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CASE STUDY

Energy audits in the tofu industry; an evaluation of energy consumption towards a green and sustainable industry

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Abstract
The tofu industry consumes a lot of energy and water for its process production and then produces wastewater in large quantities that have a negative effect on the environment. It is because tofu craftsmen still use conventional technology in the process production, and there is no SOP for the use of raw materials and energy sources, and there is also a lack of capability in waste management. This study aims to investigate the audit energy in the tofu industry, including evaluating the consumption energy in different energy sources, determining the production of wastewater in the tofu industries and determining the energy sources available in the tofu industry. The data collection method involved semi-structured interviews and questionnaire surveys carried out in 40 tofu industries in Gunung Sulah district, Bandar Lampung City, Lampung Province, Indonesia. The results showed that the highest consumption in process production in the tofu industry is for cooking that depends on the type of energy sources, namely firewood 71.1 MJ/kg, LPG 16.9 MJ/kg, and wood pellets 6.0 MJ/kg. However, the consumption of water for the production of the process is 25.2 L/kg and produces 14.5 L/kg wastewater. The tofu industry is still not efficient in consuming energy because it does not use wastewater to produce a bioenergy product that can be beneficial in economic and environmental aspects. To make energy consumption more efficient in the tofu industry, it is very useful to use wastewater to produce bioenergy material that can replace non-renewable energy as the main energy for process production. Based on the prediction that the potential for methane from tofu wastewater is approximately 0.056 m^3/kg soybeans, the use of tofu wastewater as biogas feedstock can replace 2.82% of firewood, 11.86% LPG, and 33.39% biopellets.

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Keywords Energy audit · Tofu industry · Sustainability

Abbreviations

AD	Anaerobic digestion
BOD	Biological oxigen demand
CO_2	Carbon dioxide
CH_3COOH	Acetate acid
$CaSO_4$	Potassium sulphate
COD	Chemical oxygen demand
COP	Climate change conference
SCOD	Soluble chemical oxygen demand
EU	European Union
GHG	Greenhouse gas
KJ/kg	Kilojoule/kilogram
L/kg	Litre/kilogram
LCA	Life cycle assessment
LPG	Liquid petroleum gas
MJ/kg	Megajoule/kilogram
MSMEs	Micro, small, and medium enterprise
SOP	Standard operating procedure
TS	Total solid
TSS	Total solid suspended
UAE	United Arab Emirates
USD	United State dollar
VFA	Volatile fatty acid

1 Introduction

The tofu industry is one of the most numerous and dynamic processed food industries in Indonesia. It is because the tofu industry is the main source of income and employment for the local community. The demand for tofu is high about 3.5 million tons per year, this is because the Indonesians always consume tofu in their daily diet as a source of protein (Yuliarti, 2020). Generally, the tofu industry in Indonesia consists of micro, small, and medium-scale enterprises (MSMEs); the micro and small-scale industries are known as "home industry". The tofu industry in Indonesia is a type of heritage business that will be passed down from generation to generation, the number of tofu factories has reached 84,000 business units, including a large and small-scale industry spread across all regions (Putri et al., 2022). Tofu industry that was observed in this study is located in Gunung Sulah District, Bandar Lampung City. The tofu industry is growing rapidly in Bandar Lampung City with a total of 238 tofu industries, most of them are in Gunung Sulah District with around 115 industries (Primkopti, 2016). Usually, tofu industries concentrated in one location make a cluster in the middle of residential areas. This is because tofu production is very easy with simple technology that can be produced on a home scale, therefore neighbours and relatives who live nearby also produce tofu in their homes. Therefore, the problem arises such as the lack of space to process the wastewater produced by tofu that has an impact on the environment, health, and other social aspects. Hence, the management of tofu industry is very important due to the relationship with the business actor that can

give them the benefit from waste management and create a sustainable industry with high environmental quality (Simanjuntak et al., 2021).

The tofu industry faces several challenges, including lack of outreach from relevant stakeholders to obtain a home industry business permit certificate from the government. There are no standard operating procedures (SOP) in the production process, waste management methods, and energy consumption efficiency, so that the impact not only on environment but also on economy aspect (Lisanty et al., 2021). Tofu production consumes a lot of energy, particularly when grinding the soybeans and boiling the soybean porridge. Approximately 90% of micro and small-scale tofu industry uses firewood as fuel for all production processes. The use of non-renewable energy in industry will increase the exploitation of fossil fuels and have significant effects on climate change, such as environmental pollution, especially greenhouse gas (GHG) emissions. However, the use of non-renewable energy in the tofu production process will cause an increase in CO_2 emissions, which is a big issue that caused by industrial activities.

Concerns about pollution caused by the burning of fossil fuels at the industry level are increasing globally, not only in developing countries, but also in developed countries

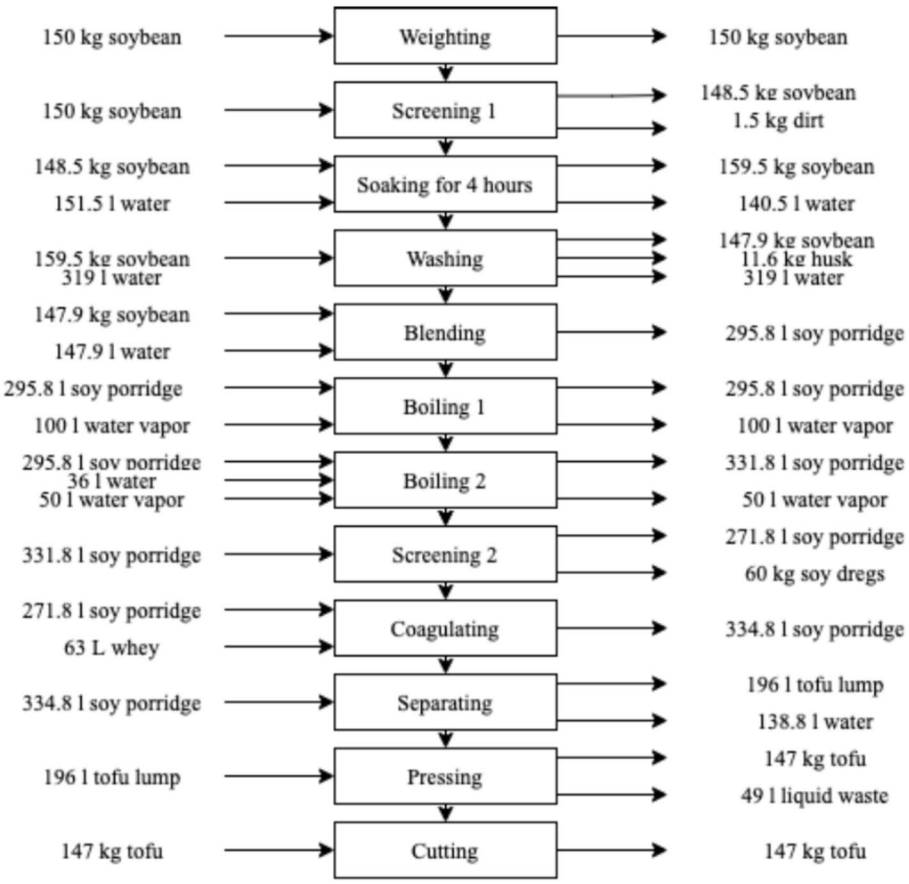

Fig. 1 Flow chart mass balance of tofu production process (Septifani et al., 2021)

