption	Liter
	Distance	Km
Production process	Water	Liter
	Soybean	Kg
	Firewood	Kg
	Gasoline/diesel	Liter
	Additional ingredient	Kg
	electricity	KwH
	Production equipment tools	Watt
	equiepment time usage	Hours
	Wastewater	Liter
	COD	Kg L^{-1}

Table 2. GHG emission formula in X's tofu Industry

Emission source	Formula	Reference
Electricity	$CO_2 = Q_e \times E_F$	Nugraha *et al.*, 2020
Wastewater	$CH_4 = V_{ww} \times C \times E_F$	Nugraha *et al.*, 2020
	$CO_2 = V_{ww} \times C \times 0{,}08$	Campos *et al.*, 2016
Fuel	$CO_2 = Q_F \times N_Q \times E_F$	Parameswari *et al.* ,2019

Where Q_e: Electricity consumption (kWh); E_F: Emission factor (Kg TJ^{-1}); V_{ww}: Wastewater volume (L); C: Chemical oxygen demand value (mg L^{-1}); Q_F: Fuel consumption (kg); and N_Q: Nett calor value (kcal kg^{-1})

Table 3. Emission factor and calor value

Product	Emission factor (E_F)			Calor value		Reference
	CO_2	CH_4	N_2O	Kcal Kg^{-1}	J Kg^{-1}	
Firewood	112,000 Kg TJ^{-1}	30 Kg TJ^{-1}	4 Kg TJ^{-1}	3.948	1.56×10^7	IPCC 2006
Electricity	586.32 tonCO_2 GWh^{-1}	-	-	-	3.6×10^8	IPCC 2006
Gasoline	77,400 Kg TJ^{-1}	3 Kg TJ^{-1}	0.3 Kg/TJ	10,500	4.04×10^7	IPCC 2006

Interpretation and Improvement Analysis

The stage is conducted to evaluate the results of the assessment and analysis. Then, improvements are determined based on the emission values produced within the research limits. Recommendations for improvement are obtained based on supporting and competent literature studies.

RESULT AND DISSCUSION

Production Process Identification in The X's Tofu Industry

The tofu industry is an industry that processes soybeans into tofu using various process stages. The process in the tofu Industry consists of soaking, grinding, cooking, filtering, coagulating, molding, cutting, and packaging. Soybean in the tofu industry is obtained from the surrounding area with a total distance of 21.6 km. Meanwhile, the tofu was distributed to the Pasir Gintung and Kalianda markets with a total distance of 150.2 km.

The results show that the 300 kg of soybeans used, produce 1,333.13 kg of packaged tofu. Meanwhile, wastewater and solid waste amounted to 4,333.4 L and 450 kg (wb). According to Indah *et al*. (2010), every 1 kg of soybeans used in making tofu will produce 15-20 L of wastewater, meanwhile, X's tofu industry produces 14.4 L kg^{-1} of soybeans. The highest wastewater is produced at the printing stage, namely 81.92% of the total wastewater. Meanwhile, according to Kurniawati *et al.* (2019), the highest wastewater is produced from the soaking process as much as 39.22% of the total wastewater. The different production systems and characteristics influenced the wastewater produced. The mass balance for tofu production can be seen in Table 4.

Solid waste is generated from several stages in the X's tofu industry, namely the grinding, cooking, filtering, and molding processes. There are two types of solid waste, namely loss materials and tofu dregs. Material loss comes from residual material that sticks to tools and materials that are dropped during the production process. Tofu dregs are the solid residue of soybeans from which the protein content has been extracted. Based on observations, tofu dregs produced by the X's tofu industry are sold to breeders and oncom producers, this is because the nutritional value is still quite high. Based on Coniwanti *et al*. (2009), tofu dregs have a high protein content, namely 21.29% and 9.96% fat, so they can be used as food products such as oncom and animal feed to increase nutritional value. Apart from increasing added value, this is also useful for reducing solid waste accumulation and reducing pollution caused by tofu dregs in industrial environments.

The tofu production process requires energy to facilitate the transformation of soybean to tofu. The results show that the X's tofu industry requires 29.48x109 J of energy. Energy sources come from electricity, fuel oil, and firewood. The highest energy is found in the soybean porridge cooking process, namely 28.44x109 J or 96.44% of the total energy, which comes from firewood to heat the steam boiler, gasoline to start the firewood, and electricity to pump water. Energy requirements in the X's tofu Industry are in Table 5.

