Mathematical Modelling of Engineering Problems
Vol. 13, No. 2, February, 2026, pp. 389-401
Journal homepage: http://iieta.org/journals/mmep

An Integrated Quality Function Deployment–Analytic Hierarchy Process Framework for Sustainable Coconut Supply Chain Development in Archipelagic Regions: Evidence from Riau Islands Province

Sanusi[1*], Larisang[1], Ismail[2], Abdul Hamid[3], Dwi Ramadhani Kumala Sari[2], Nabila Oktafia Putri Nurahmad[1]

[1] Department of Industrial Engineering, Faculty of Engineering, Ibnu Sina University, Batam 29432, Indonesia
[2] Department of Informatics, Faculty of Engineering, Ibnu Sina University, Batam 29432, Indonesia
[3] Faculty of Technical and Vocational Education, Universiti Tun Hussein Onn Malaysia, Batu Pahat 86400, Malaysia

Corresponding Author Email: sanusi@uis.ac.id

https://doi.org/10.18280/mmep.130215

Received: 10 November 2025
Revised: 22 January 2026
Accepted: 4 February 2026
Available online: 15 March 2026

Keywords:
sustainable supply chain, coconut industry, Quality Function Deployment, Analytic Hierarchy Process, archipelagic regions, decision-support framework

ABSTRACT

The coconut industry in the Riau Islands Province possesses substantial production potential and a strategic geographic position near the Singapore–Malaysia market corridor. However, its sustainability and competitiveness remain constrained by export dependency, logistics inefficiencies inherent in archipelagic regions, and fragmented supply chain coordination. This study aims to develop a prioritized strategic framework to enhance sustainable supply chain performance by integrating stakeholder requirements across economic, social, and environmental dimensions. An integrated Quality Function Deployment (QFD) and Analytic Hierarchy Process (AHP) approach was employed within a mixed-methods design involving nine key stakeholders. Instrument validation confirmed strong reliability and internal consistency. Aiken's V values were ≥ 0.67 for 9 of the 10 indicators, the Cronbach's α coefficient was 0.923, and the AHP consistency ratio was 0.03. The results indicated that economic sustainability was the dominant priority (51.14%), followed by the social (30.38%) and environmental (18.48%) dimensions, with cost efficiency, profitability, and market access identified as critical success factors. The study concluded that strategic investments in logistics infrastructure, green technology adoption, and innovation-oriented capacity building are essential for improving supply chain integration and value creation. The proposed framework provides a replicable decision-support tool for sustainable agri-supply chains in archipelagic regions, supporting value-added industrial transformation while contributing to Sustainable Development Goals (SDGs) 8 and 12.

1. INTRODUCTION

The global coconut (*Cocos nucifera* L.) industry represents a strategically significant economic sector across tropical regions, with global production reaching approximately 62 million tons annually and serving as a critical livelihood source for millions of smallholder farmers in developing countries. Indonesia ranks among the world's largest coconut producers, contributing approximately 17.13 million tons annually to global production, positioning the nation as a key player in meeting the increasing international demand for coconut-based products [1]. However, despite this substantial production capacity and Indonesia's strategic geographic location adjacent to major markets such as Singapore and Malaysia, the utilization of this potential remains suboptimal, with the majority of production still concentrated in primary form commodities rather than value-added processed products [2].

The Riau Islands Province, with its archipelagic characteristics and proximity to international trade routes, presents both unique opportunities and challenges for coconut supply chain development. Global demand for processed coconut products, including coconut oil, desiccated coconut, coconut water, and coconut-based functional foods, has demonstrated a significant upward trend. This growth is driven by increasing consumer awareness of health benefits and the versatility of coconut derivatives in the food, cosmetic, and pharmaceutical industries [3]. Nevertheless, the Riau Islands Province has been unable to fully capitalize on these market opportunities due to persistent supply chain challenges, including operational inefficiencies, quality inconsistencies, limited access to modern processing technologies, and poorly integrated distribution systems [4]. These challenges are further complicated by the region's archipelagic geography, which creates additional logistical constraints.

Contemporary global market dynamics have increasingly emphasized the imperative for products that not only meet stringent quality standards but are also produced through demonstrably sustainable processes [5]. Multiple stakeholders, including international buyers, regulatory bodies, and civil society organizations, are implementing pressures and presenting challenges related to the adoption of sustainable business practices across agricultural value chains. The ability to meet sustainability standards has emerged as a critical determinant in accessing premium international markets for food products, including processed coconut goods. This shift reflects broader trends toward corporate social responsibility and the integration of Environmental, Social, and Governance (ESG) criteria in global supply chain management. However, Indonesia's current sustainability performance, ranking 75th among 169 countries worldwide and 7th in East and South Asia, reveals a pronounced deficiency in the maturity of sustainable supply chain implementation, especially in the agricultural sector, which remains characterized by unresolved environmental externalities, institutionalized social inequities, and suboptimal economic performance.

Despite the growing body of research on sustainable supply chain management (SSCM) across various food industries, studies focusing specifically on coconut supply chains remain notably limited, and the literature lacks comprehensive frameworks that address the multi-dimensional sustainability requirements within the context of archipelagic geographies.

Existing research has predominantly focused on single dimensions of sustainability [6] or specific stages of the supply chain, failing to provide integrative solutions that simultaneously address economic viability, social equity, and environmental stewardship throughout the entire value chain from production to final distribution [7]. Furthermore, the unique challenges posed by smallholder farmer fragmentation, inadequate post-harvest handling infrastructure, and the complex logistics of island-based agricultural systems have received insufficient academic attention, creating a critical knowledge gap that hinders both theoretical advancement and practical implementation of sustainable supply chain strategies in coconut-producing regions.

This research addresses these critical gaps by developing an integrative sustainable supply chain framework that simultaneously encompasses economic, social, and environmental dimensions throughout all supply chain stages from production and processing to distribution in both domestic and international markets. The study employs an integrated Quality Function Deployment (QFD) and Analytic Hierarchy Process (AHP) approach, which has demonstrated effectiveness in translating diverse consumer and stakeholder needs into actionable technical characteristics while prioritizing complex multi-criteria supply chain development strategies [8]. Recent applications of QFD-AHP integration in agri-food supply chains have demonstrated robustness in enhancing sustainability performance measurement, optimizing green supplier selection [9], and addressing triple bottom line considerations in emerging economies [10]. This integrated methodology offers a promising analytical framework for developing sustainable supply chains that balance competing stakeholder requirements while maintaining economic viability, as evidenced by successful implementations in various agricultural commodity contexts, including coconut [11], coffee, and horticultural products.

The research adopts a comprehensive mixed-methods approach that combines quantitative and qualitative techniques through systematic literature review, semi-structured stakeholder interviews, large-scale surveys, detailed supply chain analysis and mapping, and the application of QFD and AHP methods to determine development strategy priorities based on empirically identified key factors. Importantly, the study incorporates circular economy principles in coconut waste management to support supply chain sustainability, representing a novel approach to addressing environmental challenges in coconut processing while simultaneously creating additional value streams from previously underutilized by-products such as coconut shells, husks, and processing residues. This circular economy integration aligns with global sustainability goals and offers potential pathways for enhancing both environmental performance and economic returns throughout the supply chain.

This study makes several significant contributions to the academic literature and the practical domain. First, it develops a comprehensive sustainable supply chain model specifically designed for archipelagic regions, explicitly addressing both the unique geographical challenges and the multi-dimensional sustainability requirements of modern agricultural supply chains. Second, it provides empirical evidence on the critical factors influencing supply chain sustainability and competitiveness in the coconut industry, filling an important gap in sector-specific knowledge. Third, it offers practical, evidence-based recommendations for multiple stakeholder groups, including smallholder farmers, processing industries, logistics providers, and policymakers, emphasizing the strategic importance of sustainable supply chains for meeting both local and export market demands while simultaneously enhancing local community empowerment and economic resilience.