(Thakur et al., 2020). So, in the middle of an energy transition, considering environmental aspects is a priority by developing research that is beneficial to the environment, especially emphasising on greenhouse gas (GHG) pollutions linked to conventional energy sources(Adebayo & Özkan, 2024; Adebayo et al., 2024). Pollution that occurs from the type of fuel used in industry is one of the roles related to policy makers. This issue arises when there is ambiguity regarding the scope of government organisations at various levels (local, national, and global) that will adopt and implement plan initiatives related to climate change (Liu, 2023). The use of non-renewable energy not only has an impact on the environment and the industrial economy but also has a huge impact on the national and global scale. Improving energy efficiency or using less energy to achieve the same level of production that can meet a variety of government priorities, from economic growth to the reduction of greenhouse gases in energy and food security (Dimitris, 2017).

Furthermore, the tofu industry also consumes a lot of water during the production process, thus producing large amounts of wastewater with high organic content (Fig. 1), which has a negative impact on body water (Aurora et al., 2021). The tofu industry produces two types of waste including; solid waste (tofu dregs) and wastewater. There is no negative impact of tofu dregs due to their ability to be used directly as additional material for human food and animal feed, co-substrate for biogas, and material to make paper (Annisa, 2014; Saputra & Purnomoadi, 2018). In fact, most of the tofu industries have a contract with third parties like industries or farmers to sell their tofu dregs (Lubis et al., 2022). The use of tofu dregs as additional ingredient food for humans and livestock is because it still has a high nutrition content and is rich in protein approximately 18–25%, fat 4.5%, and crude fibre 18.21% (Farabi et al., 2016).

According to the issues faced in the tofu industry, policy makers need a special strategy to handle these issues, including; (1) investment in renewable energy, (2) focus on the main issues of ecological degradation that arise from urbanisation and economic expansion, (3) implement policies and strategies related to trade openness to improve environmental quality, (4) policy makers must encourage economic development by supporting a sustainable economic environment (Adebayo et al., 2023). The current situation about global warming linked to climate change has drawn the attention of CO_2 emissions stakeholders. There are some factors that limited attention in the field of energy and environmental literature related to environmental degradation such as the combined impact of uncertainties, climate policy, and economic policy uncertainties, including geopolitical (Adebayo, 2024).

One of the solutions to control the efficiency of energy consumption at the industry level to help the policy maker and the business actor is conducting an energy audit. Conducting an energy audit is one of the efforts to achieve net zero in the tofu industry, as stated in the UN Climate change conference in glasgow (COP26) to accelerate action in controlling climate change and replace non-renewable energy such as fossil fuels (UN, 2023). Like the COP28 output held in Dubai, the United Arab Emirates with 150 heads of state and government were intensely discussed and negotiated to reach an agreement that has managed to reach an innovative agreement focused on phasing out fossil fuels, tripling the capacity of renewable energy, and increasing climate finance for the most vulnerable communities. These factors are to reach the main goals of the Paris Agreement that restrict the global average near-surface temperature increase to 1.5 ^{0}C in preindustrial levels for the long term (UNFCC, 2024; Xu et al., 2024). It is aligned with the definition of EU energy audit standard (EN 16247–1) that energy auditing is a systematic inspection of energy analysis and energy consumption of building, site, system, or organisation, the aim being to identify energy flows and potential energy efficiency improvements and report them (Thollander et al., 2020).

Energy audit is a method to estimate the amount of energy consumed in industrial activities, which have an impact to the efficiency energy consumption. Energy audit as an approach to identify opportunities for energy conservation as the first step in energy management, specifically for industrial energy efficiency (Kaur & Thakur, 2014). Energy management and conversion are the most significant variables for energy consumption since they have a direct impact on the environment and economic issues (Qandil et al., 2021). According to the results of the LCA analysis in the tofu industry, the greatest contribution to the environment in the production of the tofu process is grinding and boiling, including acidification 27.92294 kg of SO_2, eutrophication 1.987027 kg of PO_4, global warming 4026.078 kg of CO_2, human toxicity 436.9892 kg of 1.4-DB eq and photochemical oxidation 0.085625 kg of C_2H_4 eq (Lolo et al., 2021). In addition to that, the energy audit in two different tofu industries (modern and traditional method) shows that the energy consumption in the modern tofu industry that uses a steam boiler is 0.09 MJ/kg for human energy, 0.15 MJ/kg electricity, and 0.61 MJ/kg for biomass (firewood). However, the energy consumption in the traditional tofu industry is lower than in the modern industry, namely 0.13 MJ/kg of human energy, 0.71 MJ/kg of biofuel, and 0.82 MJ/kg of biomass (rice husk) (Yanti et al., 2022). The results of energy in PT. Sandria et al. not only shows the efficiency energy that used for production per year, but can also save the cos energy around 8740.79 USD per year (Wardhana & Damarwan, 2023). The result of study that eco-innovation and renewable energy is negative on CO_2 across all quantiles and periods, however, there are some factors that have a positive impact on contribution to CO_2 including; socio-economic condition, political risk, and financial risk (Adebayo & Özkan, 2024).

Therefore, the energy audit in the tofu industry as a method of achieving the SDGs 7 (affordable and clean energy), 11 (sustainable cities and communities), and 12 (responsible consumption and production) (United Nation, 2024). The energy audit in this study is a toll to distinguish and examine energy administration programme, it could be useful for industry to save the fundamental energy cost and provides some advantages such as increasing profits, better quality, and the most essential fulfilment of leading towards contributing to the global energy saving (Sharma et al., 2021). To complete the literature gap, this study aims to investigate audit energy in the tofu industry as preliminary data, to evaluate consumption energy in different energy sources, to determine the production of wastewater in the tofu industries, and to find the energy sources available in the tofu industry. The energy audit reveals how much energy is needed for industrial activities through the tofu production process, which allowed us to figure out how to reduce energy consumption and more effectively (Sharma et al., 2021). Thus, it can become a reference for industry to improve industrial activities toward sustainability for environmental protection, such as the development of environmental technology, because it restricts the discharge of waste into the environment. Another benefit of technological innovation is that it can improve environmental quality through improving the energy transition, enhance the production of renewable energy that is expected to have good impact on environmental health (Adebayo, 2023).

