Airlangga Journal of Innovation Management Vol. 06 No. 02 (2025): 303-318

Contents lists available at: https://e-journal.unair.ac.id

AJIM (Airlangga Journal of Innovation Management)

Journal homepage: https://e-journal.unair.ac.id/AJIM

A Systems Approach to Understanding the Carbon Emission Pathways and Economic Benefits of Tempeh SMEs Supply Chain in West Java

Fadil Abdullah[1*] Hafizah Aprilia[2] Siti Nur Hamidah[3]

[1] Logistic Engineering, Politeknik META Industri Cikarang, Bekasi, Indonesia
[2] Industrial Engineering, Faculty of Industrial Engineering, Telkom University, Bandung, Indonesia
[3] Industrial Engineering, Faculty of Engineering, Universitas Sehati Indonesia, Karawang, Indonesia

ARTICLE INFO

Paper Type:
Research Paper

Keywords: *CLD, Economic, Multiechelon, SMEs, Tempeh*

Article History
Received: 09-05-2025
Revised: 28-05-2025
Accepted: 10-06-2025
Available online: 28-06-2025

ABSTRACT

This study aims to identify and map the tempeh industry's supply chain to understand the economic pathway and carbon emissions. The research method uses a system-based approach with the output of a causal loop diagram that explores the dynamic relationship between variables in the small and medium scale tempeh industry supply chain. The results showed that the potential of the small and medium-scale tempeh industry in West Java is very high, especially in contributing to the economic value of the surrounding community. However, this potential has challenges regarding raw material procurement, where dependence on imported soybean raw material supplies makes the economic value for MSEs or the surrounding community not too large. This is due to the efficiency in the procurement of local soybeans and the inadequate stock of local soybean resilience to meet the needs of tempeh production in West Java's supply chain. The findings also show that the longer the supply chain, the smaller the profitability and create more environmental impacts related to the carbon emissions generated. This study recommends a policy meeting to cut and streamline, and prioritize local soybeans and increase local soybean resilience stocks to better benefit tempeh SMEs in gaining profitability and minimizing the impact of carbon footprint risks, so that business and industrial activities are more sustainable.

*Corresponding author: fadilabdullah1880@gmail.com

Cite this article as: Abdullah, F., Aprilia, H., & Hamidah, S.N. (2025). A Systems Approach to Understanding the Carbon Emission Pathways and Economic Benefits of Tempeh SMEs Supply Chain in West Java. *Airlangga Journal of Innovation Management, 6(2), 303-318.* https://doi.org/10.20473/ajim.v6i2.72663

Introduction

Tempeh is an Indonesian native food that has a high source of protein at a low price and is widely used as a staple food for most Indonesian (Pramudito et al., 2024; Suprayogi et al., 2025). Tempeh is made from fermented soybeans, which have a rich nutritional content and are easily digested. Thus, it can be used as a main meal or snack (Arifin et al., 2024; Harahap et al., 2024).

Increasing consumer interest and knowledge about the nutritional value of tempeh has resulted in rapid growth of the tempeh industry across the country. This development brings a major contribution of small and medium enterprises to the improvement of national food security and massive employment This is because the tempeh industry has an integrated business network, called the Tempeh business supply chain (Wikandari et al., 2023).

The Tempeh supply chain includes upstream activities such as soybean procurement to downstream activities that distribute Tempeh products back to end consumers. These integrated activities allow each actor to add value to increase their profits (Ryandono et al., 2022). Therefore, supply chain actors in this sector, such as farmers, producers, and distributors, compete to add substantial value to the price of their end products. However, price formation requires efficient coordination and management across the entire supply chain value addition process such as raw material costs, transformation costs, and distribution cost (Tan et al., 2024). Previous research confirms the importance of managing and coordinating actors across the supply chain through supply chain optimization methods to reduce production costs and maximize profit (Yudha et al., 2024). However, these studies only focused on operations management and pricing, while a few explored sustainability issues such as carbon emissions and agents' contribution to total economic value (Qosim et al., 2023).

Carbon emissions in the tempeh supply chain emerge from numerous sources, including the transportation of soybeans (typically imported), energy use in the fermentation process, and the handling of organic waste generated during production (Adirestuty et al., 2025). According to the Food and Agriculture Organization (FAO), the average carbon footprint of soybean-based products ranges from 1.2 to 2.0 kg CO_2-equivalent per kilogram of product, depending on production methods and transportation logistics (Unicef, 2024). For traditional tempeh production in small-scale settings in Indonesia, estimated emissions may reach up to 1.6 kg CO_2-eq/kg due to reliance on fossil-based energy and inefficient distribution systems (Wijayanti et al., 2020). Table 1 highlights the environmental cost associated with conventional tempeh production and underscores the urgent need for integrating environmental metrics into supply chain design.

Table 1. Highlight environmental cost

Production Site	Production Method	Carbon Emission (kg CO_2-eq/kg tempeh)
Kedaung	Traditional	0.296
RTI	Modern	0.676
Ibu Sujati	Small-Scale SMEs	0.488

Source: Yarlina et al. (2023)

Carbon emissions from the tempeh industry in Indonesia will vary based on scale and several production methodologies. An empirical study by (Wicaksono et al., 2024) found that traditional tempeh production in Kedaung, which employs a manual and non-mechanized production model produces approximately 0.296 kg CO_2-eq per kilogram of tempeh. However, tempering production facilities such as

RTI, which rely much more on electricity and machinery, have production close to 0.676 kg CO_2-eq/kg (Putri et al, 2018). Other very small micro-enterprises like Mrs. Sujati, whose model is a representation of most micro-enterprises in urban and peri-urban areas, are estimated to have carbon emissions that are closer to 0.488 kg CO_2-eq/kg (Fauzi et al., 2024). The carbon emissions in tempeh's supply chain is estimated to be up to 1.0 kg CO_2-eq/kg per kg of tempeh, once the emissions from transportation of soybeans upstream from production or boiling/fermentation, where fuel is used, and include other upstream activities (Sjamsuridzal et al., 2021). Even if these estimates are taken to be court as suggestions, while the tempeh production process has a relatively minor impact/symptoms compared to other industrial food systems, it does have an environmental burden, which is increased relative to the number of micro, small, and medium enterprises that operate and contribute a portion of it (Adirestuty et al., 2025).

