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Article

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Mangrove Ecosystem Management for Sustainable Renewable Energy Production: A Multi-Dimensional Analysis

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ABSTRACT

Mangrove ecosystems have become a critical habitat for sustaining renewable energy production, and their management is essential to maintain their ecological, economic, and social functions. This study aimed to analyze the multidimensional aspects of mangrove ecosystem management for sustainable renewable energy production in the Tebing Tinggi, Kepulauan Meranti, Riau. This study formulates sustainable management schemes for the mangrove ecosystem in the Tebing Tinggi, Kepulauan Meranti, Riau by analyzing the ecological, economic, social, legal-institutional, and technological aspects of the ecosystem. To conduct this analysis, researchers used the Multidimensional Scaling (MDS) approach, which relies on an algorithm called the MDS algorithm. The findings from the study reveal that the use of mangroves can increase people's income, but the level of community education is still low, and there is a lack of community participation in mangrove ecosystem management activities. Based on the Rap-Mangrove analysis, the multidimensional index of mangrove ecosystem management is considered sufficiently sustainable. The findings emphasized the significance of community participation and education in managing mangrove ecosystems. The study concludes that sustainable management schemes for mangrove ecosystems are necessary to ensure their continued contribution to renewable energy production.

Keywords: Renewable Energy, Environmental Management, Ecosystem, Mangrove, Multi-Dimensional Analysis
JEL Classification: Q20, Q42, Q57

1. INTRODUCTION

Indonesia's vast coastal regions possess a distinctive and exclusive type of ecological system, including the mangrove forest functioning as a natural climate solution (Macreadie et al., 2021). The forest experiences periodic inundation with seawater and are sufficiently supplied with fresh water while being protected against strong tidal currents and waves. The mangrove forests, which have an essential role in providing exact support to humans and animals residing inside and around them, are now under threat because of inadequate utilization patterns that do not ensure their sustainability aspects. There has been a growing interest in using mangrove forest ecosystems as a potential source of renewable energy, including biomass, biogas, and biofuels (Numbere, 2020; Dahdouh-Guebas et al., 2022). However, these forests perform various functions such as biological, ecological, and economic to support the existence of plant and animal life. The biological functions of mangrove forests include providing breeding areas for various animals, including fish, shrimp, and crabs. In contrast, the ecological functions' significance includes mitigating the risks of coastal abrasion, seawater intrusion, and wave and wind damage. Meanwhile, economically, the mangrove forests have vital importance as they promote tourism activities, provide wood and non-timber products while favoring a suitable livelihood for the population living around them (Mulyadi, 2017).

The province of Riau contains mangrove forest ecosystems along its coastal areas, including Tebing Tinggi. Mangroves are abundant in this region and were previously fertile, providing a rich source of fishery resources like shrimp and crabs (Fatonah et al., 2021). As a result, the local fishing industry has developed and employs many people. Despite this, the area has suffered from decreased fishery yields over time due to the damage caused to the mangroves. Mangrove trees have been cut down for various purposes, and the quality of surrounding waters has also decreased due to various types of pollution. These changes have had a significant impact on the ecosystem and the community that relies on it. To address this problem, it is necessary to implement sustainable management practices that will benefit both the mangroves and the local community. The sustainability of mangrove ecosystem management in Tebing Tinggi, Meranti, Riau has not been documented in previous research. However, Kavanagh and Pitcher (2004) and Fauzi (2005) have noted that a quick assessment of sustainability in natural resource management can be done using multidimensional scaling (MDS) analysis. This method has been used to evaluate the sustainability of mangrove management in several other areas in Indonesia (Pattimahu et al., 2010; Maharyudi, 2006; Suwarno et al., 2011; Mukhlisi and Purnaweni. 2014; Boer and Pratiwi, 2016; Santoso, 2018).

