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Analysis of Green Manufacturing Approach in SDGs-Based Tempeh Waste Management

Purnomo Purnomo[1], Nanta Sigit[2], Samgar[3]

[1,3,] Industrial Engineering Study Program, Faculty of Technology and Design, Ma Chung University, Malang, Indonesia.

[2] Industrial Engineering Study Program, Faculty of Engineering, University of Wisnuwardhana Malang, Indonesia.

Jl. Villa Puncak Tidar N01 Karangwidoro Regency Malang East Java 65151 Indonesia

Coressponden Autor Email : pur.nomo@machung.ac.id

Abstract

Small and Medium Industries (SMEs) have an important role in the local economy, but often face challenges in environmentally friendly waste management. This study aims to examine tempeh waste in Tempe Sanan IKM and its management based on the principles of green manufacturing and SDGs, in order to formulate sustainable management recommendations for tempeh SMEs in Sanan Village, Malang, with reference to the principles of the Sustainable Development Goals (SDGs), especially the 6th goal (clean water and sanitation), the 12th (responsible consumption and production), and the 13th (handling climate change). The research method used is a qualitative case study with data collection techniques through in-depth interviews, direct observation, and documentation. The results of the analysis show that most of the Tempe Sanan SMEs have not fully implemented the principle of green manufacturing, especially in the aspect of liquid and solid waste treatment. However, there is great potential for the development of more sustainable waste treatment technology, such as the use of tempeh pulp waste into animal feed or organic fertilizer. This study recommends the need for support from local governments and related institutions in the form of training, incentives, and supporting infrastructure to encourage the transformation of SMEs towards greener and more sustainable industries.

Keywords: Green manufacturing, waste management, SDGs, Tempe SMEs, Sustainability.

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INTRODUCTION

Small and Medium Industries (SMEs) are an important pillar in the Indonesian economy, with a significant contribution to labor absorption and local economic development (Badan Pusat Statistik, 2023). One of the fast-growing SME sectors is the fermentation-based food industry, such as tempeh. Tempeh is not only a typical Indonesian food with high nutritional value, but also has great economic potential in the domestic and export markets (Kurniawan et al., 2021).

However, behind the high productivity, the tempeh production process produces large amounts of waste, both liquid and solid waste. Liquid waste from soybean soaking and washing processes can contaminate water bodies if not managed properly, while solid waste in the form of soybean husks and tempeh pulp is often wasted without optimal utilization (Rizki et al., 2020; Sari et al., 2022). This condition is common in small and medium-scale tempeh production centers, including in the Sanan area, Malang City, which is known as a tempeh village (Putra & Wulandari, 2019).

In facing these challenges, the green manufacturing approach is a strategic alternative. Green manufacturing is a production concept that integrates energy efficiency, the use of environmentally friendly raw materials, and waste minimization to create sustainable industrial processes (Duflou et al., 2012; Kumar et al., 2020). The application of this concept to the food industry such as tempeh can reduce environmental burden while increasing operational efficiency (Jabbour et al., 2015).

In addition, the green manufacturing approach is aligned with the global agenda of the Sustainable Development Goals (SDGs), especially SDG 6, SDG 9, SDG 12, and SDG 13 (United Nations, 2015). By adopting the principles of the SDGs, the tempeh industry is not only oriented towards economic profits, but also toward social responsibility and environmental preservation (Le Blanc, 2015; Sachs et al., 2019). Green manufacturing applications have a significant positive impact on environmental and social performance (Sezen & Çankaya, 2013) and are strongly correlated with productivity (Kebenei et al., 2016).

Sanan Village, Malang City, as an iconic area of the tempeh industry in Malang, is an interesting case study because of its dense industrial scale but still traditional. Local initiatives to collectively manage waste have begun, but have not been systematically evaluated based on green manufacturing and SDGs indicators (Lestari et al., 2020; Arifin et al., 2021). Kaswinarni stated that the parameters measured in the wastewater of tempeh and tofu industries include physical and chemical parameters (Kaswinarni, 2007). This study aims to analyze the characteristics of tempeh waste in Tempe Sanan SMEs, evaluate its management strategies, and assess its suitability with green manufacturing principles and SDGs indicators.

