Exploring the relationship between land characteristics and the sustainable growth of coconut cultivation in Indonesia

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Exploring the relationship between land characteristics and the sustainable growth of coconut cultivation in Indonesia

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ABSTRACT

This study explores land types as a basis for evaluating the sustainability of coconut plantations in Indonesia, focusing on peatlands and coastal areas that affect productivity and management practices. This research aims to evaluate the sustainability of coconut plantation farming across various land types and identify critical sustainability factors. Carried out in Indragiri Hilir Regency, Riau Province, the study employed a survey methodology and utilized Rap-Coconut Ordination Analysis coupled with Multidimensional Scaling (MDS). The surveyed area encompasses peatlands and coastlands, and a purposive sampling approach, guided by the Slovin Formula, yielded a sample size of 101 coconut farmers. The sustainability assessment covered five dimensions: ecological (7 attributes), social-cultural (4 attributes), economic (4 attributes), technological (6 attributes), and institutional (7 attributes) and 28 attributes. The study assessed the sustainability of coconut farming in Indragiri Hilir Regency, Riau Province. Peatlands showed lower sustainability, while coastline lands demonstrated higher sustainability levels. Key factors affecting sustainability include ecological aspects like fertilizer and pesticide use, socio-cultural elements like family involvement and attitudes towards coconut farming, economic factors like the coconut vending system, technological considerations such as optimal planting spacing and seed quality, and institutional factors like participation in extension programs and access to financial resources.

Contribution/Originality: This study makes a unique contribution by assessing the sustainability of coconut plantations in Indonesia based on land typology, which has not been widely studied. It also directly contributes to the achievement of Sustainable Development Goals (SDGs) related to decent work, economic growth, and sustainable environmental management.

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1. INTRODUCTION

Alouw and Wulandari (2020) emphasize the success of coconut cultivation in tropical countries like Indonesia, highlighting its strategic importance due to significant economic, social, and environmental impacts. Gunawan, Trihastuti, Mulyana, and Limbara (2022) state that as a major commodity, coconuts play a crucial role in shaping the economy and culture. Additionally, Wulandari and Alouw (2021) underscore coconuts' dual utility for household and industrial purposes. Strategies to improve coconut production include accelerating the replanting of aging plantations and expanding cultivation into new areas.

According to the 2023 report by the Food & Agriculture Organization of the United Nations (FAO), Indonesia has become the world's largest coconut producer, with a production volume reaching 17.19 million tons. Small holders farmers cultivate about 98.08% of this coconut production, according to the Central Statistics Agency of Indonesia (2023). This achievement places Indonesia ahead of the Philippines, India, Brazil, and Sri Lanka regarding coconut production. The high production levels highlight Indonesia's crucial role in meeting global coconut demand, contributing 29.69 percent to the world's total coconut production.

Riau Province is the largest coconut producer in Indonesia, followed by North Sulawesi Province and East Java Province. Central Statistics Agency of Indonesia (2023) coconut production in Riau reached 406.9 thousand tons, accounting for 14.56% of the total national coconut production. Meanwhile, North Sulawesi produced 269.6 thousand tons (9.40% of the national total), and East Java produced 233.9 thousand tons (8.16% of the national total). Riau Province's position as the largest coconut producer in Indonesia underscores the significant potential of this region for the development of the coconut economy.

Indragiri Hilir Regency is the center of coconut production in Riau Province, where coconuts serve as a critical economic commodity. Vaulina and Khairizal (2016) emphasize the importance of coconuts in developing this region, which has two main types of land: peatlands and coastal areas. Coconut plants are well-suited to the area's climate, soil, and topography. Coconut cultivation in Indragiri Hilir covers 340,941 hectares (82.15% of the total land area in Riau) with a production of 307,768 tons (81.36% of Riau's total production). Figure 1 provides further details.

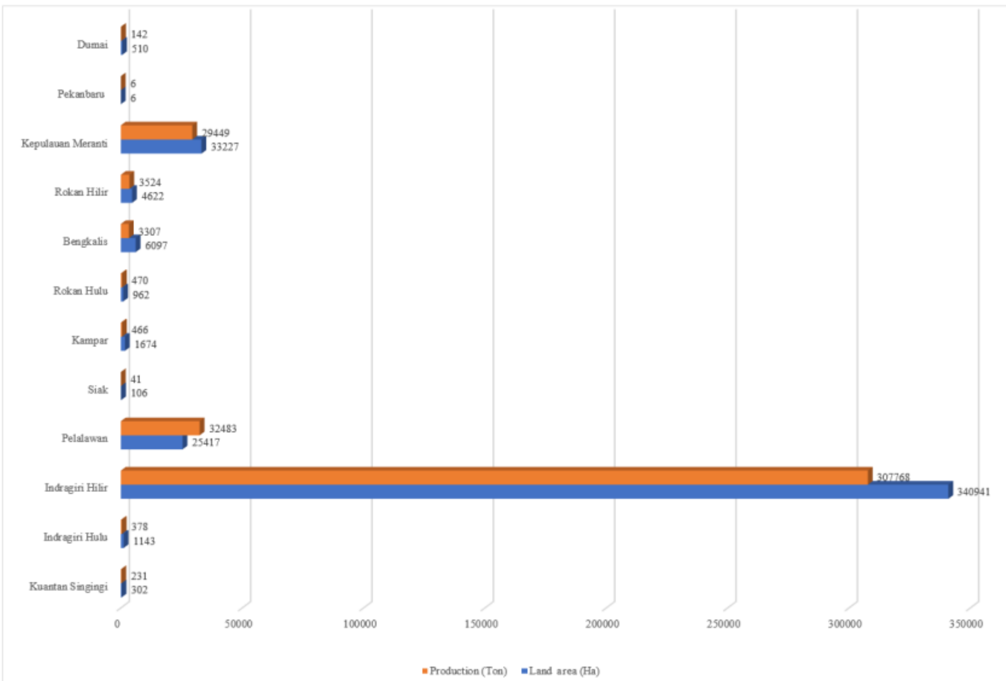


Figure 1. Land area and production of coconut in Riau province, 2023.

Smallholder coconut plantations in Indragiri Hilir Regency are characterized by small land ownership, limited use of certified high-quality seeds (Vaulina & Hajry, 2018), minimal implementation of Good Agricultural Practices (GAP), low technology adoption, and insufficient value-added processes (Gaga, 2021). These plantations generally have small farm sizes and relatively low productivity (Kumar & Kapoor, 2010). Given the significant production and demand for coconuts, the Indragiri Hilir Regency Government should prioritize its development, as coconut farming is crucial for the local economy (Syarifuddin, 2022). This traditional livelihood provides most residents with financial, social, cultural, and environmental benefits (Mawardin & Aditya, 2017).

Multiple studies have assessed the sustainability of coconut crops from various perspectives. Kotalaha and Sasongko (2018) analyzed local knowledge of "Makiriwo" within the Sustainable Livelihood Perspective in North Halmahera, Indonesia. Alouw and Wulandari (2020) evaluated the current situation of coconut development and its prospects in Indonesia. Rusli and Isa (2021) examined smallholders' attitudes toward extension agents' roles in promoting sustainability in the coconut business in Tanjong Karang, Malaysia. Dissanayaka, Nuwarapaksha, Udumann, Dissanayake, and Atapattu (2022) identified cover cropping as a beneficial practice for enhancing coconut land production. Nuwarapaksha, Udumann, Dissanayaka, and Atapattu (2023) evaluated the viability of integrating coconut production with livestock farming to improve food security and environmental sustainability. Puspaningrum, Indrasti, Indrawanto, and Yani (2023) researched the life cycle of coconut planting, copra, and charcoal production, identifying ways to minimize impacts and enhance long-term viability. Studies by Rusdi, Harianto, Hartoyo, and Novianti (2021) and Alfaliansyah and Maswadi (2021) have scrutinized the sustainability of Indonesia's coconut supply chain, emphasizing the socioeconomics of its farmers.

This research is unique because it uses land typology to assess the sustainability of coconut plantations in Indonesia. Most previous studies have focused more on general aspects of sustainability without specifically considering variations in land typology, such as peatlands, coastal areas, and highlands, which can affect productivity and management practices. This research also directly contributes to achieving Sustainable Development Goals (SDGs), particularly regarding decent work, economic growth, and sustainable environmental management in the agricultural sector. However, aging plants, improper practices, land use changes, low prices, and marketing difficulties continue to pose challenges to the sustainability of coconut farming, despite its limited research. Therefore, this study aims to (1) evaluate the sustainability of coconut farming based on land typology and (2) identify the main factors influencing that sustainability.