This study is crucial for the preservation of mangrove forest ecosystems, renewable energy production, and sustainability of coastal communities (Alongi, 2009; Onyena and Sam, 2020). Implementing sustainable management practices promote the long-term health of mangrove forests and their important functions for the earth's ecosystem. The purpose of this study is to contribute towards the preservation of mangrove forest ecosystems for sustainable renewable energy. Mangrove forests are one of the most productive ecosystems on the planet, and they provide important functions such as storm protection, carbon sequestration, and nutrient cycling (Zhu and Yan, 2022; Das et al., 2022; Kumari and Pathak, 2023). Another potential source of renewable energy from mangroves is biogas. The anaerobic decomposition of organic matter in mangrove forests can produce methane gas, which can be harvested and used as a fuel for energy generation. The importance of this study lies in its potential to inform sustainable management practices for mangrove forests. Mangrove forests provide important ecosystem services, such as carbon sequestration and coastal protection, and are also a source of renewable energy through the production of biomass and biogas. However, improper management practices can lead to deforestation, loss of biodiversity and degradation of ecosystem services. By studying the characteristics of mangrove forest ecosystems and the socio-economic conditions of communities, this research can provide insight into sustainable management strategies that can balance economic, social, and environmental priorities.

2. RESEARCH METHOD

The study was carried out in the Mangrove Ecosystem located in Tebing Tinggi, Kepulauan Meranti, Riau. A depiction of the study location can be found in Figure 1.

Conducted between March 2021 and April 2022, this study utilized survey methods, laboratory analysis, and interviews in designing research on managing the mangrove ecosystem. Field surveys were carried out to gather both biophysical and socio-economic data, institutional laws, and existing technology used in communities that utilize mangrove forests. The primary objective of data collection was to identify environmental problems that arise in managing the ecosystem, as well as the opinions of stakeholders and experts regarding its management. The study took into account ecological, economic, socio-cultural, legal, institutional, and technological aspects, with management analysis and design based on primary and secondary data obtained from field surveys and expert opinions. The process of selecting respondents from the community was done through purposive sampling using specific criteria that could represent the communities of fishermen/mangrove loggers and those involved in the use of mangrove areas in Tebing Tinggi. The primary data required for the study involves attributes associated with the five dimensions of sustainable development, which include ecological, economic, socio-cultural, technological and legal-institutional dimensions. The respondents provided the primary data, while secondary data was obtained through literature and documents from various research-related agencies. Additionally, direct observation at the research location was conducted to collect primary data.

The purpose of sustainability analysis is to assess the current level of sustainability in different dimensions of Mangrove Ecosystem management. To conduct this analysis, researchers used the Multidimensional Scaling (MDS) approach, which relies on an algorithm called the MDS algorithm (Fauzi, 2005). According to Pitcher (1999), the Rapid Appraisal for Fisheries (Rapfish) tool is an MDS approach with ordination techniques based on Multi Criteria Analysis (Clarke, 1993). The analysis was performed using the RapMangrove software, which is a modification of the RapFish tool (Preikshot et al., 1998). The RapMangrove analysis involved several stages, including identifying sustainable attributes of mangrove management, assessing these attributes based on sustainability criteria, inputting the assessment scores into the Rap Mangrove software, and compiling a sustainability index and status. The five dimensions of sustainable mangrove management include ecological, economic, socio-cultural, legal-institutional, and technological dimensions. Each attribute was evaluated on an ordinal scale based on sustainability criteria within its dimension. The MDS approach produces similarity and dissimilarity scores between pairs of individuals and variables, thus enabling researchers to assess sustainable management dimensions (Young, 2001).

Table 1 displays the sustainability index scores for every dimension, while Figure 2 exhibits the sustainability index value for each dimension in a kite diagram. Furthermore, the shape of the kite diagram is based on the symmetry of the index values for each dimension, namely ecology, economy, socio-culture, policy, and technology. Additionally, the index value for each dimension is visually displayed on the diagram.

To determine which attribute has the greatest influence on the sustainability index, a sensitivity analysis is performed by examining the shape of the Root Mean Square (RMS) ordination on the X axis. A larger RMS value signifies a greater contribution by this attribute to the sensitivity of sustainability status (Kavanagh and Pitcher, 2004; Kavanagh, 2001). As a means of increasing the accuracy and confidence in the results, Monte Carlo analysis is utilized to assess the effects of errors on the process of estimating the ordinated value of Mangrove Ecosystem management. The discrepancy between the results from the Monte Carlo analysis and the RapMangrove analysis is negligible, indicating that