It is important to note that existing carbon emission data for the tempeh industry are primarily derived from case studies at the city or enterprise level. To date, there is no comprehensive national or provincial-scale carbon footprint database specific to tempeh production. This highlights a significant research gap: while multiple life cycle assessment (LCA) studies have evaluated emissions associated with traditional and contemporary processing methods, few have overall understood how to link these processes for organizational or national sustainability models. Studies appear to treat environmental consequences as separate from economic ones and therefore lack a holistic approach focusing on interactions between value creation and carbon emissions in SMEs. In addition, while system dynamics models like Causal Loop Diagrams (CLD) could be used as a systems thinking approach, they are very underutilized in food supply chain sustainability studies, particularly in moving forward with culturally relevant, low-emission foods such as tempeh. This study felt that it needs to address these gaps in the literature when designing whole-of-system strategies for building operational efficiency with environmental stewardship, while simultaneously supporting economic empowerment and improvements to traditional food processing within Indonesia.

The system dynamics method based on the Causal Loop Diagram (CLD) is used to explore the supply chain dynamics in more detail. The CLD will illustrate how issues develop from urgency to relationships between variables, which are connected through closed loops indicating mutually reinforcing or balancing relationships (Prasetyaningsih et al., 2020). Moreover, it shows optimization points at every echelon of distribution depending on the local context, such as small-scale production of tempeh in Indonesia. This study will employ the Causal Loop Diagram (CLD); and operate to differentiate and map the optimal pathway for the tempeh business supply chain, ultimately maximizing economic value and minimizing overall carbon emissions. This study is novel because it integrates economic valuation and carbon emission analysis with the local tempeh supply chain process, which has not received significant attention in previously published literature. The results of this study are expected to provide detailed analysis to facilitate industry stakeholders, especially Small and Medium Enterprises (SMEs), to make the right choices to promote their business as a profitable, non-harmful, and environmentally sensitive activity as an effort to improve the competitiveness and sustainability of the tempeh industry in Indonesia.

Literature Review

For this study, a literature review was conducted based on published literature in Google Scholar on topics including supply chains, the economic advantages of the tempeh sector, and carbon emissions.

Tempeh Supply Chain in Local Industries

The supply chain flows from raw material acquisition to final product optimization as an integrated flow. This is confirmed by (Ryandono, Widiastuti, et al., 2025) states that the supply chain in the retail industry consists of raw material procurement, product manufacturing, and product distribution? Supply chain management is the science of managing to try to improve a company's efficiency and overall effectiveness by minimizing total costs (including raw materials, transportation, production, and inventory) (Riduwan & Wardhana, 2022; Setiawan et al., 2021). A successful supply chain management system creates and maintains better delivery efficiency and business competitiveness (Ryandono et al., 2019). The implementation of synergistic coordination between supply chain members, including suppliers and distributors, can maximize the added value created, and the price among stakeholders will be one of the main drivers of efficiency (Harisudin et al., 2022).

The tempeh sector has a supply chain that includes soybean procurement, product fermentation, and then delivery to the intended market and food industry. Soybean farmers, producers (generally medium to small in size), and traders must coordinate to create synergies of readily available raw materials and competitive prices (Zaki et al., 2024a). This is based on many shared industry challenges typically caused by disorganization, leading to differences in supply and demand, resulting in surplus or waste. Supply chain management practices rooted in production planning and controlling logistics costs can improve efficiencies and profits in the tempeh industry (Barkah et al., 2022).

Economic Valuation in the Local Tempeh Industry

The tempeh sector creates economic value in multiple layers, not only as enterprises in making a profit, but also in the national and local economies, especially where the food sector is dominated by small and medium-sized enterprises (SME) as in Java, especially Yogyakarta and Central Java - these areas identified as major producers of tempeh, seen growth in employment and household income (Febriyanti et al., 2022; Wicaksono et al., 2024). It is important to recognize that the local economies are empowered by labor relative to the size of the product, informal market economy, and short, localized value and supply chains (Yudha et al., 2024) .

The economic importance of the tempeh sector was expressed in terms of company effectiveness and efficiency, and company profitability (the relationship between production costs, revenues, and income generated) (Kuligowski et al., 2024; Wardhana & Ratnasari, 2022). Tempeh, an Indonesian food based on soybeans, has substantial economic relevance given the inexpensive cost, high demand, and the contribution of small and medium-sized enterprises (SMEs) toward job creation and food security (Zaki et al., 2024b). However, there is reliance on imported soybeans, which presents problems, especially when prices fluctuate, such as in 2012 when soybean prices increased by 31.46%, resulting in an increase in production costs by 19.80%, but the income dropped by 54.04% (Sjamsuridzal et al., 2021).

Soybeans represent the bulk of total tempeh production costs (82.99%), with the minor costs of starter culture, packaging, and labor being a distant 2nd, 3rd, and 4th place (Kuźniacka et al., 2020). Increases in soybean prices will contribute to increases in cash and total costs, which will force farmers to use strategies that maximize profits, such as reducing production of soybeans, tempeh size, or employees. Even if these approaches were used, the revenue-to-cost (R/C) ratio remains above 1.00 (for example, 1.18-1.19 after a price increase), which means producing tempeh is still considered economically reasonable. The economic character of Tempeh is further supported by the supply chain characteristics of Tempeh from production (soya bean harvest) to consumption (food industry) (Setiawan et al., 2021).

however, coordination among stakeholders (farmers-producer-retailer) is still not well developed, which means that production does not match, or is mismatched with demand (Al-Amin et al., 2015). Imported soybean prices, as well as supply chain inefficiencies, are great obstacles to Tempeh's economic valuation. Integrated supply chain management involving demand-driven production planning and logistics costs can create an efficient and value-driven process (Susanto et al., 2025). In the future, increasing the sourcing of local soybeans, in conjunction with policies such as subsidies, can improve Tempeh's economic feasibility, resulting in a sustained future role in the national economy (Pratiwi et al., 2022; Rozi et al., 2025).

Carbon Emission

Small and medium-sized enterprises (SMEs) have played an important role in the increase of global carbon emissions, particularly in the food industry that relies on traditional processing approaches(Chen et al., 2023; Fernandez Castaneda et al., 2024). In practice, the emissions phases tend to occur through boiling and frying, grinding, washing, and raw material transportation. Boiling and frying, particularly with firewood, provide the highest carbon emissions due to incomplete combustion, resulting in exhaust gases such CO_2, CH_4, and NO_2 (Wijayanti et al., 2020).