This study pursues three objectives: (1) to evaluate the current performance of the processed coconut supply chain in the Riau Islands Province, focusing on structural fragmentation, logistical inefficiencies, and limited value addition; (2) to identify key determinants of sustainability and competitiveness across integrated economic, social, and environmental dimensions; and (3) to develop a context-specific sustainable supply chain model that supports inclusive regional industrialization and global market competitiveness. By addressing these objectives, the study contributes to the advancement of SSCM theory while providing practical insights to enhance the coconut industry's role in regional economic development and global food security.

2. LITERATURE REVIEW

The global coconut industry represents a significant agricultural sector across tropical regions, particularly in Southeast Asian countries like Indonesia. Despite its economic importance, this industry faces substantial sustainability challenges across its supply chain, from cultivation to end-product distribution. The complexity of coconut supply chains, characterized by numerous smallholder farmers, geographic dispersion, and multiple processing stages, creates significant obstacles for implementing comprehensive sustainable practices. Recent developments in multi-criteria decision-making (MCDM) methodologies offer promising approaches to address these challenges systematically. This study employs an integrated methodological framework combining QFD, AHP, and Aiken's V content validity coefficient for developing SSCM models in the coconut industry [12].

2.1 Sustainable supply chain management in the coconut industry

SSCM has evolved from a peripheral concern to a central strategic element in agricultural industries worldwide. In the context of coconut production and processing, SSCM encompasses the integration of environmental, social, and economic dimensions across the entire value chain, from smallholder farmers to final consumers. The coconut industry presents unique sustainability challenges due to its dominance by small-scale producers, complex processing pathways, and diverse product lines ranging from traditional commodities to value-added health and cosmetic products.

Research consistently demonstrates that effective implementation of SSCM in the agricultural sector necessitates the simultaneous integration of economic, environmental, and social sustainability indicators and determines the drivers and barriers [13]. Contemporary SSCM frameworks emphasize the need to balance economic viability with environmental stewardship and social equity. Within the coconut industry, these requirements manifest in persistent challenges, including the optimization of by-product utilization to reduce waste, the provision of equitable remuneration for smallholder farmers, the preservation of soil fertility in plantation systems, and the mitigation of carbon emissions associated with processing and distribution activities. Furthermore, the archipelagic characteristics of major coconut-producing countries, particularly Indonesia, exacerbate sustainability constraints through logistical inefficiencies and limited infrastructure, thereby affecting overall supply chain performance.

The measurement of sustainability performance in coconut supply chains remains underdeveloped, with a noted absence of concrete frameworks and standardized indicators tailored to this industry's specific characteristics. This gap is particularly significant given the growing market demand for sustainably sourced coconut products and increasing regulatory pressures in major import markets. The integration of digital technologies into SSCM practices presents promising opportunities for enhancing transparency and efficiency. Technologies such as blockchain, IoT sensors, and data analytics can potentially address traceability challenges in complex coconut supply chains, though their application in this specific agricultural context remains limited.

The integration of QFD and AHP presents a powerful methodological synergy for addressing complex sustainability challenges in agricultural supply chains. QFD provides a structured framework for translating stakeholder requirements into technical specifications, while AHP offers a robust methodology for prioritizing complex decision criteria through pairwise comparisons. Review found that AHP is the most frequently applied MCDM method [14]. This integrated approach enables researchers and practitioners to systematically address the multidimensional nature of sustainability challenges in coconut supply chains.

QFD, originally developed for quality management in manufacturing, has found increasing application in sustainability contexts through its ability to translate often ambiguous sustainability requirements into concrete technical specifications [15]. The methodology employs a matrix structure known as the "House of Quality" that correlates customer needs (WHATs) with technical responses (HOWs), facilitating the identification of critical development areas. In the context of coconut supply chain sustainability, this approach can translate broad sustainability goals into specific operational targets, such as optimizing transportation routes to reduce carbon emissions or developing processing methods that minimize water usage.

The AHP complements QFD by offering a structured and transparent mechanism for prioritizing competing criteria inherent in sustainability-oriented decision-making. Through pairwise comparisons, AHP derives relative priority weights among decision elements, allowing subjective expert judgments to be systematically quantified while ensuring logical consistency. In the context of coconut supply chains, AHP facilitates the reconciliation of conflicting objectives, such as cost minimization versus the enhancement of social benefits for smallholder farmers, or the selection of processing technologies that simultaneously optimize economic efficiency and environmental performance.

The integration of these methods has demonstrated significant value in supply chain applications across various industries. Research in electronics manufacturing has shown that QFD-AHP integration can effectively strengthen supply chain agility while mitigating sustainability risks [16]. QFD-based optimization model for mitigating SSCM adoption challenges for Bangladeshi Ready-Made Garments (RMG) industries. These methodological integrations provide valuable templates for similar applications in coconut product supply chains [17].

3. METHODOLOGY

This section describes the multi-methodological approach followed to fulfil the research goals, starting from face-to-face interviews with stakeholders and a literature review through qualitative content analysis. The AHP pairwise comparison survey was obtained by soliciting expert opinions to determine the weighting elements for decision-making. Gladwell [18] suggested that experts in a field are a heterogeneous group with around 10,000 hours of practice. The technique of determining respondents in order to dig up information and expert knowledge (opinion acquisition) is an expert judgment method using purposive sampling. Basic consideration of determination to be used as respondents using criteria: 1) existence, and the willingness of respondents to be interviewed and fill up the questionnaires, 2) has a reputation position and has shown his credibility as an expert in the field researched, 3) has experience and is knowledgeable in the field, and 4) has more than five years in the field.

While QFD and AHP provide robust frameworks for designing and prioritizing sustainability interventions, the methodological rigor of sustainable supply chain research critically depends on the validity of data inputs. Aiken’s V coefficient offers a systematic approach to content validation by quantifying expert consensus on the relevance and representativeness of research instruments and indicators. In sustainable coconut supply chain studies, the application of Aiken’s V strengthens the credibility of sustainability indicators, expert judgments in AHP, and the structural integrity of QFD matrices, thereby enhancing the overall robustness of the analytical framework.

The review highlights key gaps in the application of integrated QFD–AHP methodologies with content validation in sustainable coconut supply chains. Although QFD and AHP have been widely applied independently, their combined use for coconut and its derivatives remains limited, despite the sector's reliance on smallholder farmers, diverse product streams, and high waste valorization potential. Existing SSCM studies also depend largely on generic sustainability indicators, underscoring the need for coconut-specific metrics validated through approaches such as Aiken's V. In addition, the roles of digital technologies, stakeholder participation, and contextual factors such as geography, market structure, and policy environments remain insufficiently explored, indicating important directions for future research.

4. DATA COLLECTION AND CALCULATION

4.1 Data collection

Using this approach, the information obtained is more in-depth, specific, and contextual, aligning with the needs of the research, particularly in relation to challenges, opportunities, and strategies for developing a sustainable coconut supply chain in the Riau Islands Province. Table 1 presents the coconut plantation area as reported in the study [19].

Tabel 1 shows coconut plantation areas in the Riau Islands province during the 2020–2024 period, the trend shows fluctuations, with the area recorded at 32.615 thousand hectares in 2020, slightly increasing to 32.633 thousand hectares in 2021, then returning to 32.615 thousand hectares in 2022, followed by a significant decline to 31.150 thousand hectares in 2023, before rising again to 32.800 thousand hectares in 2024. These dynamics indicate that although the overall plantation area remains relatively stable at around 32 thousand hectares, annual variations are influenced by factors such as land productivity, land-use changes, and government policies in the plantation sector.