Figure 1: Research locations

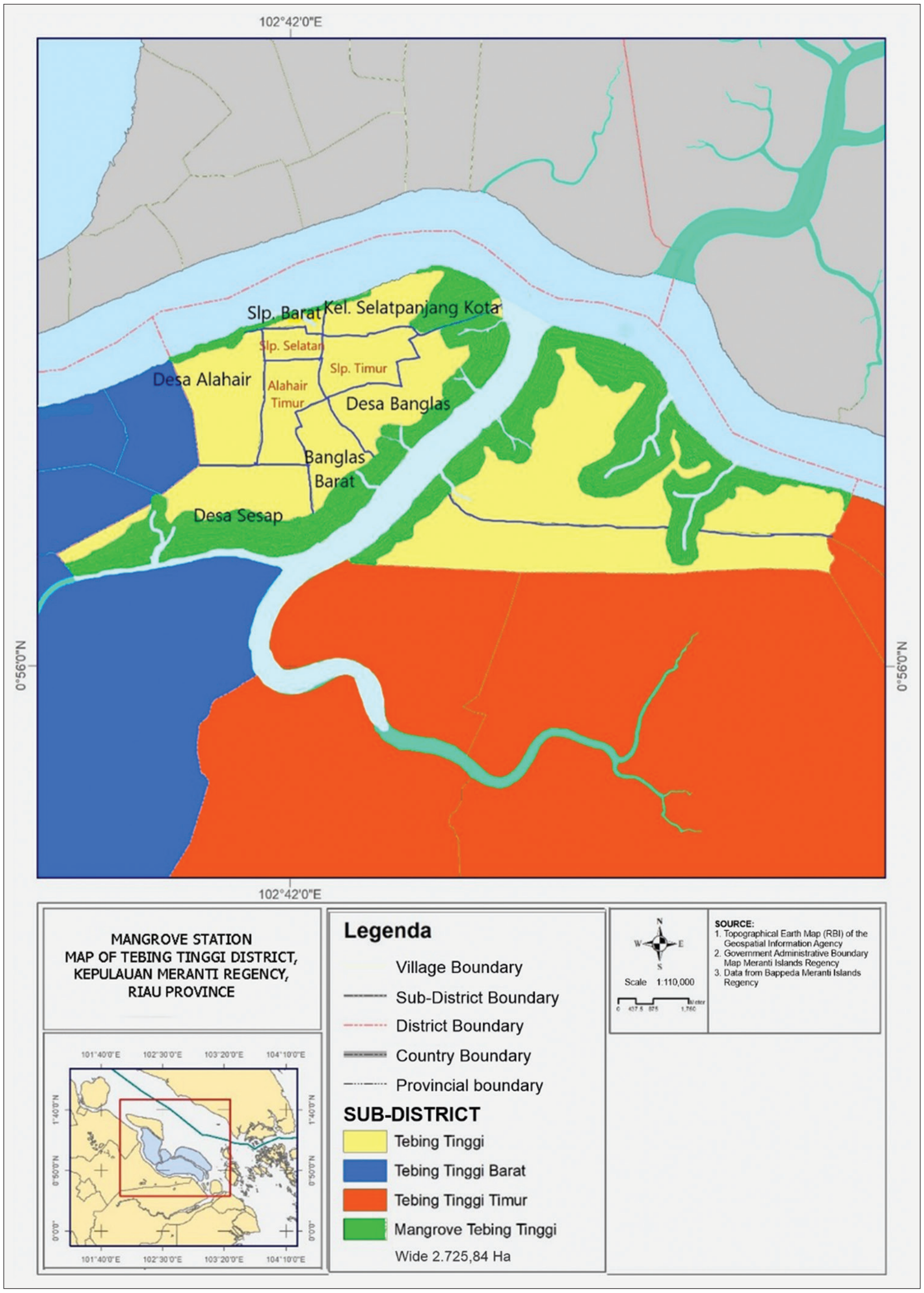


Table 1: Categories of mangrove ecosystem management sustainability status

Index value	Category
0.00-25.00	Unsustainable
25.01-50.00	Less sustainable
50.01-75.00	Sufficiently Sustainable
75.01-100.00	Sustainable

Source: Fauzi (2005)