2. METHOD

The research utilized a survey method conducted from September 2022 to February 2023 in Indragiri Hilir Regency, Riau Province. Data collection commenced with a literature review and gathering of secondary data. In contrast, primary data were gathered through questionnaires distributed among coconut farmers—the questionnaire utilized a Likert Scale with three levels, indicating measured categories and rankings. Option 1 signifies low, option 2 indicates moderate, and option 3 means high. Indragiri Hilir Regency comprises two main land types: Peatlands and Coastland, although certain subdistricts lack specific land typologies.

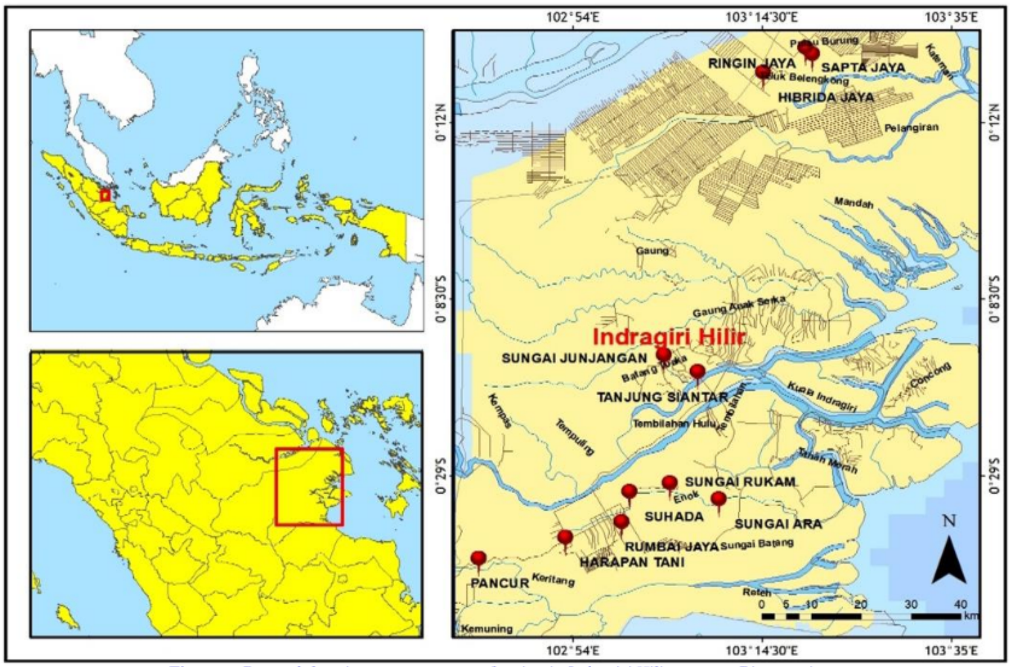


Figure 2. Research location map on coconut farming in Indragiri Hilir regency, Riau province.

Figure 2 provides a visual representation of the research location for the study on coconut farming in Indragiri Hilir Regency, Riau Province, Indonesia. The map showcases the geographical context of the region, highlighting its proximity to the equator and its location within the Indonesian archipelago. The red rectangle on the map indicates the Indragiri Hilir Regency, the primary focus of the study. This regency is characterized by a diverse landscape. To enhance the understanding of the study area, Figure 2 also includes a legend indicating the map's scale and the direction of the north. This visual aid facilitates the interpretation of the spatial distribution of the coconut plantations within the Indragiri Hilir Regency.

Moreover, the map also visually outlines the geographical distribution of coconut plantations within the region, emphasizing the prevalence of two primary land types: peatlands and coastlands. Based on land typology, we selected six districts as the study areas for the research. These include four districts with peatlands—Kempas, Batang Tuaka, Enok, and Kemuning—and two with coastlands—Pulau Burung and Teluk Belengkong. Similarly, the selection of villages was based on land typology. The Slovin Formula determined the sample, yielding 101 coconut farmers. The sample selection aims to accurately represent the population of coconut farmers in each land type. The following section outlines the framework for sample selection.

Table 1. Framework for sampling coconut research in Indragiri Hilir regency, Riau Province, 2023.

No.	Land typologies	Districts	Villages	Samples
1	Peatlands	a. Kempas	Harapan Tani	12
			Sungai Ara	10
			Rumbai Jaya	10
		b. Batang Tuaka	Tanjung Siantar	6
			Sungai Junjangan	5
		c. Enok	Suhada	3
			Sungai Rukam	10
		d. Kemuning	Pancur	11
2	Coastland	a. Pulau Burung	Ringin Jaya	11
		b. Teluk Belengkong	Hibrida Jaya	8
			Sapta Jaya	15
Total				101

Table 1 outlines the sampling framework for the coconut farming research conducted in Indragiri Hilir Regency, Riau Province, in 2023. The table provides a detailed overview of the land typologies, districts, villages, and sample sizes selected for the study. Within the peatland category, four districts were included: Kempas, Batang Tuaka, Enok, and Kemuning. These districts were further divided into villages, such as Harapan Tani, Sungai Ara, Rumbai Jaya, Tanjung Siantar, Sungai Junjangan, Suhada, and Sungai Rukam. The sample sizes for each village varied, ranging from 5 to 12. In the coastal land category, the study encompassed Pulau Burung and Teluk Belengkong districts, with respective villages of Ringin Jaya, Hibrida Jaya, and Sapta Jaya. The sample sizes for these villages also varied, ranging from 8 to 15.

Data analysis employed Rap-Fish Ordination analysis with the Multidimensional Scaling (MDS) method, adapted to the research object called Rap-Coconut Ordination (Rap Analysis). Rapfish, as described by Kavanagh and Tony (2004), is a statistical technique used to quickly assess the relative status of entities, quantitatively evaluated against predefined sets of attributes grouped into disciplines. Microsoft Excel's Rapfish software performed the RAP analysis to identify each measurable indicator.

The Rap Analysis method, as described by Pitcher (1999), Pitcher and Preikshot (2001), RAPFISH Group (2006), and Suryana, Wiryawan, Monintja, and Wiyono (2012) is a multidimensional rapid assessment technique for evaluating sustainability. The development of the Rap Analysis method encompasses five evaluation areas: economic, ecological, technological, social, and ethical. However, the analysis has primarily focused on these evaluation areas. The RAPFISH method employs straightforward and evaluated attributes to deliver a quick, cost-effective, and multidisciplinary assessment of sustainability levels (Murillas et al., 2008).

The Rap analysis encompasses the RAP, leverage, and Monte-Carlo method. Kite diagrams show the sustainability status across multiple dimensions by comparing their performance. The determination of the sustainability index draws from studies by Allahyari (2010), Jimenez, Gonzalez, Amaral, and Fredou (2021) and Chaliluddin et al. (2023). The study examined five dimensions and 28 attributes, guided by the Rapfish indicator developed by Kavanagh (2001). Sustainability analysis was conducted across ecology (7 attributes), social-cultural (4 attributes), economic (4 attributes), technological (6 attributes), and institutional (7 attributes) dimensions. Attributes were then visualized using a radar chart.

Table 2. Dimensions and attributes research.

No	Dimension	Good	Bad	Attribute
1	Ecology	3	1	1) Replanting
				2) The level of pest/Plant disease attack
				3) Use of pesticides (Weed control)
				4) Use of fertilizers
				5) Water management embankment condition
				6) Drainage channels
				7) Land area
2	Socio-cultural	3	1	1) Family participation in farming
				2) The number of workers
				3) People's perception of coconut farming
				4) The relationship between farmers and marketers
3	Economic	3	1	1) The amount of production
				2) Selling price of coconuts
				3) Coconut sales system
				4) Coconut marketing
4	Technological	3	1	1) Coconut product processing industry
				2) Coconut marketing infrastructure
				3) Coconuts planting distance
				4) Use of superior seeds/Seeds
				5) Harvest time
				6) How to harvest coconuts

No	Dimension	Good	Bad	Attribute
5	Institutional	3	1	1) Coconut farming business partnership
				2) Microfinance institutions
				3) Participation in cooperatives
				4) Participation in coconut extension activities
				5) Coconut farming extension center
				6) Involvement in farmer groups
				7) Availability of capital farmers

Table 2 provides a comprehensive overview of the dimensions and attributes used to assess the sustainability of coconut farming in the study. The table categorizes various factors into five key dimensions: ecological, sociocultural, economic, technological, and institutional. Within each dimension, specific attributes are identified to evaluate the sustainability of coconut farming practices. For instance, the ecological dimension includes factors such as replanting, pest and disease control, fertilizer and pesticide use, water management, and land area. The sociocultural dimension considers family participation, labor availability, and community perceptions regarding coconut farming. Economic factors encompass production levels, selling prices, marketing systems, and the relationship between farmers and marketers. Technological attributes focus on processing infrastructure, planting distances, seed quality, and harvesting methods. Finally, the institutional dimension evaluates business partnerships, microfinance access, cooperative participation, extension activities, and capital availability.