Table 1. Plantation area in Riau Islands Province (2020–2024)

No.	Year	Amount (Thousand Hectares)
1	2020	32.615
2	2021	32.633
3	2022	32.615
4	2023	31.150
5	2024	32.800

The coconut plantation area data in the Riau Islands Province for the 2019–2021 period, as shown in Figure 1, presents regional variations, with Natuna (11,638 thousand hectares) and the Anambas Islands (9,763 thousand hectares) as the largest contributors, followed by Bintan, Lingga, Karimun, as well as Batam City and Tanjung Pinang City with relatively small areas. Overall, the coconut plantation area increased from 34.04 thousand hectares in 2019 to 32.516 thousand hectares in 2020, and slightly rose again to 32.5385 thousand hectares in 2021, indicating a dominant land concentration in Natuna and Anambas.

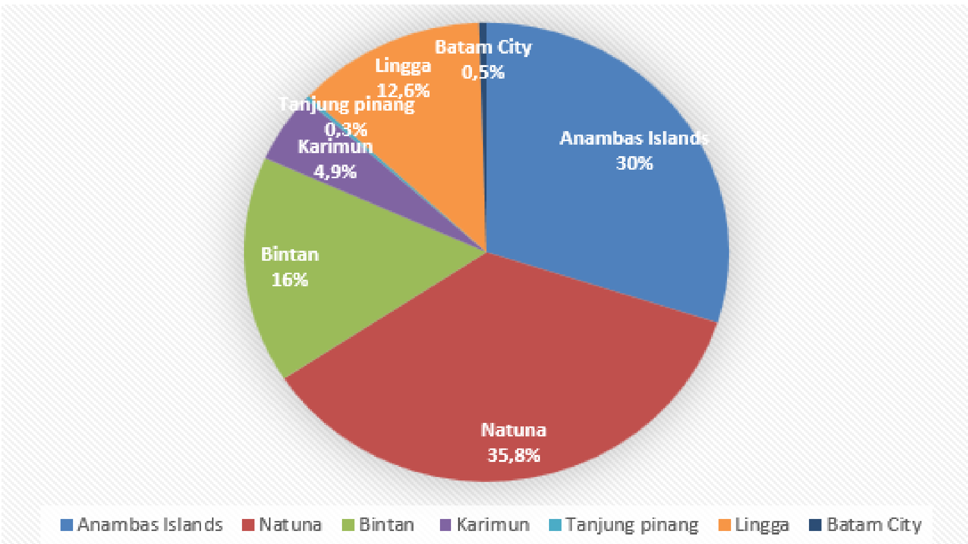

Figure 1. Plantation area in Riau Islands Province (2019–2021) by region

4.2 Data calculation

Based on the data provided, the results of the validity test using Aiken's V equation, as well as the reliability test using

$$V = \frac{\sum s}{n\,(c-1)} \tag{1}$$

The equation for Aiken's V is:
s = (r - l_0) - score transformation
r = score given by the rater
l_0 = lowest score on scale (= 1)
n = number of raters (= 9)
c = number of score categories (= 5 for 1-5 scale)
Table 2 presents the results of the validity test using Aiken's V equation and the reliability test using Cronbach's Alpha for the current supply chain conditions, as assessed by the raters, as follows:

Cronbach's Alpha equation:

$$\alpha = \frac{k}{k-1}\left(1 - \frac{\sum \sigma^2_{item}}{\sigma^2_{total}}\right) \tag{2}$$

where, k is the number of items, $\Sigma\sigma^2_{item}$ is the sum of the variances of individual items, and σ^2_{total} is the variance of the total scores.

Substitution:

$$\alpha = \frac{9}{9-1}\left(1 - \frac{4.111}{14.333}\right); \alpha = \frac{9}{8}(1 - 0.287); \alpha = 0.802$$

Table 2. Results of Aiken's V calculation

No.	Assessment Aspects	Rater Score	Σs	Aiken's V	Remarks
1	Availability of coconut raw materials	3, 4, 4	8	0.889	Valid
2	Quality of coconut raw materials	3, 3, 4	7	0.778	Valid
3	Raw material procurement system	2, 3, 2	4	0.444	Invalid
4	Processing production capacity	4, 2, 3	6	0.667	Valid
5	Processing technology	4, 2, 3	6	0.667	Valid
6	Quality of processed coconut products	4, 3, 3	7	0.778	Valid
7	Product distribution system	4, 3, 3	7	0.778	Valid
8	Access to local markets	4, 4, 3	8	0.889	Valid
9	Access to export markets	4, 2, 4	7	0.778	Valid
10	Stakeholder coordination	4, 2, 3	6	0.667	Valid

4.2.1 Validity test interpretation

9 out of 10 items were declared valid ($V \geq 0.67$). One item (Raw material procurement system) was declared invalid because the value of $V = 0.444 < 0.67$. Item No. 3 indicated a significant inconsistency in ratings. Reliability test with Cronbach's Alpha, since item number 3 is invalid, only the 9 valid items will be used for the reliability calculation. Calculation of total scores per rater. Rater 1 scored 34, Rater 2 scored 25, and Rater 3 scored 30.

4.3 Existing conditions of the coconut supply chain

4.3.1 Supply chain structure

The coconut supply chain in the Riau Islands Province follows a typical structure observed in Indonesia. Figure 2 shows an overview of the coconut supply chain in the Riau Islands Province. The supply chain starts from coconut farmers, who are the main producers of raw materials. The harvest is then distributed to collectors whose role is to collect products from farmers in large quantities to facilitate distribution. Furthermore, coconuts are distributed through Transportation to various parties, including Local Buyers and agro-industries. At the local buyer level, coconuts are generally traded for community consumption or traditional markets. Meanwhile, products that enter the agro-industrial sector will go through a processing process into various derivative products, such as coconut oil, coconut milk, shell charcoal, and other processed products. The result of this supply chain process can be in the form of products that are marketed locally or exported to the international market. This scheme shows that the coconut supply chain in the Riau Islands involves various actors with interrelated roles to support added value, competitiveness, and potential for the development of the coconut industry in the archipelago [20-22].

Figure 3 shows the flow of the coconut supply chain from upstream to downstream. The process starts with coconut farmers as the main producers of raw materials. The harvest is then distributed to collectors, who play a role in collecting coconuts from various farmers to facilitate the distribution process. Furthermore, the coconuts are transported via transportation to local buyers. In the next stage, the product goes through the transportation process again to be sent to the processing site, followed by dismantling before entering the agroindustry. In the agro-industrial sector, coconuts are processed into various value-added derivative products. The final processed products are then prepared for export to the international market.

The unprocessed coconut supply chain in the Riau Islands is still long and fragmentary. Individual farmers sell to collectors, and the process of transforming into factories or the parent market. Farmers can also sell directly to factories and even to end users. This condition applies throughout the coconut supply chain in the Riau Islands Province, creating challenges in efficiency and distribution of added value. Meanwhile, for young coconuts or fresh coconuts, collectors come directly to farmers; the entire process from harvesting to young coconut sellers is carried out by buyers.

4.3.2 Export and production performance

The Riau Islands show a positive trend in the coconut industry. Riau Islands Province recorded a significant increase in unprocessed coconut exports of processed coconut products, facilitated by the Agricultural Quarantine, reaching Indonesian Rupiah (IDR) 19.9 billion.

