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# Assessment of Status and Sustainability Index for Smallholder Rubber Plantation in Riau Province of Indonesia

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**ABSTRAK**

Konversi perkebunan karet menjadi perkebunan kelapa sawit di Provinsi Riau menimbulkan kekhawatiran akan menurunnya komoditas karet. Secara historis, provinsi ini telah menjadi penghasil utama komoditas tersebut di Indonesia. Sebaliknya, perkebunan karet milik masyarakat semakin berkurang sehingga menimbulkan siklus permasalahan yang menyulitkan program-program yang ramah lingkungan. Oleh karena itu, penelitian ini bertujuan untuk mengkaji keberlanjutan perkebunan karet rakyat di Riau. Berdasarkan pengamatan, analisis RapRubber yang komprehensif menghasilkan indeks sebesar 39,76, yang mengklasifikasikan status sebagai kurang berkelanjutan. Hasil penelitian menunjukkan bahwa pengelolaan perkebunan karet berada dalam tekanan. Jika ditelaah lebih detail, dimensi ekologi memiliki indeks sebesar 43,22 sehingga masuk dalam kategori kurang berkelanjutan. Dimensi ekonomi memperoleh skor 50,80 yang berarti relatif berkelanjutan. Sebaliknya, dimensi sosial berkurang dengan indeks sebesar 25,25 sehingga tergolong kurang berkelanjutan. Atribut yang berkontribusi terhadap ketidaklestarian dimensi ekologi adalah frekuensi kebakaran dan dampaknya, sedangkan faktor yang berkontribusi terhadap kurang keberlanjutan dimensi sosial mencakup metode awal pembukaan lahan, praktik pelestarian, dan kearifan lokal. Dalam dimensi ekonomi, status lahan dan harga merupakan faktor penentu keberlanjutan.

***Kata kunci***: Indeks Keberlanjutan, Karet, Perkebunan, Hutan, Provinsi Riau

**ABSTRACT**

The conversion of rubber plantation to oil palm cultivation in Riau province is raising concerns regarding the decline of rubber commodity. Historically, the province has been a key producer of such commodity in Indonesia. The community-owned rubber plantation, on the other hand, is diminishing, leading to a troubling cycle that makes it difficult to establish environmentally sustainable programs. Therefore, this research aimed to assess sustainability of smallholder rubber plantation in Riau. It was observed that the comprehensive RapRubber analysis yielded an index of 39.76, classifying status as less sustainable. The results showed that the management of rubber plantation was under pressure. In a more detailed analysis, the ecological dimension had an index of 43.22, placing it in the less sustainable category. The economic dimension scored 50.80, signifying a relatively sustainable status. In contrast, the social dimension reduced with an index of 25.25, classifying it as less sustainable. The attributes that contributed to the unsustainability of the ecological dimension were fire frequency and by-products, while the factors contributing to less sustainability of the social dimension included the initial land-clearing methods, preservation practices, and local wisdom. In the economic dimension, land status and pricing were essential determinants of sustainability.

***Keywords***: Sustainability Index, Rubber, Plantation, Forest, Riau Province

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## 1. INTRODUCTION

Indonesia is one of the largest agricultural countries, with an expansive land area covering approximately 1.9 million square kilometers. As an agrarian country, it is blessed with abundant natural resources and fertile land. Several key sectors such as agriculture, forestry, and fisheries play important roles in driving national development, fostering job creation, elevating community income levels, and contributing substantially to the Indonesian foreign exchange earnings through international trade (Anggraeni et al., 2023). Within the framework, plantation sector represents a key supporting industry that significantly enhances the foreign exchange income (Priyadi et al., 2022).

Rubber, a fundamental commodity within this thriving plantation sector, holds a prominent position as one of the flagship export products (Pramananda et al., 2022). Furthermore, rubber is a critical commodity in the global plantation sector, particularly in tropical regions, where it plays a significant role in the economies of producing countries. As one of the flagship export products, rubber contributes substantially to national revenue and employment, making it essential for the livelihoods of millions of smallholders and laborers (Khan et al., 2020). The rubber industry has evolved into a highly competitive market, driven by increasing demand for rubber products across various industries, including automotive, construction, and consumer goods (Chen et al., 2021).

