

International Journal of Human Capital in Urban Management
(IJHCUM)

Homepage: <http://www.ijhcum.net/>

CASE STUDY

Strengthening non-timber forest product sustainability: A multidimensional framework for forest honey management

H. Ikhsani^{1,2}, M. Maryani^{1,2*}, E.T. B. Sabri^{1,2}, G. Mohta^{1,2}, A.D. Santoso³, H. Daulay⁴

¹Department of Forestry, Faculty of Agriculture, Riau University, Riau, Indonesia

²Center for Peatland and Disaster Studies, Riau University, Riau, Indonesia

³Research Center for Industrial Systems and Sustainable Manufacturing, National Research and Innovation Agency, Tangerang Selatan, Indonesia

⁴Research Center for Behavioral and Circular Economy, National Research and Innovation Agency, Jakarta, Indonesia

ARTICLE INFO

Article History:

Received 09 October 2025

Revised 19 February 2026

Accepted 10 July 2026

Keywords:

Forest honey, Multidimensional Scaling (MDS), Non-Timber Forest Products (NTFPs), Sustainability

ABSTRACT

BACKGROUND AND OBJECTIVES: Forest honey is a non-timber forest product that supports community welfare while maintaining ecosystem biodiversity. This study aimed to evaluate the level of sustainability of forest honey production in Riau Province by determining and analyzing the sustainability index.

METHODS: Data were collected through literature review, focus group discussions, and expert questionnaires involving practitioners and stakeholders with more than five years of experience in forest honey production and management. The data obtained were then analyzed using a multidimensional scale technique covering environmental, economic, social, technological, and institutional aspects. Monte Carlo analysis and the alternating least-squares algorithm were used to examine the sustainability status and significant characteristics.

FINDINGS: The results showed that the sustainability index reached 76.26 percent, categorized as highly sustainable. The environmental, economic, and social dimensions were found to be sustainable, while institutional and technological aspects remained moderately sustainable and need further strengthening. Key attributes influencing sustainability include distribution systems, product prices, training opportunities for honey collectors, digital marketing, and product certification.

CONCLUSION: Strategic recommendations include improving institutional capacity, expanding the use of digital technology, continuous technical training, and developing long-term business strategies. This study introduces a multidimensional sustainability assessment model that integrates ecological, economic, social, technological, and institutional aspects, offering a replicable framework for sustainable forest honey management in Indonesia and beyond.

DOI: [10.22034/IJHCUM.2026.04.11](https://doi.org/10.22034/IJHCUM.2026.04.11)



NUMBER OF REFERENCES

39



NUMBER OF FIGURES

8



NUMBER OF TABLES

5

*Corresponding Author:

Email: maryani@lecturer.unri.ac.id

Phone: +62 82224150471

ORCID: [0009-0007-8851-4098](https://orcid.org/0009-0007-8851-4098)

Discussion period for this manuscript open until January 1, 2027 on IJHCUM website at the "Show Article

INTRODUCTION

Forests play a strategic role in achieving global sustainable development goals, especially in the context of climate change mitigation, biodiversity conservation, and food security. Forest ecosystems serve not only as carbon sinks but also as habitats for numerous species and sources of livelihood for local communities (Djenontin *et al.*, 2024). The increasing global concern about forest degradation and deforestation has prompted reevaluating how forests are managed, including the sustainable utilization of Non-Timber Forest Products (NTFPs). These products, including resins, medicinal plants, and forest honey, have garnered attention for their potential to align conservation efforts with local economic development (Yumantoko *et al.*, 2025). In Indonesia, with its vast tropical forests, the sustainable management of NTFPs has become a key issue at both national and regional levels (Djenontin *et al.*, 2024). Among various NTFPs, forest honey stands out as a significant ecological and economic commodity. It provides an alternative livelihood for forest-edge communities while fostering environmental stewardship. The province of Riau, located in Sumatra, is one of Indonesia's major forest honey-producing regions, with production zones categorized based on forest cover types (Pribadi and Wiratmoko, 2020). Forest honey production in this region depends heavily on the integrity of forest ecosystems, particularly the availability of nectar-producing flora and stable microclimates suitable for wild bee colonies. The high dependency of forest bees on intact ecosystems positions honey production as an indicator of biodiversity health and forest sustainability. Previous studies have emphasized the socio-economic importance of forest honey, particularly its contribution to household income improvement and conservation-oriented livelihoods (Asmara and Nurliya, 2020). However, despite its strategic potential, forest honey production in Riau faces significant sustainability challenges. Land conversion into monoculture plantations has disrupted ecological balance and altered bee foraging patterns due to declining floral diversity. Additionally, frequent anthropogenic forest fires contribute to habitat degradation, smoke pollution, and displacement of bee colonies. These environmental pressures are compounded by unsustainable harvesting practices—such as cutting entire hives—which reduce long-term productivity and hinder colony regeneration (Triyatno *et al.*, 2024).

Limited technical capacity in post-harvest handling, storage, and packaging further affects honey quality and market competitiveness (Irmawanty *et al.*, 2023). Although various community-based forest honey initiatives have emerged across Indonesia, existing studies remain largely fragmented. Most research has focused on isolated dimensions, such as socio-economic outcomes or ecological indicators, without integrating the broader institutional and technological contexts that shape sustainability outcomes. This partial approach has resulted in limited understanding of the complex interactions among ecological integrity, economic viability, social acceptance, technological capability, and institutional support within forest honey production systems. Consequently, a significant knowledge gap persists in the form of comprehensive, multidimensional assessments that can effectively inform policy formulation and adaptive forest management strategies. The absence of integrated diagnostic frameworks has also contributed to a disconnect between sustainability policies and the practical challenges faced by forest-dependent communities. There is therefore an urgent need for empirical, evidence-based assessment models that holistically capture multiple sustainability dimensions and identify key leverage factors for long-term intervention design. This study addresses these gaps by applying a comprehensive multidimensional sustainability assessment to forest honey production systems in Riau Province. The research employs a Multidimensional Scaling (MDS) approach through the Rapid Appraisal for Fisheries (RAPFISH) method to evaluate sustainability status across five dimensions: environmental, economic, social, technological, and institutional. A participatory approach is adopted by integrating primary data from structured questionnaires, interviews, and Focus Group Discussions (FGDs), alongside secondary data from literature and institutional reports. The use of MDS is particularly suited to identifying key sustainability attributes, understanding relationships between variables, and offering a visual representation of sustainability levels in each dimension (Fadilah *et al.*, 2021). Its flexibility and ease of application in participatory rural assessments make it an effective tool for sustainability diagnostics. MDS has been successfully applied in various sectors to evaluate sustainability performance. For instance, it has been employed in the analysis of algal biomass farming (Santoso *et al.*, 2023a), integrated

duck production systems (Bakrie et al., 2023), cattle production (Rohaeni et al., 2024), coconut sugar production (Handayani et al., 2025). In the realm of NTFPs, MDS has also been used to examine the sustainability of animal feed from sago (Allaily et al., 2024), landslide management (Sittadewi et al., 2025) and agricultural compost systems (Santoso et al., 2023b). However, limited research has applied this method to evaluate forest honey production systems, especially with an emphasis on ecological and socio-institutional interactions within forest-dependent communities in Indonesia. This research offers a novel contribution by integrating the MDS approach into the assessment of forest honey sustainability, which is rarely conducted in the current literature. Its uniqueness lies in the inclusion of multi-stakeholder perspectives in identifying critical leverage factors across the five dimensions. The framework developed here has the potential to be replicated in other NTFP-producing regions across Indonesia. Moreover, by employing a diagnostic lens rather than a merely descriptive one, this study bridges the knowledge-policy gap and supports sustainable forest governance models grounded in empirical evidence. From a practical standpoint, this study is expected to not only reveal the sustainability level of forest honey production in Riau but also to identify key barriers and enabling factors in each dimension. These findings can inform the prioritization of policy interventions, such as improving harvesting techniques, strengthening institutions, or enhancing technological adoption among local actors. Furthermore, by mapping the relationships among sustainability indicators, the research enables targeted strategies that can enhance the resilience of forest honey enterprises while maintaining biodiversity conservation goals. Ultimately, this research serves as a strategic input for the formulation of integrated and evidence-based forest development policies in Riau Province. The study aims to synchronize the interests of diverse stakeholders, including honey farmers, cooperatives, technical government agencies, local governments, and legislators. The outcomes are expected to contribute to a more inclusive, data-driven, and sustainable forest management system that not only enhances local well-being but also strengthens Indonesia's national agenda for biodiversity and climate resilience. To achieve these objectives, the research survey was conducted in Riau Province, Indonesia, during July and August 2025.

MATERIALS AND METHODS

Study area

This study was conducted by examining data related to forest honey production activities in Riau Province (Fig. 1). The research locations represent collection and processing centres for honey produced by local communities in each regency of Riau Province. These locations include areas that still maintain forests with *sialang* trees and other large trees as the primary habitat of *Apis dorsata* bees. Honey harvesting and processing begin with several stages, such as site selection and *sialang* tree surveys, followed by traditional forest honey harvesting. Post-harvest, the honey undergoes extraction, filtration, and packaging, as well as marketing.

The honey hunters are predominantly of Malay ethnicity and Muslim. Knowledge transfer occurs from parents to children within honey hunter families, where children are involved by observing harvesting practices or participating in the work carried out by their parents during honey collection. In terms of formal education, the older generation generally completed elementary school and junior high school, whereas some younger generations have continued their education through senior high school and even to university level. Information regarding forest honey production in Riau Province is presented in Table 1, and documentation of forest honey harvesting activities in Siak and Pelalawan Regencies, Riau Province, is shown in Fig. 2.