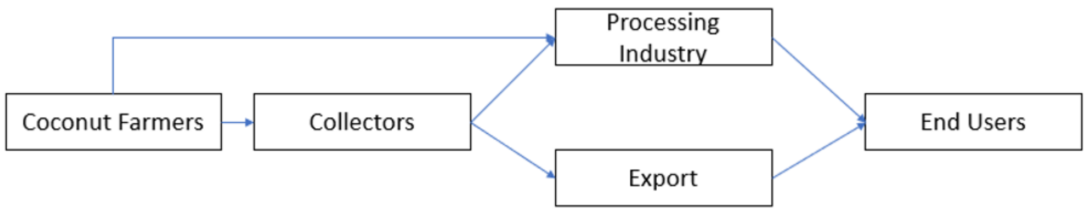

Figure 2. Coconut supply chain in general in Riau Islands

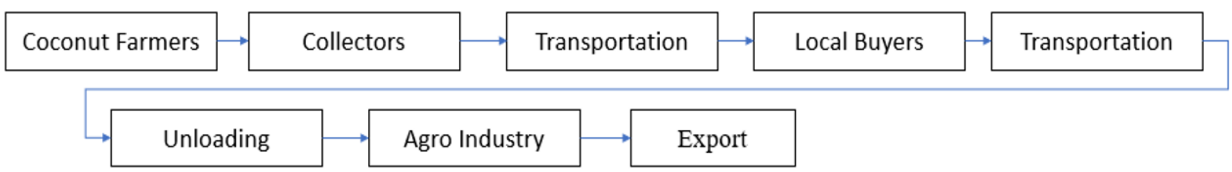

Figure 3. Coconut supply chains are specifically sold outside the Riau Islands

The first export of processed coconut products from the Riau Islands to China. This export consists of 54 tons of coconut milk and 27 tons of coconut water with a total value of IDR 1.8 billion**.** The main destination countries for coconut exports from the Riau Islands Province are Malaysia, Singapore, Thailand, South Korea, Germany, China, Taiwan, Hong Kong, and several other countries.

4.3.3 Main processed products

Primary (Unprocessed) Coconut Products. Fresh whole coconuts constitute the primary agricultural output and serve as raw materials within the coconut supply chain. These products are marketed directly by farmers to processing industries or sold in domestic markets for daily consumption without undergoing industrial processing.

Processed Coconut Products from the Riau Islands. In addition to primary products, the Riau Islands produce a range of value-added coconut derivatives that are distributed to both domestic and international markets. These processed products represent downstream supply chain activities and contribute significantly to export-oriented trade and regional economic development.

1. Liquid Products:

Coconut milk (organic and conventional) - 54 tons of coconut milk with significant export value to China. Coconut water - 27 tons of coconut water exported to China. Coconut cream

2. Solid Products:

a) Copra (dried coconut meat)

Copra is the flesh of a coconut that is dried, usually using sunlight or smoking. This product is the main raw material in the manufacture of coconut oil and has high economic value in both the domestic and export markets.

b) Coconut Flour

Coconut flour is produced from coconut pulp that has been extracted from coconut milk, then dried and finely ground. This product is widely used as a healthy food, high in fiber, low in gluten, and can be a substitute for wheat flour.

c) Desiccated Coconut

Dried grated coconut is fresh coconut meat that is grated, dried, and processed hygienically. The product is widely used in the food and beverage industry, such as cakes, bread, biscuits, and snacks.

d) Virgin Coconut Oil (VCO)

VCO is pure coconut oil extracted from fresh coconut flesh without going through a process of high heating or chemical purification. VCO is known to have a high content of lauric acid, beneficial for health, beauty, and pharmaceuticals.

e) Coconut Oil

Refined coconut oil, or Refined, Bleached, and Deodorized (RBD) Coconut Oil, is produced from copra through a process of purification, filtering, and deodorization. This product is widely used for food purposes, in the processed food industry, as well as for cosmetics and soap raw materials.

4.3.4 Other derivative products

Coconut husk, commonly referred to as coconut coir, is an agro-industrial by-product that can be converted into a wide range of value-added products. The primary derivatives include coir fiber, which is utilized in the production of ropes, mats, brushes, geotextiles, mattresses, and automotive components, and coir pith (coco peat), which is widely applied as a horticultural growing medium and soil conditioner. Additional downstream products comprise molded coir composites, insulation materials, biodegradable packaging, erosion control products, and bio-based construction panels. The utilization of coconut husk derivatives contributes to waste minimization, resource efficiency, and the advancement of circular economy principles within sustainable coconut supply chains.

5. RESULTS AND DISCUSSION

The analysis identified ten key constraints influencing the performance and development of the coconut supply chain. All constraints were validated through Aiken's V content validity assessment, with coefficients ranging from 0.75 to 1.00, exceeding the accepted threshold of 0.67 and indicating strong expert consensus. Among these factors, inadequate transportation infrastructure achieved the highest validity score (V = 1.00), underscoring its critical influence on supply chain efficiency and competitiveness, particularly within geographically fragmented and archipelagic contexts.

Limited business capital. Smallholder farmers and micro and small-scale enterprises face significant constraints in expanding production capacity and investing in improved technologies due to inadequate access to financial resources.

(1) Limited access to technology. The low adoption of modern processing and post-harvest technologies results in suboptimal production efficiency and inconsistent product quality.
(2) Low human resource capacity. Deficiencies in managerial, technical, and marketing skills among farmers and supply chain actors reduce their ability to compete in broader and higher-value markets.
(3) Inadequate transportation infrastructure. Limited inter-island transport facilities and restricted distribution networks increase logistics costs and lead times, thereby reducing overall supply chain competitiveness.
(4) Volatility of raw material prices. Coconut prices are highly sensitive to global market fluctuations, climatic variability, and extended distribution channels, creating income uncertainty for producers.
(5) Intensified market competition. Competition from coconut products originating in other regions and countries exerts downward pressure on prices and raises quality requirements, particularly in export markets.
(6) Regulatory complexity. Complicated licensing procedures, export standards, and trade regulations present significant barriers for small-scale actors seeking access to international markets.
(7) Limited access to market information. Inadequate availability of timely data on prices, demand, and market trends constrains informed strategic decision-making by farmers and enterprises.
(8) Non-compliance with quality standards. A substantial share of coconut products fails to meet national and international quality requirements, restricting access to premium and export-oriented markets.
(9) Weak supply chain coordination. Insufficient integration and collaboration among farmers, collectors, processors, and exporters generate inefficiencies and undermine the overall performance of the coconut supply chain.

Overall, the most critical constraint is the inadequate transportation infrastructure, as it obtains the highest validity value (Aiken's V = 1.00). This confirms that the improvement of transportation facilities is a top priority in strengthening the coconut supply chain in the Riau Islands [6].

5.1 Factors affecting supply chain sustainability and competitiveness

Based on the results of the assessment of stakeholders, namely business actors, academics, and the government, the unanimous availability of raw materials is considered the most important factor that is the main foundation of the coconut agroindustry. Processes and technology rank second as the key to creating added value and increasing product competitiveness. All parties also agreed that the efficiency of the supply and distribution chain is ranked third to ensure the smooth flow of products to consumers. There is a difference in emphasis on the next ranking, where business actors prioritize quality and certification, while academics and the government emphasize policy and regulatory aspects. Overall, the three stakeholders showed strong agreement on the first three main factors, reflecting the same urgency in the development of the coconut agro-industry from upstream to downstream [23-26].

Table 3 shows the results of the market needs assessment, showing that sustainable product innovation is the top priority with a weight of 10.60%, followed by the aspect of precise and environmentally friendly delivery time of 9.20% each. Meanwhile, other needs such as competitive product prices, attractive packaging, halal-organic certification, after-sales service, and product traceability are equally important with a weight of 8.50%, while consistent product quality has the lowest priority of 5.00%.

