2528-9705

Journal of Organizational Behavior Research

Vol.: 10, Is.: 4, Year: 2025, Pages: 43-57

https://doi.org/10.51847/OzdpYPdO7M

Available online

https://odad.org/

Supply Chain Transformation of Halal Industry in the Food Sector Using a Circular Economy: The ANP Approach

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ABSTRACT

This study aims to create an integrative model of circular economy (CE) practices to accelerate the transformation of the halal food supply chain towards a sustainable halal industry. The sustainability of the halal industry in Indonesia is inseparable from the main flow of supply chain management, namely material flow, financial flow, and information flow. Using the Analytic Network Process (ANP), this study identified material flow as the priority flow in minimizing supply chain waste, followed by financial and information flows. Derivative problems found nine types of waste in the supply chain flow. These were physical damage, quality degradation, product specifications, unequal profit distribution, price competition, capital waste, separate data management, logistics coordination, and halal label falsification. Alternative solutions driven by circular economy practices include closed-loop systems, precision farming, vertical integration, collaborative platforms, smart packaging, and resource recovery. Among the six circular economy practices, vertical integration is the priority, requiring good management to integrate several stages of the supply chain. This study found that material waste dominates the poultry meat supply chain, and it emphasizes the need for resource recovery and a closed-loop system to minimize, recover, and recycle this waste. Financial flows require precision farming and vertical integration to equalize profits and minimize capital wastage. Information flows require a digital system to share information through collaboration between all parties in the supply chain and stakeholders in halal product certification.

Keywords: Supply chain management, Circular economy, Analytic network process, Halal industry, Food.

Introduction

Indonesia has the advantage of being the country with the largest Muslim population in the world, leading to a growing demand for halal products (Danjuma, 2021). Export activity in Indonesia's halal industry has seen a significant increase, particularly in the food sector, which includes products such as meat, processed poultry, snacks, and other staple foods (Arifai, 2023). These products are assessed not only for their halal compliance according to Islamic law but also for their quality, food safety, sustainability, and supply chain integrity (Abderahman *et al*., 2021).

Meeting people's food needs is inextricably linked to the need for protein, as various commodities play a crucial role in maintaining global food security (Abd El-Hack *et al*., 2022). Particularly in countries with a predominantly Muslim population, these requirements must be supported by an adequate supply chain of poultry food that is guaranteed halal (Anggraini *et al*., 2024). All business actors in the food supply chain, from upstream to downstream, share a common role: meeting consumer/customer demand, both directly and indirectly (Baah *et al*., 2022). The supply chain also plays a role in ensuring the flow of materials and information from upstream to downstream between organizations operating domestically and globally, with the goal of minimizing costs while maximizing speed. In other words, the supply chain is described as a timeline of material movement from upstream to downstream, encompassing processes such as manufacturing, purchasing, transportation, warehousing, planning, and service.

Recieved: 12.07.2025 –Accepted: 28.10.2025 –Published: 15.12.2025

These concerns can be addressed by implementing a circular economy (CE) at all levels of the supply chain. Unlike the traditional linear strategy (take-make-dispose), CE emphasizes sustainability principles by efficiently managing resources, extending product life cycles, and avoiding waste using the reduce-reuse-recycle (3R) principle (Wu, 2025). Implementing this approach in the halal industry is critical given the importance of preserving purity, sustainability, and process efficiency along the supply chain while adhering to Sharia norms (Campra *et al*., 2021).

The application of a circular economy in the halal industry, particularly in the poultry food supply chain, has not been comprehensively developed, although various initiatives have been undertaken, including the use of waste as animal feed (Asiwe *et al*., 2022; Wal *et al*., 2023; Uneno *et al*., 2024), organic fertilizer, or reduction of distribution emissions (Rasyidah *et al*., 2025). However, obstacles and challenges inherent in the use of technological advances in the circular economy-based halal industry are identified (Razhaeva *et al*., 2022; Bukke *et al*., 2024). These include technological immaturity, financing, lack of business awareness, and a lack of environmentally friendly innovation (Kumar *et al*., 2024).