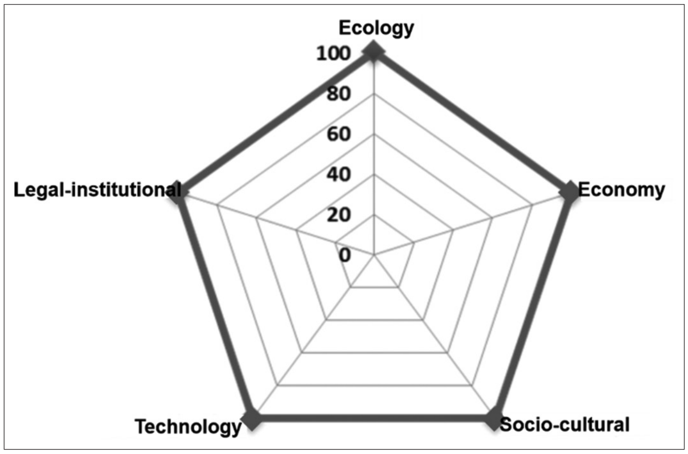
scoring errors have a marginal impact. If the difference between both analyses exceeds 5%, the results are deemed inadequate for estimating the sustainability index value, whereas a difference of <5% indicates that the analysis is sufficient to estimate the sustainability index value (Alder et al., 2000). In addition to obtaining the sustainability index, the RapMangrove analysis also produces outputs in the form of leverage of attributes. The leverage analysis aims to identify sensitive attributes that influence the sustainability index value of the ecological dimension. Moreover, the leverage attribute is the attribute that provides the highest percentage value in the sustainability of a management dimension.

3. RESULTS

3.1. Sustainability Attributes of Mangrove Ecosystem Management

The assessment of mangrove ecosystem management sustainability in Tebing Tinggi is based on five dimensions, which include ecological, economic, socio-cultural, technological, and legal-institutional aspects. Additionally, a leverage analysis was performed to identify the factors that affect the sustainability status of each dimension. This information is presented in Table 2 that correspond to each dimension.

Figure 2: Kite diagram of sustainability dimensions index



The sustainability of the mangrove ecosystem management in Tebing Tinggi was assessed through the analysis of sustainability dimensions (Rap Mangrove). This analysis resulted in a sustainability index for each of the five dimensions, namely ecological, economic, socio-cultural, technological, and legal-institutional dimensions, as shown in Figure 3. Furthermore, the RapMangrove also presents leverage analysis outputs that identify critical attributes affecting the ecological dimension's sustainability index value (Figure 4). Kavanagh and Pitcher (2004) explain that RMS values determine the magnitude of each attribute's role in sustaining status sensitivity, with higher RMS values indicating more impact on sustainability. Specifically, the leverage analysis constitutes the attribute with the highest percentage value in managing sustainability. Of the four obtained attributes that are sensitive to ecological sustainability, coastal abrasion (RMS=5.7), mangrove land pressure (RMS=4.3), rehabilitation success (RMS=4.1), and water conditions (RMS=4.0) indicate the influence of both natural and human activities on Tebing Tinggi's mangrove ecosystem. The analysis of leverage indicates the significant factors in managing the sustainability of the mangrove ecosystem in Tebing Tinggi with regards to its economic

Table 2: Overall scores of the sustainability dimensions of mangrove ecosystem management

No.	Ecological attributes	Score	Economic attributes	Score	Socio-cultural attributes	Score	Technology attributes	Score	Legal-institutional attributes	Score
1.	Number of mangrove species	2.5	Number of poor people	0.0	Community education level	2.2	Aquaculture technology	1.0	Traditional Figures	1.0
2.	Mangrove thickness	1.5	Population income	1.2	Community knowledge about mangroves/ environment (Extension)	1.0	Logging Side Effects (standard felling technique)	1.0	Customary Institution	1.2
3.	Mangrove density	2.5	Contribution to the village's gross income	0.8	Local wisdom	0.7	Mangrove Rehabilitation Technology	0.3	Availability of formal and informal regulations for management	1.0
4	Animal type	2.5	Mangrove processing industries	0.5	Beneficiary households	1.5	Means of transportation	0.5	Environmental law education	1.0
5	Mangrove land pressure	0.3	Product Price	1.0	Mangroves resources	0.0	Supervision facilities and infrastructure	1.0	Implementation of monitoring - supervision	1.0
6.	Beach abrasion	1.0	Tourism potential	0.8	Aesthetic values	0.5	Mangrove Processing Industry	1.5	Level of community compliance	1.2
7.	Water conditions	2.0	Number of tourist visits	0.7	Social cohesiveness	1.3	Waste management technology	0.3	Coordination between stakeholders	1.0
8.	Utilization of pond land	1.7	Labor absorption	0.5	Potential conflict of mangrove use	2.0	Abrasion Prevention Technology	0.0	Society participation	0.8
9.	Mangrove Rehabilitation	0.7	Dependence on mangrove as a source of livelihood	0.3	Community empowerment	1.0	Access timber market information	1.0	Law enforcement	1.0
10	Mangrove conservation	0.7	Marketing of mangrove products	1.0	-	-	-	-	-	-
11	-	-	CSR Fund Support	0.5	-	-	-	-	-	-