2 Materials and methods

2.1 Target area

Energy audits were carried out in the micro- and small-scale tofu industries in Gunung Sulah District, Bandar Lampung City, Lampung Province, Indonesia. The report of the Central

Bureau of Statistics on the classification of scale industry based on the number of labourers is divided into four scales: micro (1–4 labourers), small (5–19 labourers), medium (20–99 labourers), and big (more than 100 labourers) (Central Bureau of Statistics, 2019). Gunung Sulah District is the centre of the micro- and small-scale agro-industry in Bandar Lampung city, focussing on the soybean food processing industry such as tofu, tempeh, and oncom (traditional staple food of West Java).

2.2 Sampling method

In this study, the tofu industry was selected as a sample using simple random sampling. In total sampling, the selected sample can represent the research area. For the homogeneous population, simple random sampling is used. The sampling procedure can be performed at random; the samples and locations were chosen at random to represent the population in the study area. The tofu industry is concentrated in four regions in Gunung Sulah District. To represent each region, ten tofu industries were chosen at random, for a total sample of 40 industries.

2.3 Data collection

Semi-structured interviews and questionnaire surveys were conducted in 40 tofu industries in Gunung Sulah District, Bandar Lampung City, Lampung Province, Indonesia. The semi-structured interviews and questionnaire approach is an interview in which the researcher collects open data (Dejonckheere & Vaughn, 2019). This study focusses on the energy consumption for processing tofu production. Using a semi-structured interview and questionnaire is more relevant and flexible to the cases in this study because it allows the researcher to have new questions during the interview for the participant to explore in more detail the information (Aung & Razak, 2021).

The following steps were taken for data collection: (1) visiting each of the tofu industry, (2) sample analysis of the caloric value of firewood, biopellets, and LPG in the laboratory (Laboratory of Agro-industrial Technology, Faculty of Agriculture, University of Lampung, Indonesia), (3) data analysis.

The consumption data were calculated using the following equation:

Human energy consumption equation:

$$\mathrm{He} = JK \times T \times Hc \tag{1}$$

He = Human energy (MJ); JK = Number of labors; T = the length of time worked (hours); Hc = Human caloric value 0.53 MJ/h (Kasumov et al., 2017).

Electricity consumption is calculated with the equation:

$$Ec = P \times t \tag{2}$$

Ec = Electricity consumption (MJ); P = Electrical power used (Watt); t = Time used during the process (s)

There are two types of fuel oil consumed for soybean grinding machines in the tofu industry, namely gasoline and diesel.

Gasoline consumption is calculated with the equation:

$$Gc = V \times \rho \times cvg \tag{3}$$

Gc = gasoline consumed (kJ); V = volume gasoline used (m^3); ρ = density of gasoline 0.745 kg/l (Badarudin Hardiansyah, 2015); cvg = caloric value gasoline 43.999 (MJ/Kg) (Irzon, 2012).

Diesel fuel consumption is calculated using the following equation:

$$Dc = V \times \rho \times cs \tag{4}$$

Dc = diesel consumed (MJ); V = volume diesel used (litre); ρ = density of diesel 0.832 kg/l (Badarudin Hardiansyah, 2015); cs = diesel caloric value 42.595 (MJ/Kg) (Yohana, 1800).

Currently, three common fuels are used for cooking in the tofu industry namely; firewood, biopellets, and LPG. The energy consumption for cooking can be calculated with the following formula:

Firewood consumption is calculated with the following equation:

$$Fec = Mb \times cb \tag{5}$$

Fec = Firewood energy consumption (MJ); Mb = mass of firewood (kg); cb = heat value of firewood 20.13 (MJ/kg).

The consumption of biopellets is calculated using the equation:

$$Bc = Mb \times cb \tag{6}$$

Bc = biopellets fuel energy used (MJ)p; Mb = mass of biopellets (kg); cb = heat value of biopellets 17.187 (MJ/kg).

The LPG fuel consumption is calculated with the following equation:

$$Gc = Mg \times Cg \tag{7}$$

Gc = LPG energy used (MJ); Mg = Mass of LPG used (Kg); Cg = caloric value of LPG = 47.081 MJ/Kg.

Water consumption is the most important part in the tofu industry in the process of producing wastewater. The volume of water tanks used in the production process is measured manually to ensure the amount of water consumed. In addition, the mass balance is applied to determine the amount of wastewater produced. To calculate the energy from tofu wastewater is using the following equation:

The amount of methane (CH_4) (Eleutheria et al., 2016) can be calculated with the equation:

$$M = P \times Lw \times 0.9 \times COD \times (0.35/1000000) \tag{8}$$

M = Methane production (m^3/day); Lw = Wastewater production (L/kg soybeans); P = Production capacity of tofu factory (kg soybeans/day); 0.9 = 90% COD removal; COD = COD concentration (mg/l); 0.35 = methane production potential (m^3/kg COD removal); 1,000,000 = Conversion factor.

3 Results and discussion

3.1 Energy consumption for cooking

In Indonesia, approximately 99.99% or 56.54 million MSMEs units play an important role in economic aspects due to their significant impact on the economy, society and the environment (Indonesia, 2015). The energy sources used in industry and households in Indonesia still rely on non-renewable energy, especially fossil fuels (petroleum and coal) (Haryana, 2018). Currently, there are three types of fuels that are commonly used as the main energy for cooking in the tofu industry, including LPG, firewood, and biopellet. In Fig. 2. The highest energy consumption of fuel for cooking in the tofu industry is firewood 71.1 MJ/kg, followed by LPG 16.9 MJ/kg, and wood pellets 6.0 MJ/kg.

Most of the tofu industry that was observed in this study (38 of 40 tofu industries) used firewood as their main energy resource for their production process, particularly for cooking. Generally, the micro- and small-scale tofu industry uses firewood as the main energy source for its process production, with a low capacity around 30–150 kg of soybeans/day. Compared to other fuels (LPG and biopellet). The use of firewood in the micro and small-scale food industry is quite common because of its long-lasting heat and high calorific value, so it is very usable for the production of tofu process. Firewood types have high calorific value that are preferred as the main energy sources in the MSMEs tofu industry, usually hardwoods such as rubber, acacia, mahogany, and fruit tress (Insusanty et al., 2016). The type of firewood used in the tofu industry is old and unproductive rubber wood purchased from firewood sellers around the tofu industry (Rizwan & Miswar, 2012). The use of firewood is essential for rural communities and MSMEs in Indonesia to meet daily demands, not only for industries but also for households (Sylviani et al., 2013). Although, the economy in the Southeast Asian region has increased rapidly, the consumption of firewood in the community level also increased significantly (Dwiprabowo, 2010). The result of the observation in the field is that there is only one micro-scale tofu industry that uses LPG as the main energy source for their process production.