The prominence of rubber as an export commodity is particularly evident in countries like Thailand, Indonesia, and Malaysia, which are among the largest producers and exporters of natural rubber globally (FAO, 2023). These countries benefit from favorable climatic conditions and extensive plantation systems that enable large-scale production. However, the sector faces challenges such as fluctuating market prices, environmental concerns related to deforestation and land-use change, and the impacts of climate change on rubber yield and quality (Wang et al., 2022). Moreover, the rubber industry is increasingly scrutinized for its sustainability practices. Concerns over environmental degradation and social issues, such as labor rights and community engagement, have prompted the adoption of more sustainable practices and certifications (Saha et al., 2022). The integration of sustainable practices not only addresses these concerns but also enhances the industry's resilience to market fluctuations and environmental challenges, ensuring the long-term viability of rubber as a key export commodity (Nair et al., 2023).

Globally, Indonesia has the largest plantation area and plays a crucial role in supplying approximately 25% of the natural rubber production (Sitepu et al., 2019). Rubber is a crucial material due to its renewable nature and exceptional elasticity properties. However, the global demand for the commodity continues to increase because of its wide-ranging applications in essential daily items, including gloves, belts, soles, vehicle tires, spare parts, industrial testing equipment, and medical devices (Sitepu et al., 2019)(Phoungthong et al., 2021).

Indonesia was the second-largest rubber producer in the world from 2018 to 2022, contributing 25.85% to the total output (Jenderal, 2023). In 2021, Riau became one of the leading province in the production of the commodity, with a total output of 299,068 tons and an average monthly production of 24,000 to 25,000 tons (Statistik, 2021). The provincial statistics data released in 2022 showed that Riau comprised a total smallholder plantation area of 490,301 hectares, yielding an output of 430,031 tons (Badan Pusat Statistik Provinsi Riau, 2022). The conversion of rubber plantation to oil palm cultivation in the province raises concerns about the decline of rubber commodities. Historically, Riau has been a key producer of such commodity in Indonesia. Community-owned rubber plantation, on the other hand, are diminishing, creating a detrimental cycle, and it presents challenges for integrating sustainable and environmentally friendly programs, an issue that has seemingly been overlooked (Roza Yulida et al., 2021).

In the Indonesian rubber industry, the issue of low-quality rubber mainly produced by farmers in specific productive areas, has serious implications for their incomes. The quality of the commodity is assessed based on the Indonesian Rubber Standard (SKI), which is in line with ISO 2000-2014 standards. This international benchmark evaluates various aspects of rubber quality, including dirt content, ash, nitrogen, volatile matter, and other components. Meanwhile, a significant portion of Indonesian rubber fails to meet such standards, making it less competitive than others in Thailand and Malaysia.

The discrepancy can be attributed to the prevalence of small-scale farmers who often struggle to adapt to contemporary industry requirements. These interconnected factors collectively contribute to the limited use of rubber in the domestic market, as it cannot be readily processed into finished products (Antoni and Tokuda, 2019)(Glorya and Nugraha, 2019). The situation profoundly impacts sustainability of rubber, affecting economic viability, environmental considerations, and the broader social acceptance and adoption of farming practices by all stakeholders.

Considering that small-scale rubber plantations in Riau Province, Indonesia, are vital to the economy and livelihoods of local communities, however they face sustainability challenges due to price fluctuations, environmental degradation and limited access to modern practices. Assessing its sustainability is urgent to ensure long-term viability, which is essential for economic stability, environmental conservation and social well-being. The proposed research will use sustainability indices and status assessments to systematically evaluate economic, environmental and social factors. This approach will provide objective insight into current conditions, guide policy, and suggest sustainable practices. Thus this research aims to assess sustainability, develop relevant indices, and identify factors to improve long-term survival.

## 2. METHODS

### 2.1. Location and Time Research

This research was conducted for approximately six months in 2019, specifically within the Riau Province. The research for this study was conducted in 2019, approximately five years prior to this publication. Given the time that has elapsed, it is essential to justify the continued validity of the research findings, particularly the status assessment and sustainability index of smallholder rubber plantations in the Riau Province. Although the research was carried out before the onset of the COVID-19 pandemic, careful consideration has been given to the stability of the factors assessed during that time. The condition of the research object the smallholder rubber plantations has not significantly changed since the study was conducted. This assertion is supported by the consistency in agricultural practices, land use patterns, and the economic conditions of the smallholders over the intervening years. Furthermore, the perceptions of society and other stakeholders, including smallholders, government agencies, and market participants, are assumed to remain largely unchanged. This assumption is based on the continuous economic reliance on rubber plantations in the region and the lack of major policy shifts or environmental changes that would significantly alter the sustainability indices originally recorded. Consequently, it focused on the central rubber plantation areas situated in specific districts and cities, including Kuantan Singingi (8), Kampar (5), and Rokan Hulu (7). The research locations were shown in Figure 1.