Figure 3: RAPMangrove ordination of sustainability dimensions index

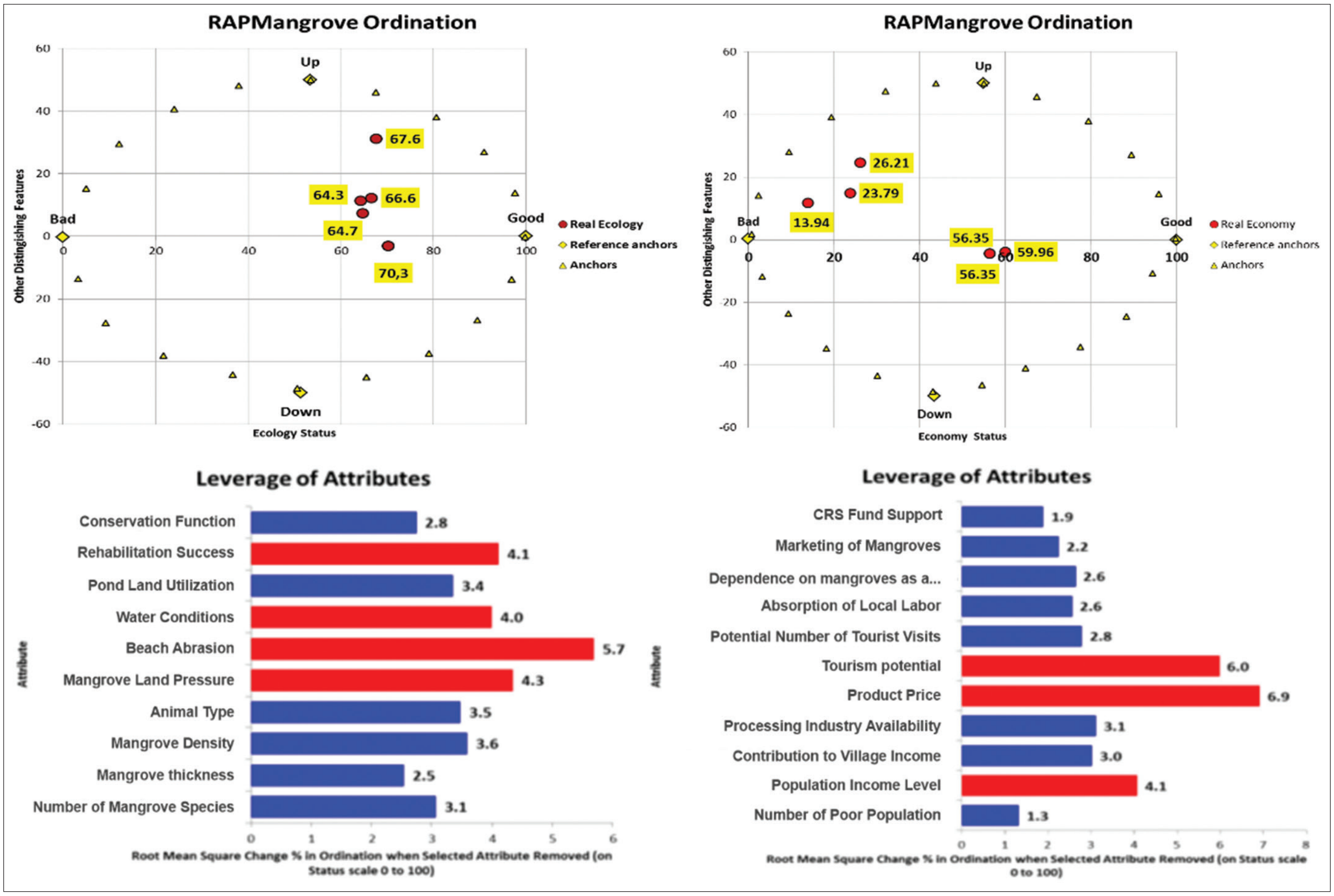
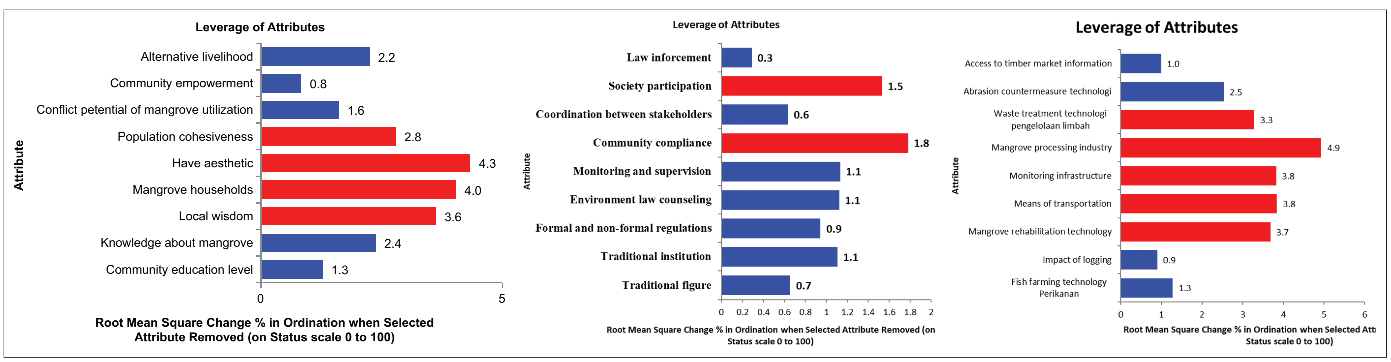