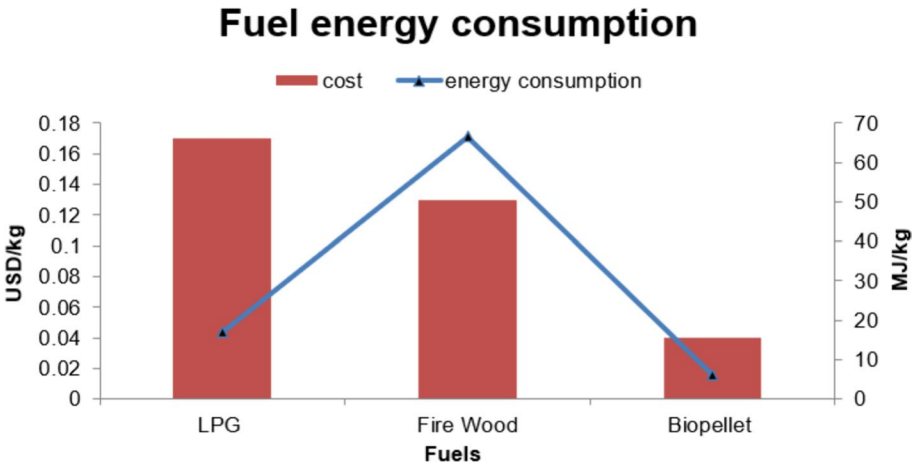

Fig. 2 Fuel consumption for cooking

Based on Fig. 2. The consumption of LPG is less than that of firewood, but the cost consumption of LPG is highest among the energy resources (firewood and biopellet). Indonesia has several years of experience in energy transition, from firewood to kerosene and recently in LPG. One of the government's strategies to switch from firewood to LPG is to provide LPG subsidies for MSMEs. However, the owner of the micro- and small- scale tofu industry must meet certain criteria to receive LPG 45 subsidised. Although LPG is subsidised by the government for MSMEs, in fact, the price is very expensive, so the owners of the ofu industry prefer to use firewood. Another reason why the owner of tofu industries are not interested in using LPG, is because of the lack of knowledge of how to use safely, as there is no training to fulfil the requirement that must be met to use the LPG. Therefore, most of the owners industry consider firewood to be more practical to use and economically profitable for producers; thus, it is still difficult to change the habits in energy consumption (Purnomo, 2022). In addition to that, the competition between industries to get LPG is high and the leakage of LPG cylinders results in explosions and huge losses for consumers causing people to be reluctant to switch from firewood to LPG. The explosion of the gas stove caused by a leak in the LPG cylinder and increases the temperature of the gas stove frame, which requires the installation of technology that includes an early warning system and a mitigation mechanism (Kurniawan & Tjahjadi, 2016).

The results from laboratory analysis show that the calorific values of firewood, biopellets and LPG, respectively, are 20.1, 17.2, and 47.1 MJ/kg. A good quality of fuel has a high calorific value; therefore, the higher the calorific value, the better the quality of the fuel (Gioda et al., 2019). According to Fig. 2. The consumption of fuel used in the tofu industry is very different, because the habits in fuel consumption and the types of fireplace used are closely related to the energy consumption efficiency. Furthermore, there are some factors that impact energy consumption, such as the production capacity and the length of the production process, and there is no SOP in the tofu industry for its processing production activities, especially in the use of fuel for the process of cooking soybean porridge. The common issue of firewood fireplaces is incomplete combustion of firewood in a simple furnace due to the fact that there is no separation between fuel and ash (Hananto & Fahriannur, 2018). The case in rice industry, the lack of awareness of the worker is a common event in industry during the processing production, causing energy losses or increasing energy consumption by approximately 0.00016 MJ/kg of rice (Hasrizal & Diswandi Nurba, 2019).

Biopellet is renewable energy produced from biomass or agricultural residues. However, to use biopellets requires a large investment and a large space to build a safe boiler, this is why home industries cannot switch from firewood to biopellets. However, biopellets have a high calorific value and a high bound carbon content that makes them more beneficial for industries that use biopellets as energy resources (Prasetyo et al., 2022). The small-scale tofu industry observed in this study requires 350 kg of biopellets per day with a production capacity of approximately 1 ton per day. To meet consumer demand, they are using biopellets as the main energy source and the appropriate type of boiling stove to optimise the efficiency of the soybean cooking process. During the burning processing of biopellets, soot and ash are produced, but the quantities are very small compared to firewood. The use of biopellets is very beneficial, because it is more efficient, environmentally friendly and economically friendly and can save up to 25–41% of the fuel cost (Ari Supriyanti Rikin, 2019). There are several reasons why tofu industry owners still use firewood; (1) Because they do not know about other fuel options, tofu industry owners only know three types of fuel: firewood, fuel oil (gasoline, diesel and kerosene), and biopellets. (2) Preserving the unique taste of tofu that cooked with the firewood (tofu has a distinct flavour when cooked

with firewood). (3) A lack of financial resources and limited space; If they want to switch to other fuels, such as bio-pellet or biogas, they must modify the fireplace for cooking to the new design, which required a lot of money, labour, and space (Tambunan & Studi, 2013). There are many types of fireplace used in the tofu industry for process production; the common fireplace used is a single furnace and steam boiler. The type of fireplace used is related to the energy consumption; the highest energy consumption in tofu industry is the operation of a steam boiler of 19.005 MJ/kg and the lowest is 6.026 MJ/kg for a single furnace (Markumningsih & Purwantana, 2013).

The energy consumption is linked to the production cost consumption. Based on the Fig. 2. That the highest cost energy consumption per kg of production capacity is 0.17 USD for LPG, then 0.13 USD for firewood and 0.04 USD for biopellets. Several factors impact the use of fuel and energy consumption cost, including financial issues related to consumer purchasing power, and the limit of knowledge of tofu craftsmen in waste management that can be beneficial to industry in saving energy cost (Dwiprabowo, 2010). The cost of energy consumption in the small-scale industry is around 42.4% of operating costs. However, the percentage of costs is not dominantly high for all production activities but remains a major consideration for industry owners when choosing the types of fuel used (Tambunan & Studi, 2013). Furthermore, the small-scale tofu industry still does not use biopellets in processing production because the target market for biopellets is not intended for small industries. Commonly, biopellets are used by medium- and large-scale industries with high-capacity production. The main market for biopellets is the international market (export activity) such as Asian countries (Japan, South Korea, China, etc.), European Union (EU), the UAE, and the United States because the consumer of these countries is much higher than the domestic consumer; hence the potential for the trade of biopellets is enormous (Sidabutar, 2018).