Furthermore, the grinding process, which is often driven by gasoline-powered machinery, contributes significantly to overall emissions, followed by electricity consumption in water pumps used for washing and soaking. Monthly emissions from all production processes exceeded 5,000 kg CO_2 equivalent (Chen et al., 2023). This data demonstrates the critical need for intervention in industrial processes, as SMEs pose a significant danger to environmental sustainability by increasing their carbon footprint (Mendo et al., 2023; Opazo-Basáez et al., 2024).

Methodology

Data Collection

This study began with problem identification and a literature review to identify and define the key variables in the local tempeh industry in balancing economic value and carbon emissions. The study was conducted in Bantul, Yogyakarta, and Cilacap, Central Java. Those two areas are widely recognized of being tempeh production centers in Indonesia. The population for this study includes actors connected to the tempeh supply chain, such as suppliers of soybeans, tempeh producers (particularly SMEs), distributors, and market vendors. A purposive sampling approach was used to collect the sample respondents based on their relevance and familiarity with the tempeh industry. The total sample selected was 20 respondents, which includes SME owners, cooperatives, and supply chain intermediaries. Data was collected over 3 months between January and March 2024. Primary data was collected through semi-structured interviews, direct observations, and field visits. The secondary data was collected from academic literature, government reports, and reports from cooperatives or local business associations.

Data Analysis

After gathering the data, this study used a Causal Loop Diagram (CLD). The purpose of using CLD was to depict dynamic interactions between critical variables: price volatility of soybeans, production costs of tempeh, carbon-emitting actions involving the supply chain, and supply chain efficiency. The selection of constructing a CLD was based on the idea that a CLD method allows modelling by capturing feedback loops over time and understanding system behavior (Prasetyaningsih et al., 2020). The development and simulation of models for larger food systems was analyzed using Vensim PLE. This software will allow for the clear diagramming of variable relationships in the odd, identifying reinforcing and balancing feedback loops, and time-based simulation of scenarios. The use of modeling software will assist in capturing the temporal nature of the interactions within the tempeh supply chain and testing combinations of potential interventions to improve performance on both economic and environmental grounds.

The insights gained from the CLD simulation were then analyzed qualitatively to identify leverage points, specific areas in the system where targeted improvements could yield significant benefits in both profitability and sustainability. The research then moves on to model development utilizing the Causal Loop Diagram (CLD) approach to capture the dynamics of the problem and discover both conflicting and descriptive linkages within the current business model environment. The study closes with insights gained from the model analysis. Figure 1 depicts the progressive steps of the total research process.

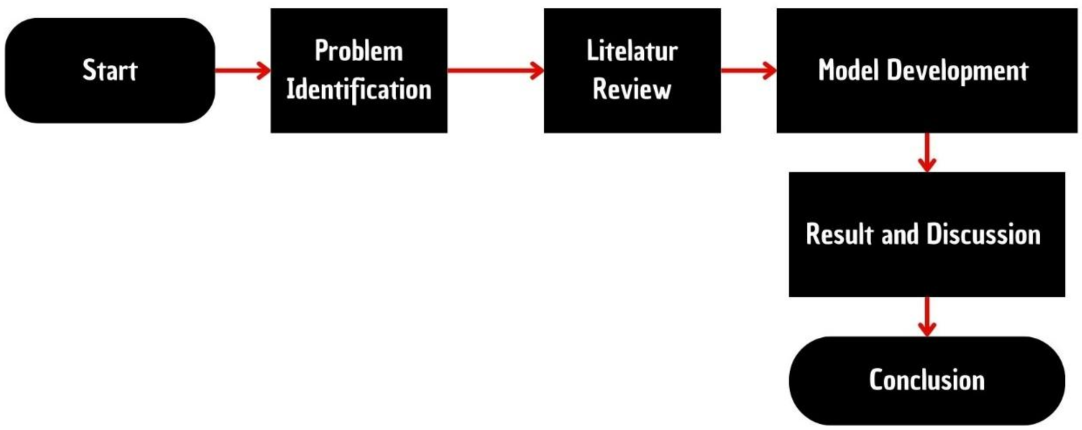

Figure 1. Research Framework

Source: Author (2025)

Results and Discussion

Results.

1. **Echelon and scenario supply chain business as usual**

The CLD model was developed in response to the requirement to examine subsystems that emerged as a result of research. In this study, the supply chain is separated into three major subsystems: raw material acquisition, manufacturing processes, and product distribution. These subsystems are further classified according to the distribution agents at each echelon level. Table 2 depicts the distribution flow possibilities across the several echelons that act as distribution agents in the Tempeh supply chain. Table 3 also includes the data needed to develop a thorough understanding of these scenarios, which may subsequently be simulated to determine the most effective strategic options.

Table 2. Distribution Flow Scenario

Supply of raw materials					Process		Shipping Product		
Import Soy Agent	Local Soy Agent	Regional Market	Local Market	Local Merchant	SMEs Tempeh	Restaurant	Local Market	SMEs Processing Tempeh	Export Tempeh

Import soy agent	Regional Market		Local Market	Local Merchant	SMEs Tempeh	Restaurant	Local Market	SMEs Processing Tempeh	Export Tempeh
Local soy	Regional Market	Local Market	Local Merchant		SMEs Tempeh	Restaurant	Local Market	SMEs Processing Tempeh	Export Tempeh
Local Soy	Regional Market		Local Merchant		SMEs Tempeh	Restaurant	Local Market	SMEs Processing Tempeh	Export Tempeh
Local Soy	Regional Market		Local Market		SMEs Tempeh	Restaurant	Local Market	SMEs Processing Tempeh	Export Tempeh

Source: (Author, 2025)

Table 3. Role Agent Distribution in Each Echelon

Echelon	Variable
Echelon 1	Local Soy Distribution (Value Added, Economic Valuation, Price of distribution, Carbon Emission Value)
	Import Soy Distribution (Value Added, Economic Valuation, Price of distribution, Carbon Emission Value)
Echelon 2	Regional Market (Value Added, Economic Valuation, Price of distribution, Carbon Emission Value)
Echelon 3	Local Market (Value Added, Economic Valuation, Price of distribution, Carbon Emission Value)
	Local Merchant (Value Added, Economic Valuation, Price of distribution, Carbon Emission Value)
Echelon 4	SMEs Tempeh (Value Added, Economic Valuation, Price of distribution, Carbon Emission Value)
Echelon 5	Restaurant Needs Quantity
	Local Market Need Quantity
	Regional Market Need Quantity
	SMEs Processing Tempeh Need Quantity
	Export Tempeh: Need Quantity

Source: (Author, 2025)

The tempeh industry supply chain is divided into five echelon levels, as shown in Table 2. The participants in the supply chain of tempeh in Central Java, represented by Bantul and Cilacap, are represented by each echelon. This diversity demonstrates how the tempeh industry supply chain is structured differently affects variations in the amount of final carbon emissions and profits made. These variations also show how each chain contributes to creating new economic value.