Literature Review

As the country with the largest Muslim population in the world, Indonesia has a significant opportunity to become a hub for the global halal industry (Febriandika *et al*., 2023). Halal products, particularly in the food sector, are not only a religious necessity but also reflect quality, hygiene, and ethical production (Febriandika *et al*., 2020; Abdelkader & Bergeron, 2022; Bratt & Naimi-Akbar, 2023). As public awareness (Lampasona & Pantaleo, 2022; Bei *et al*., 2023; Smalls & Hailemeskel, 2023; Sonbol, 2023; Pardo-Zamora & Castellano-Rioja, 2024; Umarova *et al*., 2024) of the halal lifestyle and sustainability grows, consumers now demand not only halal products but also transparency, safety, and environmental responsibility throughout the supply chain (Chatterjee & Khan, 2022; Roy *et al*., 2022). However, the national halal industry still faces serious challenges, particularly within the supply chain (Kurniawati & Cakravastia, 2023).

In Indonesia, the halal industry has experienced significant growth, one contributing factor being its predominantly Muslim population, which has become increasingly aware of the importance of halal certification (Septiani & Ridlwan, 2020). According to the 2022 State of the Global Islamic Economy (SGIE) report, Indonesia's halal industry ranks fourth among global halal industries (Harmoko, 2022). However, this requirement poses challenges, particularly for micro, small, and medium enterprises (MSMEs), due to the complexity and costs associated with obtaining halal certification (Oemar *et al*., 2023). Despite Indonesia's large Muslim population, many food products remain uncertified. This is partly due to a lack of awareness and misunderstanding of the certification process (Oemar *et al*., 2023).

Implementing halal practices involves several critical control points, such as sourcing halal ingredients and maintaining hygiene standards, which are essential to prevent contamination and ensure compliance with Islamic principles (Shalihin *et al*., 2024). The background characteristics of waste in the halal food supply chain in Indonesia are highly diverse, involving issues of food integrity, waste management, and sustainability (710 and 15,16). In Indonesia, the agricultural supply chain faces significant challenges in waste management (Abood *et al*., 2022; Idris *et al*., 2022; Li *et al*., 2022; Pinto & Sousa, 2023; Wal *et al*., 2023; Anzano *et al*., 2024; Bukke *et al*., 2024), with a significant portion of food being wasted due to inefficiency and declining awareness (Handayati & Widyanata, 2024). The halal supply chain in Indonesia, despite its extensive coverage, still implements limited sustainable practices, which is a critical area for improvement (Kurniawati & Cakravastia, 2023). The integration of circular supply chain management practices, which emphasize reducing food loss and maximizing waste utilization, is crucial to address these challenges. However, the implementation of these practices is often hampered by the need for coordinated governance and the participation of all supply chain actors (Perdana *et al*., 2023; Tseng *et al*., 2023).

The halal food supply chain also faces challenges related to differences in halal standards, which can impact waste management practices and overall supply chain integrity (Pauzi *et al*., 2019). Addressing these challenges requires a systematic approach that incorporates good agricultural practices in accordance with halal standards to ensure that the entire process is clean, pure, and compliant with Islamic principles (Alzeer *et al*., 2020).

Integrating CE principles into the halal food supply chain can also address sustainability challenges such as food waste and resource inefficiency, which are common in the agri-food sector (Jurgilevich *et al*., 2016; Esposito *et al*., 2020).

The transition from a linear take-make-dispose model to a closed-loop system that minimizes waste and optimizes resource utilization is particularly relevant in Indonesia, where small-scale livestock farmers dominate goat and sheep production, while religious and cultural celebrations influence meat demand (Esposito *et al*., 2020; Sujarwanta *et al*., 2024).

Furthermore, sustainability in the halal supply chain is further strengthened by traceability and knowledge (Alsharedeh *et al*., 2022; Xuan *et al*., 2022; Deisy *et al*., 2023; Fanani *et al*., 2023; Sari *et al*., 2023) management systems that support supply chain management aligned with consumer expectations (Nasyiah *et al*., 2024). However, significant challenges remain, particularly the need for stringent government policies, incentives, and environmental regulations for the effective implementation of a circular economy (Kumar *et al*., 2022). By addressing these barriers, circular economy practices not only promote corporate social responsibility but also support the achievement of sustainable development (Xuan *et al*., 2022; Padma *et al*., 2023; Sarkar *et al*., 2023; Doddapanen *et al*., 2024) goals aligned with the global agenda (Kumar *et al*., 2022). Overall, integrating circular economy practices into the halal food supply chain in Indonesia requires a comprehensive approach that considers religious integrity, resource efficiency, and long-term sustainability (Khan *et al*., 2021).

The following are the research questions (RQ):

RQ1 - What are the characteristics of waste in the halal food supply chain?