### 2.2. Operational Definition of Research Variable

Several components and their respective indicators were elucidated in the operational definition of research variables. More detailed information can be found in Table 1.

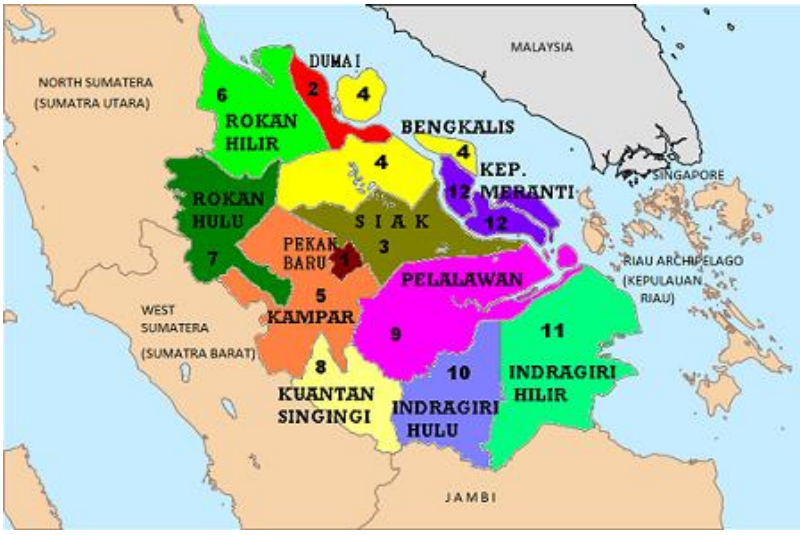


**Figure 1.** Research Location Map

**Table 1.** Operational Definition of Research Variables

| No | Dimension | Definition | Indicator |
|---|---|---|---|
| 1 | Ecologic | A core facet of sustainable plantation management is to ensure the long-term preservation of ecosystem functions and their components (abiotic and biotic). | 1. Erosion control activities<br>2. Impact of pesticides<br>3. Impact of fertilization<br>4. Irrigation/drainage system<br>5. Effect of decomposition<br>6. Frequency of fires<br>7. Side commodities<br>8. Soil pH |
| 2 | Economic | Another dimension focused on the outcomes of sustainable plantation management, ensuring well-being and social integration through variables such as community access and control over forest resources, control of the impacts of plantation operations on communities, and harmonious labor relations between management units and workers. | 1. Income<br>2. Use of labor<br>3. Price<br>4. Land area<br>5. Land status<br>6. Marketing<br>7. Availability of pesticides<br>8. Availability of fertilizer<br>9. Fertilization |
| 3 | Social | A part of forest management activities aimed at enhancing the benefits of the management unit for the local community. | 1. Engagement of farmer groups<br>2. Preservation steps<br>3. The initial method of land clearing<br>4. Changes in the production process<br>5. Application of technology<br>6. Local wisdom<br>7. Government policy<br>8. Rengkink Result<br>9. Supporting institutions |

### 2.3. Types and Sources of Data

The data collected comprised both primary and secondary sources. Primary data were obtained directly in the field through interviews and assessment of smallholder rubber plantation in the research area. Meanwhile, secondary data were sourced from literature and documents associated with rubber plantation management in Riau. A more detailed breakdown of data types and sources was presented in Table 2.

### 2.4. Data Collection Method

The data collection methods included surveys and literature reviews. Surveys were meant to gather primary data through interviews and visual observations of the existing management practices. Meanwhile, the literature reviews were used to obtain secondary data in the form of documents related to rubber plantation management in Riau. A comprehensive breakdown of the data collection methods was presented in Table 3.

### 2.5. Research Data Analysis Method

The data analysis methods were tailored to meet the research objectives and included community perception analysis through descriptive and MDS methods using the Raprubber software (modified Rapfish). A more detailed data analysis was presented in Table 4.

### 2.6. Respondent (Expert)

To meet specific requirements, a total of 5 respondents, including bureaucrats, academics, practitioners, community leaders, and non-governmental organizations were selected for in-depth interviews. The complete number of experts selected as respondents was detailed in Table 5.