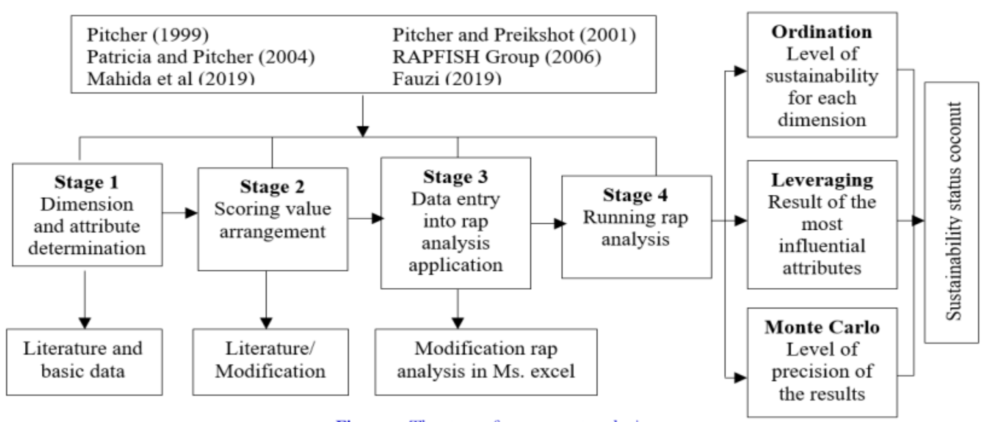


Figure 3. The stage of rap coconut analysis.

Source: Pitcher (1999); Patricia and Tony (2004); Mahida and Permana (2019); Pitcher and Preikshot (2001); RAPFISH Group (2006) and Fauzi (2019).

Based on Figure 3, in this study, Rap analysis was conducted in four stages: (1) dimension and attribute determination, (2) scoring value arrangement, (3) data entry into the Rap analysis application, and (4) running the Rap analysis. According to Kavanagh and Tony (2004) the best model assessment (goodness of fit) is indicated by an S-stress value <0.25 (S<0.25) and a high R2 value approaching 1 (100%) (Malhotra, 2006). Based on the statistical parameters suggested by Pitcher and Preikshot (2001) all assessed attributes meet the criteria, indicating their suitability for explaining the sustainability of coconut plantation farming in Indragiri Hilir Regency based on land typology. Table 3 displays the categorical values that allow us to interpret the sustainability index scale.

Table 3. Index categories and sustainability status.

Index value	Sustainability status
0.00 – 25.00	Unsustainable
25.01 – 50.00	Less sustainable
50.01 – 75.00	Moderately sustainable
75.01 – 100.00	Sustainable

3. PEATLAND AND COASTLAND

3.1. Peatland

Organic matter gradually accumulates over time to form Peatlands (Nurida, Mulyani, & Dan, 2011). Agus, Hairiah, and Mulyani (2011) explain that these areas typically develop in low-lying regions or basins, where decomposed vegetation contributes to organic composition. Xu, Morris, Liu, and Holden (2018) state that peatlands are found in every climate zone and continent, covering an area of 4.23 million km², equivalent to 2.84% of the Earth's surface. International Peatlands Society (IPS) (2024) mentions that about 84% of the world's peatlands are in a natural or near-natural condition. Noor (2001) suggests that factors influencing the characteristics and origin of peat soil include climate, topography, the type of underlying substrate, and the nature of the vegetation or organic material involved in its formation.

Indonesia is one of the countries with the largest tropical peatland areas in the world (The Ministry of Environment and Forestry, 2012). After Canada, the Soviet Union, and the United States, Indonesia ranks fourth in vast peatland areas (Masganti, Anwar, & Susanti, 2017). The peatland area in Indonesia is estimated to be 14.95 million hectares, spread across the islands of Sumatra, Kalimantan, and Papua, with a small portion in Sulawesi (Wahyunto, Nugroho, Ritung, & Sulaiman, 2014). Radjagukguk (1997) generally categorizes peat in Indonesia as either mesotrophic or oligotrophic. The peat in Sumatra typically exhibits better chemical properties due to the influx of volcanic material from the Barisan Mountains (Mulyani & Noor, 2011).

Terzano et al. (2023) state that peatlands in Indonesia also have global significance for biodiversity conservation and climate regulation, as well as national and local importance for water management and livelihood support. Therefore, as emphasized by Irwani and Kartodihardjo (2022) there is an urgent need for policy interventions to manage ecosystems in peatland areas.

Yuliana, Fina, and Puteri (2022) mention that the benefits and functions of peatlands that communities can experience include carbon sequestration, a source of energy for humans, educational tourism, and agricultural land. Juliano, Suwardi, and Sudadi (2023) assert that the principles of ecological sustainability require the cultivation of peat. Fasla (2022) recommends implementing sustainable peatland management by maximizing productivity and minimizing the level of emissions produced.

Figure 4a. Peatland in Indragiri Hilir Regency, Riau Province.

Figure 4b. Peatland in Indragiri Hilir Regency, Riau Province.

Figures 4a and 4b present visual representations of coconut plantations in peatland environments within Indragiri Hilir Regency, Riau Province. Both images offer valuable insights into the characteristics and challenges associated with coconut farming in these unique ecosystems. Figure 4a depicts a broader landscape, showcasing a network of canals and dense vegetation typical of peatland areas. The image showcases a narrow canal meandering through a dense coconut plantation.

The soil appears dark and moist, indicative of the peatland characteristics. The canal, which is likely used for irrigation or drainage purposes, highlights the importance of water management in these areas. This image highlights the importance of water management and biodiversity conservation in such environments. On the other hand, Figure 4b depicts a dense stand of coconut trees, with a pathway winding through the plantation. The ground appears to be moist and rich in organic matter, characteristic of peatland soils. The inclusion of metadata in both images provides additional context.

The date, time, GPS coordinates, altitude, and index numbers allow for precise geolocation and temporal tracking of these plantations, enabling researchers to monitor changes and assess the impact of various factors on sustainability.

3.2. Coast Land

The coast is the land adjacent to the sea, including the beach and surrounding areas. Sea activities influence the flat expanse along the shoreline, creating sandy plains in the coastal zone. Kinsela, Morris, Daley, and Hanslow (2016) demonstrated the potential for shoreline changes due to intensive deposition processes in coastal regions. Coastal land typically consists of sandy soil, often classified as regosol soil. As Sukrisno (2000) described, soil characteristics in coastal areas include a coarse and porous texture, making it highly susceptible to wind erosion. Additionally, the transport of various sand materials by erosion processes can damage cultivated plants.

Coastal areas are considered biodiversity zones (Ariadi, Benny, & Dewi, 2024). Agriculture occupies a significant portion of coastal regions worldwide, making coastal farming a relevant category for analyzing agricultural systems (Viaud et al., 2023). Increased accessibility, suitable slope gradients, and favorable climatic conditions convert coastal land into agriculture land (Olaniyi, Abdullah, Ramli, & Alias, 2012). Gunadi (2002) suggests that despite the limitations in coastal areas, technological advancements offer potential solutions to establishing suitable agricultural ecosystems. However, Ariyani and Achmad (2020) note that coastal areas provide valuable resources and hold significant environmental, economic, and social importance. Coastal protection, under the Blue Economy framework, has received special attention from authorities to minimize the impact of rising sea levels, saltwater intrusion, and tropical storms (Nong et al., 2021).

4. FINDINGS

The sustainability analysis of coconut farming on peat and coastal land revealed index values of 44.3 and 53.58, respectively, indicating the former as less and moderately sustainable. Strong relationships between dimensions were observed in both types of land, with Squared Correlation (R2) values of 0.90 for peatlands and 0.93 for coastal lands, showing close to 100% correlation. Additionally, stress values during the ordination process were 0.19 for peatlands and 0.15 for coastal lands, below the tolerance level (<25%), suggesting an acceptable error rate. Further details are provided below:

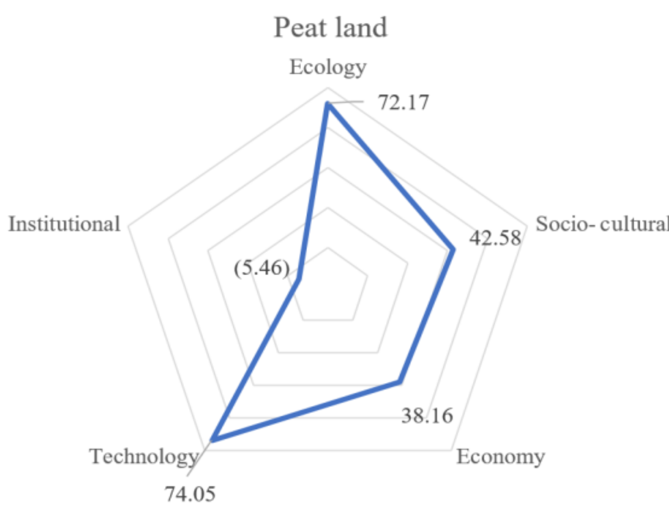
Table 4. Coconut farming sustainability in peatlands and coastal lands of Indragiri Hilir regency, Riau Province, 2022.