3.2 Energy consumption for grinding

The use of fuel oil depends on the types of soybean grinding machine used in the tofu industry. In Indonesia, most of the micro- and small-scales of tofu industries use two types of fuel oil: diesel and gasoline, diesel fuel known as "solar" (Martin et al., 2020). However, in medium- and large-scale tofu industries, they use dynamo machines that consume electricity. In Fig. 3. The total energy of the fuel oil consumption of the grinding machines for diesel and gasoline, respectively, is 3.3 MJ/kg and 1.9 MJ/kg, the fuel consumption is directly proportional to the energy produced. If the consumption of fuel is low, the energy produced will also be low, and vice versa (Sartono, 2016).

On the basis of the observation in the tofu industry, the consumption of diesel fuel is higher than that of gasoline because the grinding machines are old and require maintenance; this makes the grinding machine difficult to work and consumes a lot of fuel during the operation. In Indonesia, the grinding machines that consume diesel fuel are limited because the price of diesel fuel is very expensive and rare. The results of interviews with industry owners and tofu craftsmen revealed that there is no SOP in using the grinding machine; they only followed instincts based on their experience. Furthermore, the owner rarely performs maintenance on the grinding machine, thus it will be very costly to repair and maintain the machine. There are some factors that influence the consumption of fuel oil for the grinding machine, namely; production capacity, the age of the machine, the duration of machine operation, and maintenance (Isbandi, 2021). There are several factors that cause downtime or decreased machine performance such as; (1) there is no kanban

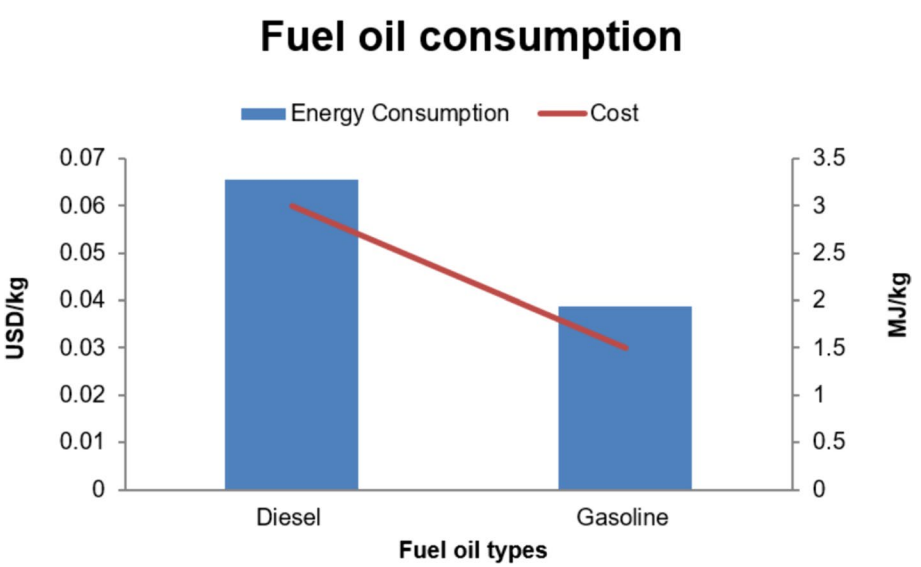

Fig. 3 Total fuel oil consumption

card that causes 20% time loss; it is because the function of kanban card is to provide the information about the strict stock and to start the operation at the right time. (2) 18% of the time lost by diamond grinding (sharpening grinding wheels for grinding rolls) that is related to machine performance. (3) there is no operator or skilled worker that causes a loss of around 17% (Kardas, 2017).

There are commonly methods used to maintain the quality of engine performance, like having a proactive maintenance schedule, and thus the engine performance remains good when operating. Not only basic maintenance to prevent the corrosion, also required daily maintenance such as checking all parts of the machine before and after operation due to the machine maintenance linked to the production activities, and minimise productivity disruptions to produce a good quality product (Singh et al., 2022). In general, there are two types of maintenance for grinding machines in the tofu industry, including corrective and preventive maintenance. Most of the micro- and small-scale tofu industry only performs corrective maintenance due to financial issues and the lack of knowledge about machine maintenance and how to use it properly for the workers in industry. In fact, corrective maintenance is more costly than preventive maintenance due to the repair and replacement of damaged machine parts, so preventive maintenance is highly recommended to keep the grinding machine in good condition for longer time (Pau Asngadi, 2021). The operator machine in industry need to know how to operate the machine with sufficient experience, because they always work with the machine for long time during the process production. To support existing resources in the industry especially machine operators, industry is obliged to provide machine operation training and its maintenance to improve worker performance to maintain the quality of product.

Currently, the Indonesian government is in a hurry to replace all diesel engines with new biodiesel engines, including vehicles that use palm oil biodiesel (Martin et al., 2020). The consumption of fuel oil for the soybean grinding machine is related to the cost of fuel consumption. In Fig. 3 shows that the total cost consumption of diesel fuel and gasoline is

0.06 USD/kg and 0.03 USD/kg with the consumption of diesel fuel and gasoline per day respectively being 2.5 L/day and 1.52 L/day. Because the grinding machines that use diesel fuel are usually old machines that require maintenance, it has an impact on the cost of fuel consumption and is wasteful in the use of diesel fuel. However, the grinding machine that uses gasoline is a new machine, the price of gasoline is cheaper than diesel fuel, as well as the consumption of gasoline is lower than diesel fuel. Although using an old machine is difficult, tofu craftsmen have another way to grind soybeans, they will ask the nearest tofu industry to grind the soybeans, then pay for the grinding service. Payment for soybean grinding services can be in cash or by purchasing fuel oil that has been used to grind soybeans.

The grinding stage is a very important process in the production of tofu, if this process fails, it will affect the further process because the quality of the tofu is not good in the moulding process, then the industry will suffer losses. Good quality tofu is produced from a perfect grinding process, resulting in a very soft soybean porridge due to the fact that it contains high protein (Wulandari, 2012). Old machines are used with a special treatment to maintain the quality of soybeans as the main ingredient in tofu production. The soybean grinding machine will rest about 5 to 15 min after grinding, waiting for the machine to cool down so that the quality of the soybean porridge remains good. The working duration of the machine for capacity production of 30 kg/day is 1.5 h, and the number of breaks during the grinding process is four times. Furthermore, to maintain the quality of soybean porridge, it is necessary to add water during the grinding process. The more water used, the faster the grinding process and the more efficient the energy consumption (Widiyarta et al., 2016). The amount of water consumed during the production process is quite high for grinding soybeans and boiling soybean porridge. The purpose of adding water is to speed up the grinding process and soften the ground soybeans to produce good soybean porridge. So, the addition of water in the boiling process is to obtain as much soluble protein as that contained in soybean porridge as a component of tofu (Mulyani & Hartono, 2013).