Research materials and procedure

Secondary data were obtained from scientific journals and other literature related to the sustainability of forest honey production. In addition, data were gathered through FGD and the distribution of questionnaires to nine experts who have extensive experience and understanding of forest honey production. The selected experts had a minimum of three years of experience in forest honey production. Respondents consisted of representatives of cooperatives, forest honey entrepreneurs, distributors, and experts involved in forest honey production programs. To determine relevant research attributes, an in-depth literature review and expert consultations were carried out. A total of approximately a dozen expert informants were involved in this study. These experts were purposively selected based on their demonstrated expertise and practical experience across the

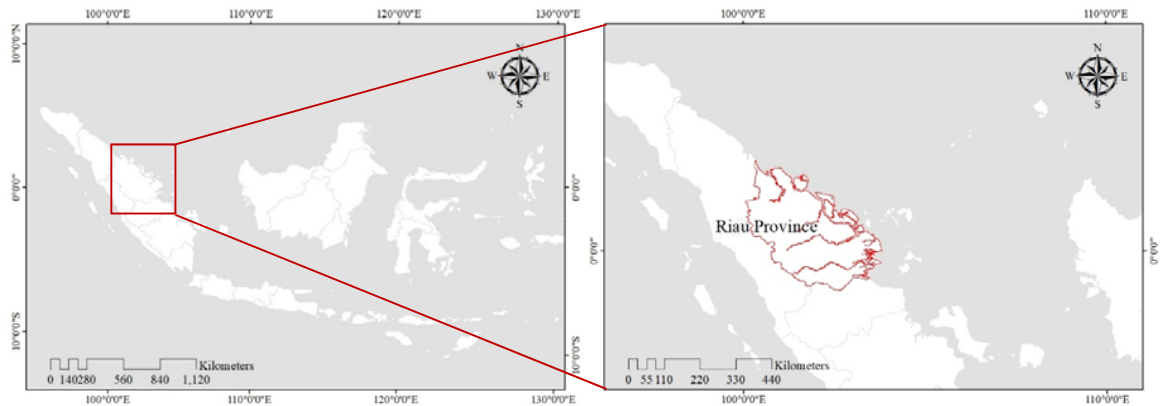


Fig. 1: Study location in Riau Province, Indonesia

entire forest honey value chain. The expert group included forest honey collectors and beekeeping practitioners, forest ecosystem specialists, entomologists, post-harvest and processing experts, honey collectors and traders, laboratory analysts responsible for honey quality testing, as well as actors involved in product distribution and marketing. All experts had a minimum of three years of professional experience in their respective fields related to forest honey production and management. Expert consultations were conducted iteratively through FGDs and follow-up

discussions to identify relevant sustainability attributes for forest honey production. Attribute selection was guided by an extensive literature review and validated through expert consensus. The attributes were organized into five sustainability dimensions: environmental, economic, social, technological, and institutional. Each expert completed a structured questionnaire assessing the condition of each attribute using a standardized scoring scale. To ensure data robustness and saturation, expert responses were examined for consistency across consultation



a)



b)



c)



Fig. 2: Documentation of forest honey harvesting in Siak Regency: a) Sialang tree; b) Bee nest on a sialang tree; c) Harvesting process of forest bee nests; d) Harvested Forest bee nests; e) Transportation of forest honey; f) Storage of forest honey. Source: Author's documentation

rounds. Data saturation was considered achieved when additional expert inputs no longer resulted in substantive changes to attribute scores or dimension-level patterns. The individual scores provided by experts were then aggregated by calculating the average value for each attribute. Attribute weighting was derived from FGD outcomes, reflecting the perceived importance of each attribute within its respective dimension. Weight normalization was applied so that the total weight of all attributes equaled one (1), ensuring internal consistency and transparency in the MDS analysis. The processed dataset consisting of averaged attribute scores and normalized weights was subsequently formatted and analyzed using the MDS method implemented through the RAPFISH software, as developed by Pitcher and Preikshot (2001). The sustainability of the honey production program was evaluated using the MDS approach and the Rapid Appraisal (RAP) quick assessment tool for forest honey production programs. The identified attributes indicate levels of sustainability across various dimensions, adjusted according to the availability of specific resource information (Kavanagh and Pitcher, 2004). Five dimensions were analyzed: environmental, eco-

nomi, social, technological, and institutional. A total of 52 attributes were evaluated. These attributes were organized in a questionnaire using a Likert scale with three options: 1 for low, 2 for medium, and 3 for high. The sustainability index value derived from the data processing ranges from 0 to 100 and is divided into four sustainability categories. The sustainability assessment index used in this study is presented in Table 2. Rapfish operates using a rapid appraisal scoring system. Scores in Rapfish generally originate from three main sources: peer-review scoring, in which scores are based on reviews of scientific documentation with predetermined thresholds; grey literature, where scores are derived from previous analyses, whether published or unpublished; and expert judgment, where scoring is determined through expert consensus, either via FGD or through other methods such as the Delphi Technique. To determine the level of influence of each attribute on the sustainability of forest honey production, a leverage factor analysis was conducted using the MDS approach. Leverage factors are used to measure the sensitivity of an attribute to changes in the sustainability index value. The resulting leverage values are

Table 1: Forest honey production data in Riau Province

Harvest Location	Number of Farmer Groups	Production (kg/month)	Honey Selling Price (IDR/kg)	Honey Distribution Areas	Remarks
Sungai Apit Sub-district, Siak Regency	8	300 - 450	100,000 – 150,000	Tanjung Balai Karimun, Padang, Kampar, Pekanbaru, Jakarta, Yogyakarta	Primary data, 2025
Tesso Nilo National Park	-	156 - 167	120,000	-	Susanto et al., 2022
RAPP Area	-	146	120,000	-	Susanto et al., 2022
Rantau Baru, Pelalawan	-	175	80,000 -120,000	-	Primary data, 2025
Pelalawan, Kampar, Siak	-	70	125,000 -140,000	Medan, Jakarta, Bekasi, Banten, Melaka (Malaysia)	Primary data, 2025
Kuala Tolam, Pelalawan	1	3,600 – 4,000	80,000	Sumatra and Malaysia	Primary data, 2025

Data analysis

Table 2: Sustainability index values

Category Index	Value	Sustainability Status
0.00 – 24.99	Poor	not sustainable
25.00 – 49.99	Fairly Poor	less sustainable
50.00 – 74.99	Moderate	moderately sustainable
75.00 – 100.00	Good	highly sustainable

Table 3: Parameter values of the leverage factor

Factor value	Category	Description
<2.0 %	neutral	not influential
2–8 %	influential	moderate to good impact
>8.0 %	significant	dominant

interpreted based on specific categorizations, allowing the identification of which factors are dominant and should be prioritized in system improvements. The criteria for leverage factor values are explained in [Table 3](#), as outlined by [Pitcher and Preikshot \(2001\)](#). In the MDS method, each object or point is represented in a multidimensional space, where the distance between two points reflects the degree of difference between objects; the closer they are, the more similar they are. The distance analysis is carried out using Euclidean distance in n -dimensional space (n -space). Widely separated points were employed to denote items or points that differed from each other. In MDS, ordination or dis-

tance determination is based on Euclidean distance in n -space using [Eq. 1](#) ([Lloyd et al., 2022](#)).

$$d = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2 + \dots} \quad (1)$$

In MDS, configurations of objects or points were estimated by regressing Euclidean distance (d) from point i to point j with the point of origin (0) using [Eq. 2](#) ([Lloyd et al., 2022](#)):

$$d_{ij} = \alpha + \beta \delta_{ij} + \varepsilon \quad (2)$$

The Alternating Least Squares Scaling (ALSCAL) algorithm was employed for the regression analysis of [Eq.](#)

2. The ALSICAL method optimizes squared distance (squared distance = $\sum$) against squared data (point of origin = $\sum$), which in three dimensions (i, j, k) is called s-stress using Eq. 3 (Lloyd et al., 2022):

$$s = \sqrt{\frac{1}{m} \sum_{k=1}^m \left[\frac{\sum_i \sum_j (d_{ijk}^2 - o_{ijk}^2)^2}{\sum_i \sum_j o_{ijk}^4} \right]} \quad (3)$$

Where the squared distance is the Euclidean distance assigned a value using Eq. 4 (Lloyd et al., 2022):

$$d_{ijk} = \sum_{a=1}^r w_{ka} (x_{ia} - x_{ja})^2 \quad (4)$$

Sustainability analysis of honey production

The levels of sustainability performance of honey production are divided into 4 levels, resulting in intervals of 0, 25%, 50%, 75%, and 100%. The assessment categories are as follows: 0.00 - 25, poor category and unsustainable; 25.01 - 50, less category, less sustainable; 50.01 - 75, adequate category, fairly sustainable; 75.01 - 100.00, good category, sustainable (Arofi et al., 2015). Employing analysis techniques can also assist in pinpointing characteristics that are attuned to sustainability considerations. The indicator with the highest Root Mean Square (RMS) value is the most sensitive (Pitcher and Preikshot, 2001). The values of the leverage factors fall within the range of 2%-8%, indicating a moderate to good impact. If < 2%, the factor is considered not influential, while if > 8%, the factor is considered dominant (sustainable) according to Pitcher and Preikshot (2001). Table 4 presents the factors that have an impact and are dominant. Monte Carlo analysis helps in determining the error and assessing the uncertainty in MDS. If the discrepancy between the MDS value and the Monte Carlo value is small, it indicates that the MDS analysis for determining sustainability is sufficiently accurate with a 95% confidence level. An overview of the comprehensive research analysis techniques, with an emphasis on the stages and various steps carried out in conducting the research or analysis, is visualized using a flowchart to facilitate understanding.

RESULTS AND DISCUSSION

The MDS technique is applied to produce a sustainability index value in the forest honey production process and to identify variable features. The MDS dimensions measured include five dimensions and their attributes. Input data for this calculation are obtained through a scientific assessment questionnaire.

In addition, this analysis will reveal sensitive attributes and influential variables that play a role in the sustainability of the process.

Sustainability index

Scientific assessment of the attributes within each sustainability dimension is crucial for accurately estimating the sustainability index level. Consideration of specific and temporal characteristics is essential in determining an attribute (Pitcher and Preikshot, 2001). The attributes of all dimensions consist of environmental, economic, social, technological, and institutional aspects, as listed in Table 5. The environmental dimension attributes include flowering tree availability, bee smoking materials, harvesting habitat damage, production tool condition, waste management, energy source, honey packaging material, honey storage condition, distribution system, and eco-friendly packaging. The economic dimension includes market delivery cost, harvest travel cost, labor cost, honey volume increase, filtered honey yield, price increase, net profit, selling price, production cost percentage, sales improvement, branded packaging impact, and utility cost. The social dimension is determined by beehive location knowledge, community cooperation, training frequency, farmer group role, local harvesting ethics, honey quality acceptance, community involvement, education outreach, price negotiation, and local promotion participation. The technological dimension includes honey extraction method, moisture reduction tool, filtration process, storage method, laboratory testing, digital record-keeping, digital marketing, and temperature control. The institutional dimension includes legal group basis, management structure, activity planning, member attendance, participatory monitoring, administrative completeness, capacity building, distribution permit, the Indonesian National Standard (SNI), and Halal certification.