2. Model Development CLD

Tables 1 and 2 provide a framework for developing the CLD model to better understand the Tempeh industry's distribution flow, particularly in identifying economic and carbon emission paths. The causal loop diagram model is based on a synthesis of previous research findings, which show that business models in small and medium-sized enterprises (SMEs), such as Tempeh production, can be divided into three major components: material procurement, processing, and product distribution. Each of these stages has significant economic and carbon valuation implications. Figure 1 depicts the generated causal loop diagram model.

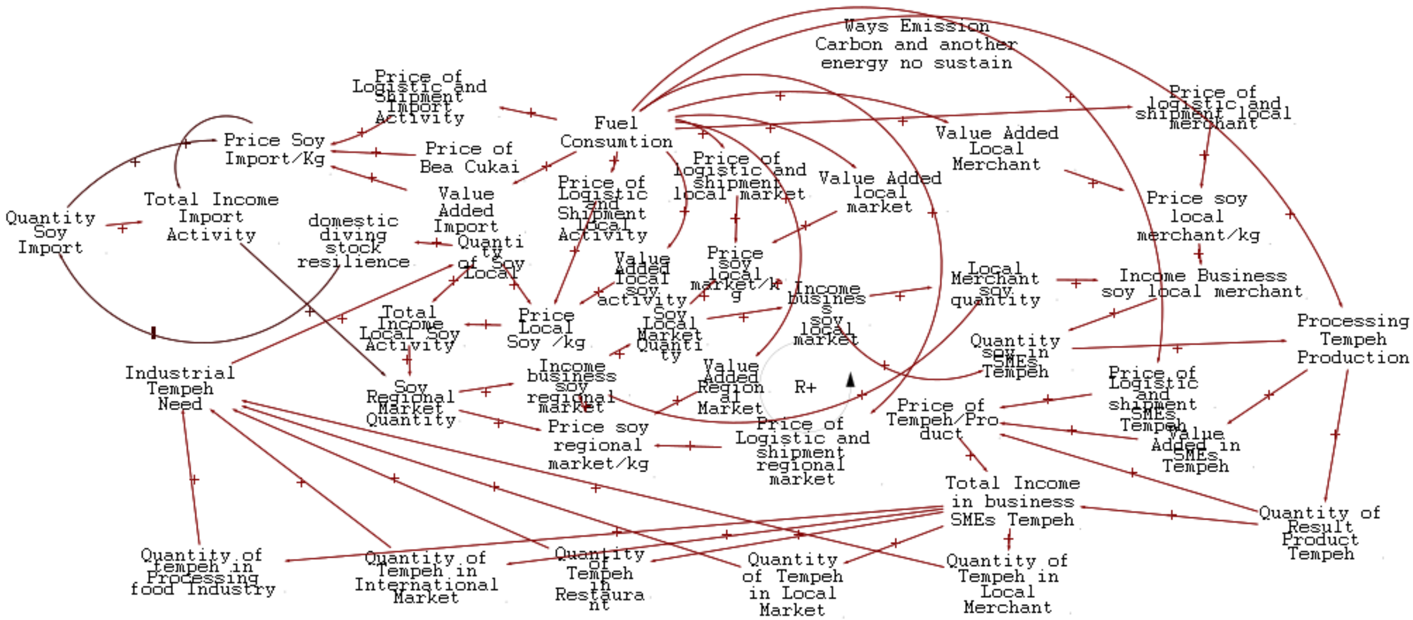

Figure 2. CLD Model in Pathways Emission Carbon and Economic Values in SMEs Tempeh Local Industry

Source: Author (2025)

Figure 2 depicts the Causal Loop Diagram (CLD) representing the dynamics of economic value and carbon emissions in Tempeh manufacturing. The CLD is divided into many subsystems and distribution levels (echelons). The upstream subsystem is responsible for raw material procurement, the processing subsystem is in charge of Tempeh production steps, and the downstream subsystem is in charge of product allocation or distribution to other industries. The CLD also depicts the dynamic interactions across distribution echelons, allowing linkages from one distribution level to the next, so ensuring the continuity of Tempeh business dynamics.

Discussion

Causal Loop Diagram (CLD) and Supply Chain Structure

The Causal Loop Diagram (CLD) method illustrated the dynamic interactions between the various variables across the efficiency of the supply chain, sustainability, and the impacts of policy. Through CLD, efficiency, sustainability, and the impact of policy on the supply chain of the tempeh industry can be examined more broadly from upstream to downstream (Rozhkov et al., 2025). The supply chain structure is established in echelons, starting with the raw materials procurement subsystem (Echelon 1) using agents for imported and domestic soybeans. This distinction reflects dramatic and substantial changes in cost, quality, and carbon emissions (Mafruchati et al., 2023; Sjamsuridzal et al., 2021). For instance, imported soybeans span longer distances, which increases carbon dioxide emissions from transportation, and are subject to international logistics regulations, and there is a cycle demonstrated (Al-Amin et al., 2015; Wardhana et al., n.d.). Because of steady supply and price stability, processors' multiple down their reliance on imported soybeans diminishes the incentive to grow soybeans locally (Ghifara et al., 2022). Local soybeans, by comparison, are a more sustainable and comparatively low-carbon option and not only have fewer transportation-related emissions but can also assist in supporting some rural economies. However, the issue with local soybeans largely lies with supply; usually, inconsistent supply, unreliable volumes, and inability to compete due to less government support, underinvestment in farming technology, and disappearance when prices fluctuate. Hence the balancing act. The system has no desire to switch back without prescriptive help like subsidies, better infrastructure, or training for farmers; the system fully relies on importing soybeans.