RQ2 - What is the most appropriate strategy to accelerate halal certification?

RQ3 - What is the most relevant circular economy strategy to implement in halal supply chain transformation?

RQ4 - How can we develop an efficient, scalable, and technology-based halal supply chain transformation framework? What are the types of waste and opportunities for improvement in TVSCs in developing countries from a supply chain perspective?

Based on existing research, we selected six circular economy approaches that can be implemented as alternative waste management tools in each supply chain stream as mentioned in **Table 1**. Closed-loop systems, precision farming, vertical integration, collaborative platforms, smart packaging, and resource recovery are among the systems mentioned by Jayalath *et al*. (2025). These circular economy-driven practices are important components of the circular economy-driven practices that can be integrated into the chicken meat supply chain in poor countries such as Indonesia.

Table 1. Identified practices based on the circular economy

Circular Economy (CE) Strategy	Practices driven by the Circular Economy (CE)	Description
Recycling and Reuse	Closed Loop System (Gholian-Jouybari *et al*., 2023)	Systems and strategies that promote recycling and reuse of materials, and reduce environmental impact and waste generation, such as reuse of packaging materials, recycling, and utilization of slaughter waste as animal feed.
Reduce	Precision Farming (Panetto *et al*., 2020)	4.0-based techniques to optimize the use of livestock inputs such as livestock seeds, water, fuel, and feed crop seeds and ensure efficient resource utilization and minimize wastage while improving animal monitoring processes.
Update	Vertical Integration (Dong *et al*., 2020)	Encourage farmers to participate in processing, packaging, and distribution. This minimizes the need for multiple intermediaries and reduces the potential for material waste due to repetitive logistics activities.
Giving new purpose	Collaborative Platform (Ciccullo *et al*., 2021)	A supply chain information-sharing platform and network that connects farmers directly with consumers, reducing reliance on intermediaries and ensuring fair prices for farmers.
Reuse	Smart Packaging (Kabadurmus *et al*., 2023)	Technology that incorporates biodegradable materials as packaging materials to extend shelf life, and provides real-time information about product freshness to reduce spoilage.

Recovery	Resource Recovery (Krishnan *et al*., 2020)	Resource recovery practices include composting organic waste from slaughter animal production to produce nutrient-rich fertilizer and producing biogas via anaerobic digestion for use in electricity generation throughout the supply chain.

Materials and Methods

Circular Economy and Food Supply Chain in Halal Industry

Berikut versi lebih ringkas dalam **dua paragraf**: --- Halal policies, circular economy principles, and supply chain stages form the foundation of this study's conceptual framework. To find waste throughout the chicken meat supply chain, field observations and interviews with supply chain participants, from upstream to downstream, were carried out in the first phase. Participating directly in the slaughterhouse (RPA) audit and verification process with LPPOM MUI Central Java demonstrated that waste management procedures and halal compliance are closely related, highlighting the significance of circular economy objectives. The second phase involved reviewing literature and empirical studies on supply chain stages and circular economy principles, followed by integrating primary and secondary data to analyze problems and develop alternative solutions. These data were modeled using the Analytic Network Process (ANP) through Super Decision software. ANP, an advancement of AHP, enables decision-making in systems with interrelated elements through pairwise comparisons to generate priority rankings. This approach is well-suited for determining strategic priorities to support a sustainable halal industry driven by circular economy practices (Ascarya, 2005).

Steps of the ANP Method

Halal policies, the circular economy's tenets, and the supply chain's phases are all major factors in establishing the foundation of the research's conceptual framework. Field observation and interviews with supply chain participants from upstream to downstream were used in the first phase of the study to classify the different kinds of waste produced at different points in the supply chain for poultry meat. Direct observation was also carried out by taking part in the Chicken Slaughterhouse (RPA) audit and verification process run by LPPOM MUI Central Java Province. Through involvement in these activities, it was discovered that the halal product is also impacted by the waste processing process, which is then related to the circular economy's goals.

Step 1: Define objectives, identify problems, and make decisions.

Step 2: Build a network using the Super Decision application, which then becomes a model construction.

• Element 1: Goal (G): Realizing a sustainable halal industry: transforming the food sector supply chain.

• Element 2: Criteria (G1, G2, G3, …, G4), supply chain flow.

• Element 3: Sub-Criteria (SC1.1, SC1.2, …, SC2.1, SC2.2, …, SC3.1, SC3.2, …, SCnr) Waste categories.