Dimension	Peat land				Coast land			
	MDS	Monte Carlo	S-stress	R^2	MDS	Monte Carlo	S-stress	R^2
Ecology	72.17	57.24	0.17	0.88	62.11	39.54	0.14	0.94
Economy	38.16	37.70	0.18	0.88	35.15	36.02	0.15	0.92
Institutional	-5.46	9.52	0.21	0.89	51.57	51.33	0.16	0.94
Socio-cultural	42.58	55.76	0.20	0.91	54.04	53.79	0.16	0.92
Technology	74.05	58.53	0.17	0.92	65.05	64.01	0.14	0.94
Multi dimension	44.30	43.75	0.19	0.90	53.58	48.94	0.15	0.93
Sustainability	44.3				53.58			

Table 4 presents a comparative analysis of coconut farming sustainability in peatland and coastal land areas within Indragiri Hilir Regency, Riau Province. The table provides insights into the performance of various dimensions, including ecology, economy, institution, socio-cultural aspects, technology, and overall sustainability. The study used Multidimensional Scaling (MDS) and Monte Carlo simulations to find the S-stress and R^2 values that showed how well the data filled the model and how strong the links were between the variables. For each dimension, the MDS values indicate the relative importance of that dimension in explaining the overall sustainability of coconut farming.

After calculating the sustainability index values for coconut plantation farming in Indragiri Hilir Regency based on peatland, the results are as follows: ecological dimension 72.17%, economic 38.16%, socio-cultural 42.56%, technology 74.05%, and institutional -5.46%. These values are categorized into the less sustainable range, with a total of 44.30.

Conversely, the sustainability index values for coastal land are as follows: ecological dimension 62.11%, economic 35.15%, institutional 51.57%, socio-cultural 54.04%, and technology 65.05%. These values, with a total of 53.58, fall into moderately sustainable range. The analysis proceeds using a radar chart depicted in Figure 5.



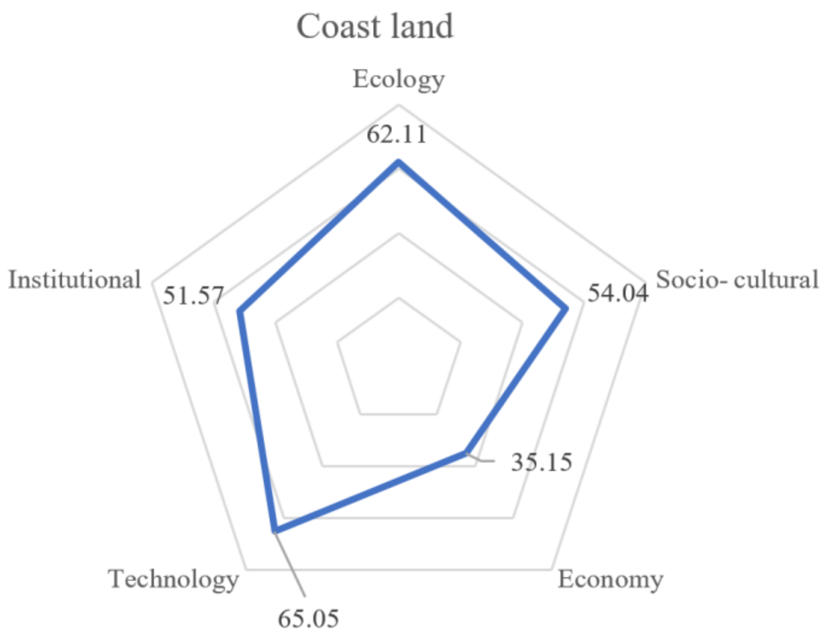


Figure 5. Diagram of the sustainability index of coconut farming in Indragiri Hilir Regency, Riau province.

Information from Figure 5 reveals that both land types show the technological dimension, with high index values falling into the moderately sustainable category, at 74.05 and 65.05, respectively. On the other hand, the index value of -5.46 categorizes the institutional dimension for peatlands as unsustainable. Meanwhile, in coastal areas, the economic dimension has the lowest index value of 35.15, placing it in the moderately sustainable category. These findings align with Vaulina and Saipul (2015) research, indicating low income among coconut farmers in Indragiri Hilir Regency. Additionally, Vaulina and Hajry (2018) find that coconut plantations in the area have not reached optimal economic efficiency. Rasihen, Andriyono, and Suprehatin (2021) emphasize the government's expected intervention, leveraging the substantial potential of coconuts and ample land area through initiatives such as increasing coconut productivity, implementing pricing strategies, and empowering coconut farming communities.

4.1. Ecological Dimensions Sustainability

The ecological dimension of coconut farming sustainability is categorized as moderately sustainable because, although some ecological aspects are managed adequately, areas still need improvement. Indicators in this dimension, such as land use, water management, and environmental practices, show satisfactory but not optimal performance. For example, pesticide use is crucial for controlling pests and diseases but can negatively impact the environment if not managed carefully. The ordination analysis gives index values like 72.17 for peatlands and 62.11 for coastal lands, which put the ecological dimension in the "moderately sustainable" category. This means that ecological management could be improved to make it more sustainable. This is supported by field observations from Zulkarnaini, Sujianto, and Wawan (2022) which highlight land degradation, illegal logging, and land conversion in peatland ecosystems.

The leverage analysis on peatlands in Figure 6 shows that fertilizer usage, with a Root Mean Square (RMS) value of 11.16%, is the most dominant factor. RMS is a statistical measure that represents the effective value of a fluctuating quantity. The higher the RMS value, the more significant the attribute is in influencing the overall sustainability of that dimension. In this case, most farmers only fertilize coconut plants once or twice a year, as continuous fertilization may shorten their lifespan. Typically, coconut trees in the research location are over 30 years old. The land area attribute has the lowest value (RMS 4.32%) and is the least dominant factor in ecological sustainability. Other factors, such as fertilizer usage, have a more significant impact on plant productivity and health. Therefore, although land area is important, other factors may carry more weight in determining coconut farming sustainability. Figure 6 provides details.

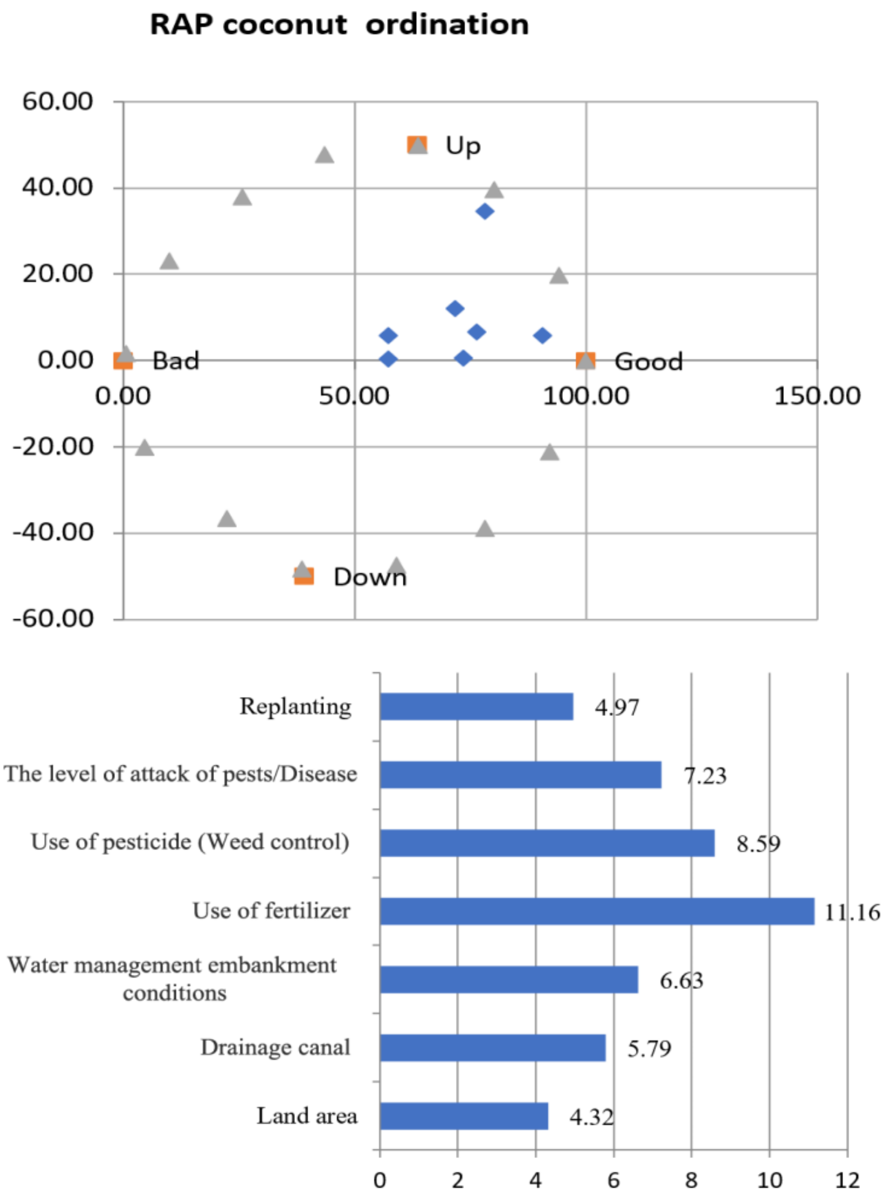


Figure 6. Peatlands: Ecological dimension and sensitive factors influencing ecological sustainability.