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LITERATURE REVIEW

Tempeh Industry and Its Waste Characteristics

Tempeh liquid waste is known to contain high levels of Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD), which can potentially pollute the environment if discharged without proper treatment (Rizki et al., 2020; Sari et al., 2022).

Green Manufacturing Concept

Green manufacturing emphasizes resource use efficiency, waste reduction, and environmentally friendly materials (Kumar et al., 2020). The main principles include environmentally friendly product design, production efficiency, optimal waste management, and green technology (Jabbour et al., 2015). Implementation in SMEs improves cost efficiency and environmental compliance (Fauzi & Maulana, 2022).

Waste Management Strategy for the Small-Scale Food Industry

Waste management in small-scale food industries can be implemented through various approaches, including solid waste composting, biogas production from liquid waste, and the reuse of waste as secondary raw materials (Hadiyanto et al., 2018). However, the success of these strategies largely depends on the technical and institutional capacities of industry players. A community-based waste management approach has also proven effective for SMEs, as demonstrated by collective liquid waste management initiatives in the Sanan area (Lestari et al., 2020). This approach enables efficiency in waste treatment infrastructure and shared monitoring.

Integration of Green Manufacturing and SDGs

The green manufacturing concept is closely linked to the achievement of several Sustainable Development Goals (SDGs), particularly SDG 6 (clean water and sanitation), SDG 12 (responsible consumption and production), and SDG 13 (climate action) (United Nations, 2015). The implementation of green manufacturing directly contributes to pollution reduction, improved resource efficiency, and decreased carbon emissions (Le Blanc, 2015).

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Figure 1. Sustainable Development Goals (SDGs)
(Source: United Nations. (2015). *Sustainable Development Goals*. Retrieved from https://sdgs.un.org/goals

Figure 1. The Sustainable Development Goals (SDGs) are 17 global goals set by the United Nations to end poverty, reduce inequality, protect the environment, and ensure prosperity and peace for all by 2030. The SDGs invite all countries, sectors, and individuals to work together for a more just, inclusive, and sustainable future.

METHOD

Types and Approaches to Research

This study employs a descriptive qualitative approach using a case study as the main research strategy. This approach was selected to obtain an in-depth understanding of tempeh waste management practices implemented by Tempe Sanan SMEs from the perspective of green manufacturing and their alignment with Sustainable Development Goals (SDGs) indicators.

The case study method enables researchers to explore contextual phenomena holistically and comprehensively (Creswell, 2014).

Research Location and Time

The research was conducted in Tempe Sanan Village, Purwantoro Subdistrict, Blimbing District, Malang City, East Java, Indonesia. This location was purposively selected due to its status as a nationally recognized tempeh production center (Jabbour et al., 2015; Kumar et al., 2020). The research was carried out from May to October 2025, covering field observations, in-depth interviews, documentation, and data analysis stages.

Research Subjects / Informants

The informants in this study were selected using purposive sampling, focusing on individuals

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with direct involvement and adequate knowledge of tempeh production and waste management processes. The criteria for informants included:

- Owners or managers of tempeh SMEs in Sanan
- Leaders or administrators of cooperatives or tempeh producer communities
- Officers responsible for collective waste management (if applicable)
- Representatives from the Malang City Environmental Agency or Industry Office

The number of informants was determined based on the principle of data saturation, whereby data collection was concluded when no significant new information emerged (Miles et al., 2014).

Data Collection Techniques

Data collection in this study involved several techniques, including participatory observation, in-depth interviews, and documentation studies. Participatory observation was conducted to directly examine the tempeh production process, waste flow, and existing waste management systems. In-depth interviews were used to explore stakeholders' understanding of green manufacturing concepts, current waste management practices, as well as the challenges and opportunities associated with their implementation.