To determine the sustainability level of each forest honey production process, the attributes within each dimension were incorporated into a questionnaire and submitted for relevant scientific assessment. In addition, the MDS approach and the Rapfish program were used to evaluate the results of expert assessments. The MDS analysis results for forest honey production performance in Riau show a sustainability score of 76.26% on a 0–100 scale, with $R^2 > 0.97$. This indicates that the program falls into the highly sustainable category. The score represents the evalua-

Table 4: List of dimensions and their attributes

Environment	Economy	Social	Technology	Institution
1. Flowering tree availability	1. Market delivery cost	1. Beehive location knowledge	1. Honey extraction method	1. Legal group basis
2. Bee smoking materials	2. Harvest travel cost	2. Community cooperation	2. Moisture reduction tool	2. Management structure
3. Harvesting habitat damage	3. Labor cost	3. Training frequency	3. Packaging and labeling	3. Activity planning
4. Production tool condition	4. Honey volume increase	4. Farmer group role	4. Filtration process	4. Member attendance
5. Waste management	5. Filtered honey yield	5. Local harvesting ethics	5. Storage method	5. Participatory monitoring
6. Energy source	6. Price increase	6. Honey quality acceptance	6. Laboratory testing	6. Administrative completeness
7. Honey packaging material	7. Net profit	7. Community involvement	7. Digital record-keeping	7. Capacity building
8. Honey storage condition	8. Selling price	8. Education outreach	8. Digital marketing	8. Distribution permit
9. Distribution system	9. Production cost percentage	9. Price negotiation	9. Temperature control	9. SNI certification
10. Eco-friendly packaging	10. Sales improvement	10. Local promotion participation		10. Halal certification
	11. Branded packaging impact			
	12. Packaging cost			
	13. Utility cost			

tion of 52 attributes across five different dimensions. The environmental dimension scored 87.36 %, the technological dimension 66.49%, the social dimension 82.12%, the economic dimension 86.81%, and the institutional dimension 58.51 %. The detailed results of the sustainability analysis can be seen in Table 5. Two of the five sustainability dimensions for forest honey were found to be moderately sustainable: the institutional dimension (58.51%) and the technological dimension (66.49%). Institutional capacity is a common weakness in NTFP development. It remains a weak link not only in NTFPs management but also in broader sectors such as oil palm plantations. Therefore, strong local institutions are crucial for ensuring conservation and long-term economic sustainability of NTFPs (Harbi *et al.*, 2023). Hence, improvements are needed in all three areas to achieve long-term sustainability. Forest honey production still requires legal intervention, official administrative systems, and support mechanisms. A synergistic pattern can

be established in which economic and social dimensions can be strengthened relatively quickly, while technological and institutional improvements require medium-term planning that includes incentives, training, and integrative regulations. This supports the development of an inclusive, sustainable, and adaptive model for NTFP products that can respond to both market and ecological challenges.

Environmental dimension

Among various aspects, the environmental dimension stands out by contributing the highest sustainability index score, recorded at 87.36% (Table 5), with a stress value (R^2) of 0.98 (Table 5). This means that 98% of the data variation is explained by the factors included in the model. Based on the stress value and R^2 , the MDS result for the environmental dimension can be considered a good model that effectively captures the existing issues. Therefore, it is not necessary to add additional attributes to reflect

Table 5: Results of RAPFISH analysis on the sustainability status of forest honey

Dimension	Index Score (%)	Stress Value	SQR/R ²	Sustainability Status	Monte Carlo Simulation	Index Difference and Monte Carlo
Environmental	87.36	0.12	0.98	Highly	87.57	0.21
Economical	86.81	0.11	0.99	Highly	86.83	0.02
Social	82.12	0.11	0.99	Highly	82.17	0.05
Technological	66.49	0.11	0.99	Moderately	65.85	0.64
Institutional	58.51	0.11	0.99	Moderately	58.51	0.00
Average	76.26			Highly		

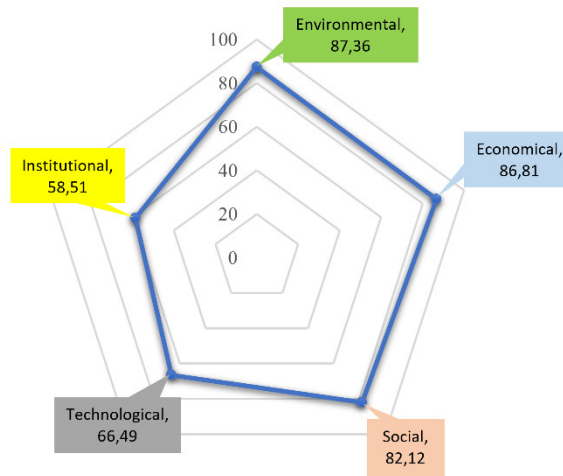


Fig. 3: Sustainability status of forest honey production

the actual conditions. A Monte Carlo simulation of the sustainability of forest honey production in Riau Province for the environmental dimension shows an average value of 87.57. The results of the Monte Carlo analysis indicate a relatively dense distribution of units, suggesting that there are no significant errors affecting the environmental dimension. The MDS analysis results indicate that the attribute with the highest impact (3.95%) is the distribution system and the energy source, which relates to the type of energy used by vehicles in honey production activities. In contrast, the environmental attribute with the lowest impact is eco-friendly packaging, with a score of 1.15% (Fig. 4). The long-distance (inter-island) and fossil fuel-based distribution system of forest honey can significantly increase its carbon footprint. Fossil fuel-powered transportation emits greenhouse gases (GHGs) that are harmful to the environment, including carbon dioxide, nitrogen oxides, sulfur dioxide,

and particulate matter (PM2.5 and PM10). Long-distance shipping can contribute up to 35–40% of the total GHG emissions in the food supply chain, thereby increasing the overall carbon footprint (Arzoumanidis et al., 2019). Extended distribution in forest honey production also results in hydrocarbon waste and soil contamination. These substances are difficult to degrade, may accumulate in the food chain, reduce soil fertility, and pose toxicity risks to aquatic organisms if they enter drainage systems (Stepanova et al., 2022). This is closely related to the energy source attribute, which also shows a high environmental impact (3.54%). To reduce these negative impacts, it is necessary to localize distribution and adopt low-emission transportation modes. Transitioning to renewable energy sources such as bioenergy or solar panels is a key element in enhancing the sustainability of agro-industrial systems (Zahrawi and Aly, 2024).

The attribute within the environmental dimension

Fig. 4: Sensitivity of attributes in the environmental dimension

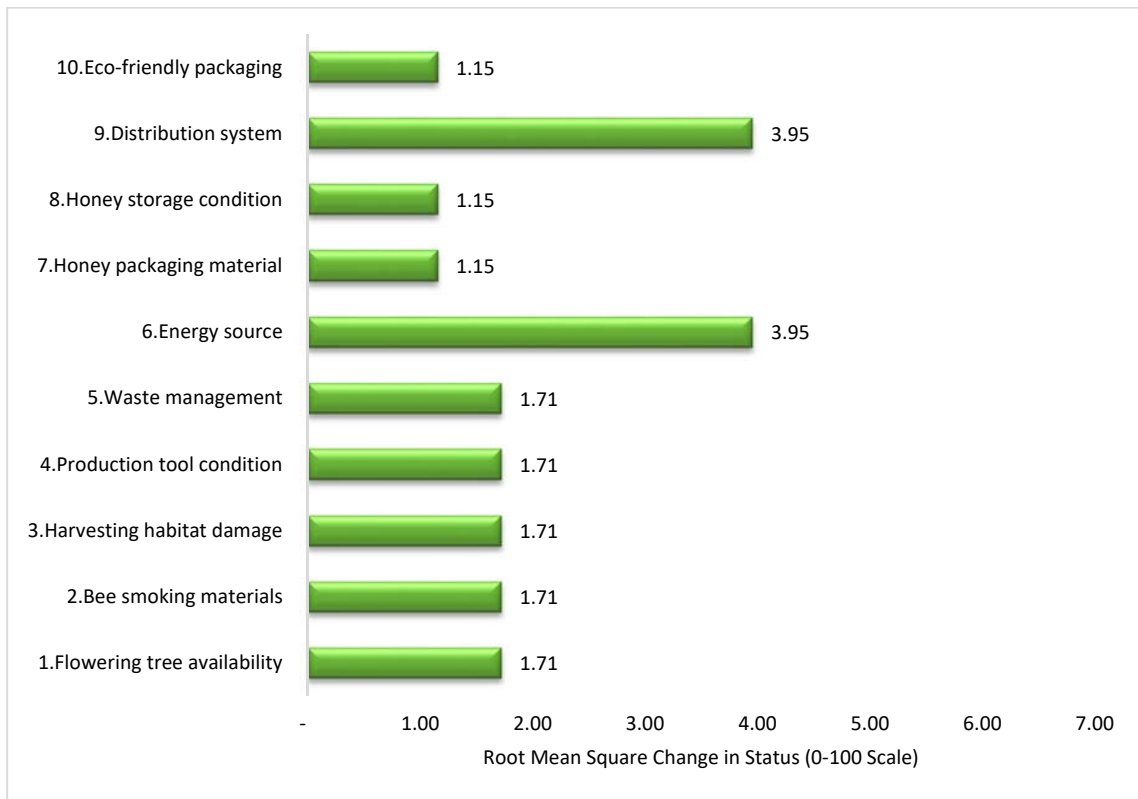


Fig. 4: Sensitivity of attributes in the environmental dimension

that has the lowest impact is eco-friendly packaging, which relates to storage conditions and packaging materials. This attribute plays an important role in maintaining honey quality and reducing the potential for environmental pollution. The use of single-use plastics or unhygienic containers can accelerate product degradation and contribute to non-biodegradable waste. Non-eco-friendly packaging materials are a major source of pollution in small-scale food supply chains. In addition, five other attributes, including waste management, production tool condition, harvesting habitat damage, bee smoking materials, and flowering tree availability, each show a leverage value of 1.01 %, which is considered low. Although their individual impact on the sustainability index is minor, these attributes remain relevant for shaping long-term environmental strategies when managed in an integrated manner. Waste management in bee-keeping involves treating by-products such as residual wax, damaged combs, and cleaning wastewater. Improper handling may contaminate soil and water, threatening environmental sustainability. Effective