3.3 Electricity consumption

Electricity consumption in the tofu industry has two functions, including utilities and grinding. The energy consumption for the utilities is not as high as for grinding, because the tofu production process starts early in the morning until noon (5 a.m–15 p.m.), so the use of electrical energy for lighting does not consume a lot of energy. The source of electrical energy in the micro and small-scale tofu industry is from the State Electricity Company, known as 'PLN', which used based on each industry capacity (Biantoro & Permana, 2017). In Fig. 4. it is shown that the total electricity consumed for utilities is 0.019 MJ/kg and for grinding is 0.03 MJ/kg. Generally, small, medium, and large-scale of tofu industries use a dynamo machine to grind the soybeans which use electricity as the main source of energy. Like grinding machines that use fuel oil as their energy source, grinding machines with dynamo are also related to the production capacity and the length of work. In the small-scale tofu industry, the production capacity is 1 ton per day, to meet consumer demand, the working duration of the dynamo machine is 12 h continuously non-stop, the duration of duration for the production process is 24 h (with a two-shift system), the electricity consumption for grinding is higher than utilities because the working duration of dynamo machines is longer compared to utilities such as lightning, water pumps, and blowers.

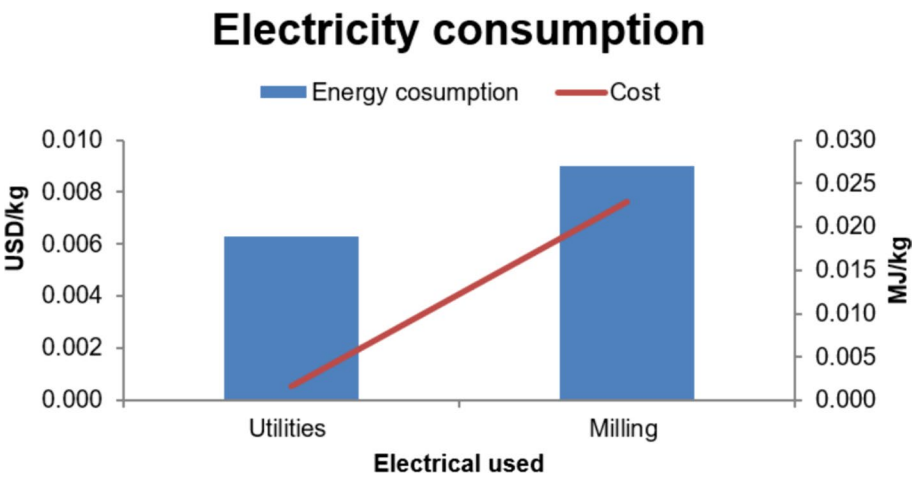

Fig. 4 Electricity consumption

The consumption of electricity for utilities and grinding has an impact on the cost of consumption. According to Fig. 4, the cost of consumption for utilities is 0.001 USD/kg and for grinding is 0.0076 USD/kg. The use of electricity for tofu production in micro and small-scale industries is combined with household electricity, so the electricity bill for industry is combined with the household electricity bill (Aulia, 2015). In this study, data collection focused on electricity consumption for utilities in tofu production processes such as water pumps, lightning, blowers, and grinding. The highest electricity consumption for utilities in the micro-scale tofu industry is the water pump to fill the water tank which is used for the tofu production process. In addition, the consumption of electricity in the production process is for lightning and blower; blower is very important to burn firewood during process production, thus the wood always burns. The working times of the water pumps and blowers are different in each tofu industry because each industry has different methods in water consumption and production capacities. According to the LCA analysis, the main problem of energy consumption for tofu processing production is boiling soybean porridge using firewood, and the use of electricity in water pumps and soybean grinding machines (Lolo et al., 2021). The use of electricity for processing production in the tofu industry required a solution to increase efficiency in energy consumption, especially the use of electricity in the management of waste into a bioenergy product to replace non-renewable energy. Utilisation of tofu waste is a solution to energy efficiency in the tofu industries and optimal waste management.

3.4 Water consumption

Water consumption is an important aspect that influences industrial sustainability. To make the activities of the tofu industry more sustainable and environmentally friendly, water consumption management is required (Lubis, 2021). In Fig. 5. It is shown that the water consumption in tofu industry is different in each industry due to the production capacity and the production process methods are not the same.

From the results of calculations and predictions, water consumption in the micro- and small-scale tofu industries is 25.2 L/kg of soybeans, and the wastewater produced from the

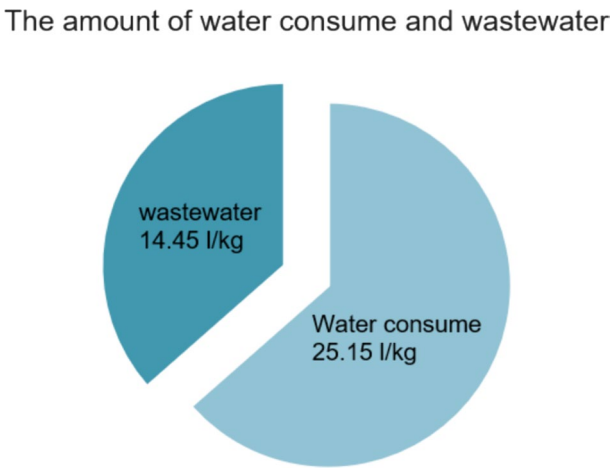

Fig. 5 Water consumption for processing production in the tofu industry

production process is 14.5 L/kg of soybeans, which is approximately 53.4% of the water consumed. From the production of the tofu process, around 15–20 L/kg of wastewater will be produced with a high nutritional content (Sadzali, 2010). Because tofu wastewater still has a high nutritional content and acetic acid, tofu craftsmen usually keep some of the wastewater in a container as an acid solution resource for coagulation in the next day's production. The use of wastewater as an acid solution for coagulation will be mixed with CH_3COOH (acetate acid) or $CaSO_4$ (potassium sulphate), the addition of these acids causing different characteristics of wastewater (Yudhistira et al., 2018). Unfortunately, there is no SOP for the use of water in small and medium-scale tofu industries, hence tofu craftsmen consume unlimited water and rely only on their instinct without a specific amount. According to Table 1, the characteristic tofu wastewater in Gunung Sulah district has a high COD content and a low pH value of 5.17.