Documentation studies included the review of internal reports, production records, and relevant local government policies. Data analysis was carried out based on green manufacturing principles—such as energy efficiency, waste minimization, and clean technology—and their compatibility with SDGs indicators (Jabbour et al., 2015; Kumar et al., 2020).

RESULTS AND DISCUSSION

Water Use in the Production Process

The tempeh industry is a food industry that requires water in its production process. The tempeh production process in the Sanan Malang industrial estate consists of 4 main stages before the fermentation process, namely: boiling, soaking, separation & washing of soybeans, and fermentation. Water sources used by the tempeh industry in Kelurahan. Sanan comes from deep groundwater with a well depth of 50 m. In the tempeh production process, water from PDAM is not used because (1) the cost will be higher, (2) the water in PDAM contains chlorine chemical compounds. These chemical compounds can inhibit the growth of tempeh yeast.

The water use to process 1 kg of soybeans into 1 kg of tempeh is 13.3 liters of clean water and produces 12.2 liters of wastewater. In Sanan Malang Village itself, the reuse of wastewater left over from the production process is carried out but only for the wastewater of the boiling process, where the water will be used for additional animal feed by some artisans and wastewater from

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the other production processes will be directly disposed of and channeled to the local drainage channel. The process of tempeh production by artisans in Sanan village is shown in Figure 2. The production process of tempeh in a week from 200 kg of soybeans using the required water will be shown in Table 1.