As shown in Figure 7, the use of pesticides dominates the ecological dimension of coconut farming sustainability, with an RMS value of 6.49%. Pesticides are used to eliminate weeds around coconut trees. Previously, farmers used machetes to control weeds, but this method was time-consuming and labor-intensive. Sharma et al. (2019) state that pesticides are widely utilized in contemporary agriculture as they are effective and cost-efficient for improving crop yields' quality and quantity. Although pesticides are important for controlling pests and diseases in coconut plants, their use directly impacts the environment and ecosystem, which can lead to adverse effects. Denver and Ator (2016) mentioned that certain pesticides can be detected at low levels (usually less than 0.1 micrograms per liter) in surface groundwater. According to Martínez-Megías, Mentzel, Fuentes-Edfuf, Moe, and Rico (2023) pollution from agricultural pesticides is one of the most significant pressures affecting coastal land.

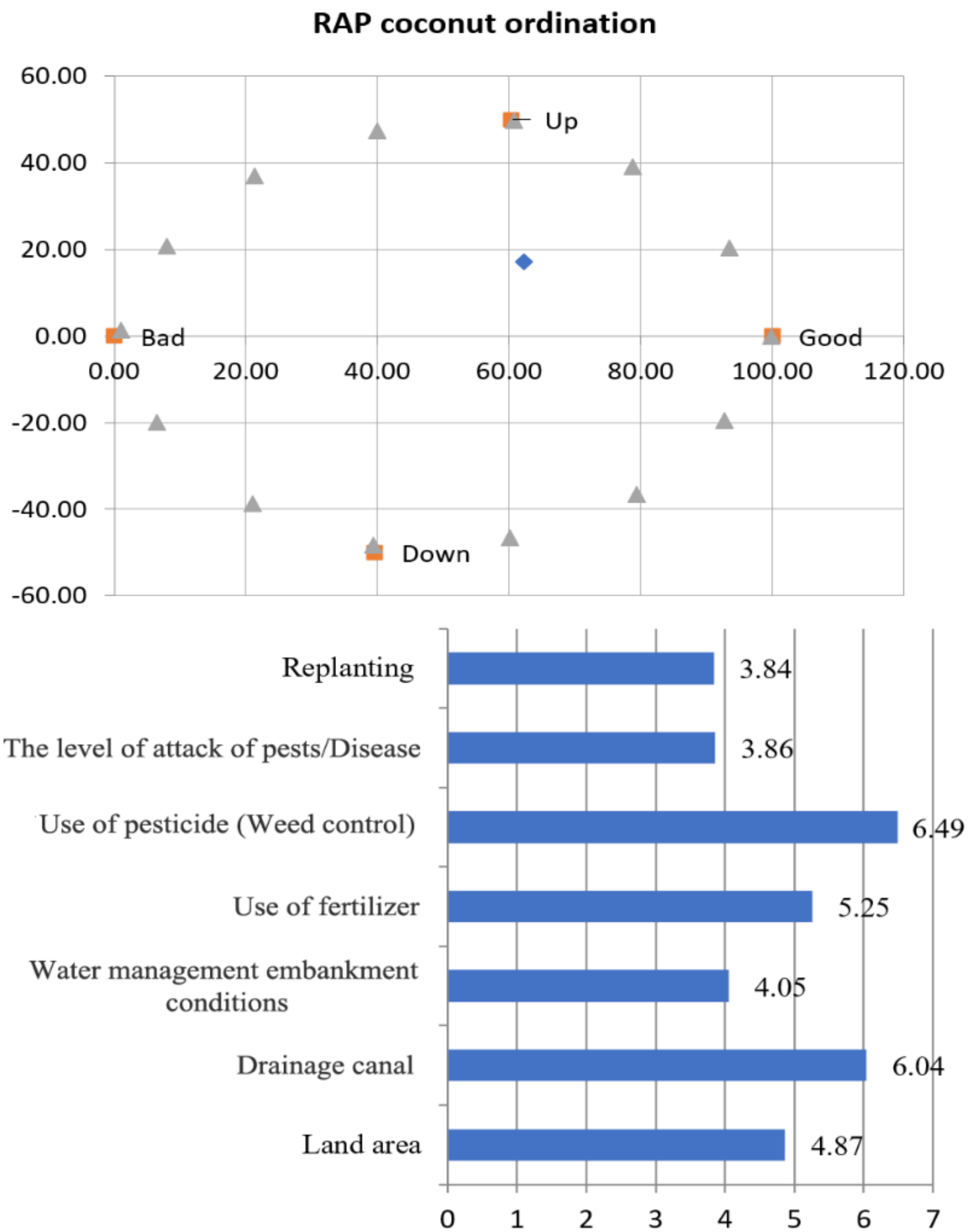


Figure 7. Coast lands: Ecological dimension and sensitive factors influencing ecological sustainability.

The leverage analysis indicates that to improve the ecological sustainability dimension for both types of land, adjustments are needed in fertilizer application on peatlands to meet the standards set by the Indonesian Ministry of Plantations. The current practice of only applying fertilizer during harvest time falls short of meeting the standards. Additionally, attention is needed for pesticide use in coastal lands, especially for weed management, as weeds are only cleared during harvest time, leading to smaller coconut sizes. According to Kamakaula (2024) from an ecological perspective, practices such as soil and water conservation, biodiversity management, and reducing chemical use are crucial for environmental preservation. Supriatna, Djumarno, Ahmad, and Deden (2024) emphasize promoting and supporting sustainable farming methods, such as organic farming and integrated pest management, to enhance ecological sustainability.

4.2. Socio-Cultural Dimensions Sustainability

Based on the ordination analysis of the socio-cultural dimension of coconut farming sustainability, the results reveal differences in sustainability levels between peatland and coastland. For Peatland, the index value is 42.58, categorized as less sustainable. This indicates that socio-cultural practices in coconut farming face significant challenges, including community participation and local traditions. Rosyani, Edison, and Asmadi (2019) highlight that farmers' views on family values are crucial for sharing cultivation knowledge. On the other hand, for coastland, an index value of 54.04 shows that socio-cultural sustainability is in the moderately sustainable category. This suggests that socio-cultural management on coastal land is relatively better than peatland. While current practices are adequate, there is room for improvement to achieve higher sustainability. Sunarminto, Joko, and Eka (2019) note that, from a socio-cultural perspective, plantations contribute to developing educational, religious, health, and other infrastructure.

The analysis of attribute leverage in the socio-cultural dimension of coconut plantation farming in peat lands in Indragiri Hilir Regency highlights that family participation in farming activities is the key factor influencing socio-cultural sustainability, with an RMS value of 12.16% (Figure 8). Active participation for family members across various farming tasks, such as decision-making, cultivation, and profit-sharing, reflects a sense of unity and solidarity within the family in backing coconut farming efforts. This unity ultimately contributes to bolstering sustainability in social-cultural dimensions.