management is therefore essential to maintain ecosystem health and product quality, as honey and bees serve as bioindicators of environmental contaminants. Production tool condition is associated with energy efficiency and hygiene in the harvesting and extraction processes. Outdated or poorly maintained tools can increase energy consumption and the risk of product contamination. In the honey industry, energy and transportation represent the dominant sources of carbon emissions, exceeding 90%, while machinery and tools contribute less than 10%. Despite this smaller proportion, optimizing production tools remains a relevant strategy for emission mitigation (Pignagnoli *et al.*, 2021). Even though their contribution is relatively small, optimizing production tools holds significant potential for emission reduction. Other studies show that modernizing equipment, such as using electric extractors or ultrasonic technology and performing regular maintenance, can reduce the risk of leakage and excessive energy use (Landaverde *et al.*, 2023). Harvesting habitat damage refers to disturbances in bee ecosystems resulting

from unsustainable harvesting practices such as cutting down nesting trees, especially sialang trees. Habitat degradation of this kind can decrease food availability and disrupt colony regeneration. Agroforestry approaches around bee habitats, as implemented in Wanagama, have been proven to preserve natural habitats and enhance sustainable pollination services (Anita et al., 2022). Flowering tree availability is also a crucial factor in maintaining bee populations. The presence of local flowering species such as *Melaleuca* (Gelam), *Sonneratia*, and *Avicennia* plays a role in reproductive cycles and supports the foraging activity of wild honey bees. Although some attributes show leverage values below 2 %, implementing collective strategies and improving technologies can result in a significant cumulative impact on sustainability. The recommended policy actions include modernization of production tools through incentives for transitioning to energy-efficient and contaminant-free technologies, as well as technical training for farmers in the maintenance and calibration of production equipment. In addition, routine certification and inspection of tools and production facilities are necessary to ensure quality and safety standards. Habitat restoration and the participatory planting of flowering trees should also be encouraged as part of forest honey agroforestry programs. Lastly, the implementation of integrated waste management systems is essential to minimize the impact of local environmental pollution.

Economic dimension

The MDS analysis shows that the sustainability index for the economic dimension is 86.81%, classified as sustainable, with a stress value of 0.12 and an R^2 of 0.99 (Table 5, Fig. 3). This dimension ranks as the second strongest contributor to sustainability, with the most dominant attribute being selling price (3.52%). The selling price of honey is a key determinant of business unit profitability. Price increases, whether through organic certification, local branding, or premium packaging design, can directly boost profit margins. Organic and nationally branded honey enjoys a price premium of 18–69% compared to conventional honey, significantly enhancing the product's economic competitiveness (Bimbo et al., 2025). The attributes Branded Packaging Impact and Sales Improvement each have a leverage value of 2.55%, placing them in the moderate influence category. Branded packaging is strongly correlated with consumer perception, loy-

alty, and purchasing preferences. Labels such as 100% Local, Geographical Indications, and Protected Designation of Origin (PDO) have been shown to increase consumer willingness to pay (Min et al., 2023). In addition, the use of aesthetically pleasing and eco-friendly premium packaging positively impacts the upper-market segment. Meanwhile, increased sales volume plays an important role in improving medium-term economic performance. Digital marketing strategies, online promotional channels, and e-commerce expansion have been proven to accelerate the growth of the forest honey market. Sales transformation through digital approaches and branding strategies can increase revenue by up to 40% for a small-scale honey producer (Min et al., 2023). Other attributes, such as utility costs, packaging costs, net profit, and logistics expenses, show leverage values below 2%, categorized as having low influence. Although these attributes may not significantly contribute to the structural sustainability index, they remain relevant in the context of operational efficiency. When managed collectively, these cost components can have a cumulative effect on improving business margins and stability.

Based on the analysis, several strategic recommendations can be implemented to improve the economic sustainability of forest honey production. These strategies include optimizing selling prices through the adoption of organic certification, geographical origin labels, and informative premium packaging, which are believed to increase product value and expand market reach. Furthermore, enhancing branding and packaging by using eco-friendly, ergonomic materials that reflect local identity, thereby increasing consumer appeal and strengthening brand positioning in both domestic and export markets. Additionally, strengthening distribution channels and digitizing sales through the integrated use of online platforms and digital promotions is necessary to drive sales volume growth and reach a wider consumer base. Finally, operational cost efficiency can be improved through large-scale procurement of packaging materials, conducting utility cost audits, and optimizing supply chain management to sustainably increase profit margins.

Social dimension

Based on the analysis of the Sustainability Index using MDS for forest honey production, the sustainability index score for the social dimension is 82.12%, indicating a sustainable condition. This dimension has

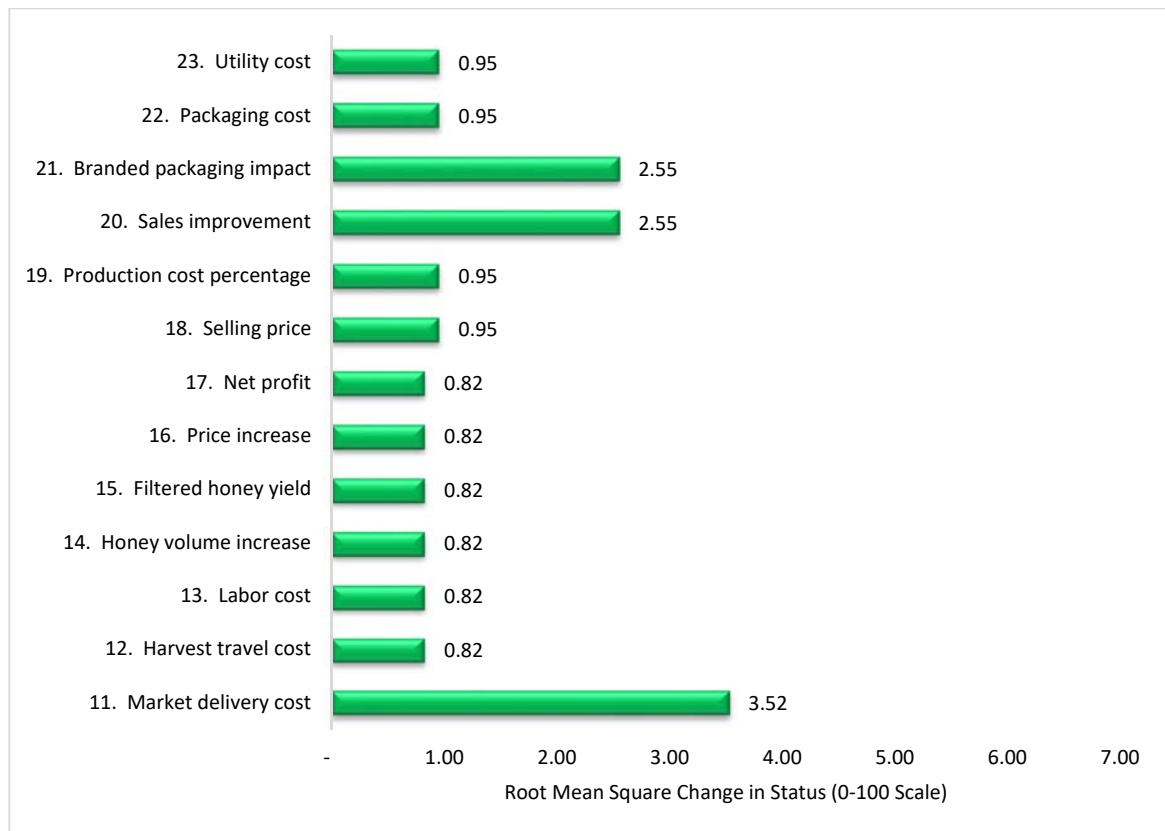


Fig. 5: Sensitivity of attributes in the economic dimension

a stress value of 0.11 and an R^2 of 0.99. The Monte Carlo simulation results yielded a score of 82.17 with a dense repetition distribution (Table 5). These findings indicate that community involvement plays a significant role in supporting the sustainability of forest honey production. The leverage factor analysis for the social dimension reveals that the frequency of training (3.68%) is the most dominant attribute influencing the sustainability index (Fig. 6). Training frequency is directly related to increasing the knowledge capacity of honey hunters regarding harvesting practices that optimize both the quantity and quality of honey, as well as understanding the benefits of forest honey sustainability. Higher training frequency correlates positively with the quality of forest honey production. Structured and repeated training can strengthen network governance, accelerate the adoption of sustainable production practices, and enhance ecosystem conservation participation (Punya *et al.*, 2024). Meanwhile, the attributes within the social

dimension that have the lowest impact are price negotiation and education outreach, each contributing only 0.93%. Price negotiation reflects the capacity of honey hunters to negotiate the selling price of honey with buyers (Hernandez-Martinez *et al.*, 2021). This attribute represents structural social change, such as the formation of community institutions or networks. Education outreach relates to efforts in increasing community education and public awareness about the benefits of honey and sustainability. Although it raises awareness, this attribute also influences social sustainability through the formation of groups and collective forest honey production practices. However, these impacts tend to be indirect and temporal, placing them in the category of low leverage. Furthermore, price negotiation and education outreach show low impacts in the social sustainability analysis because their contributions are individual, long-term, and dispersed, rather than contributing to the establishment of robust social systems and institutions.