### 2.7. Analysis Data Method

#### 2.7.1. Sustainability Analysis/Multi-Dimensional Scaling Analysis (MDS)

MDS analysis, a statistical tool, was used to discern the positions of objects by evaluating their similarities or differences. MDS served as a common technique for appraising respondents based on their resemblance in relation to stimuli or choices described through indicators or attributes. The application of MDS was aimed at representing the similarities among objects within a specific group (Fadilah et al., 2021). In the context of this research, the sustainability analysis aimed to provide an overview of the sustainability status of smallholder rubber plantation in Riau. The analysis was conducted using the MDS method, specifically with the Rapfor software, which was a modified version of Rapfish, signifying "Rapid Appraisal for Forest."

**Table 2.** Types and Sources of Data for Research on the Management Level of Rubber Plantation in Riau

| Aspect | Variable | Types Data | Data Sources |
|---|---|---|---|
| The perception of rubber farmers regarding the concept of sustainability | Fundamental knowledge of sustainability concepts and sustainability implementation | Primary data | Results of the primary data analysis |
| The level/status of sustainability management | Dimensions and attributes of sustainability | Primary data and secondary data | Results of the secondary data analysis |

**Table 3.** Data Collection Method

| Purpose | Variable | Data Type | Data Collection Method |
|---|---|---|---|
| Research of perceptions of rubber farming communities towards the concept of sustainability | Basic knowledge of sustainability concepts, and sustainability implementation | Primary data | Interview, questionnaire. |
| Research of the level/status of sustainability of Riau rubber management | Dimensions and attributes of sustainability | Primary data and secondary data | - Survey (measurement and observation)<br>- Research Of Literature |

**Table 4.** Research Data Analysis Method

| Purpose | Variable | Analysis Method | Analysis Result |
|---|---|---|---|
| Research of perceptions of rubber farming communities towards the concept of sustainability | Basic knowledge of sustainability concepts, and sustainability implementation | Descriptive | Perception Level |
| Research of the level/status of sustainability of Riau rubber management | Dimensions and attributes of sustainability | MDS Analysis (Raprubber) | - Sustainability Index<br>- Sensitive Attribute |

**Table 5.** Number of Experts Chosen as Respondents

| No. | Expert | Total | |
|---|---|---|---|
| | | ∑ | % |
| 1 | Bureaucrat | 1 | |
| 2 | Academics (Forestry Experts) | 1 | |
| 3 | Practitioner | 1 | |
| 4 | Public figure | 1 | |
| 5 | LSM | 1 | |
| | Total | 5 | 100% |

Assessment scores for each dimension were expressed on a scale ranging from the worst (bad) at 0% to the best (good) at 100%. The scores were categorized into four groups as follows (Najmi et al., 2019):

- 0–25% categorized as poor (not sustainable),
- 25.01–50% (less sustainable),
- 50.01–75% (sufficiently sustainable), and
- 75.01–100% categorized as good (highly sustainable).

Sustainability points could be visualized on both horizontal and vertical axes, with index values ranging from 0% (poor) to 100% (good). A system with index value greater than or equal to 50% was considered sustainable. Conversely, when index value was less than 50%, the system was considered unsustainable (Kavanagh and Pitcher, 2004).

### 2.7.2. Leverage Sensitivity Analysis

Sensitivity analysis was performed to identify attributes with a significant impact on the ordination and high sensitivity to sustainability scores. The results of the Leverage analysis showed the most influential attributes that made substantial contributions to the sustainability index, offering insights for targeted interventions to improve sustainability. The analysis was performed by observing changes in the Root Mean Square (RMS) of the ordination on the X-axis. A substantial change in the RMS value signified greater sensitivity of the attribute to the sustainability status (Kavanagh and Pitcher, 2004).

### 2.7.3. Monte Carlo Sensitivity Analysis

Monte Carlo Sensitivity Analysis was adopted to assess the magnitude of influence. The statistical simulation method was used to evaluate the impact of random errors on the estimation process and was essential for examining uncertainties stemming from several factors. These factors included errors in scoring due to an imperfect understanding of research location conditions, errors in attribute comprehension, or the determination of attribute scores. Additionally, it assessed the impact of score variations resulting from different opinions or judgments among several reviews, the stability of the repeated MDS analysis, data entry errors, missing data, and high S-stress values. The results of the Monte Carlo analysis were presented in a scatter plot diagram that showed the estimated median ordination position, along with a 95% confidence interval on the median (Kapa et al., 2017).