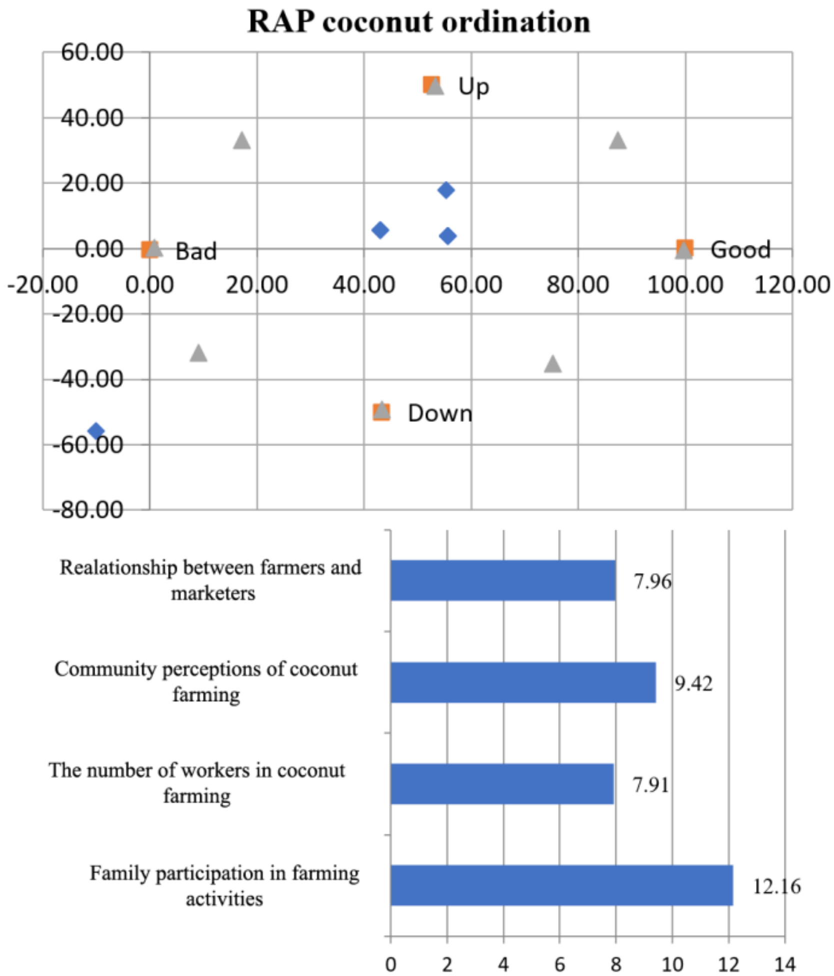
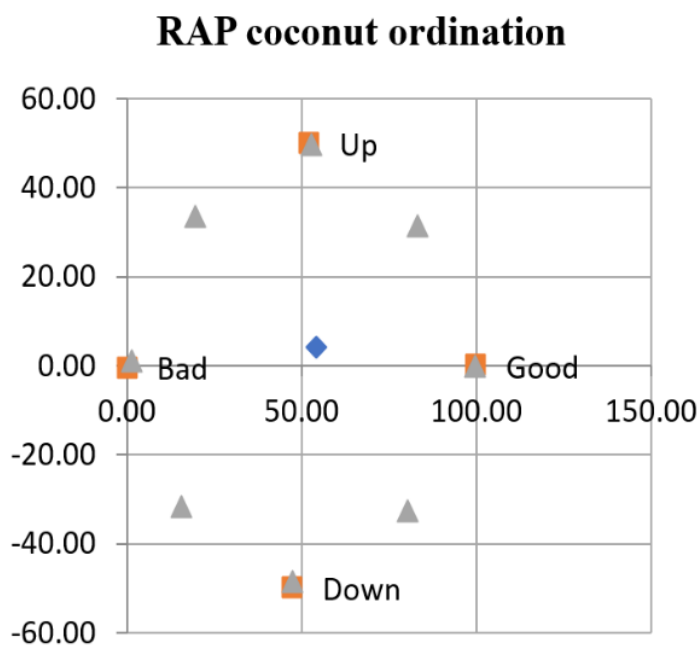


Figure 8. Peat lands: Socio-cultural dimension and sensitive factors influencing socio-cultural sustainability.

Based on Figure 9, the leverage RMS value of 11.11% is associated with community perceptions of coconut farming in coastal areas. Improving community perceptions and participation in agricultural activities can help increase job absorption. Prasetyo and Annisa (2023) state that farmer participation should be seen as a basic human need and a human right. Huis, Lensink, Vu, and Hansen (2019) also mention that regional economic development can be achieved through the involvement and empowerment of farming communities, potentially increasing family income.



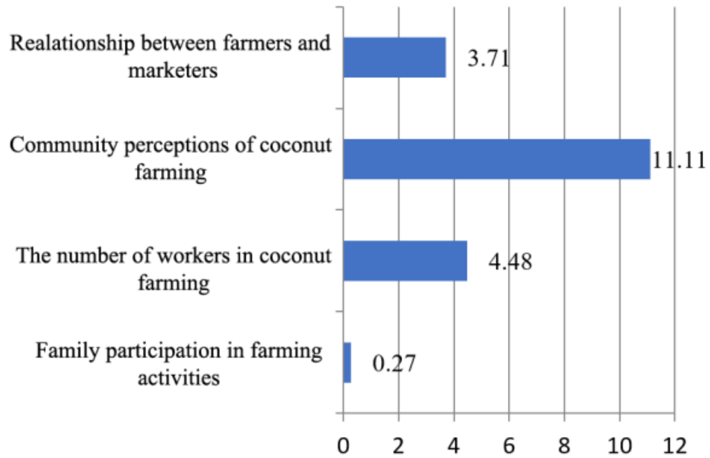


Figure 9. Coast lands: Socio-cultural dimension and sensitive factors influencing socio-cultural sustainability.

4.3. Economic Dimensions Sustainability

The economic dimension delineates the prerequisites for coconut farming, managed by farmers. It encompasses four attributes: coconut marketing, coconut selling system, selling price, and production amount. Sustainability assessments within this dimension yielded values of 38.16 and 37.70 for both land types, indicating a relatively lower sustainability index.

Leverage analysis identified the selling price attribute as the most sensitive, with 16.99% (Figure 10) and 15.06% (Figure 11) for both land types. Typically, middlemen or collectors purchase coconuts and distribute them to companies, thereby, lowering farmers' prices. Ensuring profitability in farming is essential for enhancing sustainability and improving family welfare.

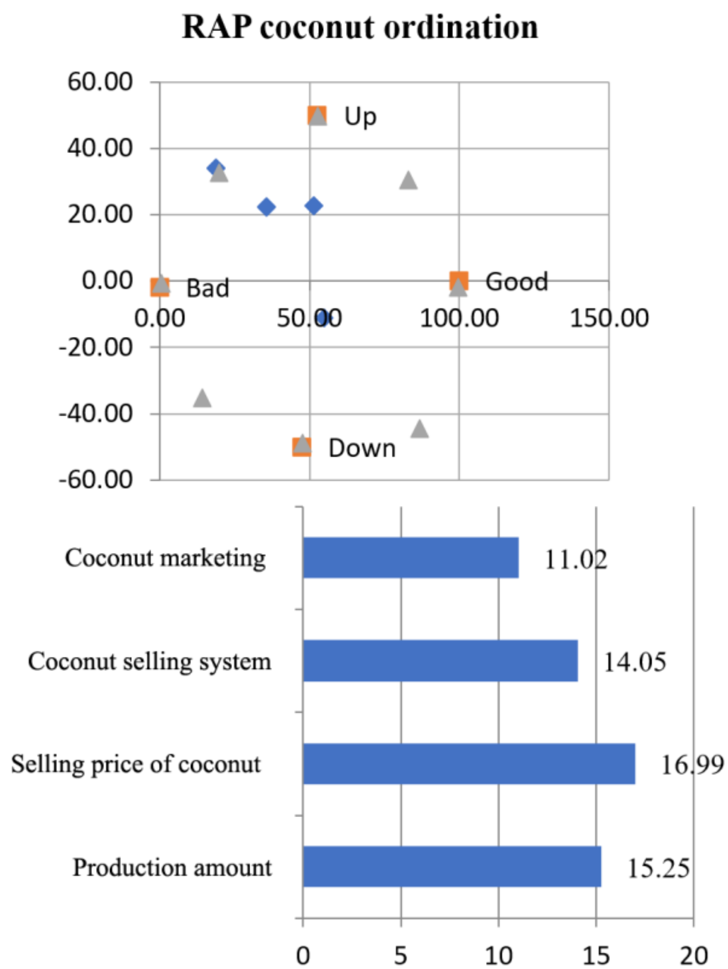
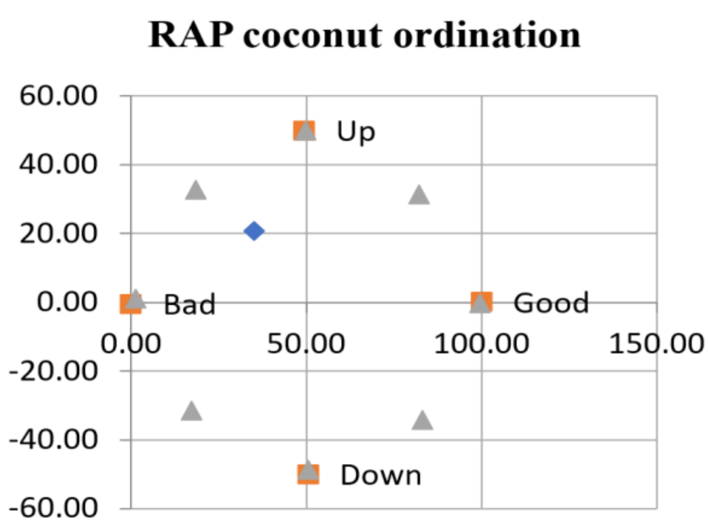


Figure 10. Peat lands: Economic dimension and sensitive factors influencing economic sustainability.