Echelon 2 encompasses regional marketplaces that serve as distribution terminals for raw material suppliers and larger consumer markets. Centralized distribution at the Echelon 2 level can enhance logistics efficiency through consolidated shipment. This is particularly important for SMEs, as their production typically falls short of meeting demand from export markets or processing companies (Zakik et al., 2022). Centralized control also helps coordinate inventory levels, coupled with the cost savings associated with less transportation cost through consolidated ordering; both are important whenever managing fresh products such as soybeans and Tempeh. Distribution challenges exist, including infrastructure access and potential delays, all of which decrease product freshness and responsiveness in the market (Lo et al., 2022).

Echelon 3 contains local marketplaces and traditional traders, which help to distribute fresh Tempeh to end users and SMEs. Given Tempeh's perishable nature, this tier relies on quick distribution networks. This stage works well because local logistics have to be fast and reliable, and good connections between traders and customers are important. Also, this part of the supply chain is key to keeping the Tempeh fresh and good quality when it reaches consumers. If there are problems here, it can cause more waste and loss of income for both producers and sellers (Sjamsuridzal et al., 2021).

Echelon 4, consisting of Tempeh-producing SMEs, is a crucial component of the supply chain, both commercially and environmentally. Small and medium-sized enterprises (SMEs) provide a key service in processing raw materials into finished products. However, the reliance on traditional energy sources (e.g., firewood) also entails high levels of carbon and carbon emissions. Moreover, the limited access to efficient technology and financing makes the production efficiency of SMEs an important consideration in sustainability initiatives. In particular, such issues make it challenging for SMEs to expand their production or transition to cleaner methods, not only limiting their ability to compete and impacting the environment. Programs by the government or better access to green technology could help them to overcome those issues.

Finally, Echelon 5 comprises the rest of the distribution channels, such as restaurants, local and regional markets, processing industries, and exports. The many market requirements at this stage embody the intricacies of sustaining demand, the quantitative amount of availability in supply for sale which the economy, or a specific market, offers, price levels, emission set by the system, value addition for the entire system, and emissions set upon the addition load at once. In this step, it is necessary to strike a balance between the level of reputation, sustainable sourcing, and pricing, along with a strong supply chain, while aiming to minimize ecological damage.

1. Echelon and Scenario Supply Chain Business as Usual

The Tempeh supply chain, in a business-as-usual paradigm, follows an orthodox distribution approach that neglects entire sustainable development strategies (Wicaksono et al., 2024). According to the Causal Loop Diagram (CLD), growth in Tempeh Demand leads to an increase in Soybean Supply, locally produced as well as imported, which then raises output by SMEs. This development creates a self-reinforcing loop that improves productivity in the industry. However, it uncovers a strong dependence on the unsustainable system of supply.

The heavy reliance of this system on imported soybeans poses a significant risk. The first loss stems from selling a product of soybeans, which is highly susceptible to world prices as it is tied to the economy's international relations. This increases the chance that conflict can result in the shipment of soybeans needed. Therefore, more than one supplier is necessary, which is expensive. Alternative supply routes will increase costs in the long run will disrupt the semi-federal finances semi federal of the state and the Standard of living. In addition, the logistical burden of transporting the less-than-competitively priced soybeans internationally and distributing them on the domestic plant significantly increases operating costs. This, in turn, results in lower profit margins and reduced structural competitiveness of Tempeh on the international market.

In terms of the environment, global transportation has a great deal of carbon emissions, which deepens global warming, and carbon emissions in Tempeh production are significant (Fauzi et al., 2024). The use of carbon-intensive fuel in the production processes of SMEs also worsens the ecological impacts, demonstrating the system's lack of responsiveness to more rigorous environmental policies (Ryandono, Widiastuti, et al., 2025; Ryandono, Wijayanti, et al., 2025; Wardhana, 2023). For example, the implementation of a carbon price or more stringent emission limits could directly raise operational difficulties and exacerbate the stress on SMEs to adopt more sustainable practices.

Moreover, the lengthy and inefficient multiechelon distribution system worsens logistical efficiency, not only raising operational costs but also contributing to increased carbon emissions from transportation. While inefficient distribution may add value through higher production volumes, the environmental and economic costs are significant (Pratiwi et al., 2022; Wijayanti et al., 2021). The misalignment between upstream-downstream policies and sustainability principles underscores the need for reformulating distribution strategies and production policies that prioritize sustainability to reduce ecological footprints and enhance long-term competitiveness (Lo et al., 2022).

2. Model Development CLD

The CLD model shows the prioritization of economic pathways and environmental impacts represented by carbon emission pathways in each distribution agent, whose orientation is on adding added value that can increase the profitability of each agent (Ramasu & Kanakana-Katumba, 2025). The economic path begins with an increase in the stock of soybeans, both from local and imported sources, whose function is to encourage the creation of Tempeh products made by West Java Tempeh SME, which can add value from an economic point of view. This process could increase SME income and create opportunities for reinvestment, such as production expansion or market growth. However, the system has limits. Limited capital capacity and poor technologies at the SME level can limit future growth and development (Sjamsuridzal et al., 2021). Furthermore, relying on imported soybeans, which require external distributors or third parties for export, adds layers to the supply chain, raising prices and complicating logistics (Rozhkov et al., 2025). As a result, overall system efficiency suffers, with growing operational expenses owing to extensive transit routes and reliance on third parties (Iman et al., 2022; Rahman et al., 2022).

On the other hand, the carbon emission trajectory represents a growing environmental impact with greater output and consumption. Transportation of soybeans is funded especially with imports and uses fossil fuels to a great extent. Thus, causing high carbon emissions. The increasing number of tiers in the distribution system (due to long-distance transportation, SMB units processing soybeans, and so forth) contributes to a larger carbon footprint. Relying on non-eco-friendly energy sources like non-renewable fossil fuels for manufacturing could damage the environment further. This increase in carbon emissions raises greater environmental concerns and introduces long-term policy risks, such as carbon taxes, which could disproportionately affect SMEs (Zaki et al., 2020). These effects may raise Tempeh manufacturing costs and impair SME competitiveness in a market that is more concerned with sustainability.

In light of these issues, it is necessary to find an appropriate supply chain strategy for economic value creation and carbon emission reduction (Wijayanti & Ryandono, 2020). An important approach is to generate local supply chains through replacing imports with high-quality local soybeans (Cho & Yoon, 2025). It would decrease the reliance on foreign sources, cut down on carbon emissions associated with shipping from far away, and promote domestic food security. Additionally, integrating green technologies into smallholder (Poverty Rice Production) production, small and Smee scale industry processing, such as the use of renewable energy resources (e.g., solar, biomass) and minimizing energy waste of the Temping method. These green inventions have the potential to cut energy costs and carbon emissions associated with production (Wardhana & Ratnasari, 2022).