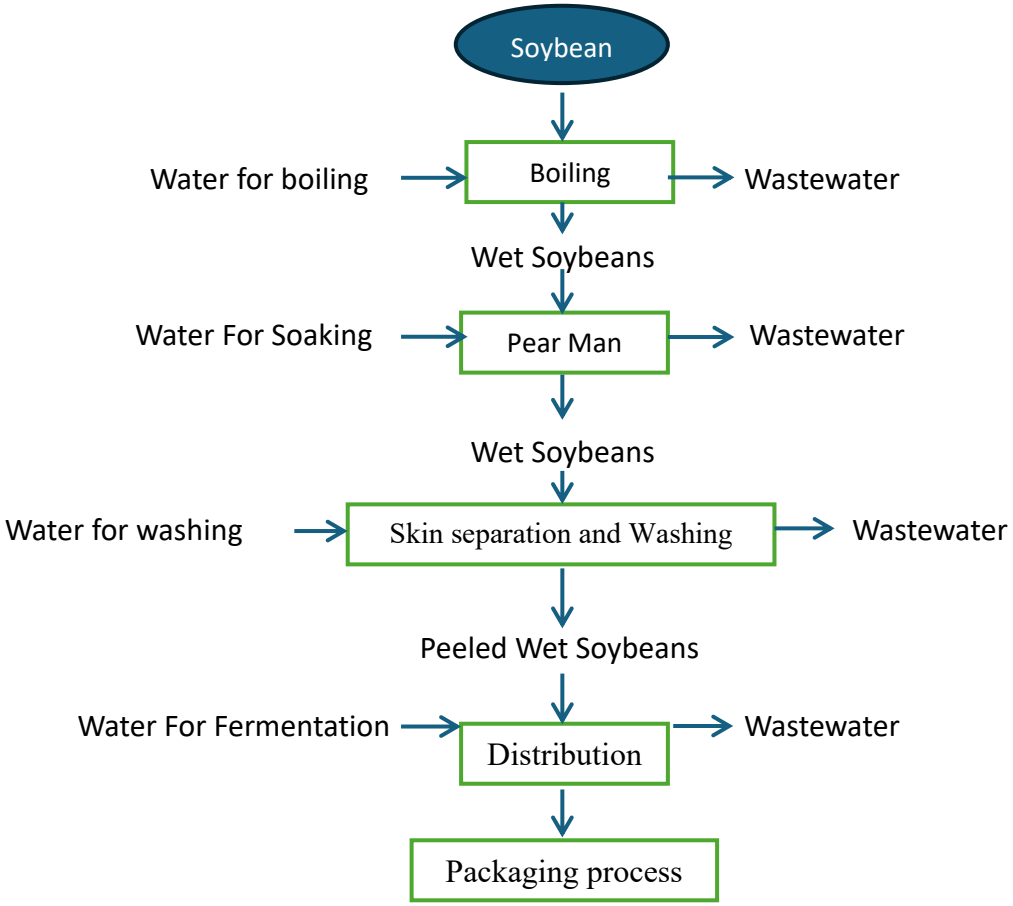


Figure 2. Flow Diagram of the Tempeh Production Process in Sanan

In figure 2, it is explained that the tempeh production process takes 2-4 days starting from the boiling process until it is ready to be marketed. The processes carried out are as follows:

- **Boiling process**
  The existing soybean raw materials are boiled first. The boiling process can last between 2-3 hours. This aims to make soybeans more lazy so that they are young in breaking the skin.

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- **Soaking process**
  After boiling later, then the soybeans are soaked in cold water for about overnight, this process aims to make the taste of the soybean smell sour so that it can speed up the fermentation/drying process.
- **Skin separation and washing**
  After the damping process, then wash the soybeans which aim to remove/peel off the skin of the soybeans. This washing process plays a very important role in the process of making tempeh. This is because to be the quality of tempeh both in terms of taste or bad and in terms of (durability or not) it depends on the washing process.
- **Fermentation process**
  After undergoing the washing process, the soybeans are mixed with yeast with a different ratio between soybeans and yeast because it is adjusted to the weather at that time.
- **Packaging process**
  Soybeans that have been mixed with yeast are wrapped in perforated plastic. This aims to allow air circulation so that it can speed up the drying process. After packaging/plastic packaging that already contains soybeans and yeast, it is perforated again and stored on the shelf overnight. Tomorrow the tempeh will be ready to be marketed.

Sanan Industrial Center Waste Treatment

Sanan Industrial Center is one of the centers of the household industry in Malang City. In the tempeh industry, it produces waste, namely liquid and solid waste. Solid waste comes from soybean husks that float during the washing process, while liquid waste is in the form of soybean soaking water and soybean used water. Some industries use liquid waste as animal feed, but there are also industries that do not use liquid waste and are directly dumped into rivers and sewers.



Figure 3. Liquid and solid waste from soybean husks (Source: primary data, 2025).

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Figure 3. is liquid and solid waste that comes from soybean husks, in this case waste needs to be considered as another challenge by business actors. According to Arief (2016), waste is a waste product of the results of a production that is considered unwanted and has no selling value if left unchecked. According to Madu (2001), in protecting the surrounding environment can be done by minimizing waste, efforts to minimize waste and make it as a processed substance is one of the applications in the field of *sustainable development* , *namely green manufacturing*.

According to Rizal (2018), *green manufacturing* is a method in manufacturing to prevent environmental damage by minimizing waste through *recycling* with the main goal being for a better life. In this case, indirectly the waste they produce pollutes the environment if left unchecked, where their solid waste that is collected for days will cause a smell in addition to the liquid waste they produce will be discarded because there is no place to accommodate, so that the use related to this waste is very rarely considered as a result of environmental pollution occurring.