• Element 4: Alternatives (A1, A2, A3, A4, …, An) Circular economy principles.

Step 3: Develop pairwise comparison questions in the form of a questionnaire based on the model construction.

Step 4: Respondents complete the questionnaire.

Step 5: Process the respondent assessment data using the Super Decision application.

• Geometric Mean: The average value of respondents' assessments.

The following is the formula for calculating the geometric mean (Ascarya, 2005):

$$GMk = (R1 * R2 * \dots * n)^{1/n} \quad (1)$$

Where GM = Geometric Mean

R = Respondent

n = number of respondents

• Rater Agreement (Kendall's W): Agreement among respondents

The formula for obtaining the W value is:

$$U = {(T1 + T2 + \dots + Tp)}/{p} \quad (2)$$

$$S = (T1 - U)2 + (T2 - U)^2 + \dots + (Tp - U)^2 \quad (3)$$

$$MaxS = (n - U)^2 + (2n - U)^2 + \dots + (pn - U)^2 \quad (4)$$

$$W = {S}/{MaxS} \quad (5)$$

U = average value of the total ranking
S = sum of squared deviations
P = number of nodes
n = number of respondents
If the agreement value is 1 (W=1), it indicates perfect agreement among respondents. If the W value is 0 or close to 0, there is disagreement among respondents.
Step 6: Interpret the results.

Data Collection

The research team conducted interviews with livestock owners, slaughterhouse operators, certification specialists, and academics in the halal industry, integrating the findings with a literature review to develop an adapted model consisting of objectives, supply-chain-based criteria, problem-derived sub-criteria, and circular-economy alternatives. These elements were structured into pairwise comparisons that formed the basis of the questionnaire. During data collection, respondents were guided on how to assign scores and were asked to justify their judgments, which were later validated through source triangulation. Although the ANP method does not prescribe a specific number of respondents, prior studies suggest using an odd, categorized group of experts; accordingly, the questionnaire was completed by qualified academics, practitioners, and industry experts using a 1–9 ratio scale. Data were processed with Super Decision software to calculate the geometric mean, assess rater agreement, and identify the highest-priority strategy, while respondent characteristics are summarized in **Table 2**.

Table 2. Respondent Information

Category	Role	Expertise
Academics	Lecturer	Lecturer who is an expert in the field of Islamic economics, Islamic finance, halal industry
	Researchers	Researcher (Passionate about Sustainable Development and Tech Industry Growth)
	Researchers	Researcher (Slaughter according to halal standards)
Expert/regulators	Halal Product Process Companion (P3H)	Accompanying the entire halal certification process
	Halal Auditor	Checking and auditing at every stage of the production process to ensure the halalness of the product
	DKPP Employees in the Animal Husbandry Sector	Develop and implement technical policies for livestock development
Practitioners	Breeder	Farm owners who are able to produce quality livestock products
	Chicken Slaughterhouse	Able to slaughter animals in accordance with Islamic law, and produce quality broiler chickens
	Consumer (Restaurant Owner)	Able to market processed chicken products

Results and Discussion

Identification of Waste and Losses in the Poultry Meat Supply Chain

Based on the primary data obtained by the author in the initial stage, taking into account semi-structured interviews conducted during the initial background assessment with stakeholders and consultants, the researcher also directly observed the poultry food supply chain (Ajwa *et al*., 2022; Ansari *et al*., 2023; Arora *et al*., 2024; Botelho *et al*., 2024;

Al-Sunbul *et al*., 2024). The following is a summary of several problems and challenges in the poultry food supply chain in Indonesia, as shown in **Table 3** below.