In addition, reducing the non-relevant layers within the distribution structure is a crucial element in reducing energy use in logistics (Juliansyah et al., 2021; Loestefani et al., 2022). Tidying up the distribution channel by removing as many intermediaries as possible and shortening the transportation distance may curtail the logistical cost and transport emissions of SMEs. "Reducing the distance of goods distribution can increase efficiency of the supply chain, decrease carbon footprints and enhance operational efficiencies," the report says.

Implementing these measures will result in a more sustainable Tempeh supply chain, both economically and environmentally (Santoso & Kusuma, 2023). Small and medium-sized enterprises (SMEs) can improve their competitiveness in a market focused on sustainability by avoiding negative environmental consequences while maintaining economic potential. Furthermore, this strategy will assist SMEs in adapting to increasingly stringent environmental laws, such as emissions (Mafruchati et al., 2022).

Conclusion

This study effectively traces the supply chain of the tempeh industry using a Causal Loop Diagram (CLD) approach that considers economic value and carbon emissions. Key findings show that, while the tempeh business can significantly contribute to the economic empowerment of SMEs, the industry's heavy dependence on imported soybeans is associated with a high carbon footprint, posing a threat to its long-term environmental sustainability. Furthermore, the mismatch between increasing market demand and the limited production capacity of SMEs, along with the continued use of fossil-based energy in production, aggravates the ecological impact. The model emphasizes the importance of strengthening local supply chains as a strategic solution to reduce dependency on imported raw materials and to lower carbon emissions. It may also lower the costs, emissions, and regulatory challenges associated with carbon pricing if planners eliminate redundant intermediating layers and increase the efficiency of distribution networks.

Nevertheless, several caveats must be noted. Firstly, the specific CO_2 emission data is not enough in the tempeh industry, which may have an impact on the accuracy of the model. Secondly, the present study only concerned one study site in a specific region (Yogyakarta and Central Java) and may not be completely generalizable to other areas in Indonesia. Third, because of limited time and access, model validation was performed at a relatively small scale and with relatively few actors. This could be overcome by collecting information from other regions and by including a range of additional sectors in future studies. The addition of quantitative tools such as LCA or agent-based models coupled to system dynamics would make the analysis even more attractive. Furthermore, by analyzing institutional and policy factors like local subsidies for soybean production or policies to promote clean energy, there would be more to learn about under what circumstances the tempeh industry could develop into more resilient and sustainable outcomes.

Author's Contribution

All authors participated to this study, which included: Fadil Abdullah helped collect data, write the article, and create the causal loop diagram model. Hafiza Aprilia and Siti Nur Hamidah helped design the research technique and data gathering.

Acknowledgements

The author wishes to thank the Cikarang Industrial Meta Polytechnic, Universitas Sehati Indonesia and Universitas Telkom for their willingness to assist the author with the research and support the completion of this research.

Declaration of Competing Interest

The authors declare that they have no competing interests

Funding

This study did not receive any funding.

References

Adirestuty, F., Ratnasart, R. T., Wardhana, A. K., Miraj, D. A., & Battour, M. (2025). Gastronomy of religious tourism: Overview and future research agenda. *Geo Journal of Tourism and Geosites*, *58*(1), 188–199.

Al-Amin, A. Q., Alam, G. M., Fei, Y. S., Azam, M. N., & Karim, Y. O. (2015). Price and Trade Mechanism for Palm and Soybean Oils: A Comparative Analysis of Economic Development between Asia and Contemporary World. *Asian Journal of Agricultural Research*, *9*, 1–11.

Arifin, S., Zaki, I., Ryandono, M. N. H., Zulaikha, S., Hendratmi, A., Rani, L. N., Bayuny, A. F. R., & Wijayanti, I. (2024). Penguatan Kesejahteraan Masyarakat melalui Pelatihan Ternak, Manajemen Keuangan, dan Koperasi Syariah. *Jurnal Ilmiah Pengabdian Dan Inovasi*, *3*(2), 103–124.

Barkah, T., Rusgianto, S., & Wardhana, A. (2022). Impact of Agricultural Land and the Output of Agricultural Products Moderated with Internet Users toward the Total export of Agricultural Product in Three Islamic South East Asian Countries. *Media Agribisnis*, *6*(1 SE-Articles). https://doi.org/10.35326/agribisnis.v6i1.2261

Cho, S., & Yoon, H. (2025). Evaluating the economic and environmental benefits of rice-soybean