Tofu wastewater characteristics do not meet the Regulation of the Governor of Lampung Province 2006, so waste water must be treated first before discharged into water bodies or used as renewable energy such as biogas. The utilisation of wastewater in biogas is a good solution not only from an environmental point of view, but also from an economic and

Table 1 Tofu wastewater characteristic

Parameter	Unit	Lab. analysis	Government regulation (Lampung, 2010)
COD	Mg/L	12,400	300
BOD_5 (Novan Bagas Sayoga, 2014)	Mg/L	8852	150
SCOD	mg/L	7150	–
TS	mg/L	3800	–
TSS	mg/L	1188.3	100
pH	–	5.17	6–9
Alkalinity	mg/L	280	–
VFA	mg/L	1500	–

social point of view to achieve net zero to become a sustainable green industry72. The prediction of tofu wastewater from 10 tofu industries with production capacities 150–500 kg/day is around 45,900 kg/day with a COD content ranging from 5000–8500 mg/L that has the potential to produce approximately 128.52 m^3/day of methane gas (Faisal et al., 2014).

The use of tofu wastewater as biogas feedstock is very profitable for the industry and farmers because the main product of AD is biogas that can be used directly for the tofu industry as the main energy for their process production, by-product is digested which also has economic value as an organic liquid fertiliser that farmers can use to apply to their plantations in field (Budiyono & Syaichurrozi, 2020). Waste management in the tofu industry is very important due to the relationship in the issue of sustainable urbanisation that is essential for emerging nations. The tofu industry is one of the most significant contributors to greenhouse gas pollution, which confirms the theory of the 'life effect' of urbanisation as an inevitable consequence of urbanisation (Adebayo et al., 2023).

3.5 Human energy consumption

Human energy consumption is related to the production capacity and the number of workers. Generally, the micro-scale tofu industry in Indonesia does not have labour because the production capacity is too low. Based on production capacity, there are 3 types of micro- and small-scale tofu industries, namely; (1) low production capacity (20–50 kg soybean/day) with 1–2 labourers, (2) medium production capacity (> 50–75 kg soybean/day) with 2–3 labourers, and (3) high production capacity (100–150 kg soybean/day) with 3–4 labourers (Nurhayati, 2012). Therefore, based on its scale, industry is divided into three types including; small-scale (1–19 employees), medium-scale (20–99 employees), and large-scale (big industry) (more than 100 employees) (Nurhayati, 2012).

The audit of human energy consumption in industry is linked to physiological factors of the worker as the key in determining the size of physical work for heavy or light workloads. The workload category in the tofu industry consists of medium and heavy workloads, the medium workload is for the grinding section, the heavy workload is the boiling and moulding section. Human energy consumption in tofu industry consists of the washing and soaking process, milling, boiling, filtering, clumping and acidification, and moulding (Fathimahhayati et al., 2019; Yanti et al., 2022). The detailed information on human energy consumption in the MSMEs tofu industry is provided in Table 2.

Based on the information provided in Table 2, that human energy consumption in each industry is different due to the methods including the section of process production and capacity production. In Fig. 6, it is shown that the average human energy consumption in the tofu industry is 0.09 MJ/kg with two labourers in each industry. The highest human energy consumption is in industry 38, it is because of the imbalance between production capacity and the number of workers. Industry 38 has 5 labourers with production capacity of 75 kg/day, which means that the consumption of human energy is higher than necessary. Low production capacity means low human energy consumption; conversely, high production capacity in large-scale industry means the consumption of human energy also high (Soleh et al., 2016).

Human energy is linked not only to labour, but also to wages as one of the main problems for MSMEs in the tofu industry (Soleh et al., 2016). Based on the results of interviews with various tofu artisans and the owner of the tofu industry, there are some issues related to labour and wage; (1) the owner cannot afford the labourer's compensation, (2) the price of fuel is expensive due to the limited availability of firewood that has created competition

Table 2 Human energy consumption in the tofu industry of MSMEs

No	Types of human energy consumption	Amount	Reference
1	Milling	2.59 kcal/min	Fathimahhayati et al. (2019)
	Boiling	8.542 kcal/min	
	Filter section	7.06 kcal/min	
2	Washing and soaking	44.208 kJ/kg	Trilaksono (2022)
	Milling	20.945 kJ/kg	
	Boiling/cooking	57.6 kJ/kg	
	Filtering	11.52 kJ/kg	
	Clumping and acidification	11.304 kJ/kg	
	Moulding	14.76 kJ/kg	
	Cutting	7.253 kJ/kg	
	Total of human energy consumption	167.59 kJ/kg	
3	Human energy consumption in tofu industry, Sampang Village (conventional method)	0.13 MJ/kg	Yanti et al. (2022)
	Human energy consumption in tofu industry, Brani Village (modern method using a steam boiler)	0.09 MJ/kg	

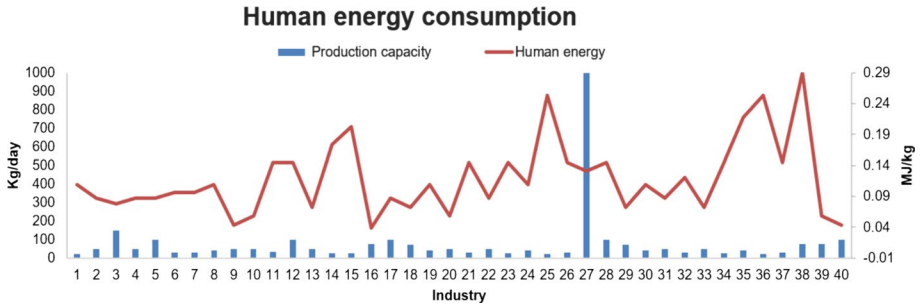

Fig. 6 Human energy in the tofu industries

in the industry, (3) People's purchasing power is low due to the pandemic situation and several activities such as schools, universities and offices are not fully active (work from home) which has an impact on low industrial income, (4) The price of soybeans as the main material is high due to imports from the United States (US), so the price will change depending on the situation and is very fluctuating, (5) human energy consumption serves to control the gap between environmental and economic accounting.

Generally, the analysis of environmental aspects ignores the aspect of labour (human energy consumption). Eventhough from the economic prespective that labour cost is costly, the audit of human energy consumption is useful to reduce the disparities between environmental and economic aspects. Thus, it is easy to take a wise policy on which parts that prioritize for these aspects (Zhang & Dornfeld, 2007). In the economic aspect, the goals of audits of human energy consumption are to optimise labour productivity based on skills and knowledge in the field to obtain efficiency that relate to the ratio of production to labour absorption according to industry or production per capita. Therefore, it can

be initiated that wages depend on the skill and education levels of labour, the increase in wages and salaries has a positive effect on labour productivity (Kebede & Heshmati, 2020). This situation reveals that the employee in the country Mexico, Indonesia, Nigeria, and Turkey (MINT) comes from the rural to urban region to get better employment, lifestyle, healthcare, and education that put some strain on the resources of the city and environment (Adebayo et al., 2023).