Table 3. Summary of waste and losses in the poultry meat supply chain

Supply Chain Flow	Trash Category	Description
Material Flow (C1)	Physical Damage (SC1.1)	Chicken becomes non-halal due to improper slaughtering, and it dies during delivery to the slaughterhouse due to temperature fluctuations.
	Quality Deterioration (SC1.2)	Chickens are slaughtered at one time (in the morning only) for the day's stock, even though not all are necessarily sold, resulting in excess supply and waste.
	Product Specifications (SC1.3)	Production results do not meet consumer quality standards, such as uneven carcass size, inconsistent slaughter weight, excessive moisture or fat content, and failure to meet hygiene and halal standards.
Financial Flow (C2)	Uneven Profit Distribution (SC2.1)	Farmers suffer financial losses due to an imbalance in bargaining power between small-scale farmers and intermediaries, resulting in unfair profit sharing.
	Price Competition (SC2.2)	Market price differences affect supplier profits.
	Capital Waste (SC2.3)	Operating costs are wasted on non-productive activities, such as excessive investment in inputs like fertilizers, pesticides, and water resources that do not match actual market demand.
Information Flow (C3)	Disjointed Data Management (SC3.1)	Separate, manual (written) product data management in the supply chain is not real-time, hindering the flow of information.
	Poor Logistics Coordination (SC3.2)	The lack of a structured coordination system within the supply chain leads to delivery delays, excess stock, and increased transportation costs.
	Halal Label Counterfeiting (SC3.3)	Many RPAs still display fake halal labels; many of them have not passed the audit but have already displayed halal labels.

Developing an ANP Model to identify Waste Categories and Circular Economy Practices

Prioritizing the identified circular economy concepts is critical for understanding how they apply in food supply chain processes, particularly chicken. Interviews and collaboration with practitioners and experts at the grassroots level are required to incorporate their knowledge into the theoretical framework (Souza *et al*., 2022; Novak *et al*., 2023; Figueroa Valverde *et al*., 2024; Petrauskas *et al*., 2024). While traditional interviews provide a thorough understanding of this phenomenon, ranking criteria, sub-criteria, and alternatives are required to prioritize and weight each with the purpose of decreasing waste and conserving resources. This method enables us to obtain both a ranking and a level of importance. As a result, the ANP approach was created to rank the effects of supply chain flows in order to reduce waste in the food supply chain, notably chicken. The ANP model was built on existing challenges in the poultry supply chain, as well as alternatives based on circular economy principles to promote resource conservation by minimizing supply chain waste in the food sector, particularly chicken. This is built using **Figure 1** below, with references to **Table 3**. The goal is to identify best practices based on circular economy principles that can be implemented in food sector supply chains, particularly poultry meat, to improve resource conservation by reducing supply chain waste.