To find out what factors determine the sustainability of the sustainable supply chain, the following stages are carried out. AHP is used to determine priority [27].

Step 1: Identify Voice of Customer

VOC refers to the systematic identification and translation of explicit and implicit stakeholder needs, expectations, and priorities into measurable requirements for decision-making and system design.

Step 2: Identify Technical Responses (HOWs)

Technical requirements and difficulty level

The results indicated that the efficient logistics system and the tracking and monitoring system exhibit the highest implementation difficulty, with an average score of 4, signifying substantial challenges related to infrastructure, coordination, and technological integration. In contrast, the adoption of modern processing technologies is perceived as relatively less complex, with an average difficulty score of 3, suggesting greater feasibility of implementation within the current operational and institutional context.

Step 3: Relationship Matrix

Relationship scale:

9 = Very strong relationships
3 = Strong relationships
1 = Relationship is in the process
0 = No relationship

Step 4: Integration of AHP for Weighting

Paired comparison matrix - key criteria

Table 4 shows that economics, environment, and social criteria are considered equally important in pairwise comparisons (all values = 1), indicating balanced priorities among sustainability dimensions. Each criterion receives the same AHP weight of 0.33.

Table 3. Market needs and customer priorities

No.	Market Needs (WHATs)	Businessman	Academician	Government	Total	Relative Priority (%)
1	Competitive product price	4	4	4	12	8.50%
2	Consistent product quality	3	3	1	7	5.00%
3	Stable product availability	4	3	3	10	7.10%
4	Attention and functional packaging	4	4	4	12	8.50%
5	Halal and organic certification	5	3	4	12	8.50%
6	Sustainable product innovation	5	5	5	15	10.60%
7	More delivery options	5	4	4	13	9.20%
8	After-sales service	4	4	4	12	8.50%
9	Product traceability	5	3	4	12	8.50%
10	Environmentally friendly	5	4	4	13	9.20%
		Total			141	100%

Table 4. Paired comparison matrix of key criteria

Criteria	Economics	Environment	Social	Analytic Hierarchy Process (AHP) Weight
Economics	1	1	1	0.33
Environment	1	1	1	0.33
Social	1	1	1	0.33

Note: *Consistency Ratio (CR) = 0.02 (< 0.1 → Consistent)*.

5.2 Interpretation of House of Quality results

From the results of mapping market needs (WHATs) with technical responses (HOWs), the order of technical priority (Ranking 1–10) was obtained. This sequence represents the most important strategic step to improve and strengthen the sustainable coconut supply chain in the Riau Islands.

Rank 1 – HOW 7 (On-Time Delivery and Efficient Distribution)

Being a top priority because distribution in the archipelago is very challenging. Improving logistics and transportation systems will directly increase market satisfaction related to product availability.

Rank 2 – HOW 6 and HOW 10 (Sustainable and Environmentally Friendly Innovation)

Both are equally important. Innovations in processing processes, green technologies, and eco-friendly products not only meet the needs of global consumers but also support long-term sustainability.

Rank 3 – HOW 1 (Competitive Prices)

Keeping prices competitive in the international market is important to strengthen export competitiveness, especially in the face of product competition from other countries.

Rank 4 – HOW 3 (Stable Availability of Raw Materials)

Ensuring the continuity of the supply of raw materials from farmers to industry is a key factor in maintaining production consistency.

Rank 5 – HOW 9 (Product Traceability)

Transparency of product origins is increasingly important in the global market. The traceability system strengthens consumer confidence and opens access to premium markets.

Rank 6 – HOW 2 (Consistent Product Quality)

Stable quality greatly determines customer loyalty and the ability to penetrate export markets that demand high standards.

Rank 7 – HOW 4 (Functional and Attractive Packaging)

Good packaging increases selling value and competitiveness, especially for processed coconut products that enter the modern retail market.

Rank 8 – HOW 5 (Halal Certification and Quality Standards)

Halal certification is a mandatory requirement for the domestic market and most export destination countries.

Rank 9 – HOW 8 (After-Sales Service and Customer Support)

Although not very critical for primary products, after-sales service will add value for premium processed products.

Ranking 10 – HOW 2 additional (High-Difficulty, Low-Weight Components)

Environmentally friendly indicates that there are some technical aspects with a high level of difficulty, but the impact on market needs is relatively small.

The House of Quality results confirm that logistics (on-time delivery), sustainable innovation, and environmentally friendly aspects are key strategic priorities in the development of sustainable coconut supply chains. Meanwhile, quality, packaging, and certification serve as a competitive booster in the global market.

Step 5: Analysis of Strategy Priorities

The results of the QFD-AHP analysis show that efficient logistics systems, sustainable product research and development, and environmentally friendly technologies are the most critical technical priorities in supporting the development of the coconut supply chain. Meanwhile, production cost optimization is at a high priority level, signaling the importance of operational efficiency for competitiveness. The tracking/monitoring system is in the medium category, but it still needs to be considered to ensure transparency and reliability of distribution.

Step 6: Integration into the Supply Chain Model

The Riau Islands contextual model places an economic focus (51.14%) on cost optimization efforts, logistics systems, and inventory management to improve supply chain efficiency. On the environmental aspect (18.4%), priority is given to the application of environmentally friendly technologies and sustainable research and development. From the social side (30.38%), attention is focused on certification, after-sales service, and product traceability to build consumer trust. Finally, the competitiveness focus is supported by improving product quality and packaging innovation to strengthen its position in the market. The QFD integrated with AHP shows that the QFD sustainability strategy integrated with AHP shows that the sustainability strategy should focus on three main areas: efficient logistics systems, sustainable research and development, and environmentally friendly technologies. The model has taken into account multi-stakeholder needs and technical difficulties, so it is ready for validation through Forum Group Discussion (FGDs) and implementation due diligence.

5.3 Development of a sustainable supply chain model

Based on the analysis of stakeholder needs through QFD and strategic priorities through AHP, an integrative and participatory sustainable supply chain model is designed. Sustainable supply chains include three key dimensions of sustainable development (economic, social, and environmental) known as *The Triple Bottom Line*, as well as additional dimensions such as institutions and competitiveness that are relevant in the context of agriculture. This multi-dimensional integration forms a comprehensive framework to ensure supply chains are not only economically profitable, but also socially inclusive and environmentally friendly [28-32].

Table 5. Sustainability and competitiveness factors of the coconut processed products supply chain

Aspects	No.	Factor
Economics	1	Profitability
	2	Cost Efficiency
	3	Market Access
	4	Income Stability
Social	1	Employee Wellbeing
	2	Community Empowerment
	3	Gender Equality
	4	Human resource development
Environmental	1	Resource Use
	2	Waste management
	3	Biodiversity Conservation
	4	Water Carbon Emissions

Table 5 summarizes the economic, social, and environmental factors influencing the sustainability and competitiveness of the coconut-processed products supply chain, highlighting financial viability, social inclusion, and environmental responsibility as key pillars for long-term resilience. To determine the model to be developed, the stages are as follows:

Stage 1: Creating a Paired Comparison Matrix

a. Key Sustainability Criteria

Data from Respondents:

Economy vs. Environment = 1 (Equally Important)

Economic vs. Social = 1 (Equally Important)

Environmental vs. Social = 1 (Equally Important)

Table 6 illustrates the pairwise comparison matrix of key sustainability criteria as assessed by businessmen, academicians, and government stakeholders, highlighting variations in priority perceptions across groups. Businessmen consider economic, environmental, and social dimensions equally important, while academicians place greater emphasis on economic criteria compared to environmental and social aspects, and government stakeholders prioritize environmental considerations more strongly than economic and social criteria, as indicated by the relative comparison values and aggregated column sums.