## 3. RESULTS AND DISCUSSION

### 3.1. Ecological Dimension

The analysis using MDS RAPRUBBER focused on eight influential ecological attributes. As a result of the analysis, the sustainability index value for the ecological dimension of smallholder rubber plantation in Riau was determined to be 43.22. This value fell within the range of 25.01 to 50.00, categorizing it as "less sustainable" (Figure 2). Based on the Leverage analysis shown in Figure 3, there were two main attributes with a substantial impact on sustainability of Riau rubber. The attributes were "fire frequency" with a value of 4.12 and "byproduct" with a value of 3.35. Addressing the two main leverage attributes was crucial for improving sustainability status of rubber plantation in Riau. It was important to observe that fire frequency posed a significant risk to plantation, thereby leading to ecological decline and damage. The presence of rubber trees within or adjacent to plantation could also prevent the development of byproducts or other crops. For instance, when oil palm trees were cultivated alongside rubber trees, they often struggled to thrive under the conditions. Similar challenges were encountered with other crops.

Furthermore, the data analyzed by raprubber analysis illustrates the influence of eight ecological dimension attributes on the sustainability of smallholder rubber plantations. It measures the root mean square change in ordination when each selected attribute is removed, using a continuity scale from 0 to 100. the results show that Fire frequency has the highest impact with a score of 4.12 which shows that this attribute has a significant effect on sustainability. Side Commodities (Secondary Commodities) are next with a score of 3.35, showing a strong influence on sustainability. Other attributes such as the Impact of Fertilization, the Effect of Decomposition (Effect of Decomposition), and the Impact of Pesticides (Impact of Pesticides) have a moderate impact, while Soil Ph (Soil PH) has the smallest effect. The highlighted values (4.12 and 3.35) emphasize the large influence of fire frequency and secondary commodities on the overall ecological sustainability of plantations.

### 3.2. Economic Dimension

Based on the analysis using MDS RAPRUBBER and considering nine influential economic attributes, sustainability index value for the economic dimension of smallholder rubber plantation in Riau was determined to be 50.80. The value fell within the range of 50.01 to 75.00, categorizing it as "sufficiently sustainable" (see Figure 3).

Based on the leverage analysis in Figure 3, there were two main attributes with a substantial effect on the sufficiency of Riau rubber sustainability. These attributes were "land status" with a sustainability value of 6.67 and "price" with a value of 4.95. The sustainability of rubber plantation businesses in Riau was significantly influenced by land status. Land possessing clear ownership rights, substantiated by certificates, held a higher value. However, rubber plantation land owned by community farmers are often faced with issues related to ownership clarity. This stemmed from the limited awareness among the community when it came to acquiring land certificates.

In the aspect of the influence of nine economic dimension attributes on the sustainability of smallholder rubber plantations, which is measured by the root mean square change in ordination when each attribute is removed on a sustainability scale from 0 to 100. Land Status emerged as the most influential factor. with a score of 6.67 which shows a significant impact on plantation sustainability. Price also plays an important role, with a score of 4.95. Other attributes, such as Labor Use and Fertilizer, show a moderate influence, while factors such as Fertilizer Availability, Pesticide Availability, Marketing, Land Area, and Income show a relatively lower impact. The prominent values in Land Status and Price show their dominant role in shaping the economic sustainability of smallholder rubber plantations.

Many of the plantations had been acquired through the clearing of former forests or had customary land origins. Prices were another substantial determinant of sustainability of rubber plantation businesses in Riau. In the past decade, the prices received by farmers for the commodity had experienced a significant decline, ranging from Rp. 5,000 to Rp. 6,000. The decline was attributable to several factors, affecting not only Rokan Hulu but also neighboring districts and provinces such as Kampar, North Sumatra, and West Sumatera.

Firstly, the global market had a higher demand for synthetic rubber than its natural counterpart. Synthetic rubber, also known as polymers, were artificial elastomers synthesized from petroleum by-products. These elastomers possessed unique mechanical properties to deform elastically under pressure and return to their original shape without permanent changes. Annually, approximately 15 billion kilograms of rubber were produced, with two-thirds being synthetic products. Synthetic rubber was widely used across various industries, from household goods to large-scale, including door and window profiles, hoses, belts, weaving, flooring, and insulation.

The second reason for the drop in rubber prices was the global economic downturn and the depreciation of the dollar against the rupiah. According to the Ministry of Trade, the Indonesian natural rubber exports had reached 7.3 billion US dollars in 2010. The figure saw a significant increase to 11.7 billion US dollars in 2011 but dropped to 6.9 billion US dollars in the following year. The decline in natural rubber exports has been attributed to various price-related factors.