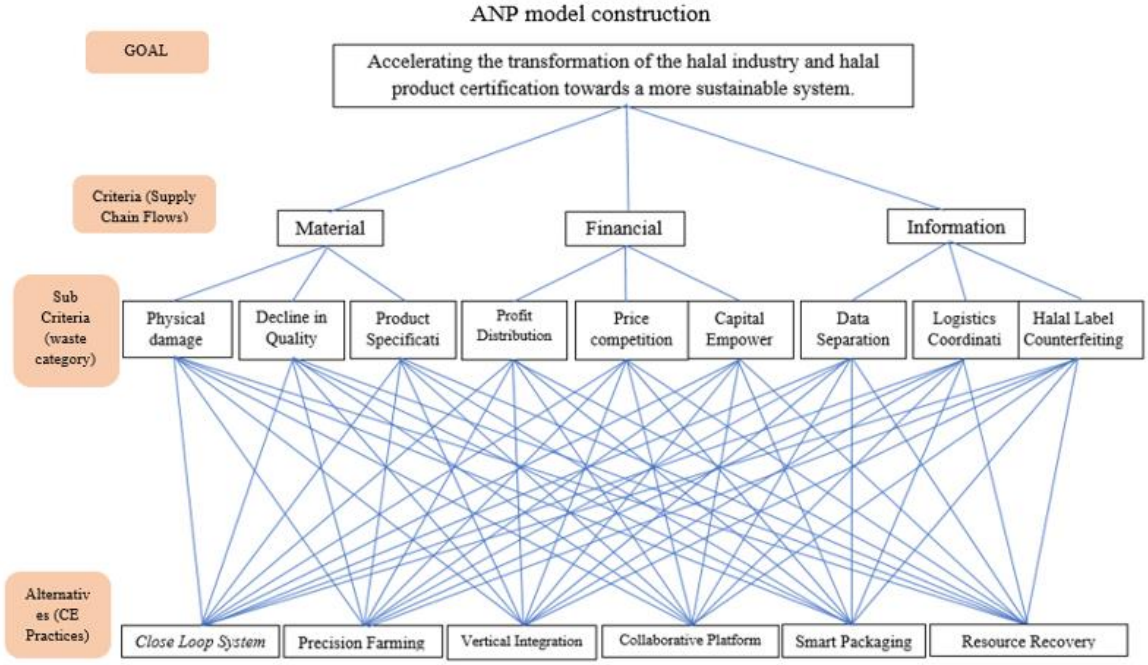

Figure 1. ANP Model Constructing

Objective Priority

Based on ANP processing, the Consistency Ratio (CR) values for each supply chain flow are valid, indicating consistent judgments and clear prioritization. Nine respondents—academics, experts, and practitioners—were analyzed using geometric means to assess agreement levels. Perfect agreement occurs when W = 1 (Ascarya, 2005). Only academics reached perfect agreement (W = 1), while the overall agreement was moderate (W = 0.346). Overall results show that material flow is the most important flow (CR = 54.99%), followed by financial flow (24.02%) and information flow (20.98%). Experts, however, ranked information flow first (54.69%), emphasizing the importance of halal certification information for a sustainable halal poultry supply chain. Material flow becomes the top priority because product quality affects all supply chain stages. Challenges mostly occur in slaughterhouses, including physical damage, quality decline, and product specification issues. Academics prioritized physical damage (44.34%), quality decline (38.74%), and product specifications (16.92%).

Practitioners, however, prioritized quality decline (49.34%) due to non-fresh meat caused by bulk cutting, followed by product specifications (31.08%) and physical damage (19.58%), which they argued still allows products to be repurposed (e.g., for catfish feed). Financial flow ranks second, requiring strong coordination across supply chain actors. Academics identified unequal profit distribution as the main issue (CR = 47.42%), linked to weak bargaining power among small farmers. However, the overall geomean shows price competition as the main concern (41.26%). Practitioners highlighted pricing as a key determinant of business success. Capital waste had the lowest influence overall (25.99%), although academics and practitioners ranked it second, stating that business profitability depends heavily on the owner's management capability. Information flow ranked last due to its relatively smaller impact on resource conservation. Field observations showed the absence of real-time data recording in farms and slaughterhouses, leading to inefficiency and waste.

The primary issue is widespread falsification of halal labels, as only a few slaughterhouses meet MUI standards and obtain BPJPH certification. Barriers include low awareness, high registration costs, and a complicated audit process (Idris *et al*., 2022; Li *et al*., 2022; Pinto & Sousa, 2023). As a result, some businesses use fake halal labels. Both overall and academic geomean results show halal label falsification as the main issue (44.34%), followed by fragmented data management (38.74%) and inadequate logistics coordination (16.92%). To resolve these issues,

integrating circular economy principles is essential to strengthen resource efficiency and sustainability in the poultry meat supply chain. A summary of local weights and priority rankings is presented in **Table 4**.

Table 4. Results of ANP Analysis of Criteria & Sub-Criteria

	Academics		Expert/regulator		Practitioners		Overall	
Criteria	Bobot Lokal	Rank	Local Weight	Rank	Bobot Lokal	Rank	Local Weight	Rank
1. MATERIAL	58.42%	#1	34.45%	#2	55.84%	#1	54.99%	#1
2. FINANCIAL	23.18%	#2	10.85%	#3	31.96%	#2	24.02%	#2
3. INFORMATION	18.40%	#3	54.69%	#1	12.20%	#3	20.98%	#3
W Value (Rater Agreement)	1.000		0.778		0.778		0.346	
Sub Criteria								
Material								
1. Physical damage	55.84%	#1	59.36%	#1	19.58%	#3	44.34%	#1
2. Quality degradation	31.96%	#2	24.93%	#2	49.34%	#1	38.74%	#2
3. Product specifications	12.20%	#3	15.71%	#3	31.08%	#2	16.92%	#3
W value (Rater Agreement)	1.000		0.333		0.111		0.309	
Financial								
1. Profit distribution	47.42%	#1	37.64%	#2	18.40%	#3	32.75%	#2
2. Price competition	14.94%	#3	47.42%	#1	58.42%	#1	41.26%	#1
3. Capital wastage	37.64%	#2	14.94%	#3	23.18%	#2	25.99%	#3
W value (Rater Agreement)	0.111		0.444		0.333		0.111	
Information								
1. Data segregation	38.74%	#2	40.67%	#1	41.26%	#1	38.74%	#2
2. Logistics coordination	16.92%	#3	36.95%	#2	25.99%	#3	16.92%	#3
3. Halal label falsification	44.34%	#1	22.38%	#3	32.75%	#2	44.34%	#1
W value (Rater Agreement)	0.778		0.333		0.444		0.259	