Table 6. Matrix comparison of key criteria

	Businessman			Academician			Government		
Comparison	**Economics**	**Environmental**	**Social**	**Economics**	**Environmental**	**Social**	**Economics**	**Environmental**	**Social**
Economics	1	1	1	1	5	5	1	7	1
Environmental	1	1	1	0.2	1	1	0.143	1	0.2
Social	1	1	1	0.2	1	1	1	5	1
Column Sum	3	3	3	1.4	7	7	2.143	13	2.2

Table 7. Matrix comparison of economic sub-criteria

Comparison Matrix												
	Businessman				Academician				Government			
Criteria	**PROF**	**CE**	**MA**	**IS**	**PROF**	**CE**	**MA**	**IS**	**PROF**	**CE**	**MA**	**IS**
PROF	1	1	1	1	1	1	7	1	1	1	1	1
CE	1	1	1	7	1	1	9	9	1	1	9	1
MA	1	1	1	9	0.14	0.11	1	1	1	0.1	1.0	9
IS	1	0.14	0.11	1	1.00	0.11	1	1	1	1.0	0.1	1

Note: PROF: Profitability; CE: Cost Efficiency; MA: Market Access; IS: Income Stability.

Table 8. Matrix comparison of environmental sub-criteria

Comparison Matrix												
Comparison	Businessman				Academician				Government			
	RU	**WM**	**CE**	**BC**	**RU**	**WM**	**CE**	**BC**	**RU**	**WM**	**CE**	**BC**
RU	1	1	1	9	1	1	1	9	1	1	7	9
WM	1	1	1	1	1	1	1	1	1	1	1	1
CE	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.1	1	1	1
BC	0.1	1.0	1.0	1.0	0.1	1.0	1.0	1.0	0.1	1	1	1
Sum	3.11	4	4	12	3.11	4	4	12	2.25	4	10	12

Note: RU: Resource Utilization; WM: Waste Management; CE: Carbon Emissions; BC: Biodiversity Conservation.

Table 9. Matrix comparison of social sub-criteria

Comparison Matrix													
No.	**Competence**	Businessman				Academician				Government			
		B-EW	**B-CE**	**B-GE**	**B-HRD**	**A-EW**	**A-CE**	**A-GE**	**A-HRD**	**G-EW**	**G-CE**	**G-GE**	**G-HRD**
1	**EW**	1	1	1	1	1	1	1	1	1	1	1	1
2	**CE**	1	1	0	1	1	1	0	1	1	1	1	1
3	**GE**	1	0.1	1	9	1	0.1	1	9	1	0.13	1	5
4	**HRD**	1	1	0.1	1	1	1	0.1	1	1	0.2	1	1

Note: EW: Employee Wellbeing; CE: Community Empowerment; GE: Gender Equality; HRD: Human Resource Development.

b. Economic Sub-Criteria

Table 7 presents the comparative pairwise matrix of economic sub-criteria profitability (PROF), cost efficiency (CE), market access (MA), and income stability (IS) as evaluated by businessmen, academicians, and government stakeholders. The results indicated differing priority structures across stakeholder groups, where businessmen tend to assign relatively balanced importance among sub-criteria with slight emphasis on market access and income stability, academicians strongly prioritize market access and cost efficiency over other factors, and government respondents emphasize cost efficiency and market access as dominant drivers of economic sustainability, reflecting diverse strategic perspectives in strengthening the economic performance of the coconut processed products supply chain.

c. Environmental Sub-Criteria

Table 8 presents the pairwise comparison matrix of environmental sub-criteria resource use (RU), waste management (WM), carbon emissions (CE), and biodiversity conservation (BC) as evaluated by businessmen, academicians, and government stakeholders. The results indicate that resource use is consistently perceived as the most critical environmental factor, particularly by businessmen and government respondents, while waste management, carbon emissions, and biodiversity conservation are generally regarded as equally important, reflecting a shared emphasis on efficient resource utilization as the primary driver of environmental sustainability in the coconut processed products supply chain.

d. Social Sub-Criteria

Table 9 shows the pairwise comparison matrix of social sub-criteria as assessed by academicians and government stakeholders, highlighting differences in perceived importance among social dimensions. The results indicate that academicians emphasize human resource development more strongly relative to community empowerment and gender equality, while government stakeholders assign relatively balanced importance across employee conditions, community empowerment, gender equality, and human resource development, reflecting a policy-oriented perspective that values social inclusiveness and workforce capacity building in the supply chain.

Stage 2: Calculate Priority Weights

Table 11 shows that, on average, economic criteria (0.5114) receive the highest priority across stakeholders, followed by social criteria (0.3038) and environmental criteria (0.1848), indicating a stronger overall emphasis on economic considerations in the decision-making process.

Table 10. Economics normalization matrix

	Normalized Matrix								
Criteria	Economics	Environmental	Social	Economics	Environmental	Social	Economics	Environmental	Social
Economics	0.3333	0.3333	0.3333	0.7143	0.7143	0.7143	0.4667	0.5385	0.4545
Environmental	0.3333	0.3333	0.3333	0.1429	0.1429	0.1429	0.0667	0.0769	0.0909
Social	0.3333	0.3333	0.3333	0.1429	0.1429	0.1429	0.4667	0.3846	0.4545

Table 11. Average criteria

Criteria	Businessman	Academician	Government	Average
Economics	0.3333	0.7143	0.4866	0.5114
Environmental	0.3333	0.1429	0.0762	0.1848
Social	0.3333	0.1429	0.4353	0.3038

Table 12. Consistency test

Stakeholder	λ_{max}	CI	RI	CR	Status
Businessman	3	0	0.58	0	Consistent
Academician	3	0	0.58	0	Consistent
Government	3.0126	0.0063	0.58	0.0109	Consistent

Note: CR: Consistency Ratio; CI: Consistency Index; RI: Random Index.

Table 13. Global weights

Rank	Sub-Criteria	Category	Global Weight	Percentage
1	Cost Efficiency	Economic	0.2029	20.29%
2	Profitability	Economic	0.1249	12.49%
3	Market Access	Economic	0.1172	11.72%
4	Community Empowerment	Social	0.1116	11.16%
5	Gender Equality	Social	0.0827	8.27%
6	Resource Use	Environmental	0.0814	8.14%
7	Income Stability	Economic	0.0664	6.64%
8	Worker Welfare	Social	0.0578	5.78%
9	Human Resource Development	Social	0.0518	5.18%
10	Waste Management	Environmental	0.0414	4.14%
11	Carbon Emissions	Environmental	0.0355	3.55%
12	Biodiversity Conservation	Environmental	0.0265	2.65%

Stage 3: Consistency Test

Table 12 indicates that the AHP judgments of businessmen, academicians, and government stakeholders are consistent**,** as all consistency ratios (CR) are below the acceptable threshold of 0.10, confirming the reliability of the pairwise comparison results.

Stage 4: Global Weights

Table 13 presents the priority rankings. Cost efficiency (20.29%) emerges as the dominant criterion, followed by profitability (12.49%) and market access (11.72%), indicating that economic viability through operational efficiency is the primary driver of sustainable coconut supply chain development. Community empowerment ranks fourth (11.16%), representing the highest-weighted social criterion and demonstrating stakeholder recognition that inclusive development is essential for long-term sustainability. Environmental criteria collectively account for only 16.48% of total weight, with resource use (8.14%) being the most significant, while biodiversity conservation receives minimal priority (2.65%) despite the coconut's potential contribution to ecosystem preservation. This economic-dominated weighting structure suggests that immediate financial sustainability concerns outweigh environmental considerations, potentially creating risks for long-term market access as global buyers increasingly demand environmentally certified products and sustainable sourcing practices.