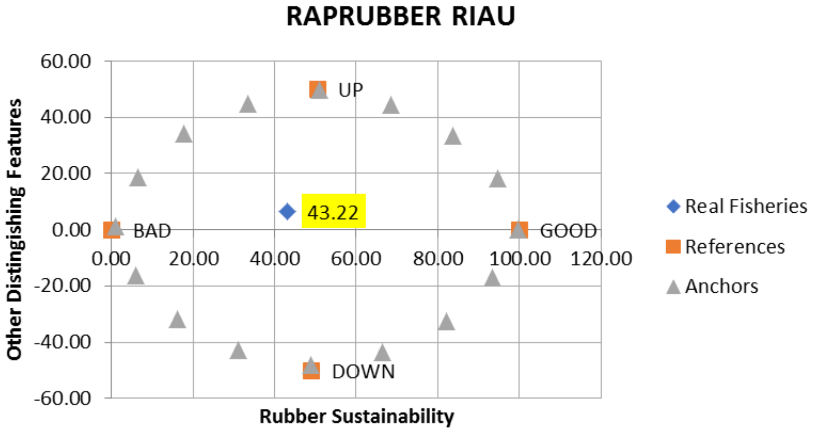


**Figure 2.** The Position of Sustainability Status of the Ecological Dimension of Smallholder Rubber Plantation Management in Riau Province Based on the RAPRUBBER Analysis

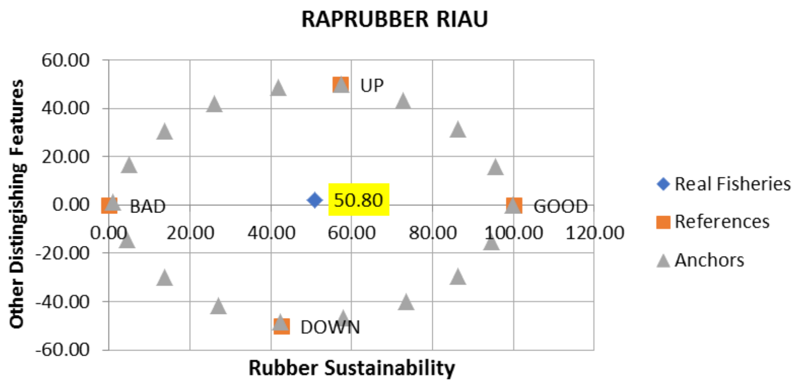


**Figure 3.** The Position of Sustainability Status of the Economic Dimension of Smallholder Rubber Plantation Management in Riau Province Based on the RAPRUBBER Analysis

### 3.3. Social Dimension

Based on the analysis using MDS RAPRUBBER and considering nine influential social attributes, sustainability index value for the social dimension of smallholder rubber plantation in Riau was calculated to be 25.25. This value fell within the range of 25.01 to 50.00, classifying it as "less sustainable" (seeFigure 4). Based on the leverage analysis in Figure 4, there were three main attributes with a substantial impact on sustainability issues of Riau rubber. The attributes included the "initial land opening method" with sustainability value of 8.17, followed by the "conservation measures" with a value of 5.59, and the "local wisdom" with a value of 5.49. Rubber farmers in Riau adopted various land-clearing methods, including felling large trees using chainsaws and using machetes and parangs for smaller trees.

Despite government regulations that prohibited burning when opening land for cultivation, as stipulated in Law No. 4 of 2001, it remained a prevalent practice. The persistence of burning was influenced by limitations in labor and capital resources available to farmers and the perception that it was a more convenient method, despite having environmental consequences. Farmers often faced the challenge of adhering to regulations and prohibitions against land burning to prevent haze. The concept of local wisdom observed in this research included the entire rubber farming production process, from land clearing and burning to equipment usage, land clearing restrictions, seedling, planting, maintenance, tapping, and processing of the harvest. However, the analysis results showed that the traditional local wisdom practiced in the past had waned. Concrete steps for preservation were minimal, with limited efforts from both the government and farmers.

### 3.4. Multidimensional Sustainability Status

The total analysis using RapRubber resulted in sustainability status of 39.76%, categorizing it as "less sustainable." This condition showed that rubber plantation efforts in Riau were under pressure in terms of their management. Table 6 presented the sensitive attributes within each dimension. The attributes were key factors with a substantial influence and were instrumental in shaping policies to enhance sustainability index in rubber plantation management based on developmental principles.