Figure 4: Leverage analysis of sustainability dimensions in root mean square (RMS)



dimension. The three sensitive attributes are the price of products (RMS=6.9), potential for tourism (RMS=6.0), and income levels of the population (RMS=4.1). Additionally, leverage analysis identifies four sensitive attributes that influence the index value of the socio-cultural dimension of sustainability, namely, aesthetics (RMS=4.3), households utilizing mangrove resources (RMS=4.0), local wisdom (RMS=3.6), and Social cohesiveness (RMS=2.8). Lastly, the sustainability index of technology-infrastructure dimension was analyzed using leverage analysis.

Moreover, the results of the RapMangrove analysis indicate that the sustainability of the technology-infrastructure dimension is mostly influenced by the mangrove processing industry (RMS=4.9), supervision facilities and infrastructure (RMS=3.8), means of transportation (RMS=3.8), mangrove rehabilitation technology (RMS=3.7), and waste treatment technology (RMS=3.3). The legal-institutional dimension is greatly influenced by community compliance (RMS=1.8) and community participation (RMS=1.5). Monitoring/supervision implementation, environmental law counseling, and customary institutions are also important factors in managing sustainable mangrove ecosystems. The level of community compliance and community participation have the greatest impact on the sustainability of the legal-institutional dimension. The attributes of monitoring/supervision implementation, environmental law counseling, and customary institutions also share equal influence and need to be prioritized in managing sustainable mangrove ecosystems. The leverage analysis identifies the level of community compliance and community participation as the most sensitive attributes for the sustainability of the legal-institutional dimension.

3.2. Multidimensional Sustainability Status

The MDS analysis revealed that three dimensions, namely the ecology, socio-cultural and legal-institutional dimensions, had sustainability index values higher than 50%. However, two other dimensions, namely the economy and technology dimensions, had sustainability index values <50%. These findings suggest that the efforts to manage the mangrove ecosystem in the Tebing Tinggi sub-district currently prioritize ecological and socio-cultural aspects, while economic, legal-institutional, and technological dimensions receive less attention. The results of the MDS analysis are visually represented in Figure 5 as a kite diagram.

The kite diagram illustrates the multi-dimensional analysis of Tebing Tinggi District sustainability index and status. The ecological, socio-cultural and legal-institutional dimensions display a relatively sustainable figure, with 67.29, 54.67, and 50.44 points, respectively. However, the economy and technological dimensions showcase a less sustainable score of 39.43 and 38.94, respectively. To achieve sustainable management of mangrove ecosystem, the legal-institutional and technological-infrastructure dimensions require prompt attention. Nevertheless, enhancing all sustainability dimensions is necessary to attain sustainable management fully.