The electricity usage in the X's tofu Industry there are in several processes, namely soaking, grinding, cooking, filtering, and packaging. The electricity is needed to run a water pump to the water supply during the tofu production process. The results show that tofu production in X's tofu Industry requires electrical energy of 0.90×10^9 J (3.05%) in production. Apart from that, gasoline is also an energy source used in tofu production as much as 17.38 L or equivalent to 0.50×10^9 J (1.70%). 12.28 L of gasoline is equivalent to 0.36×10^9 J is used for procurement of raw materials and delivery to the market, 5 L of gasoline or 0.14×10^9 J is used for grinding machines, meanwhile, 0.1 L of gasoline with an energy of 0.003×10^9 J is used as a means of starting a fire on firewood.

Table 4. Mass balance in X's tofu industry

No	Process	*Input*		*Output*	
		Material	**Total**	**Waste**	**Product**
1.	Soaking	Soybean Water	300 Kg 900 L	Water (783 L)	Wet Soybean (417 kg)
2.	Grinding	Soybean Water	417 kg 181 L	Material losses (1.1 kg)	Soybean porridge (596.9 kg)
3.	Cooking	Soybean porridge Water	596.9 kg 2,149.2 L	Material losses (2.2 kg) vapor (37.3 kg)	Soybean porridge (2,706.6 kg)
4.	Filtering	Soybean porridge Water	2,706.6 kg 2,000 L	Tofu dregs (450 kg)	Soybean juice (4,256.6 kg)
5.	Coagulating	Soybean juice Whey	4,256.6 kg 375 L	-	Crude (4,631.6 kg)
6.	Molding	Crude	4,631.6 kg	Whey (3,550.4 L) Material losses (1.2 kg)	Tofu (1,080 kg)
7.	Packaging	Tofu Water Plastic	1,080 kg 250 L 3.13 kg	-	Tofu packaged (1,333.13 kg)
	Total	**19,847.03 kg**		**19,847.03 kg**	

Table 5. The energy needed in X's tofu Industry

No	Process	Source			Energy		Total (J)
		Material	**Total**	**Unit**	**Total**	**Unit**	
1	Raw material procurement	Gasoline	0.36	L	$0.0104x10^9$	J	$0.01x10^9$
2	Soaking	Electricity	0.41	kWh	$0.1475x10^9$	J	$0.15x10^9$
3	Grinding	Gasoline Electricity	5 0.08	L kWh	$0.1447x10^9$ $0.0297x10^9$	J J	$0.17x10^9$
4	Cooking	Firewood Gasoline Electricity	1.800 0,1 0.98	kg L kWh	$28.08x10^9$ $0.0029x10^9$ $0.3523x10^9$	J J J	$28.44x10^9$
5	Filtering	Electricity	0.91	kWh	$0.3278x10^9$	J	$0.33x10^9$
6	Packaging	Electricity	0.11	kWh	$0.0410x10^9$	J	$0.04x10^9$
7	Distribute to Kalinda market	Gasoline	11.27	L	$0.3260x10^9$	J	$0.33x10^9$
8	Distribute to Pasir Gintung market	Gasoline	0,65	L	$0,0188x10^9$	J	$0.02x10^9$
			Total				**$29,48x10^9$**

Apart from electricity and gasoline, energy is also produced from the use of firewood. Firewood is the highest energy source for making tofu in the industry. Firewood is used as a fuel source for cooking soybean porridge. The use of firewood in one tofu production in the tofu Industry is 1,800 kg with the energy produced being $28.08x10^9$ J (95.25%) (Figure 3).

One kg of packaged tofu in distributed requires $2.2x10^7$ J of energy. Meanwhile, according to Anggraini *et al*. (2022), the energy required for 1 kg of tofu varies. In an industry with a production capacity of 80 kg, 220 kg, and 500 kg of soybeans, the energy required is 1.7×10^5 J, 2.9×10^4 J, and 7.9×10^3 J Kg^{-1} of tofu produced. Based on this data, the greater the production capacity, the energy consumption will also decrease.