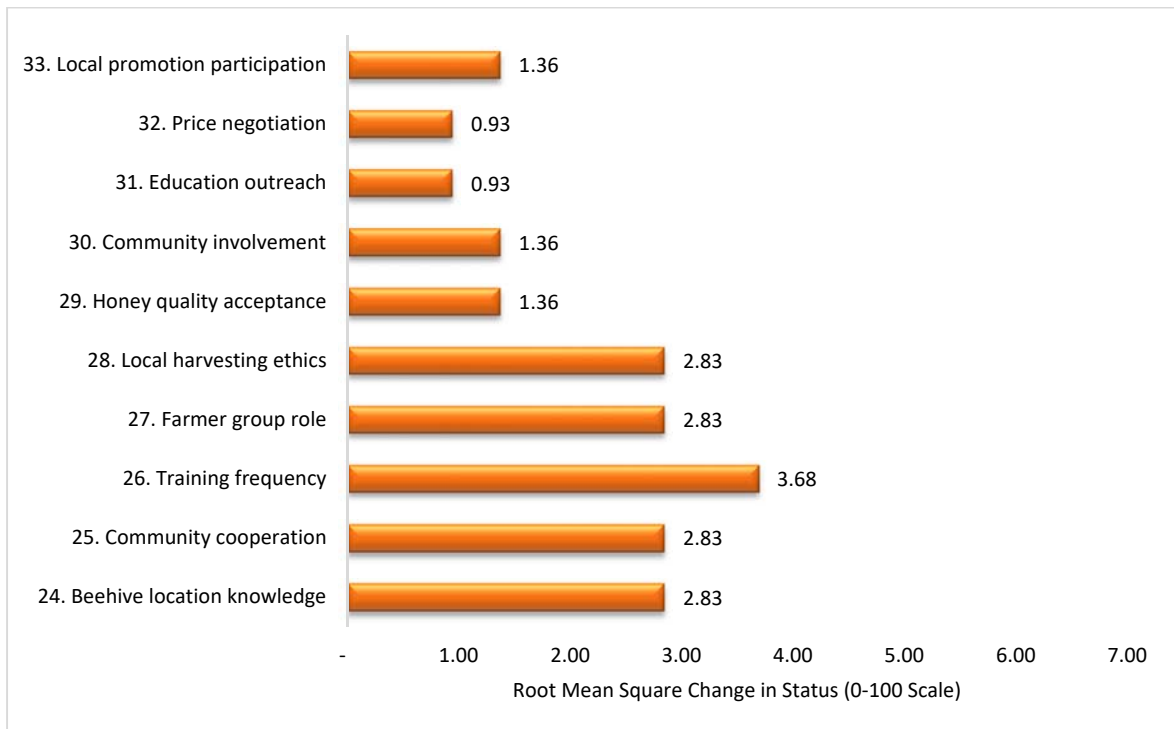


Fig. 6: Sensitivity of attributes in the social dimension

Four other attributes, namely Local harvesting ethics, Farmer group role, Community cooperation, and Beehive location knowledge, each have a leverage value of 2.83% and are interrelated in strengthening the structure of local social systems (Fig. 6). Local harvesting ethics function to prevent habitat degradation and preserve the cultural values of the community. The role of farmer groups has been shown to enhance institutional capacity, broaden access to information, and strengthen bargaining power. Community cooperation is essential for building locally based distribution systems and reinforcing promotional networks. Accurate knowledge of beehive locations correlates with the productivity and stability of forest honey production. Meanwhile, attributes such as Local promotion, Honey quality acceptance, and Community involvement have leverage values of 1.36%, while Price negotiation and Education outreach each have a leverage value of 0.93%. Although these values fall below the 2% threshold, the attributes remain relevant in strengthening social capacity and collective awareness, even if their impact on changes in social sustainability status is indirect. The social dimension plays a vital role in ensuring the

sustainability of forest honey production. High-leverage attributes such as training frequency, the role of farmer institutions, and community cooperation serve as key social foundations that can be mobilized to increase competitiveness and the long-term sustainability of the production system. On the other hand, low-leverage attributes still act as supporting elements in fostering an inclusive and resilient social environment. A participatory approach and active community engagement are essential to the success of the social transformation rooted in the forest honey ecosystem in Riau Province. To enhance social sustainability in forest honey production, several actions can be taken. These strategies include conducting regular and continuous training by organizing sessions at least two to three times per year, covering ethical harvesting techniques, post-harvest management, and product marketing. These trainings should be tailored to local conditions and involve supporting partner organizations. Furthermore, strengthen farmer institutions and harvesting ethics by encouraging the formation of legally recognized cooperatives or beekeeping and honey hunter groups, supported by a harvesting Standard Operating Procedure (SOP) that

promotes habitat conservation and ecological ethics. Additionally, promoting local educational campaigns and product marketing by implementing public education programs and local promotions through village events, honey festivals, and digital platforms to raise awareness, enhance the social value of forest honey, and increase youth engagement.

Technology dimension

The sustainability analysis of the five attributes indicates that the technological aspect is moderately sustainable, as evidenced by a sustainability index score of 66.49%, a stress value of 0.09, and an R^2 of 0.99. The Monte Carlo simulation produced a score of 65.85 with a dense distribution of iterations (Table 5). Within the technological dimension, the attribute with the greatest influence is the utilization of digital marketing and digital record-keeping, with a leverage value of 4.09% (Fig. 7). This indicates that the implementation of digital marketing has proven effective in enhancing product visibility, expanding market access, and improving sales record management, particularly in the premium market segment. These findings align with previous research showing that honey enterprises in Indonesia adopting digital marketing strategies experienced increased resilience and sales growth under certain conditions, such as during the COVID-19 pandemic. Active use of websites significantly improves consumer responsiveness and accelerates sales conversion. The digital record-keeping attribute highlights the importance of digitized records in managing production systems. The digitalization of production, financial, and supply chain data enables real-time quality tracking and simplifies the auditing process. Platforms such as ApiManager and HiveTracks are widely used for managing colony data, bee health, and production efficiency (Volokhovych, 2024). Moreover, Internet of Things (IoT) technologies contribute to more accurate and timely monitoring of beekeeping operations. Leverage values ranging from 2% to 4% reflect a moderate but significant impact, suggesting that technology-based interventions should be prioritized in strategies to develop a sustainable production system. With the highest leverage value of 4.09%, digital marketing is categorized as an influential factor. Its application has clearly demonstrated the ability to boost product visibility, broaden market reach, and enhance sales records, especially in premium segments. A study by Putria-

mara *et al.* (2023) revealed that honey businesses in Indonesia that adopted digital marketing strategies showed increased resilience and sales growth during the COVID-19 pandemic. Active website utilization significantly improves customer response and accelerates sales conversions.

The Digital Record-Keeping attribute shares the highest leverage value of 4.09%, indicating its critical role in the management of production systems. The digitalization of production, financial, and supply chain data enables real-time quality tracking and facilitates the auditing process. Platforms such as ApiManager and HiveTracks have been widely used for managing colony data, bee health, and production efficiency (Volokhovych, 2024). IoT technologies also contribute significantly to the accuracy and precision of operational monitoring in beekeeping practices. The Storage method attribute recorded a leverage value of 3.91%, suggesting that proper storage methods have a considerable impact on product sustainability. Storing honey under controlled temperature and humidity conditions helps preserve its chemical and microbiological quality and prevents fermentation or contamination. IoT technology can be utilized to monitor hive temperature and humidity in real time, thus protecting against post-harvest spoilage and quality degradation (Krishnasamy *et al.*, 2023). Two other attributes, Temperature control and laboratory testing, each recorded leverage values of 2.33%. Temperature regulation and laboratory testing are essential components of quality assurance systems. Innovative technologies, such as IntelliBeeHive, facilitate precise environmental monitoring through temperature-based data collection, while visual recognition methods enable the identification of ion activity, assessment of bee health, and detection of disease risks, thereby enhancing the comprehensiveness and scientific rigor of hive quality evaluations (Alex *et al.*, 2024). Meanwhile, other attributes such as filtration, labeling, moisture reduction tools, and extraction methods showed leverage values below 2%, indicating that their individual contribution to the sustainability index is relatively low. However, collectively, these attributes still play a vital role in shaping an integrated technological system that supports holistic and sustainable honey production practices. The following recommendations can be implemented to enhance technological sustainability in forest honey production systems. The first is comprehensive adop-

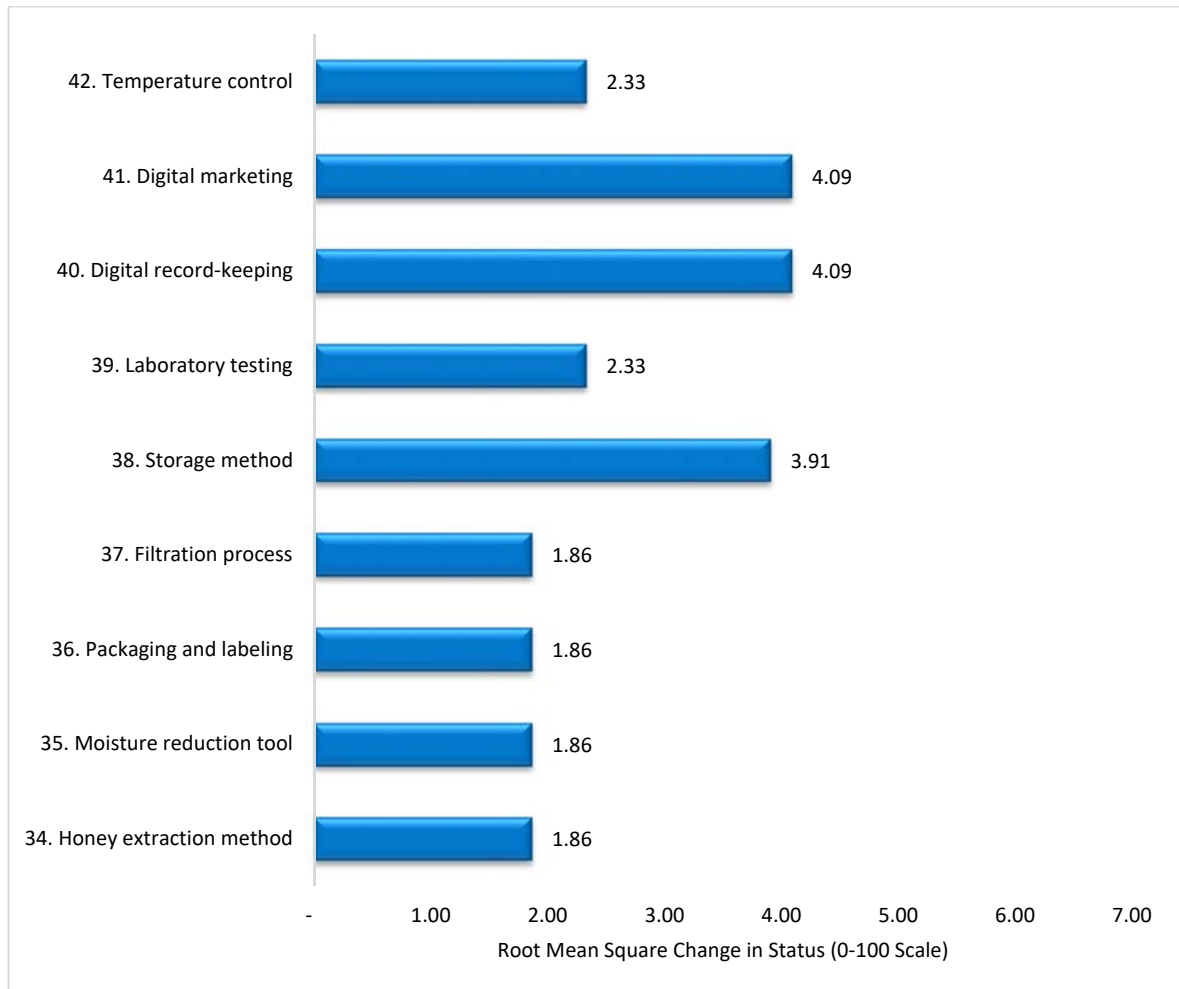


Fig. 7: Sensitivity of attributes in the technological dimension

tion of digitalization by encouraging the use of digital platforms such as social media, websites, and online marketplaces to expand market reach and strengthen the identity of local honey products. Furthermore, the implementation of digital record-keeping systems through the integration of digital platforms such as HiveTracks or ApiManager for efficient and structured management of production and financial data. Additionally, improvement of storage facilities and quality testing by ensuring proper temperature and humidity control, along with the establishment of local laboratories to conduct routine honey quality testing in accordance with national food safety standards. Finally, technology training for honey producers through intensive capacity-building programs for honey hunters and beekeepers focused on the use

of digital tools, quality monitoring, and data-driven product evaluation.