The sustainability analysis conducted on the five dimensions - ecology, economy, social, technology, law and institution - resulted in 18 sensitive attributes. These sensitive attributes act as leverage factors for each dimension partially. Therefore, this data becomes the basis of information about attributes that need to be improved and maintained in quality. It is hoped that by treating these sensitive attributes accordingly, the sustainability index of mangrove ecosystem management will increase. The sensitive attributes are presented in Table 3.

The leverage factors were then analyzed to determine the determining factors that influence the strategy for managing mangrove ecosystems. The results of the prospective analysis of determining factors in mangrove ecosystem management are presented in Figure 6.

3.3. Stress Value, Coefficient of Determination and Error Effect

Table 4 provides information on the measurement of the precision of a particular point that mirrors the initial data through the examination of the stress value obtained from the results of Rap-Mangrove ordination analysis for every analyzed dimension. Additionally, the contribution of each attribute to the sustainability of the system is evaluated by assessing the coefficient of determination (R^2) value for each dimension. The stress value and coefficient of determination for each dimension are included in Table 4.

Table 4 displays that the mean stress value dimension is 0.17 and the mean R2 value is 0.94. According to the Rapfish method, a low stress value below 0.25 is considered good, as it suggests that the resulting output is similar to the actual situation and indicates a better fitting model with less stress. Conversely, a high stress value implies a less suitable model. Pitcher and Preikshot (2001) suggest a stress value lower than 20% can be tolerated, thus the model with an average stress value of 17% is acceptable. The goodness of fit test demonstrated that the sustainability index estimation model is applicable with an R2 value of 0.94. A Squared

Figure 5: Kite diagram for sustainable status of mangrove ecosystem management

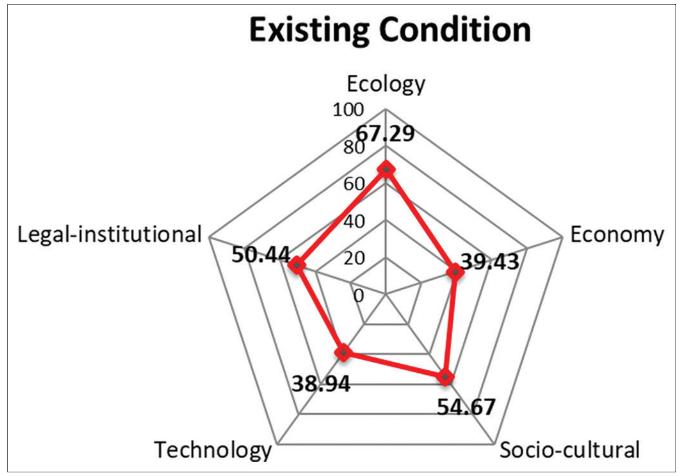


Table 3: Leverage analysis for sustainability dimensions

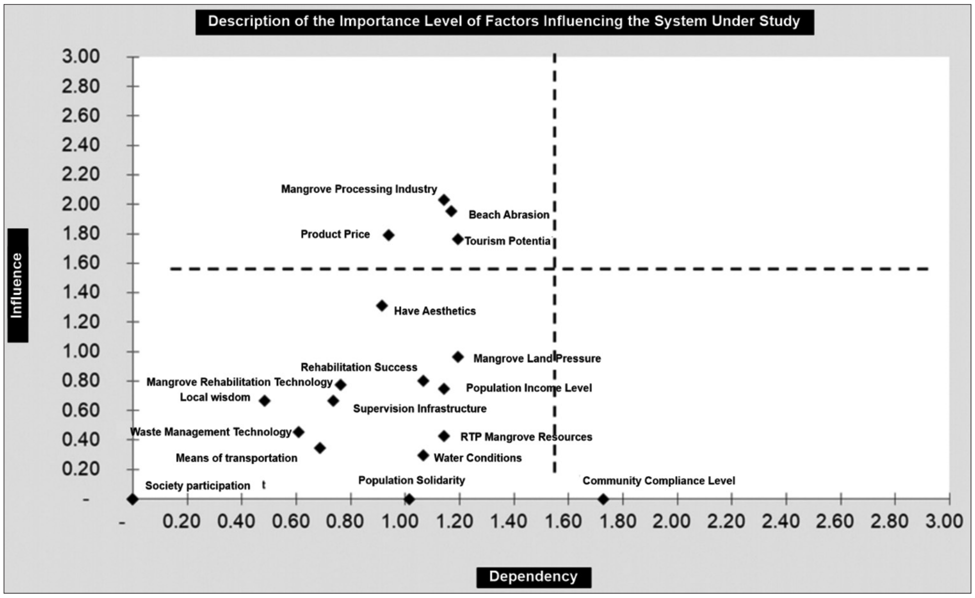
Dimensions	Attributes	Score
Ecology	Beach abrasion	5.7
	Mangrove land pressure	4.3
	rehabilitation success	4.1
	Water conditions	4.0
Economy	Product price	6.9
	Tourism potential	6.0
	Population income level	4.1
Socio-culture	Have an aesthetic	4.3
	Mangrove resources industries	4.0
	Local wisdom	3.6
	Social cohesiveness	2.8
Law and institutions	Level of community compliance	1.8
	Society participation	1.5
Technology	Mangrove processing industry	4.9
	Supervision facilities and infrastructure	3.8
	Means of transportation	3.8
	Mangrove rehabilitation technology	3.7
	Waste treatment technology	3.3