The types of worker in agro-industry are typical sort workers including casual and temporary employees depending on how much the industry can afford to pay them based on the agreement between the two parties. Generally (International Labour Organization, 2007). The labour in the MSMEs tofu industry is a typical part-time worker who has other jobs outside of production activities in the tofu industry, such as construction laborers, online taxi drivers, seasonal factory workers (sugar cane factories, pineapple can factories, etc.), they will continue to work in their respective fields after finishing working in the tofu industry. There are two types of work carried out by laborers in the tofu industry, namely: (1) men labouring in tofu production processes that focus on washing, grinding, and moulding. (2) women workers usually work on tofu wrapping, frying, selling tofu in traditional markets, and managing sales funds. Generally, the women workers who helped in the tofu industry are the wife or daughter of the owner industry. They sell tofu in the traditional market from the morning until the afternoon, and they also manage the financial for industry and profit.

According to the division of labour, the energy consumption of the men workers is focused on processing, while the energy consumption of the women workers is focused on product sales and financial management (Soleh et al., 2016). Because most of the tofu industries in Indonesia are on a home industry scale, usually the owner works alone or assisted by their wives or relatives, thus the division of labour tasks is not obligated like in the medium and large-scale industry, so it will be more economically efficient (Rosita et al., 2019). However, when the owner of industry got sick and the costumer demand increases, they will hire freelance workers to help them in the production process activities, then the owner of industry let the workers adjust their preferring the allocation time that suits them better (Golden, 2012).

3.6 Total energy consumption

The tofu industry consumes a lot of energy during process production. The energy sources used in the production process of the tofu are mainly biomass (firewood) and fuel oil (gasoline and diesel). One thing that is closely related to energy consumption in tofu industry is production capacity as a standard to determine the amount of energy consumed in an industry. Each stage of the tofu production process requires energy consisting of washing and soaking, cooking, filtering, clumping and wrapping. (Wahyuni, 2006). The total energy consumption in the tofu industry consists of human energy, energy consumption for cooking and grinding, and electrical consumption (for utilities and grinding).

In Fig. 7, it is shown that the average total of energy consumption is 70.68 MJ/kg with cost energy consumption 0.15 USD/kg. The lowest energy and cost consumption based on Fig. 7 is in industry 27, namely 6.1 MJ/kg with 0.041 USD. Industry 27 is a small-scale industry that uses the dynamo machine to grind soybeans and biopellets as the main energy sources for cooking, so that energy consumption is low and cheaper than other fuels which used in tofu industry, such as firewood, LPG, and fuel oil (diesel and gasoline for grinding machines). The production capacity in industry 27 is high

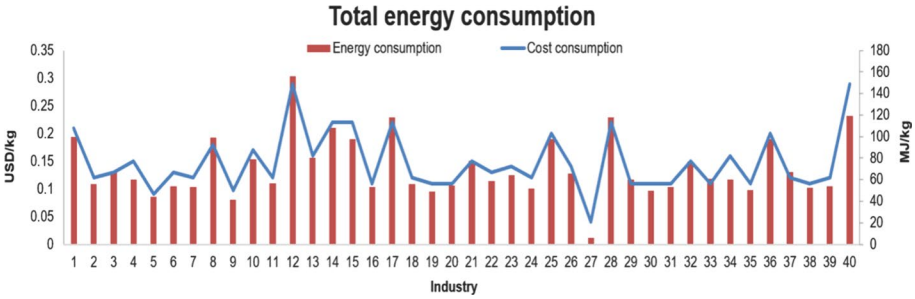

Fig. 7 Total energy consumption in the tofu industry

around 1 ton per day, the duration of process production activities is 24 h; they have a shift system for workers that makes human energy consumption not so high.

According to the audit, the energy and the calculation of the water consumption for 1 kg of soybean is 70.68 MJ/kg and 25.25 L/kg of water. Grinding and cooking are the steps that require a lot of energy, in this stage the fuel used is mainly firewood and human energy. From preparation to extinguishing firewood, a long process is required, especially if the wood is in wet condition (usually in the rainy season) and produces GHG in high amounts. The owner of industry only knows the price of firewood per day that is consumed without knowing how many sticks of firewood are used, that is why the energy consumption in the tofu industry is high and unpredictable. Usually, the remaining wood charcoal from the production of the tofu process is too much, then used to cook to meet the household needs of the owner's industry.

However, the energy consumption in the tofu industry is high, but still more efficient in life cycle assessment (LCA) than other food industries that have protein sources such as chicken, beef, etc. (Sahirman, 2014). Based on the LCA calculations, the resource input required to produce and package tofu, for 1 kg of package tofu, 16% of CO_2e (1699.52 g/kg of tofu CO_2e) from soybean production, 52% from the tofu production process, 23% from packaging and 9% from transportation (Mejia et al., 2017). The result of calculation with equation no.8 that the utilisation of tofu wastewater into biogas will decrease the emission of methane around 0.056 m^3/kg soybeans or equivalent to approximately 1.12 kg CO_2e/kg soybeans. Therefore, with the production capacity of the tofu and tempeh industry in Lampung Province in 2022 at 54,000 tons (Fakhruddin, 2022), the use of wastewater in biogas will reduce the emission of approximately 60,480 tons of CO_2e. Therefore, the national production capacity for the tofu and tempeh industry in 2022 is 400,000 tons 88, and the reduction in carbon emissions is around 448,000 tons of CO_2e. The use of tofu wastewater in biogas is very useful not only to replace current non-renewable energy sources used for processing production but also to reduce the emission of GHG.

To make energy consumption in tofu industry more efficient, wastewater can be used as renewable energy material, such as biogas feedstock, which will be more environmentally and economically friendly. The main energy sources for cooking (firewood, LPG, and biopellets) and electricity for utilities can be replaced with biogas so that the tofu industry can be more sustainable and become green industry.

4 Conclusion and recommendation

4.1 Conclusion

The energy consumption in tofu industry is not efficient as there is no SOP in its process production and most of them still use non-renewable energy sources. The total energy consumption in tofu industry for the production process is 70.68 MJ/kg, with an energy consumption cost of 0.15 USD/kg that consists of human energy, energy for cooking and grinding, and electricity. The water consumption in the process production is 25.25 L/kg of soybeans and produces 14.45 L/kg of wastewater. From 14.45 L/kg of tofu wastewater, it will produce 0.056 m^3/kg of methane 0.056 m^3/kg soybeans which have a great potential to use as biogas feedstock.

4.2 Recommendation

To improve the quality of industrial activities to become sustainable and efficient in energy consumption, the use of wastewater in biogas is highly recommended. The utilisation of tofu wastewater into biogas can substitute the non-renewable energy approximately 2.82% of firewood, 11.86% LPG, and 33.39% biopellets. It is very beneficial in economic and environmental aspects.

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Data availability The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of interest The authors declare no conflict of interest.

Ethics approval Not applicable.

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