Institutional dimension

The institutional dimension has the lowest sustainability index compared to the other dimensions, as indicated by a sustainability index score of 58.51%, with R^2 of 0.99 (Table 5). The Monte Carlo simulation yielded a similar score of 58.51, with a tightly clustered repetition distribution. The attribute with the highest impact, SNI certification of forest honey products, has a leverage value of 6.01% (Fig. 8). SNI certification, including international standards such as ISO 22000, plays a crucial role in ensuring the quality, safety, and credibility of honey products. These certifications not only enhance consumer trust but

also broaden market access, especially for export and premium market segments. Quality certification significantly improves product quality perceptions and economic value among global consumers (Huang *et al.*, 2024). The attributes Participatory Monitoring and Management Structure recorded leverage values of 4.34% each, indicating a moderate to strong influence. Participatory monitoring within the forest honey institutional system fosters transparency, accountability, and trust among farmers and stakeholders. Furthermore, a well-established institutional structure, such as legally recognized and active cooperatives or farmer groups, has a direct impact on the success of production management, quality control, marketing, and access to financing. Collaborative monitoring systems between village governments and beekeeping groups have been shown to significantly improve regulatory compliance, organizational stability, and long-term institutional sustainability (Roengtam and Agustiyara, 2022).

On the other hand, several other attributes showed leverage values below 2% and are thus categorized as having insignificant influence. Attributes such as member attendance, activity planning, and legal group basis, while essential for the day-to-day operations of farmer groups, do not exert a strong structural impact on the institutional sustainability index. Similarly, distribution permits, capacity building, and administrative completeness, though relevant from a governance perspective, have limited influence on institutional outcomes based on the MDS results. There are recommendations to improve the stability of forest honey production in the province. Firstly, improving access to certification (SNI), where local governments and supporting institutions should facilitate technical training, assistance in document preparation, and subsidize certification costs for SNI or other NTFP certification schemes. These efforts will enhance the product's added value and expand its market competitiveness. Furthermore, strengthening participatory monitoring systems by developing a collaborative reporting mechanism between honey farmer groups and stakeholders, including village authorities and forestry agencies.

This regular monitoring can be used to assess group performance, evaluate production quality, and ensure compliance with ethical and environmental standards. Additionally, optimizing the organizational structure of farmer groups by restructuring

institutional governance alongside management training, capacity building, and the development of standardized operating procedures. Such improvements are crucial for enhancing the group's legitimacy in the eyes of business partners and government bodies. Finally, formulating long-term strategies by encouraging each forest honey production group to develop business plans and long-term strategies, including market development, risk management, and institutional sustainability. This is essential to reduce dependency on short-term programs and strengthen organizational resilience.

The future and prospects of forest honey production

Forest honey production is one form of NTFP utilization that has high ecological, social, and economic value. In Riau Province, which is known for its peat swamp forests and tropical rainforests, forest honey is produced through traditional beekeeping practices rooted in the local wisdom of indigenous peoples and rural communities. Based on the sustainability dimensions, the environmental and economic dimensions fall into the strong category. This is attributed to the fact that forest ecosystems and floral forage sources still support honey production, combined with high market demand and the value of NTFPs. Literature indicates that tropical forest landscapes enhance the diversity of bee foraging resources and support the quality of forest honey, providing a competitive advantage in honey marketing. Another factor supporting the sustainability of honey production is consumer interest in health aspects, as the antioxidant content and biological properties of forest honey are often perceived as higher, boosting consumer perception of its health benefits and thus supporting product sustainability (Mahani *et al.*, 2025). These factors maximize market opportunities in line with the growing global demand for organic honey and environmentally friendly forest-based products (Bimbo *et al.*, 2025). The main constraints that need to be addressed from the institutional aspect are certification and organizational capacity. Forest honey production is currently still dominated by traditional production and distribution systems that are less adaptive to technological developments and global quality standards (Harianja *et al.*, 2023). This results in low supply chain efficiency, potential loss of added value, and difficulties in penetrating export markets. The high leverage of SNI and certification (6.01) indi-

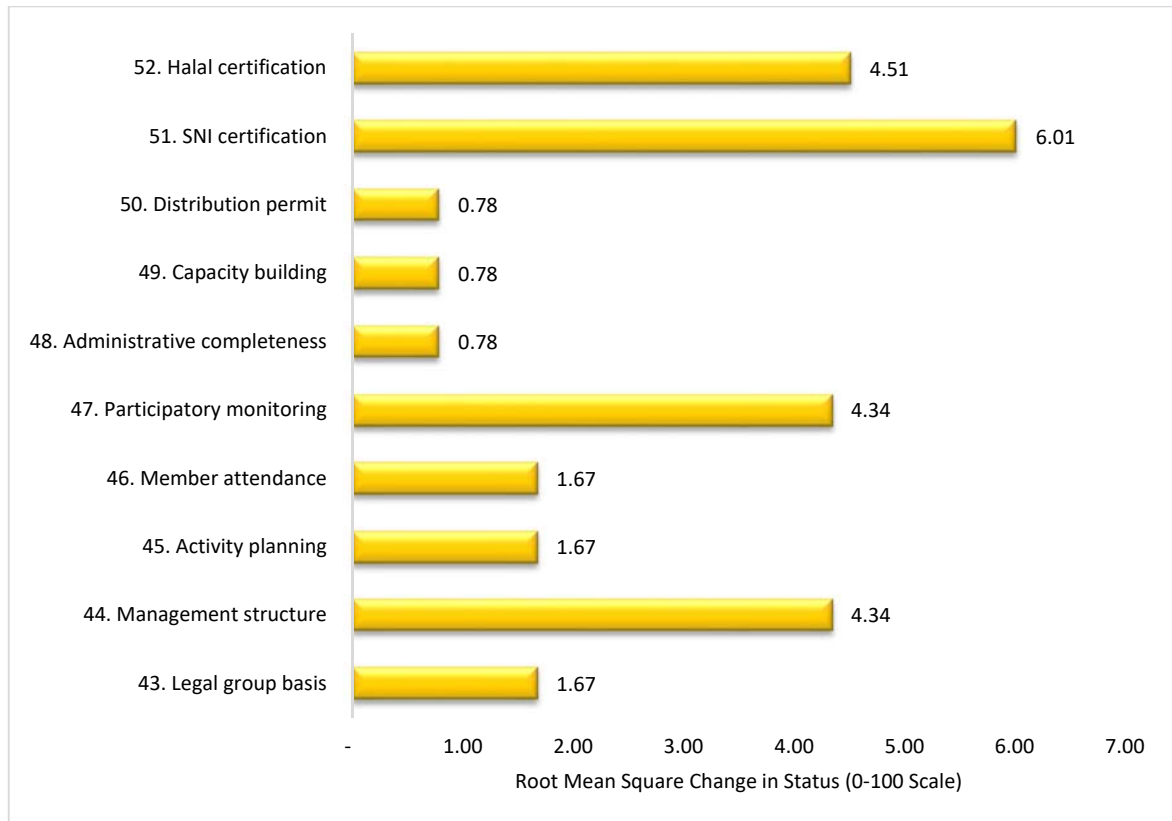


Fig. 8: Sensitivity of attributes in the institutional dimension

cates that the absence of or low compliance with national standards (SNI 8664:2018) and weak institutions (participatory monitoring, management structure) can restrict market access, particularly in premium and export segments. Without quality standards and certification, forest honey struggles to enter labeled markets (SNI, halal, organic), leading to lower prices and a higher risk of rejection. BSN/SNI 8664 is the quality reference that Indonesian producers need to comply with. From the technological aspect, namely digital marketing, digital record-keeping, and storage, digital marketing and record-keeping (RMSE ~ 4.09), as well as storage methods (~ 3.91), have a strong influence on the status. The lack of traceability, online marketing, and proper storage facilities causes products to lose value or deteriorate in quality (HMF, moisture content, and fermentation). Producers who adopt digital marketing and traceability systems can improve market reach, reputation, and selling value. Concerns have arisen regarding habitat fragmentation and the loss of forage trees

due to the conversion of natural forests in Riau into large-scale plantations such as oil palm and industrial timber estates. This conversion has led to the disappearance of *sialang* trees (*Koompassia excelsa*), which serve as nesting sites for wild honey bees (*Apis dorsata*). As a result, bee colony populations have declined, leading to reduced honey yields. Other environmental disturbances, such as forest and land fires, have direct impacts on bee habitats, colony migration, and population quality, resulting in drastic declines in forest honey production. Without habitat conservation and ecosystem regeneration efforts, forest honey production is at risk of sharp declines in the future. Currently, forest honey is not only an alternative source of income for farmers and forest-adjacent communities, but also plays an important role in supporting biodiversity conservation and ecosystem sustainability (Buchori et al., 2022). Building on these challenges, the following synthesis highlights how recommendations across all sustainability dimensions can be integrated to shape the future of