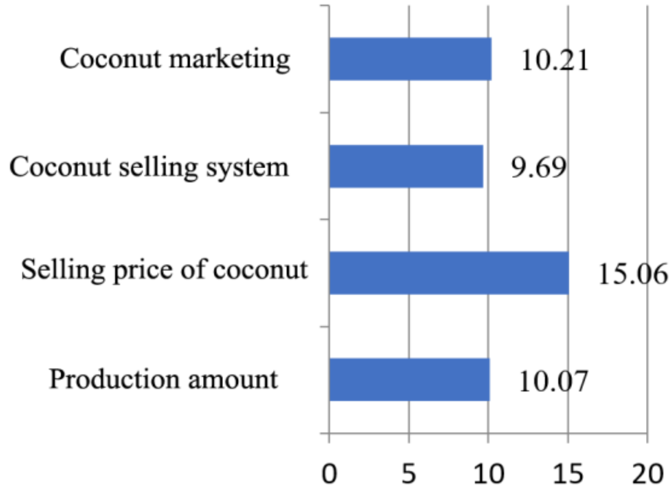


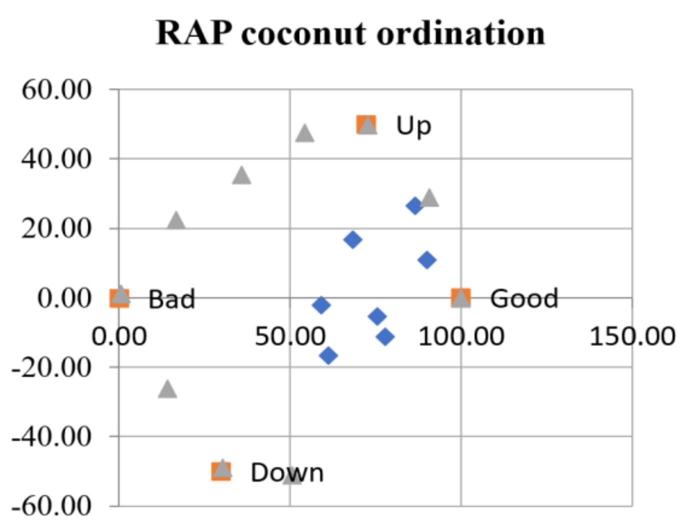
Figure 11. Coast land: Economic dimension and sensitive factors influencing economic sustainability.

The price of coconuts profoundly affects farming sustainability, as low prices can diminish farmers' income, limiting their capacity to sustain or enhance environmentally friendly farming practices. Nuryanti (2017) discovered that price fluctuations of coconuts in Indragiri Hilir Regency greatly affect the income of the local community, particularly farmers, leading to income instability and reduced purchasing power within coconut farming communities. Additionally, low prices may diminish farmers' incentive to invest in technology and other resources necessary for enhancing productivity or mitigating agriculture's environmental footprint.

4.4. Technology Dimensions Sustainability

The ordination analysis of the technology dimension in coconut farming, yielding index values of 74.05 and 65.05, categorizes both types of land as highly sustainable. This indicates that the current management is sustainable but requires attention and improvement to enhance it.

On peat lands (Figure 12), the coconut planting distance is the attribute with the highest value at 21.44, while the coconut product processing industry has the lowest value at 11.44%. In the peatlands of Indragiri Hilir Regency, the common planting distance used by farmers is 9m x 9m x 9m, with a planting system in straight rows. According to Vaulina (2019) the number of coconut trees per row varies between 27 and 30 trees, with around 150 to 255 coconut trees per hectare of land. This is higher than the Indonesian Ministry of Agriculture (2014) standard, which states that there should be 106 to 175 coconut trees per hectare. Planting with closer spacing maximizes land use, although it can increase competition among trees for resources.



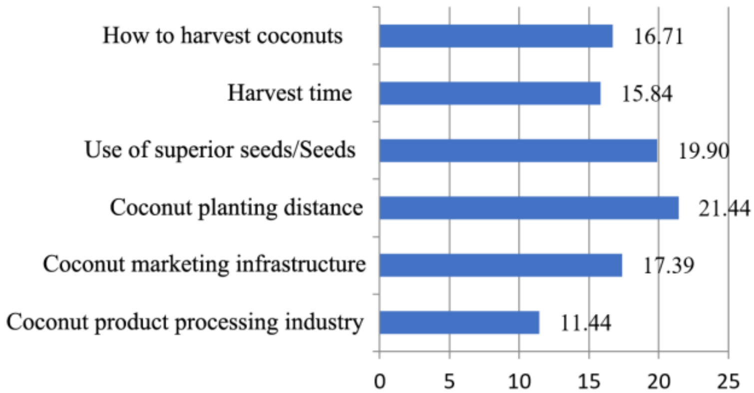
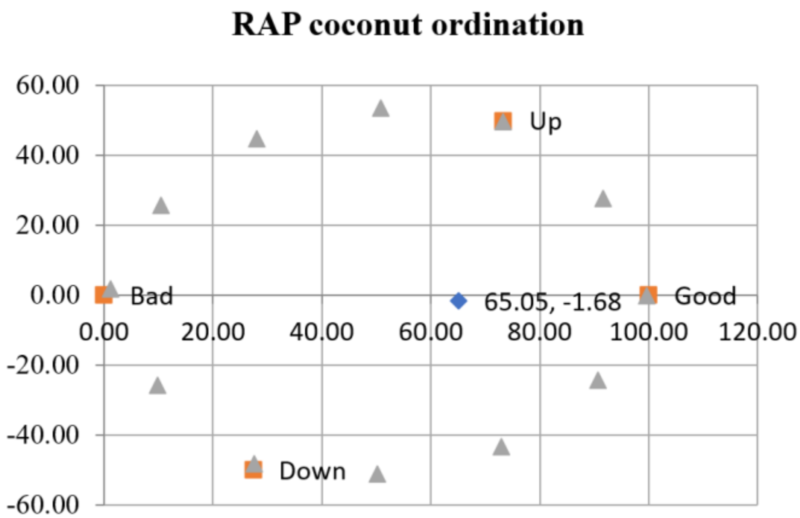


Figure 12. Peat lands: Technology dimension and sensitive factors influencing technology sustainability.

The planting distance for coconuts at 9m x 9m x 9m is crucial for optimizing land use, increasing yield per tree, and positively impacting farmers' income. In peatlands, the appropriate planting distance is crucial to ensure the sustainability of coconut farming by facilitating irrigation and drainage management and maintaining optimal soil moisture.



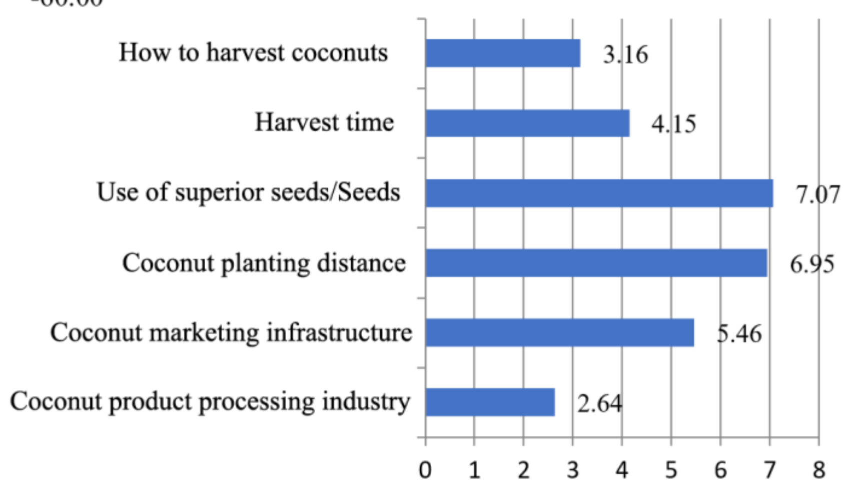


Figure 13. Coast lands: Technology dimension and sensitive factors influencing technology sustainability.

In coastal lands (Figure 13), the use of superior seeds has a significant impact on the sustainability of farming, particularly in terms of technology. The most influential attribute is using superior seeds, with a value of 7.07%. Coconut farmers in the Indragiri Hilir Regency, Riau Province, commonly use coconuts that fall from the mother tree. Characteristics of these superior seeds include resistance to certain diseases or pests, rapid growth, large fruit size, and high fruit production.