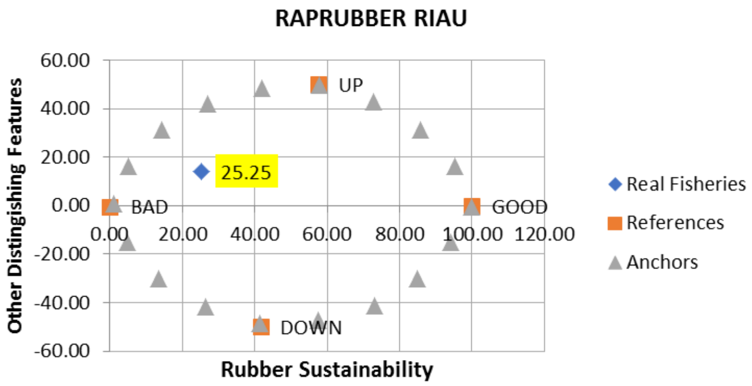


**Figure 4.** Sustainability Status Position of the Social Dimension of Smallholder Rubber Plantation Management in Riau Province Based on RAPRUBBER Analysis

**Table 6.** Sensitivity Attributes Affecting Sustainability Index in Plantation Management Based on Sustainable Development Principles

| Dimension | Sensitive Attributes |
|---|---|
| Ecology | Fire Frequency<br>Side Commodities |
| Economic | Land Status<br>Price |
| Social | Initial Method of Land Clearing<br>Preservation Steps<br>Local Wisdom |

**Table 7.** Sensitivity Attributes Affecting Sustainability Index in Plantation Management Based on Sustainable Development Principles

| Dimension | Indeks MDS | Stress | $R^2$ (%) | Iteration |
|---|---|---|---|---|
| Ecology | 43.22 | 0.15 | 94.32 | 2 |
| Economic | 50.80 | 0.14 | 94.73 | 2 |
| Social | 25.25 | 0.13 | 94.63 | 2 |
| Average | 39.76 | 0.42 | 94.56 | 2 |

**) Index Value 25.01-50.00 is categorized as less sustainable, and 50.01-75.00 is categorized as moderately sustainable.*
***) Stress Value <0,25 goodness of fit.*
****) R Value² >80%: kontribusinya sangat baik*
*Sources: Processing of Primary Data, 2019*

### 3.5. Stress Value and Coefficient of Determination

The ability of each attribute to explain and contribute to sustainability of the system under analysis was assessed from the coefficient of determination ($R^2$) of each dimension. The stress and $R^2$ values for each dimension were presented in Table 7 below. Table 7 showed that the average stress and $R^2$ values for each dimension were 0.42 and 94.56% respectively. In Rapfish, the stress value was considered good when it was below 0.25 (Malhotra, 2006). This represented a goodness of fit in MDS and the attribute configuration showed the original data. An $R^2$ value of 0.9456 indicated that the attributes or factors evaluated in each dimension could explain and contribute to sustainability of the system by 94.56%. According to Kavanagh (2001), an $R^2$ value was considered good when it exceeded 80% or method 100%.

### 3.6. Error Effect

Monte Carlo analysis assessed the impact of random errors and aimed to determine: (a) the effect of errors in attribute scoring, (b) the variations in score assignments, (c) the stability of the repeated MDS analysis process, (d) the errors in data input or missing data, and (e) whether the stress value was acceptable when it was <20%. The results of the Monte Carlo analysis for all dimensions were presented in Table 8.

Monte Carlo analysis showed that sustainability index values for rubber plantation management at a 95% confidence level represented no significant difference between the results of the RAPFISH and the MDS analysis with Monte Carlo. The small discrepancy between the two analyses suggested that:

- Errors in attribute scoring were relatively small.
- The variation in scoring due to differences in opinions was small.
- The analysis process conducted repeatedly was relatively stable.
- Errors in data input and missing data could be minimized.

**Table 8.** Results of Monte Carlo Analysis for Each RAPRUBBER Dimension at the 95% Confidence Interval

| Dimension | MDS RAP Rubber | Monte Carlo* | Difference (MDS – MC) |
|---|---|---|---|
| Ecology | 43.22 | 43.63 | -0.41 |
| Economic | 50.80 | 50.72 | 0.08 |
| Social | 25.25 | 27.14 | -1.89 |

**Error at the 95% confidence level.*

The MDS RAPRUBBER analysis results suggested that all attributes assessed for sustainability status of rubber plantation management based on the principles of sustainable development were reliable. The reliability was evidenced in the stress and $R^2$ values which were <0.25 and 0.9456 respectively. This was in line with the observations of Fauzi and Anna (2007), who stated that the analysis results were adequate when the stress value was below 0.25 (25%) and the $R^2$ method a value of 1.0 (Table 9 and Figure 5).