forest honey production. The sustainability assessment indicates that ecological, economic, and social dimensions are already relatively strong, while institutional and technological aspects require significant improvement. Therefore, future strategies must not only address weaknesses but also build on existing strengths through an integrated approach. Ecological sustainability should be reinforced by conserving *si-alang* trees and restoring flowering tree habitats, while economic value can be enhanced through certification, branding, and digital marketing. On the social side, continuous training and cooperative strengthening are essential for ensuring inclusive participation. Technological upgrades such as digital record-keeping, improved storage, and quality testing will raise product competitiveness, while institutional reforms, including participatory monitoring and easier access to certification, will ensure credibility and long-term resilience. This synthesis underscores the importance of viewing each dimension not in isolation but as interdependent pillars that must be advanced simultaneously to secure the future of forest honey production in Riau Province. Various efforts are needed to promote sustainable forest honey production. In light of the Social Forestry program, which provides legal access and institutional arrangements for forest communities to form farmer groups, this legality helps local communities access training, obtain capital, and improve marketing opportunities. Such support facilitates the transformation of forest honey production from a subsistence activity into a community-based sustainable management unit. Future strategies involving certification, strengthening of farmer institutions, digital marketing, and the application of post-harvest technologies are expected to enhance the competitiveness of Riau Forest honey in both domestic and international markets (Yunianto *et al.*, 2024). The government, which plays a central role in creating a policy framework and supervision that supports wild bee conservation, is expected to develop regulations for sustainable honey harvesting by establishing standard operating procedures for ethical harvesting that do not damage bee nests or habitats. The government should also take an active role in enforcing laws against land burning and illegal deforestation near bee habitats, strengthening the Social Forestry program as a platform for empowering forest-adjacent communities, providing technical assistance for local bee cultivation and sustainable

forest honey management, mapping and designating wild bee conservation zones into regional spatial plans, and integrating these efforts into climate change adaptation policies. As large-scale forest landscape users, Industrial Plantation Forest companies carry ecological responsibilities within their business practices, including the implementation of High Conservation Value and High Carbon Stock approaches to protect the natural habitats of bees within concession areas. They are expected to collaborate in bee agroforestry programs (*bee-friendly plantations*) that integrate local flowering species such as *Melaleuca*, *Acacia auriculiformis*, and *Shorea* spp., to implement environment-based Corporate Social Responsibility schemes through training for honey farmers, provision of sustainable harvesting equipment, and marketing support, as well as to monitor bee biodiversity as part of regular environmental impact assessments. Non-Governmental Organizations (NGOs) act as facilitators, providers of technical knowledge, and independent monitors of conservation efforts. Their roles include conducting outreach on sustainable honey harvesting techniques, training local farmers to strengthen their capacities, developing local certification systems such as forest honey eco-labels to increase product value without harming habitats, conducting research, monitoring wild bee populations to provide scientific data for policymaking, and engaging in advocacy for bee conservation as an indicator species of ecosystem health while promoting biodiversity. Local communities and honey farmers or honey hunters, as the main actors in honey harvesting, play a crucial role. They are expected to adopt sustainable harvesting techniques (honey hunting ethics), such as minimizing the use of fire, avoiding the felling of nesting trees, and practicing partial harvesting; conserve local flowering trees (bee forage flora) through agroforestry and reforestation practices; diversify their livelihoods based on honey and other NTFPs to reduce pressure on wild bees; and establish and strengthen forest honey cooperatives as collective platforms for production, marketing, and quality control. Therefore, an analysis of the prospects of forest honey production in Riau Province becomes essential. This study is important for formulating policies and intervention strategies capable of addressing multidimensional challenges to ensure the transformation towards an inclusive, adaptive, and sustainable forest honey production system.

CONCLUSION

This study concludes that forest honey production in Riau Province has reached a highly sustainable status, with an average sustainability index of 76.26%, primarily supported by strong environmental, economic, and social dimensions. The research offers novelty by applying an MDS approach that integrates ecological, economic, social, technological, and institutional aspects into a single sustainability assessment framework, which has rarely been applied to NTFPs such as forest honey. Ecological integrity, market potential, and community participation are relatively well established, whereas institutional and technological dimensions remain moderately sustainable, indicating the need for targeted improvements in eco-friendly distribution systems, digital record-keeping, advanced storage technologies, and institutional governance. Key leverage attributes such as selling price, training frequency, digitalization, and certification play a critical role in shaping holistic sustainability outcomes. Policy actions should prioritize strengthening technological capacities, enhancing the skills of honey hunters, and embedding participatory monitoring into institutional frameworks. These insights are highly relevant for regional governments, cooperatives, NGOs, and the private sector, as they provide an empirical basis for designing adaptive forest governance and community-based livelihood programs. Looking ahead, the sustainability assessment model developed in this study can be replicated in other regions of Indonesia to strengthen the management of non-timber forest products. Positioning forest honey as a flagship sustainable commodity not only enhances local economic competitiveness but also contributes to biodiversity conservation and climate resilience at the national level. The findings further highlight that forest honey production in Riau is not only an economic enterprise but also a cornerstone for biodiversity conservation and cultural heritage preservation. Strengthening farmer cooperatives, promoting ethical harvesting practices, and aligning production systems with global quality standards will enhance the competitiveness of Riau's Forest honey in both domestic and international markets. Collaborative efforts among government institutions, the private sector, NGOs, and local communities are vital for positioning forest honey as a flagship sustainable commodity that simultaneously supports rural livelihoods and safeguards ecosystems.

AUTHOR CONTRIBUTIONS

The study was conceptualized and designed by H. Ikhsani, H. Daulay, and A. D. Santoso, who laid the foundational framework for the research. Data collection was carried out by M. Maryani, A.D. Santoso, and E.T.B. Sabri, while the analysis and interpretation of the gathered data were subsequently performed by M. Maryani and A.D. Santoso. The initial manuscript was drafted by Hanifah Ikhsani, after which it underwent critical review and revision by H. Ikhsani, M. Maryani, and E.T.B. Sabri to ensure accuracy and coherence. Additional contributions, including technical support and other forms of assistance, were provided by E.T. B. Sabri, G. Mohta, and H. Daulay, who played supporting roles throughout the research process.

ACKNOWLEDGMENTS

Appreciation is extended to the experts and local communities who kindly shared their time and knowledge during the data collection process.

CONFLICT OF INTEREST

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy, have been completely addressed by the authors.

OPEN ACCESS

©2026 The author(s). This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution, and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made. The images or other third-party material in this article are included in the article's Creative Commons license unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this license, visit: <http://creativecommons.org/licenses/by/4.0/>

PUBLISHER NOTE

Tehran Urban Research & Planning Centre (TURPC) takes a neutral position about claims on disputed territories, place names, international boundaries, jurisdiction in published maps, and institutional affiliations. TURPC is committed to retracting a paper after its publication if it becomes apparent that there are serious problems in its content, in terms of research and publication ethics (<https://www.ijhcum.net/journal/process?ethics>).

ABBREVIATIONS (NOMENCLATURE)

%	Percent
AI	Artificial Intelligence
ALSCAL	Alternating Least Squares Scaling (an algorithm of MDS)
<i>d</i>	Euclidean Distance
<i>d_{ij}</i>	Euclidean distance from point <i>i</i> to point <i>j</i>
<i>d_{ijk}</i>	Squared distance
<i>E_q</i>	Equation
FGD	Focus Group Discussions
GHGs	Greenhouse Gases
IDR	Indonesian Rupiah
ISO	International Organization for Standardization
<i>i, j, k</i>	Dimensions
kg	Kilogram
MDS	Multidimensional Scaling
NGOs	Non-Government Organizations
NTFP	Non-timber forest product
<i>O_{ij}</i>	Point of origin
PDO	Protected Designation of Origin
PM	Particulate Matter
RAP	Rapid Appraisal
RAPFISH	Rapid Appraisal for Fisheries
<i>R</i> ²	Coefficient of Determination
SNI	Standar Nasional Indonesia (The Indonesian National Standard)
Stress	Dissimilarities in MDS
RMS	Root mean square
<i>S</i>	Stress
SOP	Standart Operation procedure

SQR	Structured Query Report
SDGs	Sustainable Development Goals
<i>y</i>	Year

REFERENCES

- Alex, A.J.; Barnes, C.M.; Machado, P.; Ihianle, I.; Markó, G.; Bencsik, M.; Bird, J.J., (2025). Enhancing Pollinator Conservation: Monitoring of Bees through Object Recognition. *Comput. Electr. Agric.* 228 (January):109665-109676 (12 pages).
- Allaily, A.; Santoso, A.D.; Rofiq, M.N.; Sasongko, N.A.; Daulay, H.; Wiloso, E.I.; Widjaja, E.; Utomo, B.N.; Yanuar, A.I.; Suryani, S. (2024). Sustainability assessment of animal feed production from by-products of sago palm smallholder industry. *Glob J Environ Sci Manag.*, 10: 1275–1296 (22 pages).
- Anita, D.; Musyafa, M.; Widyastuti, S.M., (2022). The potency of honey bee forage on beekeeping of Apis Cerana F. in Wanagama education forest, Gunungkidul, Yogyakarta. *JIK*, 16, 198–208 (11 pages).
- Arofi, F.; Rukmana, D.; Ibrahim, B., (2015). The analysis of integration sustainability of coffee plantation and goat husbandry (A case study in Ampelgading Subdistrict, Malang Regency, East Java, Indonesia); Online, *JESD*, Vol.6, No.10 (9 pages).
- Arzoumanidis, I.; Raggi, A.; Petti, L., (2019). Life cycle assessment of honey: Considering the pollination service. *Adm Sci.*, 9 (13 pages).
- Asmara, W.H.; Nurlia, A., (2020). Sialang honey: potency, productivity, and management in Musi Banyuasin (Case in Lubuk Bintialo Village, Musi Banyuasin Regency, South Sumatra) 8 (ICCESI 2019): 107–112 (6 pages).
- Bakrie, B.; Sirnawati, E.; Rohaeni, E.S.; Hutahaean, L.; Santoso, A.D.; Wasito, W.; Indrawanto, C., (2023). Sustainability analysis of intensive duck farming system in Sliyeg District, Indonesia: MDS and MICMAC analysis approach. *Intl. J. Sain. Dev. Plann.*, 18(10): 3181-3193 (13 pages).
- Bimbo, F.; Nico, K.; De Meo, E., (2022). Assessing the quality and floral variety market value: A hedonic price model for honey. *Sustainability*, 17(9), 3903 (16 pages).
- Buchori, D.; Rizali, A.; Priawandiputra, W.; Raffiudin, R.; Sartiami, D.; Pujiastuti, Y.; Jauharlina; Pradana, M.G.; Meilin, A.; Leatemia, J.A.; et al., (2022). Beekeeping and Managed Bee Diversity in Indonesia: Perspective and Preference of Beekeepers. *Diversity*, 14(1), 52 (14 pages).
- Djenontin, I.N.S.; Larson, A.M.; Miller, D.C., (2024). Trends in forest livelihoods research – taking stock in 2024. *For. Policy Econ.*, 169 (8 pages).
- Fadilah, S.; Rosdiana, Y.; Maemunah, M.; Hernawati, N.; Sukarmanto, E.; Hartanto, R., (2021). Multidimensional Scaling (MDS): Sustainability assessment model of community economic empowerment. *Polish J. Manage. Studies*, 24, 119–135 (17 pages).
- Handayani, T.; Santoso, A.d; Sastranegara, M.H.; Lestari, S.; Djarot, I.N.; Widyastuti, N.; Nuha, N.; Sitomurni, A.I.; Hadi, A.; Prihatin, A.L.; Suryanto, F., (2025). Assessing the multidimensional sustainability of crystal coconut sugar production in Banyumas Regency, Central Java, Indonesia. *Intl. J. Design Nature Ecodynamics*, 20: 147–158 (12 pages).
- Harbi, J.; Cao, Y.; Milantara, N.; Mustafa, A.B., (2023). Assessing the sustainability of NTFP-based community enterprises: A viable business model for Indonesian rural forested areas. *Forests*, 14 (24 pages).
- Harianja, A.H.; Adalina, Y.; Pasaribu, G.; Winarni, I.; Maharani, R.; Fernandes, A.; Saragih, G.S.; Fauzi, R.; Tampubolon, A.P.; Njurumana, G.N.; et al., (2023). Potential of beekeeping to support the livelihood, economy, society, and environment of