Table 1 Data on the Amount of Soybean Waste of Sanan SMEs

Sanan SMEs Soybean Waste Data	
Waste (Skin of the Skin)	Waste (boiled water)
50-60 kg/hari	> 45 liters / Hari
1500-1800 kg/month	> 1350 liters/month

Source: Interview Results with Mrs. Iis Owner of SMEs

Analysis of Tempeh Liquid Waste Content

Tempeh liquid waste, both boiled water and soybean soaking water, indirectly the waste they produce pollutes the environment if left unchecked, where their solid waste that is collected for days will cause a smell in addition to that the liquid waste they produce will be disposed of due to the unavailability of a place to accommodate, so that the use related to this waste is very rarely noticed as a result of environmental pollution occurs. From the results of laboratory tests of tempeh liquid waste, boiling water and soybean soaking water (Table 2)

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Tabel 2. Liquid Waste Content of Tempe SMEs

No	Parameter	Unit	Industrial Wastewater Quality Standards	Liquid Waste Soy Boil Average	Soybean Soaking Liquid Waste Average
1	Suhu	^{0}C	45	75	32
2	TSS	mg/l	100	1894	2396
3	pH	-	6,0 – 9,0	6	4,16
4	BOD	mg/l	150	9763	3298
5	COD	mg/l	300	1672	5892
6	TDS	Mg/l	5000	5192	3815

Source : Secondary Data, 2025

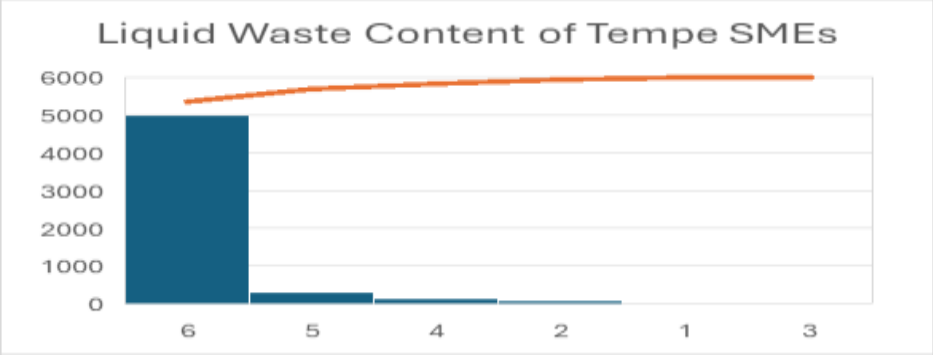


Figure 4. Graph of Liquid Waste Content of Tempe SMEs

Some of the water quality parameters of the tempeh industry are then analyzed as follows:

1. Total *Suspended Solid* (TSS)

TSS itself consists of mud, fine sand and small bodies carried in water. TSS or suspended solids are substances that float and are insoluble in water. Suspended solids are closely related to the level of turbidity of the water. The tempeh production process in Semanan the quality of the wastewater exceeds the set quality standards where in the boiling process the TSS value obtained is the industrial wastewater quality standard 100 mg/l, the average soybean boiled liquid waste: 1894 mg/l, the average soybean soaking liquid waste: 2396 mg/l

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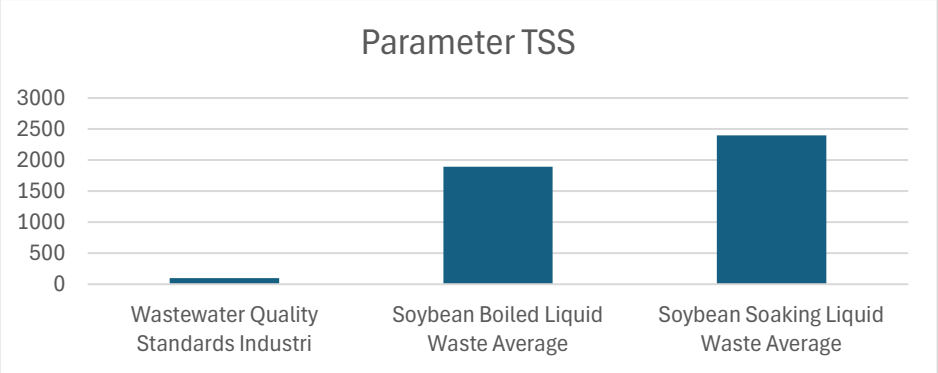