Stage 5: Interpretation of Results

Based on an analysis of the coconut industry's supply chain that spans eight stages from farmer to export, the study identifies priority criteria that are critical for the sector's sustainable development.

5.4 Main criteria and weight

The results of the analysis show that the economic pillars of sustainability have the highest score (51.14%), followed by social (30.08%), and environmental (18.84%), respectively. Consistent with research conducted by Sanusi et al. [32], economic is the top priority. While research conducted by Holmes et al. [33], social is the top priority. In developing countries' agricultural supply chains, the economic dimension receives priority focus because high populations and large proportions of people living below the poverty line mean substantial scope for improving economic outcomes [34]. Study results showed the highest level of economic sustainability occurred in the food insecurity group with severe hunger, highlighting that economic concerns often take priority in agricultural contexts [35].

5.5 Strategic recommendations

The coconut industry must prioritize cost efficiency improvements across all eight supply chain stages while simultaneously embedding quality standards into operational processes, as the current separation of competitiveness (4.0%) from economic factors undermines the industry's ability to capture premium markets where product quality drives competitive advantage. Environmental criteria require urgent rebalancing from their current 16.48% total weight to meet international sustainability standards and access eco-conscious markets, particularly by elevating biodiversity conservation beyond its critically low 2.65% weight to leverage coconut agroforestry's unique ecological benefits. Community empowerment programs (11.16%) should be strengthened and integrated with gender equality initiatives (8.27%) to create an inclusive value chain that ensures equitable benefit distribution from farmers to exporters, thereby building social capital necessary for sustained industry transformation. A holistic recalibration strategy is recommended where cost efficiency measures incorporate environmental resource optimization (8.14%) and waste reduction (4.14%) as cost-saving mechanisms rather than competing priorities, enabling the industry to achieve economic viability while meeting evolving global sustainability requirements and securing long-term market competitiveness.

The implementation of this recommendation requires close coordination between stakeholders at every stage of the supply chain, from coconut farmers as the main producers, collectors as aggregators, efficient transportation systems, local buyers who apply quality standards, unloading processes that maintain quality, agro-industries that apply sustainable technology, and export systems that meet international standards.

6. CONCLUSION

This research successfully developed a comprehensive sustainable supply chain framework for processed coconut products in the Riau Islands Province, Indonesia, through an integrated QFD and AHP methodology. The study addressed critical gaps in understanding and optimizing the coconut supply chain in this strategically located but geographically challenging archipelagic region.

The analysis revealed that the current coconut supply chain in the Riau Islands Province faces significant structural challenges, including fragmentation with multiple intermediaries, inadequate transportation infrastructure (identified as the most critical constraint with Aiken's V = 1.00), and limited value addition at the producer level. Despite having substantial plantation areas of approximately 32,000 hectares and a growing export performance reaching IDR 19.9 billion, the region has not fully capitalized on its proximity to major markets like Singapore and Malaysia.

The key findings demonstrate that the integrated QFD-AHP framework identifies three sustainability pillars, with economic aspects receiving the highest priority (51.14%), followed by social (30.08%) and environmental (18.84%) dimensions, and social (30.08%). Based on the priority rankings, cost efficiency (20.29%) emerges as the dominant criterion followed by profitability (12.49%) and market access (11.72%), with community empowerment ranking fourth (11.16%) as the highest-weighted social criterion, while environmental criteria collectively account for only 16.48% of total weight a structure that reveals immediate financial sustainability concerns outweigh environmental considerations despite coconut's ecosystem preservation potential and the growing global demand for environmentally certified products, potentially creating risks for long-term market access in international supply chains.

The House of Quality analysis prioritized on-time delivery and efficient distribution systems as the top technical requirement, followed closely by sustainable and environmentally friendly innovation. This finding directly addresses the archipelagic geography challenge and aligns with global market demands for sustainably produced coconut products.

The research addresses sustainability imperatives facing agricultural commodity chains globally while accounting for specific challenges in developing economies and island contexts. As international markets increasingly mandate sustainability compliance, frameworks providing practical implementation pathways become essential for maintaining competitiveness. The developed framework offers coconut industry stakeholders systematic guidance for supply chain transformation while contributing methodological innovations applicable across agricultural sectors.

Implementation success requires coordinated action across multiple stakeholder groups, substantial investments in capacity building and infrastructure, and supportive policy environments. The framework provides a roadmap for this transformation journey, balancing economic viability, environmental stewardship, and social equity to achieve genuinely sustainable coconut supply chains.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the partial support and sponsorship provided by KEMRISTEKDIKTI and Universitas Ibnu Sina for this research.

REFERENCES

[1] Sutoni, A. (2020). Analysis of coconut supply chain as industry potential in Sula Islands Regency, North Maluku Province. Jurnal Media Teknik Dan Sistem Industri, 4(1): 18-24. https://doi.org/10.35194/jmtsi.v4i1.874

[2] Sambodo, L.A.A.T. (2025). Coconut Downstreaming Roadmap 2025-2045. Ministry of National Development Planning/National Development Planning Agency, Jakarta. https://perpustakaan.bappenas.go.id/e-library/file_upload/koleksi/dokumenbappenas/konten/Upload Terbaru/Peta Jalan Hilirisasi Kelapa 2025-2045 ISBN Protected_Rev.pdf.

[3] Hoe, T.K. (2018). The current scenario and development of the coconut industry. The Planter, Kuala Lumpur, 94 (1108): 413-426.

[4] Arumugam, T., Hatta, M.A.M. (2022). Improving coconut using modern breeding technologies: Challenges and opportunities. Plants, 11(24): 3414. https://doi.org/10.3390/plants11243414

[5] Alouw, J.C., Wulandari, S. (2020). Present status and outlook of coconut development in Indonesia. IOP Conference Series: Earth and Environmental Science, 418(1): 012035. https://doi.org/10.1088/1755-1315/418/1/012035

[6] Mardiana, D.P., Primadasa, R. (2023). Design of key

performance indicators (KPI) for sustainable supply chain management (SSCM) in textile industry with analytical hierarchy process. Jurnal Rekayasa Sistem Industri, 12(1): 43-50. https://doi.org/10.26593/jrsi.v12i1.5549.43-50

[7] Nabillah, R., Fawzi, N.I., Awuh, H.E., Rijanta, Qurani, I.Z., Suwardi, Danapriatna, N. (2025). Exploring the dynamics of supply chain sustainability and resilience in the coconut agriculture: The case of Indragiri Hilir in Indonesia. Environment, Development and Sustainability. https://doi.org/10.1007/s10668-025-06756-6

[8] Gholipoor, A., Paydar, M.M., Safaei, A.S. (2019). A faucet closed-loop supply chain network design considering used faucet exchange plan. Journal of Cleaner Production, 235: 503-518. https://doi.org/10.1016/j.jclepro.2019.06.346

[9] Ahmed, W., Sarkar, B. (2019). Management of next-generation energy using a triple bottom line approach under a supply chain framework. Resources, Conservation and Recycling, 150: 104431. https://doi.org/10.1016/j.resconrec.2019.104431

[10] Costa, Y., Duarte, A., Sarache, W. (2017). A decisional simulation-optimization framework for sustainable facility location of a biodiesel plant in Colombia. Journal of Cleaner Production, 167: 174-191. https://doi.org/10.1016/j.jclepro.2017.08.126

[11] Sanusi, S.A.B., Larisang, A.H. (2023). Validity and reliability tests to determine critical indicators for coconut supply chain sustainability. International Journal of Progressive Sciences and Technologies, 41(1): 376-386. https://doi.org/10.52155/ijpsat.v41.1.5698