diversification in South Korea. *Agricultural Systems*, *224*, 104258.
Fauzi, Q., Ulfah, U., & Wijayanti, I. (2024). Ethical challenges in transportation: A study on the implementation of Islamic business values. *Al-Uqud: Journal of Islamic Economics*, *8*(2).
Febriyanti, A. R., Ratnasari, R. T., & Wardhana, A. K. (2022). The Effect of Economic Growth, Agricultural Land, and Trade Openness Moderated By Population Density on Deforestation in OIC Countries. *Quantitative Economics and Management Studies*, *3*(2).
Ghifara, A. S., Iman, A. N., Wardhana, A. K., Rusgianto, S., & Ratnasari, R. T. (2022). The Effect of Economic Growth, Government Spending, and Human Development Index toward Inequality of Income Distribution in the Metropolitan Cities in Indonesia. *Daengku: Journal of Humanities and Social Sciences Innovation*, *2*(4), 529–536.
Harahap, I. A., Kuligowski, M., Cieslak, A., Kołodziejski, P. A., & Suliburska, J. (2024). Effect of tempeh and daidzein on calcium status, calcium transporters, and bone metabolism biomarkers in ovariectomized rats. *Nutrients*, *16*(5), 651.
Harisudin, M., Adi, R. K., & Qonita, R. R. A. (2022). Synergy Grand Strategy Matrix, Swot and Qspm as determinants of Tempeh product development strategy. *Journal of Sustainability Science and Management*, *17*(8), 62–80.
Iman, A. N., Wardhana, A. K., Rusgianto, S., & Ratnasari, R. T. (2022). Venture vs Investment, Which Type of Financing was more Demanded by Agriculture, Forestry, and Aquaculture Sector? *Daengku: Journal of Humanities and Social Sciences Innovation*, *2*(5), 587–595.
Juliansyah, A. F., Putri, A. E., Suryadana, M. L., Endyana, C., & Wardhana, A. K. (2021). Global Muslim Response to Bandung Halal Tourism Branding. *International Journal of Applied Sciences in Tourism and Events*, *5*(2), 197–206. https://doi.org/https://doi.org/https://doi.org/10.31940/ijaste.v5i2.197-206
Kuligowski, M., Radziejewska-Kubzdela, E., Górna, O., Jasińska-Kuligowska, I., & Kidoń, M. (2024). Sustainable Use of By-Products (Okara and Linseed Cake) in Tempeh Fermentation: Effects on Isoflavones and Lignans. *Sustainability*, *16*(22), 9936.
Kuźniacka, J., Biesek, J., Banaszak, M., Rutkowski, A., Kaczmarek, S., Adamski, M., & Hejdysz, M. (2020). Effect of Dietary Protein Sources Substituting Soybean Meal on Growth Performance and Meat Quality in Ducks. *Animals*, *10*(1), 133.
Lo, D., Romulo, A., Lin, J.-Y., Wang, Y.-T., Wijaya, C. H., & Wu, M.-C. (2022). Effect of different fermentation conditions on antioxidant capacity and isoflavones content of soy tempeh. *AIMS Agriculture & Food*, *7*(3).
Loestefani, V., Poan, R., Suwitorahardjo, B., & Wardhana, A. K. (2022). Service Quality and Product Quality as An Influence on Customer Loyalty at Naturalis Koffie. *FIRM Journal of Management Studies*, *7*(2), 211–236.
Mafruchati, M., Othman, N. H., & Wardhana, A. K. (2023). Analysis of the Impact of Heat Stress on Embryo Development of Broiler: A Literature Review. *Pharmacognosy Journal*, *15*(5).
Mafruchati, M., Wardhana, A. K., & Ismail, W. I. W. (2022). Disease and viruses as negative factor prohibiting the growth of broiler chicken embryo as research topic trend: a bibliometric review. *F1000Research*, *11*(1124), 1124.
Mendo, A. Y., Singh, S. K., Yantu, I., Hinelo, R., Bokingo, A. H., Dungga, E. F., Juanna, A., Wardhana, A. K., Niroula, B., & Win, T. (2023). Entrepreneurial leadership and global management of COVID-19: A bibliometric study. *F1000Research*, *12*(31), 31.
Opazo-Basáez, M., Bustinza, O. F., & Molina, L. M. (2024). The effect of industrial solution services (ISS) on innovation performance: The moderating role of sustainable development goals (SDGs). *Journal*

of Cleaner Production, *455*(November 2023). https://doi.org/10.1016/j.jclepro.2024.142265

Pramudito, T. E., Desai, K., Voigt, C., Smid, E. J., & Schols, H. A. (2024). Dextran and levan exopolysaccharides from tempeh-associated lactic acid bacteria with bioactivity against enterotoxigenic Escherichia coli (ETEC). *Carbohydrate Polymers*, *328*, 121700.

Prasetyaningsih, E., Renosori, P., & Satori, M. (2020). Conceptual model of start-up business for strengthening Madrasah funding using Dynamic System approaches. In W. I. A. A. I. H. U. D. N. N. R. P. T. D. W. F. F. B. N. C. A. S. A. C. U. M. S. A. N. Abdullah A.G. Suhartanto D. (Ed.), *IOP Conference Series: Materials Science and Engineering* (Vol. 830, Issue 4). Institute of Physics Publishing. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85086272877&doi=10.1088%2F1757-899X%2F830%2F4%2F042011&partnerID=40&md5=c4ad5294f595cc13cf42cc3447d29e60

Pratiwi, A. C., Wardhana, A. K., & Rusgianto, S. (2022). Application of Vector Error Correction Model on Macroeconomic Variables toward Changes in the Composite Stock Price Index. *Daengku: Journal of Humanities and Social Sciences Innovation*, *2*(2), 219–229.

Qosim, N., Ratnasari, R. T., Wardhana, A. K., Fauziana, H., & Barkah, T. T. (2023). Eight Years of Research Related to the Green Sukuk in the Global Stock Exchange Market to Support the Implementation of SDG: A Bibliometric Review. *Journal of Islamic Economic and Business Research*, *3*(2), 161–180.

Rahman, I., Ratnasari, R. T., & Wardhana, A. K. (2022). Effect of Certificate of Bank Indonesia Sharia and Indonesian Bank Seven Days Repository Rate to Inflation Ratio in Indonesia During Covid-19 Pandemic. *Economic Education and Entrepreneurship Journal*, *5*(1), 157–174.

Ramasu, T., & Kanakana-Katumba, G. (2025). Evaluating the dynamics of fee-free higher education in South Africa: a causal loop diagram approach. *F1000Research*, *13*, 780.

Riduwan, R., & Wardhana, A. K. (2022). Effect of industrial digitalization on total halal meat production in Java. *Journal of Halal Product and Research*, *5*(1), 24–31.

Rozhkov, A., Zellner, M., Murphy, J. T., & Massey, D. (2025). Identifying leverage points for sustainable transitions in urban–rural systems: Application of graph theory to participatory causal loop diagramming. *Environmental Science & Policy*, *164*, 103996.

Rozi, F., Subagio, H., Elisabeth, D. A. A., Mufidah, L., Saeri, M., Burhansyah, R., Kilmanun, J. C., Krisdiana, R., Hanif, Z., & Astuty, E. D. (2025). Indonesian foodstuffs in facing global food crisis: Economic aspects of soybean farming. *Journal of Agriculture and Food Research*, 101669.

Ryandono, M. N. H., Mawardi, I., Rani, L. N., Widiastuti, T., Ratnasari, R. T., & Wardhana, A. K. (2022). Trends of research topics related to Halal meat as a commodity between Scopus and Web of Science: A systematic review. *F1000Research*, *11*(1562), 1562.

Ryandono, M. N. H., Permatasari, S. A., & Wijayanti, I. (2019). Business behavior in an islamic perspective: Case study of muslim woman entrepreneurs in Ikatan Wanita Pengusaha Indonesia (IWAPI). *12th International Conference on Business and Management Research (ICBMR 2018)*, 154–159.