4.5. Institutional Dimensional Sustainability

The coordination analysis of the institutional dimension of coconut farming yielded a score of -5.46 for peatland, which is considered unsustainable, and 51.57 for coastal land, which is considered moderately sustainable. This indicates that the current institutional aspect is still lacking and requires attention from the government and stakeholders to ensure the sustainability of this dimension in supporting coconut farming activities. The role of farmer group institutions, particularly coconut field extension workers, it is highly dominant and crucial. Anwarudin and Dayat (2019) state that farmer participation is one of the pillars of successful extension services. Polan, Pontoan, and Merung (2021) emphasize that implementing agricultural extension in the era of regional autonomy strongly focuses on community empowerment and shifting the content of extension material from cultivation to agribusiness.

Based on Figure 14, the most influential attribute in the institutional dimension is participation in coconut extension activities, with an RMS value of 4.57%. Farmers who attend these extension activities are more likely to adopt new technologies introduced through the programs, such as using superior seeds. Participation in extension activities also fosters interaction between farmers and agricultural experts. Participation in coconut extension activities significantly impacts the adoption of new technologies and strengthens the institutional dimension of agriculture.

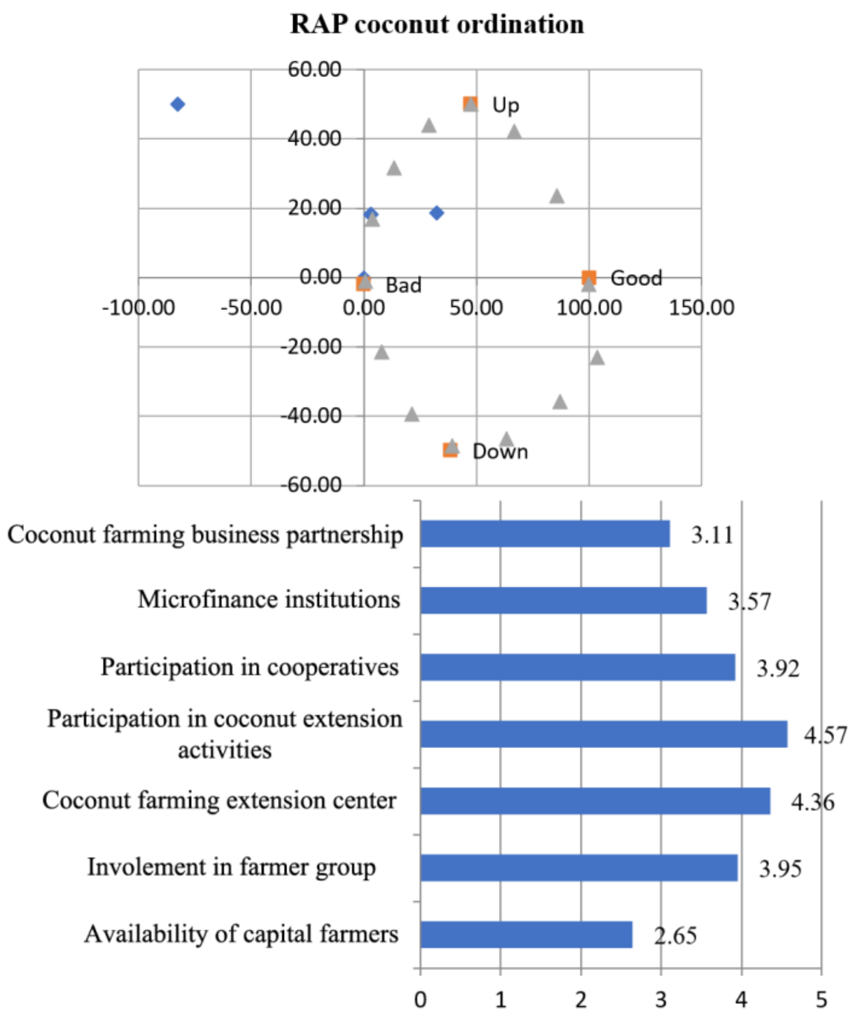


Figure 14. Peat lands: Institutional dimension and sensitive factors influencing institutional sustainability.

Based on Figure 15, the sensitivity of coastal land is associated with the availability of capital, with an RMS value of 1.65%. There is a lack of capital for institutions related to coconut farming. So far, farmers have used their capital in their farming activities. Oktarina, Henny, and Resi (2021) note that the lack of capital is detrimental to farmers, making it necessary to establish cooperatives or savings and loan businesses that can accelerate agricultural development. Zhang, Zhu, and Zhang (2022) emphasize that the stability of a region's natural capital stock is a crucial criterion in assessing the sustainable development of that region.

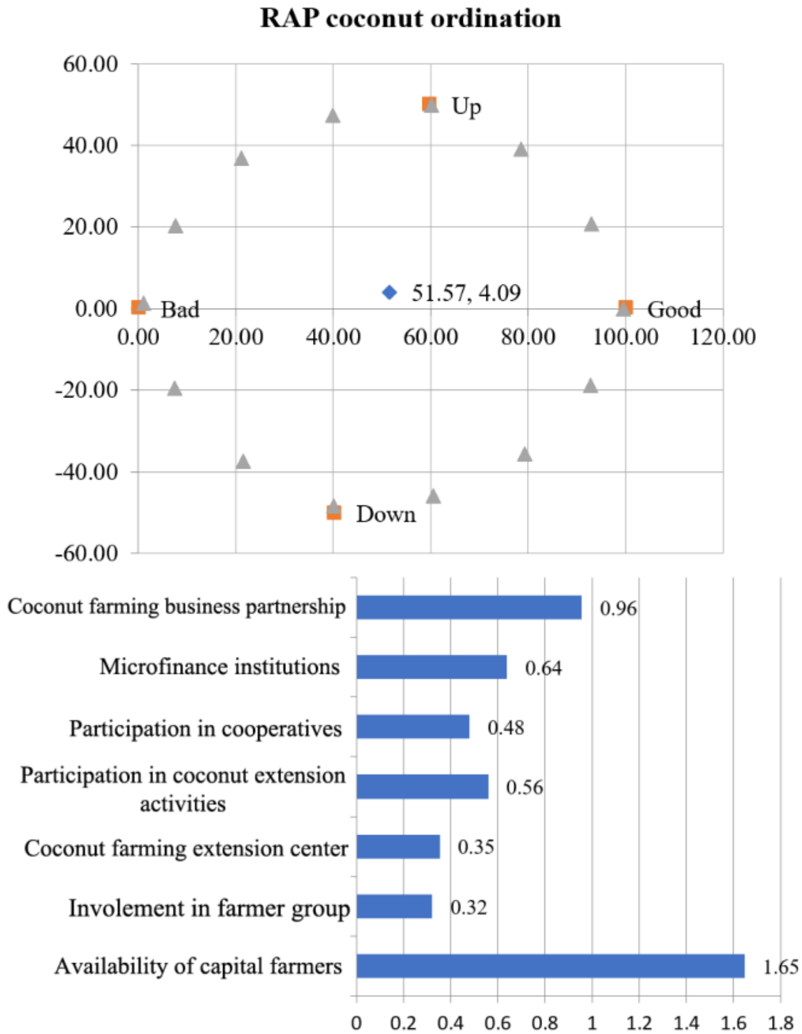


Figure 15. Coast lands: Institutional dimension and sensitive factors influencing institutional sustainability.

5. CONCLUSIONS

The sustainability status of coconut farming in Indragiri Hilir Regency, Riau Province, is evaluated based on five main dimensions: ecology, economy, socio-cultural, technology, and institutional. The results of this evaluation indicate differences in sustainability levels between peatland and coastal land. The obtained sustainability index value for peatland is 44.30, indicating lower level of sustainability. Coastland: The sustainability index value obtained is 53.58, categorized as moderately sustainable. The most sensitive and influential attributes of the sustainability of coconut farming on both types of land are as follows: (1) Ecology: use of fertilizers and use of pesticides; (2) Socio-cultural: family participation in coconut farming and people's perceptions of coconut farming; (3) Economy: coconut sales system; (4) Technology: coconut spacing and use of superior seeds; (5) Institutional: participation in coconut extension activities and availability of capital. Overall, this analysis indicates that the sustainability status of coconut farming in Indragiri Hilir Regency differs between peatland and coastal land. Peatland requires more attention to achieve a more sustainable status, while coastal land falls into a moderately sustainable category but still needs improvement. This highlights the need for tailored strategies to manage these land types effectively and improve sustainability outcomes.

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Institutional Review Board Statement: The Ethical Committee of the Universitas Islam Riau, Indonesia has granted approval for this study on 1 August 2022.
Transparency: The authors state that the manuscript is honest, truthful, and transparent, that no key aspects of the investigation have been omitted, and that any differences from the study as planned have been clarified. This study followed all writing ethics.
Competing Interests: The authors declare that they have no competing interests.
Authors' Contributions: All authors contributed equally to the conception and design of the study. All authors have read and agreed to the published version of the manuscript.

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PAGE 14

PAGE 15

PAGE 16

PAGE 17

PAGE 18

PAGE 19

PAGE 20