Figure 5. TSS Parameter Analysis Results

2. Biological Oxygen Demand (BOD)

BOD is a parameter used to assess the amount of dissolved organic substances and shows the amount of oxygen required by microbial activity in biologically decomposing organic substances in wastewater. The boiling process of the BOD value obtained is the standard quality of industrial wastewater 150 mg/l, the average soybean boiled liquid waste: 9763 mg/l, the average soybean soaking liquid waste: 3298 mg/l

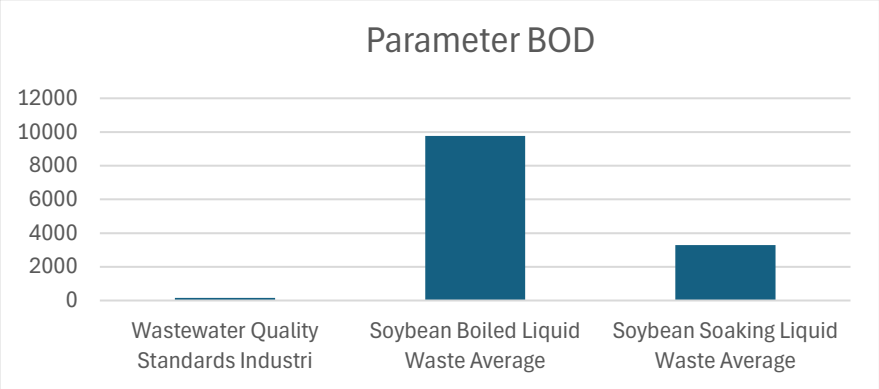


Figure 6. BOD Parameter Analysis Results

3. Chemical Oxygen Demand (COD)

Chemical Oxygen Demand (COD) is the amount of oxygen needed for waste materials in water to be oxidized through chemical reactions (MetCalf and Eddy. 2003). If the content of organic and inorganic compounds is large enough, then the dissolved oxygen in the water can reach zero so that aquatic plants, fish and other aquatic animals that need oxygen cannot survive.

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The COD value content obtained is industrial wastewater quality standard 300 mg/l, average soybean boiled liquid waste: 1672 mg/l, average soybean soaking liquid waste: 5892mg/l

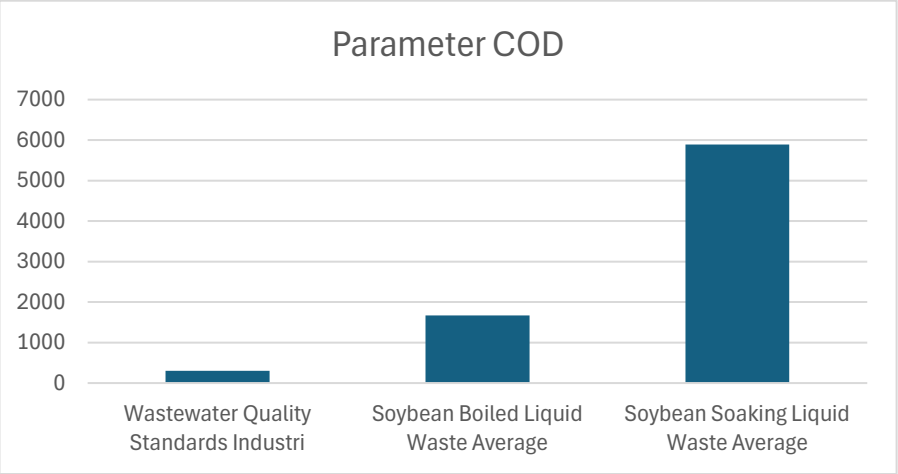


Figure 7. COD Parameter Analysis Results

4. Acidity Degree (pH) Tempeh industrial wastewater tends to be acidic, in this acidic state it will release substances that are easy to evaporate. This results in the tofu industry's liquid waste emitting a foul odor. pH is very influential in the wastewater treatment process. The quality standard is set at 6-9. The effect that occurs when the pH is too low is the decrease in dissolved oxygen.