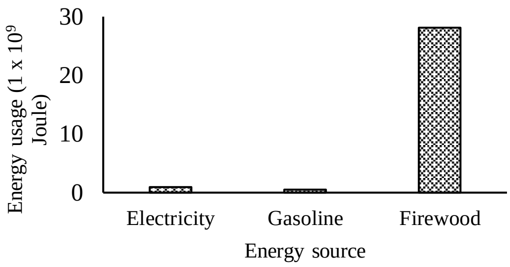

Figure 3. Source and energy usage in the X's tofu industry

GHG Emission in The X's Tofu Industry

Industrial activities can hurt the environment. The impacts are caused by production process activities or production activities, energy use, use of raw materials and additional materials as well as the use of machines and transportation equipment in the tofu industry. One of the impacts caused by industry is greenhouse gases (GHG). Several types of gases that are GHG contributors are CO_2, CH_4, and N_2O (Pujianto *et al*., 2022; Wahyudi, 2017; Ariani *et al*., 2011). The results show that the GHG produced from making tofu in the industry is 3,373.51 $kgCO_{2eq}$ in a production or 2.53 $kgCO_{2eq}$ a kg of packaged tofu product. This shows that the emissions produced in X's tofu Industry are greater than in the research of Kurniawati *et al*. (2019) which is only 0.18 $kgCO_{2eq}$ per kg of product. The highest GHG contributor is in the cooking process, namely 3,198.81 $kgCO_{2eq}$ with emission sources coming from firewood, electricity, and gasoline. This is then followed by the molding process of 110.62 $kgCO_{2eq}$ which comes from wastewater, and distribution to the Kalianda market of 25.29 $kgCO_{2eq}$ which comes from the use of gasoline. The distribution of GHG resulting from tofu production in the tofu Industry can be seen in Table 6.

Firewood is the highest GHG-producing source in X's tofu Industry, with as much as 3,198.20 $kgCO_{2eq}$. Firewood is used as an energy source for the cooking process. The high emissions produced are due to use in large quantities and high emission factor values (Wahyudi, 2017). The amount of firewood used in the tofu cooking process is 1,800 kg. Burning wood produces CO_2, CH_4, and N_2O gas emissions. The high gas emissions produced from burning wood have a high potential for causing GHG (Wahyudi, 2017). Sources of GHG production in the tofu production process in the industry can be seen in Table 7.

Tabel 6. GHGs Distribution in X's tofu industry

No.	Process	Source	Emission (kg)			Emission ($kgCO_{2eq}$)	Total Emission ($kgCO_{2eq}$)
			CO_2	CH_4	N_2O		
1	Raw material procurement	Gasoline	0.81	$3.3x10^{-4}$	$3.3x10^{-5}$	0.81	0.81
2	Soaking	Electricity	0.24	-	-	0.24	24.65
		Wastewater	0.34	1.05	-	24.41	
3	Grinding	Electricity	0.05	-	-	0.05	11.27
		Gasoline	11.2	$4.3x10^{-4}$	$4.3x10^{-5}$	11.22	
4	Cooking	Firewood	3,144.96	0.84	0.11	3,198.,20	3,198.81
		Gasoline	0.04	$8.6x10^{-6}$	$8.6x10^{-7}$	0.04	
		Electricity	0.57	-	-	0.57	
5	Filtering	Electricity	0.53	-	-	0.53	0.53
6	Molding	Wastewater	1.52	4.74	-	110.62	110.62
7	Pacaking	Electricity	0.07	-	-	0.07	0.07
8	Distribute to Kalinda market	Gasoline	27.46	$9.8x10^{-4}$	$9.8x10^{-5}$	25.29	25.29
9	Distribute to Pasir Gintung market	Gasoline	1.46	$5.6x10^{-5}$	$5.6x10^{-6}$	1.46	1.46
Total							**3.373,51**

Table 7. GHGs emission source

Source	GHGs ($kgCO_{2eq}$ a production)	GHGs ($kgCO_{2eq}$ a kg packaged product)
Electricity	1.46	$1.1x10^{-3}$
Firewood	3,198.81	2.40
Gasoline	38.01	0.029
Wastewater	135.03	0.10

In addition, wastewater has the potential for GHG emissions of 135.03 $kgCO_{2eq}$, followed by gasoline at 38.01 $kgCO_{2eq}$ and electricity at 1.46 $kgCO_{2eq}$ per production. The high GHG content in tofu wastewater is due to the

high amount and content of pollutant loads. This is proven by the COD value in tofu wastewater in X's tofu Industry reaching 5,346 mg L^{-1}. Degraded tofu wastewater will form CH_4 gas. The effect of CH_4 in capturing heat is 23 times greater than CO_2 (Nurhayati and Widiawati, 2017). Meanwhile, gasoline is used for the transportation of raw materials and distribution of tofu products, and electricity is used as an energy source to operate water pumps to meet water needs during the production process. GHG emissions resulting from electricity are indirect emissions.