Ryandono, M. N. H., Widiastuti, T., Filianti, D., Robani, A., Al Mustofa, M. U., Susilowati, F. D., Wijayanti, I., Dewi, E. P., & Atiya, N. (2025). Overcoming barriers to optimizing cash waqf linked sukuk: A DEMATEL-ANP approach. *Social Sciences & Humanities Open*, *11*, 101588.

Ryandono, M. N. H., Wijayanti, I., Wardhana, A. K., Imron, M. A., & Miraj, D. A. (2025). Stock Market Valuation in Sharia Compliance Lens: An Evaluation of the Intrinsic Value of Sharia-Compliant Stocks. *Journal of Posthumanism*, *5*(2), 1248–1265.

Santoso, T. B., & Kusuma, A. (2023). The Development of the Usage of Blockchain for Waqf and Zakat Globally: A Bibliometric Study. *International Journal of Mechanical Computational and Manufacturing Research*, *13*(3), 83–91.

Setiawan, B., Aulia, S. S., Sinaga, T., & Sulaeman, A. (2021). Nutritional content and characteristics of pumpkin cream soup with tempeh addition as supplementary food for elderly. *International Journal of Food Science*, *2021*(1), 6976357.

Sjamsuridzal, W., Khasanah, M., Febriani, R., Vebliza, Y., Oetari, A., Santoso, I., & Gandjar, I. (2021). The effect of the use of commercial tempeh starter on the diversity of Rhizopus tempeh in Indonesia. *Scientific Reports*, *11*(1), 23932.

Suprayogi, N., Fianto, B. A., Febriyanti, A. R., Sukmaningrum, P. S., Filianti, D., & Wijayanti, I. (2025). PEMBERDAYAAN MASYARAKAT PESISIR DI DESA KWANYAR BARAT, BANGKALAN, MADURA: PERSPEKTIF KEBERLANJUTAN LINGKUNGAN, KESEHATAN, DAN EKONOMI DIGITAL. *Jurnal Terapan Abdimas*, *10*(1), 1–10.

Susanto, A. A., Suprayitno, A., Zulaikha, S., & Wardhana, A. K. (2025). How Islamic Leadership and Islamic Worldview Play a Role in Restoring a Country's Economic Glory: Blibliometrical Analysis. *Jurnal Transformatif (Islamic Studies)*, *9*(1), 40–56.

Tan, Z. J., Bakar, A., Lim, M. F., & Sutimin, H. (2024). Nutritional composition and sensory evaluation of tempeh from different combinations of beans. *Food Research*, *8*(2), 138–146.

Unicef. (2024). *The State of Food Security and Nutrition in the World 2024*.

Wardhana, A. K. (2023). Applying Islamic Leadership In Working Environment: A Bibliometric Study. *Journal Human Resources 24/7: Business Management*, *1*(1), 25–32.

Wardhana, A. K., & Ratnasari, R. T. (2022). Impact of Agricultural Land and the Output of Agricultural Products Moderated with Internet Users toward the Total export of Agricultural Product in Three Islamic South East Asian Countries. *Iqtishodia: Jurnal Ekonomi Syariah*, *7*(2), 11–20.

Wardhana, A. K., Rusgianto, S., & Fauziana, H. (n.d.). *Effect of Timber, Palm Oil, and Gold Output on GNI in Indonesia in the Maqashid Framework*.

Wicaksono, W. A., Akinyemi, O. E., Wassermann, B., Bickel, S., Suwanto, A., & Berg, G. (2024). Traditionally produced tempeh harbors more diverse bacteria with more putative health-promoting properties than industrially produced tempeh. *Food Research International*, *196*, 115030.

Wijayanti, I., Herianingrum, S., & Ryandono, M. N. H. (2020). Islamic Crowdfunding Mechanism to Answer Renewable Energy Investment Challenge in Indonesia. *Test Engineering and Management*, *83*, 3596–3605.

Wijayanti, I., & Ryandono, M. N. H. (2020). Zakat institutions' mustahiq transformation in developing countries: Comparison study. *Opcion*, *36*(S26), 350–366.

Wijayanti, I., Ryandono, M. N. H., & Petra, D. H. S. P. H. (2021). Financial Inclusion through Zakat Institution: Case Study in Indonesia and Brunei Darussalam. *International Journal of Islamic Business and Economics (IJIBEC)*, *5*(2), 128–140.

Wikandari, R., Tanugraha, D. R., Yastanto, A. J., Gmoser, R., & Teixeira, J. A. (2023). Development of meat substitutes from filamentous fungi cultivated on residual water of tempeh factories. *Molecules*, *28*(3), 997.

Yarlina, V. P., Djali, M., Andoyo, R., Lani, M. N., & Rifqi, M. (2023). Effect of soaking and proteolytic microorganisms growth on the protein and amino acid content of Jack bean tempeh (Canavalia ensiformis). *Processes*, *11*(4), 1161.

Yudha, A. T. R. C., Huda, N., Maksum, M., Sherawali, S., & Wijayanti, I. (2024). The Moderating Effect of Religiosity on Fashion Uniqueness and Consciousness in Halal Fashion Purchase. *Indonesian Journal of Halal Research*, *6*(2), 71–84.

Zaki, I., Herianingrum, S., Hapsari, M. I., Bayuny, A. F. R., & Wijayanti, I. (2024a). Diversifikasi Pengolahan Frozen Nugget, Pengemasan dan Pemasaran Google Bisnis. *JILPI: Jurnal Ilmiah Pengabdian Dan Inovasi*, *2*(3), 1–10.

Zaki, I., Herianingrum, S., Hapsari, M. I., Bayuny, A. F. R., & Wijayanti, I. (2024b). Diversifikasi Pengolahan Tanaman Obat Tradisional, Pengemasan dan pemasaran Online Di Desa Sugihwaras Kecamatan Prambon Kabupaten Nganjuk. *Janaloka*, *3*(1), 1–8.

Zaki, I., Widiastuti, T., Yudha, A. T. R. C., Wijayanti, I., & Mi'raj, D. A. (2020). Implementation of Islamic entrepreneurial culture in Islamic boarding schools. *International Journal of Innovation, Creativity and Change*, *11*(11), 452–469. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85083043515&partnerID=40&md5=9a6a13d9ca867c26594c27b9a7e69a14

Zakik, Z., Kamil, A., Prasetyo, A. S., Ryandono, M. N. H., & Wijayanti, I. (2022). Economic development on Madura Island through halal tourism: A business feasibility study. *Al-Uqud: Journal of Islamic Economics*, *6*(2), 289–303.