Alternative

Circular economy practices can be applied to the chicken meat supply chain once waste categories in each stream are identified **(Table 5)**. ANP results show that all respondents prioritized vertical integration (21.39%) as the top alternative, since unifying all supply chain stages under one management can reduce inefficiencies such as price competition, limited market access, and unequal profit distribution. Precision farming, which uses Industry 4.0 technology like automated feeding, environmental sensors, and input optimization to increase resource efficiency and decrease waste, is the second priority (20.33%). The third priority is collaborative platforms (17.89%), which enhance transparency, data sharing, and coordination among farmers, slaughterhouses, consumers, and certification bodies within a single digital ecosystem. This directly addresses waste from fragmented data management and poor logistics coordination. The Closed Loop System (14.82%) ranks fourth, focusing on continuous monitoring of product outputs to minimize waste along the supply chain (Ajwa *et al*., 2022; Al-Sunbul *et al*., 2024; Arora *et al*., 2024; Botelho *et al*., 2024).

Smart packaging (14.68%) also supports waste reduction by extending shelf life and providing real-time freshness information, thus reducing physical damage and quality loss (Ranganadhareddy, 2022a; Ranganadhareddy, 2022b;

Ranganadhareddy & Chandrsekhar, 2022; Reddy, 2022). Resource recovery (10.90%) is the final alternative, aiming to maximize reusable resources and significantly cut supply chain waste. Examples include converting chicken manure into organic fertilizer, processing feathers into protein flour, purifying waste effluent for reuse, and producing biogas through anaerobic digestion (Ranganadhareddy, 2022a; Ranganadhareddy, 2022b; Ranganadhareddy & Chandrsekhar, 2022; Reddy, 2022; Bukke *et al*., 2024). Although overall agreement is low (W = 0.064), academics show higher alignment (W = 0.168), with rankings similar to the overall results. Prioritizing these circular economy strategies is essential for reducing waste and improving resource efficiency in poultry supply chains, especially in developing countries like Indonesia.

Table 5. Alternative ANP Analysis Results

	Academics		Expert/regulator		Practitioners		Overall	
Alternatives								
1. Closed-Loop System	13.14%	**#5**	13.78%	**#4**	16.04%	**#4**	14.82%	**#4**
2. Precision Farming	22.41%	**#2**	19.33%	**#3**	18.74%	**#2**	20.33%	**#2**
3. Vertical Integration	22.96%	**#1**	24.02%	**#1**	23.00%	**#1**	21.39%	**#1**
4. Collaborative Platform	18.68%	**#3**	20.52%	**#2**	18.37%	**#3**	17.89%	**#3**
5. Smart Packaging	15.50%	**#4**	11.38%	**#5**	13.23%	**#5**	14.68%	**#5**
6. Resource Recovery	7.31%	**#6**	10.97%	**#6**	10.63%	**#6**	10.90%	**#6**
W Value (Rater Agreement)	**0.168**		**0.153**		**0.111**		**0.064**	

Assessing Supply Chain Waste with Circular Economy-Driven Practices

ANP results show that material flow is the top priority for improving resource conservation, followed by financial and information flows. Physical damage is the key waste category in material flow, largely caused by untrained and uncertified halal slaughterers. Vertical integration can improve control across production stages, while resource recovery allows damaged products to be repurposed (e.g., as fish feed). Further identification of material-flow waste is still needed. In the financial flow, price competition is the main issue. Large-scale farmers benefit from unified management, while small-scale farmers face unequal profit distribution. Transparent and fair financial practices are therefore essential. Collaborative digital platforms can help by providing real-time pricing, strengthening bargaining power, improving logistics coordination, and increasing transparency in halal certification.

This aligns with their ranking as the third most important circular economy alternative. Digital platforms also support halal certification outreach. Many businesses resist certification due to cost and audit complexity, prompting facilitators like P3H officers to rely on social media and direct communication to raise awareness. Information flow has the least impact but faces major issues such as widespread halal label falsification. Medium-scale businesses often avoid certification due to cost burdens, despite legal requirements. Digitalization and precision farming can reduce waste by improving information accuracy, traceability, and stakeholder monitoring. Closed-loop systems rank fourth, enabling reuse of non-conforming products. Smart packaging ranks fifth by extending shelf life and improving freshness monitoring, although adoption is limited in developing countries (Abood *et al*., 2022; Wal *et al*., 2023; Anzano *et al*., 2024; Kounatidis *et al*., 2024). Resource recovery ranks last but still contributes to minimizing waste across the poultry meat supply chain.