X's tofu Industry has loyal consumers in the Kalianda market and Pasir Gintung Market. The Different distance between consumers causes differences in fuel consumption levels. Thus, emissions produced from 2 different markets also cause differences in the emissions produced. If all products produced in one production are concentrated in one market, then the emissions produced in the Pasir Gintung market (Bandar Lampung) are 3,348.22 $kgCO_{2eq}$ (2.51 $kgCO_{2eq}$ a kg packaged tofu product), while in the Kalianda market it is 3,372. 05 $kgCO_{2eq}$ (2.53 $kgCO_{2eq}$ a kg packaged tofu product). A comparison of GHG with different delivery destinations can be seen in Figure 4.

GHG Emission Reduction Strategy

The production process in each industry will have a GHG impact on the environment caused by several sources of emissions from the various stages carried out to produce tofu. The high GHG emissions produced will harm the environment over a certain period. Improvement analysis is carried out to reduce the resulting GHG impact and increase production productivity and industrial environmental performance. Improvement efforts in reducing GHG based on LCA for the tofu industry can apply Resource Efficiency and Cleaner Production (RECP) or resource efficiency and clean production. The high emissions produced by the use of energy (firewood) and wastewater are priorities that need to be improved to reduce emissions in X's tofu industry. The strategies that can be implemented for X's tofu Industry are in Table 8

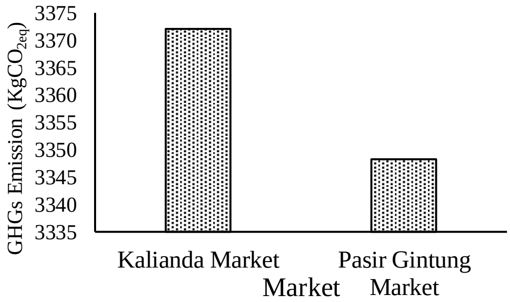

Figure 4. Total GHG emissions in different places.

Table 8. Improvement strategy in X's tofu industry

Strategy	Advantages	Reference
Minimizing water usage	Reducing the water usage in the soybean extraction and soybean porridge filtering process so that the wastewater (whey) produced is reduced.	Darmajana *et al.*, 2013
Reuse wastewater in washing and soaking	Reducing water usage in washing and soaking in the next batch	Jaya *et al.*, 2018
Optimization of raw material transportation processes	Carrying out the raw material procurement process by selecting closer suppliers to make GHG reduction more effective in the tofu industry.	Lolo *et al.*, 2021
Converting firewood to LPG	GHG impact reduction from firewood to LPG. It caused emission factor LPG lower than from firewood.	Sukmana *et al.*, 2019
Utilizing wastewater to biogas production for the cooking process	Tofu wastewater conversion to biogas. It can reduce pollutants in the environment and GHG emissions. Biogas can be used as an energy source in the tofu industry.	Wahyudi, 2017; Putri and Waluyo, 2022

CONCLUSIONS AND RECOMMENDATIONS

Conclusion

The X's tofu Industry contributes to GHG emissions of as much as 3,373.53 $kgCO_{2eq}$ (2.53 $kgCO_{2eq}$ a kg packaged tofu), where firewood as an energy source is the highest contributor to GHG, then followed by wastewater, gasoline, and electricity as much as 3,197.58 $kgCO_{2eq}$ (94.85%), 133.21 $kgCO_{2eq}$ (3.95%), 38.82 $kgCO_{2eq}$ (1.15%), dan 1.46 $kgCO_{2eq}$ (0.04%). Energy use is a source of emissions that dominant to contributes to the formation of GHG emissions. The cooking process is the stage that contributes most to the high GHG emissions in X's tofu Industry. The strategies that can be implemented to reduce GHG emissions are minimizing water use, reusing wastewater, optimizing the process of transporting raw materials, converting the firewood to LPG, and utilizing wastewater into biogas production for the cooking process.

Recommendation

Further research needs to be carried out regarding other impact categories, such as eutrophication and acidification in the tofu industry.

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