[12] Sanusi, Ahmad, B.S., Larisang. (2024). Drivers and barriers for sustainability in the coconut supply chain: An exploratory case-based research. Journal of Sustainability Science and Management, 19(5): 63-83. https://doi.org/10.46754/jssm.2024.05.005

[13] Cicciù, B., Schramm, F., Schramm, V.B. (2022). Multi-criteria decision making/aid methods for assessing agricultural sustainability: A literature review. Environmental science & policy, 138: 85-96. https://doi.org/10.1016/j.envsci.2022.09.020

[14] Hsu, C.H., Yu, R.Y., Chang, A.Y., Liu, W.L., Sun, A.C. (2022). Applying integrated QFD-MCDM approach to strengthen supply chain agility for mitigating sustainable risks. Mathematics, 10(4): 552. https://doi.org/10.3390/math10040552

[15] Santoso, I., Rau, H., Choirun, A., Aprilianto, H.C., Lestari, K., A'yuniah, S., Kusumaningtyas, O.W. (2024). Application of QFD in sustainable new product development in the agro-industrial sector: A systematic literature review. International Journal of Sustainable Engineering, 17(1): 926-944. https://doi.org/10.1080/19397038.2024.2417016

[16] Al Amin, M., Baldacci, R. (2024). QFD-based optimization model for mitigating sustainable supply chain management adoption challenges for Bangladeshi RMG industries. Journal of Cleaner Production, 472: 143460. https://doi.org/10.1016/j.jclepro.2024.143460

[17] Vieira, F., Santana, H.E., Jesus, M., Santos, J., et al. (2024). Coconut waste: Discovering sustainable approaches to advance a circular economy. Sustainability, 16(7): 3066. https://doi.org/10.3390/su16073066

[18] Gladwell, M. (2008). Outliers: The Story of Success. Hachette UK.

[19] Central Statistics Agency of Riau Islands Province. (BPS-Statistics Riau Islands Province). (2023). Area of Smallholder Plantation Crops by Crop Type in the Riau Islands Province (thousand hectares). https://kepri.bps.go.id/id/statistics-table/3/UWpGUlpUZzJZbkJhWlhGdUwzUkhXVzA0WmpoMFVUMDkjMw==/luas-areal-tanaman-perkebunan-rakyat-menurut-jenis-tanaman-di-provinsi-kepulauan-riau--ribu-ha---2023.html?year=2023.

[20] Gunawan, C. (2025). Riau Islands Faces Coconut Supply Crisis, Proposes Export Restrictions. https://gokepri.com/kepri-krisis-pasokan-kelapa-usulkan-pembatasan-ekspor/.

[21] Provincial Government Riau Islands. (2024). The Governor of the Riau Islands Discusses Food Security and Agricultural Industry Potential with the Indonesian Minister of Agriculture. https://kepriprov.go.id/berita/pemprov-kepri/gubernur-kepri-bahas-ketahanan-pangan-dan-potensi-industri-pertanian-bersama-menteri-pertanian-ri.

[22] Gunawan, I., Trihastuti, D., Mulyana, I.J. (2021). Sustainability issues of the coconut supply chain in Indonesia. In 2021 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM), Singapore, pp. 158-162. https://doi.org/10.1109/IEEM50564.2021.9672964

[23] Motevalli-Taher, F., Paydar, M.M., Emami, S. (2020). Wheat sustainable supply chain network design with forecasted demand by simulation. Computers and Electronics in Agriculture, 178: 105763. https://doi.org/10.1016/j.compag.2020.105763

[24] Zalynda, P.M., Govindaraju, R., Cakravastia, A., Suryadi, K., Andryanto, B. (2023). Design of sustainability criteria for strategic supplier evaluation in automotive industry X using the QFD method. Journal of Research in Industrial Engineering and Management, 1(1): 31-40. https://doi.org/10.61221/jriem.v1i1.7

[25] Bhavsar, A., Diallo, C., Ülkü, M.A. (2021). Towards sustainable development: Optimal pricing and sales strategies for retailing fair trade products. Journal of Cleaner Production, 286: 124990. https://doi.org/10.1016/j.jclepro.2020.124990

[26] Dutta, P., Mishra, A., Khandelwal, S., Katthawala, I. (2020). A multiobjective optimization model for sustainable reverse logistics in Indian E-commerce market. Journal of Cleaner Production, 249: 119348. https://doi.org/10.1016/j.jclepro.2019.119348

[27] Bortolini, M., Galizia, F.G., Gamberi, M., Mora, C., Pilati, F. (2019). Enhancing stock efficiency and environmental sustainability goals in direct distribution logistic networks. International Journal of Advanced Operations Management, 11(1-2): 8-25. https://doi.org/10.1504/IJAOM.2019.098518

[28] Lenort, R., Wicher, P., Samolejova, A., Zsifkovits, H., Raith, C., Miklautsch, P., Pelikanova, J. (2022). Selecting sustainability key performance indicators for smart logistics assessment. Acta Logistica, 9(4): 467-478. https://doi.org/10.22306/al.v9i4.350

[29] Hosseini-Motlagh, S.M., Samani, M.R.G., Saadi, F.A. (2020). A novel hybrid approach for synchronized development of sustainability and resiliency in the wheat network. Computers and Electronics in Agriculture, 168:

105095. https://doi.org/10.1016/j.compag.2019.105095
[30] Dorsch, C., Häckel, B. (2012). Matching economic efficiency and environmental sustainability: The potential of exchanging excess capacity in cloud service environments. In International Conference on Information Systems, pp. 1695-1712. https://aisel.aisnet.org/icis2012/proceedings/GreenIS/10/.
[31] Singh, A., Trivedi, A. (2016). Sustainable green supply chain management: Trends and current practices. Competitiveness Review, 26(3): 265-288. https://doi.org/10.1108/CR-05-2015-0034
[32] Sanusi, Bareduan, S.A., Larisang, Hamid, A. (2024). Critical indicators for sustainable coconut supply chain using analytical network process. International Journal of Sustainable Development and Planning, 19(5): 1703-1711. https://doi.org/10.18280/ijsdp.190508
[33] Holmes, F., Shukla, M., Dhurkari, R.K. (2025). Design of multi-criteria decision framework for supplier evaluation and supply chain sustainability risk (SCSR) management. British Food Journal, 127(5): 1730-1755. https://doi.org/10.1108/BFJ-05-2024-0532
[34] De Silva, L., Jayamaha, N., Garnevska, E. (2023). Sustainable farmer development for Agri-food supply chains in developing countries. Sustainability, 15(20): 15099. https://doi.org/10.3390/su152015099
[35] Sahraei, S., Pakravan-Charvadeh, M.R., Gholamrezai, S., Rahimian, M. (2022). Assessing the association of sustainable agriculture with rural household food security (considering ecological, economic, and social aspects). Frontiers in Nutrition, 9: 899427. https://doi.org/10.3389/fnut.2022.899427

NOMENCLATURE

Acronyms	**Description**
AHP	Analytic Hierarchy Process
QFD	Quality Function Deployment
SSCM	Sustainable Supply Chain Management
VOC	Voice of Customer
CR	Consistency Ratio
CI	Consistency Index
RI	Random Index
ESG	Environmental, Social, and Governance
SDGs	Sustainable Development Goals

Indices and Sets

i	Index of sustainability criteria
j	Index of sub-criteria
k	Index of stakeholders
n	Number of experts/respondents

Parameters and Variables

V	Aiken's V content validity coefficient
r	Rating given by an expert
lo	Lowest score on the rating scale
c	Number of score categories
s	Adjusted score in Aiken's V calculation