Analysis of SDGs Implementation on Tempeh Processed Food SMEs.

The implementation of *the Sustainable Development Goals* in Small and Medium Industries (SMEs) of tempeh processed food as a driver of the people's economy and the absorption of labor can also strengthen economic strength. Sustainable *Development Goals* are activities in the economic, social, and environmental fields. Furthermore, for the achievement target of 17 Sustainable *Development Goals* in tempeh sanan processed food SMEs in Malang City. Development that continues should always be accompanied by a balance with environmental needs and resilience, to achieve environmental welfare.

The concept of sustainable development that should help the welfare of the community can be seen from the aspect of at least being able to support the achievement of the SDGs divided into 7 main parts that are the main parts of the implementation of the program shown in table 2 as follows:

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Table 2 Forms of SMEs Programs that Support the SDGs

No	Purpose	Achievement targets
1	No Poverty	Ensuring that the poor and vulnerable have equal rights to economic resources that produce goods and services for a profitable society.
2	Zero *Hunger*	The second SDGs point has the main goal of ending hunger, achieving food security, and advancing a sustainable small and medium tempeh processed food industry..
3	Quality Education	The establishment of education and health facilities around SMEs, expanding the number of scholarships for underprivileged community members and social protection for local residents.
4.	Good *health and well-being*	SMEs care about the sustainable environment, reducing waste, and controlling pollution to improve mental health and community welfare.
5	Clean water and proper sanitation	Provision of efficient and equitable clean water facilities for safe and affordable water use for all communities around SMEs.
6	Decent jobs and economic growth	Achieve a higher level of economic productivity, through diversification, improvement and technological innovation, including a focus on increasing the high added value of SMEs
7.	Clean and affordable energy	Ensuring access to efficient and affordable production and energy use for all communities around SMEs, sustainable and modern tempeh processed food for all.

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Figure 8. Achievement of the SDGs

It is hoped that in addition to production activities becoming greener, the suggestions for improvement can support the SDGs program which includes 7 points and SDGs Point 12 (Responsible Consumption and Production), Point 17 (Partnership for Goals)

CONCLUSION

The results of this study show that the use of water for the tempeh production process in the Sanan area is used during the following processes: Boiling, Soaking Skin Separation & Washing, and Fermentation. Where the waste (Husk) is 50-60 kg/day and produces > 45 liters / day with the quality of the wastewater of the tempeh production process which has a value that far exceeds the quality standards set by the government both for BOD, COD and TSS parameters. The parameters of the BOD value obtained are industrial wastewater quality standards of 150 mg/l, average soybean boiled liquid waste: 9763 mg/l, average soybean soaking liquid waste: 3298 mg/l. The boiling process obtained the TSS value obtained is the standard quality of industrial wastewater 100 mg/l, the average soybean boiled liquid waste: 1894 mg/l, the average soybean soaking liquid waste: 2396 mg/l. The content of the COD values obtained is the standard quality of industrial wastewater 300 mg/l, the average soybean boiled liquid waste: 1672 mg/l, the average soybean soaking liquid waste: 5892mg/l.

The implementation of *the Sustainable Development Goals* in Small and Medium Industries (SMEs) of tempeh processed food as a driver of the people's economy and the absorption of labor can also strengthen economic strength. Sustainable *Development Goals* are activities in the economic, social, and environmental fields. The concept of sustainable development that should help the welfare of the community can be seen from the aspect of at least being able to support the achievement of the SDGs divided into 7 main parts that are the main part of the implementation of the program. It is hoped that in addition to production activities becoming greener, the suggestions for improvement can support the SDGs program which includes 7 points and SDGs Point 12 (Responsible Consumption and Production), Point 17 (Partnership for Goals)

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