Defining Waste Recycling in the Poultry Meat Supply Chain and Integrating the Circular Economy

There are three main flows in any supply chain: material, financial, and information flows (Zhang *et al*., 2020). The loss of any one of these flows can have multiple consequences for the entire downstream supply chain. In this study, we explore the current definition of waste and loss in the context of the poultry meat supply chain and identify the supply chain waste that occurs in each flow due to disruptions. All waste from these three supply chain flows is important to address, without considering only one priority flow (Ashraf *et al*., 2025). Based on the analysis, the priority flow here is the material flow, where waste from the material flow can be physically seen and tangible, making

it easier to address. Unlike waste from the material flow, which can be visualized, waste from the financial and information flows cannot be physically visualized, such as financial losses and loss of information, which will affect the main pillars of the supply chain flow (Jayalath *et al*., 2025).

Effective information flow is essential for achieving supply chain objectives, especially when transforming toward sustainability through circular economy principles that require strong internal and external collaboration. Proper planning, sourcing, procurement, conversion, and logistics are ensured by coordinated management across all streams: material, financial, and information. This includes strong coordination between halal certification officers and chicken supply chain participants. Waste categories identified across supply chain **(Tables 4 and 5)** stem from disrupted flows, causing physical damage and quality reduction in poultry products, and are addressed using circular economy–based alternatives such as vertical integration to resolve capital waste and logistics issues, precision farming and collaborative platforms to tackle data fragmentation and halal fraud, and closed-loop systems and smart packaging to reduce damage and optimize resources. Field observations show that some slaughterhouses already apply circular practices, such as converting non-halal or unsuitable chicken by-products into fish feed used only for non-food recreational fish, following halal certification protocols (Razhaeva *et al*., 2022; Souza *et al*., 2022; Novak *et al*., 2023; Figueroa Valverde *et al*., 2024; Petrauskas *et al*., 2024). Overall, applying circular economy strategies (reduce, reuse, recycle, rethink, and recover) can significantly minimize waste while improving sustainability, efficiency, and value across the halal poultry supply chain.

Conclusion

This study applied the Analytic Network Process (ANP) to identify and prioritize nine waste categories across material, financial, and information flows in the poultry meat supply chain, while integrating circular economy principles to support halal industry development. The results show that material flow is the top priority, followed by financial and information flows—highlighting the central role of material management in minimizing waste. Physical damage is the main waste category in the material flow, market price competition dominates the financial flow, and halal label falsification is the key issue within information flow. Among circular economy practices, vertical integration ranks first for its ability to control critical production stages and reduce intermediaries, followed by precision agriculture to replace manual data input with real-time digital systems. Collaborative platforms rank third for improving transparency and coordination, while closed-loop systems, smart packaging, and resource recovery follow as additional strategies for reducing waste and optimizing resource use.

Overall, this study provides strategic guidance for policymakers and industry stakeholders to enhance efficiency, strengthen halal assurance, and promote sustainability in the poultry supply chain through circular economy adoption. Successful implementation requires regulatory support, technological advancement, and adequate funding. The conceptual model developed in this research is based on comprehensive waste mapping and expert-driven ANP prioritization, offering a systematic framework for transforming the halal supply chain. By increasing distribution efficiency, spotting waste trends, and allocating resources optimally, digital technologies like IoT, big data analytics, and data-based halal testing and traceability are anticipated to hasten this shift. Future research can validate these strategies through pilot testing of circular economy–based initiatives.

Acknowledgments: The author would like to thank the Ministry of Education, Culture, Research, and Technology (MoECRT) of the Republic of Indonesia for the enormous financial support in writing this research through the "Regular Fundamental Research" funding scheme with contract number 0419/C3/DT.05.00/2025 and Agreement/Contract Number 127/C3/ DT.05.00/PL/2025; 007/LL6/PL/AL.04/2025; 168.36/A.3-III/LRI/VI/2025.

Conflict of Interest: None

Financial Support: This research was funded by the Ministry of Education, Culture, Research, and Technology (MoECRT) of the Republic of Indonesia through the "Regular Fundamental Research" funding scheme with contract number 0419/C3/DT.05.00/2025 and Agreement/Contract Number 127/C3/ DT.05.00/PL/2025; 007/LL6/PL/AL.04/2025; 168.36/A.3-III/LRI/VI/2025.

Ethics Statement: None

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