The analysis of the sustainability index and status of multidimensional rubber plantations in Riau Province, based on sustainable development principles, reveals varying levels of sustainability across ecological, economic, and social dimensions. Ecology Dimension: The ecological dimension has an index of 43.22, categorized as "Not Enough," indicating that the ecological practices in these rubber plantations are insufficient. The "Less Sustainable" status suggests that environmental sustainability is compromised, possibly due to issues like deforestation, biodiversity loss, or inadequate environmental management practices. Economic Dimension: The economic dimension scores 50.80, falls into the "Enough" category and is classified as "Sufficiently Sustainable." This indicates a moderate level of economic viability, where the rubber plantations are managing to maintain a balance between profitability and sustainability (Jamil et al., 2019).

**Table 9.** Index and Sustainability Status of Multidimensional Rubber Plantation Based on Sustainable Development Principles in Riau Province

| No | Dimension | Index | Category | Status |
|---|---|---|---|---|
| 1 | Ecology | 43,22 | Not Enough | Less Sustainable |
| 2 | Economic | 50,80 | Enough | Sufficiently Sustainable |
| 3 | Social | 25,25 | Not Enough | Less Sustainable |

**) Index values from 25.01 to 50.00 are categorized as less sustainable, and values from 50.01 to 75.00 are categorized as moderately sustainable.*
*Source: Primary Data Analysis, 2019*

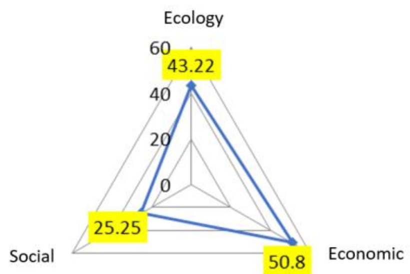


**Figure 5.** Index and Sustainability Status of Multidimensional Rubber Plantation Based on Sustainable Development Principles in Riau Province

However, there may still be challenges related to market stability, pricing, and resource allocation that need attention to ensure long-term economic sustainability. Social Dimension: The social dimension has the lowest index at 25.25, also categorized as "Not Enough," with a "Less Sustainable" status. This reflects significant shortcomings in social sustainability, which could be due to factors such as poor labor conditions, lack of community engagement, or inequitable distribution of benefits. This dimension requires substantial improvement to ensure that the rubber plantations contribute positively to the well-being of the local communities (Zou et al., 2024).

## 4. CONCLUSION

In conclusion, the comprehensive RapRubber analysis yielded an index of 39.76, categorizing status as less sustainable. The results showed that rubber plantation efforts in Riau were under management pressure. In a more detailed analysis, the ecological dimension had an index of 43.22, placing it in the least sustainable category. The economic dimension scored 50.80, signifying a relatively sustainable status. In contrast, the social dimension reduced with an index of 25.25, classifying it as less sustainable. The attributes that contributed to the unsustainability of the ecological dimension were fire frequency and by-products, while the factors contributing to less sustainability of the social dimension included the initial land-clearing method, preservation steps, and local wisdom. In the economic dimension, land status and prices were essential determinants of sustainability. Relevant institutions, with a particular emphasis on the government, needed to take a proactive stance and prioritize the crucial factors that would elevate the status of smallholder rubber plantation from being less to a highly sustainable category. This could be achieved through well-communicated programs meeting the needs of the farmers. It was observed that a significant portion of the Riau population depended on rubber tapping for their livelihoods.

The study identifies several limitations impacting its findings, including data availability and reliability issues regarding smallholder rubber plantations, which could introduce biases in sustainability assessments. Its temporal scope may miss long-term trends and seasonal variations, while the geographical focus on Riau Province restricts generalizability due to diverse ecological and socio-economic conditions. The complexity of interactions among ecological, economic, and social factors may lead to oversimplifications, and the study may not fully represent all stakeholder perspectives. Future research could address these limitations through longitudinal studies, comparative analyses, and investigations into climate change impacts, along with exploring technological innovations, evaluating policy effectiveness, and emphasizing social sustainability.

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