- Indonesia. *Forests*, 14 (37 pages).
- Hernandez-Martinez, N.; Mutlu, N.; Fransoo, J.C., (2021). Social equity in supplier–buyer relationships in smallholder agri-food supply chains. *Flex Serv. Manuf. J.*, 33, 1027–1089 (63 pages).
- Huang, A.; Liu, X.; Rao, C.; Zhang, Y.; He, Y., (2022). A new container throughput forecasting paradigm under COVID-19. *Sustainability*, 14(5), 2990 (20 pages).
- Irmawanty, I.; Syam, H.; Rufaidah, S.(2023). pemanfaatan inovasi teknologi pada proses produksi madu yang berkualitas dan berkelanjutan. *Madaniya*, 4, 1155–1161 (7 pages).
- Kavanagh, P.; Pitcher, T.J., (2004). Implementing Microsoft Excel software For Rapfish: A technique for the rapid appraisal of fisheries status, Vol. 12 (80 pages).
- Krishnasamy, V.; Sridhar, N.; Niranjan, L., (2023). An IoT-based beehive monitoring system for real-time monitoring of Apis Cerana Indica colonies. *Sociobiology*, 70, 1–12 (12 pages).
- Landaverde, R.; Rodriguez, M.T.; Parrella, J.A., (2023). Honey production and climate change: Beekeepers' perceptions, farm adaptation strategies, and information needs. *Insects*, 14 (16 pages).
- Lloyd, C.; Ananthan, P.S.; Ramasubramanian, V.; Sugunan, V. V; Panikkar, P.; Landge, A.T., (2022). Rapid reservoir fisheries appraisal (r-RAPFISH): Indicator based framework for sustainable fish production in Indian reservoirs. *J. Clean Prod.*, 379, 134435 (17 pages).
- Mahani; Ferdian, P.R.; Ghibran, H.M.; Herlina, A.F.; Nurhasanah, S.; Nurjanah, N.; Elfirta, R.R.; Pribadi, A.; Amalia, R.L.R.; Samudra, I.M., (2025). A report on the physicochemical and antioxidant properties of three Indonesian forest honeys produced by Apis Dorsata. *Food Chem. X*, 25 (12 pages).
- Min, T.; Lu, K.; Chen, J.; Niu, L.; Lin, Q.; Yi, Y.; Hou, W.; Ai, Y.; Wang, H., (2023). Biochemical mechanism of fresh-Cut Lotus (*Nelumbo Nucifera* Gaertn.) Root with exogenous melatonin treatment by multiomics analysis. *Foods*, 12 (18 pages).
- Pignagnoli, A.; Pignedoli, S.; Carpana, E.; Costa, C.; Prà, A.D., (2021). Carbon footprint of honey in different beekeeping systems. *Sustainability*, 13(19): 11063 (14 pages).
- Pitcher, T.J.; Preikshot, D., (2001). Rapfish: A rapid appraisal technique to evaluate the sustainability status of fisheries. *Fish Res.*, 49, 255–270 (16 pages).
- Pribadi, A.; Wiratmoko, M.E., (2020). Karakter madu lebah hutan (*Apis dorsata* Fabr.) dari berbagai bioregion di Riau. *J. Penelitian Hasil Hutan*, 37, 184–196 (13 pages).
- Punya, S.; Sinpoo, C.; Phokasem, P.; Disayathanoowat, T., (2024). Exploring network governance in sustainable beekeeping management in the Mekong subregion and its challenges. *Front Sustain. Food Syst.*, 8 (12 pages).
- Putritamara, J.A.; Hartono, B.; Toiba, H.; Utami, H.N.; Rahman, M.S.; Masyithoh, D., (2023). Do dynamic capabilities and digital transformation improve business resilience during the COVID-19 pandemic? Insights from beekeeping MSMEs in Indonesia. *Sustainability*, 15(3), 1760 (21 pages).
- Roengtam, S.; Agustiyara, A., (2022). Collaborative governance for forest land use policy implementation and development. *Cogent Soc. Sci.*, 8 (16 pages).
- Rohaeni, E.S.; Ilham, N.; Saptati, R.A.; Rahayu, H.S.P.; Priyono; Anggraeny, Y.N.; Qomariah, R.; Pamungkas, D.; Ermuna, S.S.; Mahendri, I.G.A.P.; et al., (2024). Developing a sustainable beef cattle business model for smallholder farms in South Kalimantan's drylands. *Intl. J. Sus. Dev. Plann.*, 19: 481–500 (20 pages).
- Santoso, A.D.; Arianti, F.D.; Rohaeni, E.S.; Haryanto, B.; Pertiwi, M.D.; Panggabean, L.P.; Prabowo, A.; Sundari, S.; Wijayanti, S.P.; Djarot, I.N.; Kurniawati, F.D.; Sahwan, F.L.; Prasetyo, T.; Barkah, A.; Adibroto, T.A.; Ridlo, R.; Febijanto, I.; Wasil, A.A.; Lusiana, S.; Rosmeika, R.; Heryanto, R.B., (2023a). Sustainability index analysis of the organic fertilizer production from ruminat and rice straw waste *Global J. Environ. Sci. Manage.*, 9(SI): 193-218 (26 pages).
- Santoso, A.D.; Hariyanti, J.; Pinardi, D.; Kusretuwardani; Widyastuti, N.; Djarot, I.N.; Handayani, T.; Sitomurni, A.I.; Apriyanto, H., (2023b). Sustainability index analysis of microalgae cultivation from biorefinery palm oil mill effluent. *Global J. Environ. Sci. Manage.*, 9(3): 559-576 (18 pages).
- Sittadewi, E.H.; Tejakusuma, I.G.; Handayani, T.; Santoso, A.D.; Tohari, A.; Mulyono, A.; Zakaria, Z.; Budiman, E.B.; Fatahillah, H.E.H.; Fitriani, R., (2025). Novel rap-landslide method for assessing agroforestry sustainability in landslide-prone areas. *Resources*, 14: 93 (28 pages).
- Stepanova, A.Y.; Gladkov, E.A.; Osipova, E.S.; Gladkova, O.V.; Tereshonok, D.V., (2022). Bioremediation of soil from petroleum contamination. *Processes*, 10 (17 pages).
- Susanto, A.A.; Qomar, N.; Rifai, A., (2022). Analysis of households welfare forest honey harvester in tesso nilo national park and surroundings in Riau Province., 18, 45–54 (10 pages).
- Triyatno, T.; Febriandi, F.; Rahmi, L.; Falah, N.; Fauzan, M.R.; Prayoga, R.; Mardiansyah, R., (2024). pemberdayaan masyarakat dalam optimalisasi budidaya lebah madu berbasis agroforestri. *JMM (Jurnal Masyarakat Mandiri)*, 8, 713-724 (12 pages).
- Yumantoko; Al Hasan, R.; Wahyono, E.; Wicaksono, A.; Agustine, R.; Ishak, A.; Manan, A., (2025). Income contribution from forest honey: digital era opportunities for economic and environmental sustainability in Sumbawa. *IOP Conf. Ser. Earth Environ. Sci.*, 1438 (15 pages).
- Yunianto, A.S.; Pribadi, A.; Kurniawan, H.; Junaedi, A.; Wahyuningsih, S.; Wiratmoko, M.D.E., (2024). Small and medium scales business development model and value chain of Apis mellifera I. bee cultivation in Riau Province. *Jurnal Ilmu Kehutanan*, 18, 49–58 (10 pages).
- Zahrawi, A.A.; Aly, A.M., (2024). A Review of Agrivoltaic Systems: Addressing challenges and enhancing sustainability. *Sustainability*, 16(18), 8271 (36 pages).

COPYRIGHTS

©2026 The author(s). This is an open-access article distributed under the terms of the Creative Commons Attribution (CC BY 4.0), which permits unrestricted use, distribution, and reproduction in any medium, as long as the original authors and source are cited. No permission is required from the authors or the publishers.



HOW TO CITE THIS ARTICLE

Ikhsani, H.; Maryani, M.; Sabri, E.T.B.; Mohta, G.; Santoso, A.D.; Daulay, H., (2026). Strengthening non-timber forest product sustainability: A multidimensional framework for forest honey management. *Int. J. Hum. Capital. Urban Manage.*, 11(4): 810-830

DOI: 10.22034/IJHCUM.2026.04.11

URL: https://www.ijhcum.net/article_737441.html