Table 4: Stress value and multidimensional determination coefficient

Dimensions	Sustainability index	Stress*	R^2****
Ecological dimension	67.29***	0.15	0.95
Economic dimension	39.43**	0.15	0.93
Socio-cultural dimension	54.67***	0.16	0.93
Technology dimension	38.94**	0.22	0.92
Legal-institutional dimension	50.44***	0.15	0.95
Mean	50.15	0.17	0.94

*Stress value<0.25 means goodness of fit; **MDS value between 26-49 is considered somewhat unsustainable; ***Stress value between 50 and 74 falls under the moderately sustainable category; ****R^2 value is >0.76 or very close to 1, it signifies an excellent contribution

Figure 6: Influence and dependence between leverage factors of sustainability analysis



Correlation (R2) value closer to 1 indicates better mapping of the data, and the current value explains that 94% of the model is justifiably explained, leaving only 6% to be attributed to other factors. Additionally, Pitcher and Preikshot (2001) recommend an R2 value >80% as a good and sufficient sustainability index estimation model.

Furthermore, the objective of conducting Monte Carlo analysis to assess the impact of random errors is to ascertain (a) how error scoring features affect the outcome, (b) the extent to which variations in scoring influence the result, (c) the consistency of the repeated MDS analysis procedure, and (d) any input or missing data errors. The findings related to all aspects of the Monte Carlo analysis are displayed in Table 5.

Table 5 displays that there is no noteworthy distinction between the MDS index value and the outcome of the Monte Carlo analysis, in terms of the dispersion value and the influence of errors at the 95% level. This suggests that scoring errors, variations in scores, the stability of the MDS analysis process, and errors in input or missing data had no impact. According to Kavanagh and Pitcher (2004), the Monte Carlo analysis can be used as a simulation method to determine the influence of random errors in statistical analysis conducted on all dimensions. This was also mentioned by Fauzi (2005) that Monte Carlo analysis can be an indicator of errors caused by scoring on each attribute, multidimensional variations in scoring due to different opinions, the repetition of data analysis, and errors in input data or missing data. The outcome of the Mangrove Ecosystem RapMangrove analysis is acceptable because the difference in the sustainability index value obtained from the validation test with the Monte Carlo value is between 0.99 and 4.83, indicating an error of <5. This demonstrates that the effect of errors is relatively small. Therefore, the Mangrove Ecosystem RapMangrove model for the management of the Mangrove Ecosystem in Tebing Tinggi is regarded as adequate as an estimator of the sustainability index value. As per Kavanagh and Pitcher (2004), if the difference in value between the Monte

Table 5: Monte carlo analysis

Dimensions	Sustainability index (MDS) (%)	Monte Carlo analysis *) (%)	Difference (MDS–MC) (%)
Ecological dimension	67.29	64.68	2.61
Economic dimension	39.43	38.44	0.99
Socio-cultural dimension	54.67	49.84	4.83
Technology dimension	38.94	37.87	1.07
Legal-institutional dimension	50.44	47.66	2.78

*95% significance level

Carlo Analysis and the RapMangrove Analysis is >5, the analysis outcomes are not sufficient to estimate the sustainability index value. However, if the difference in the values is <5, then the analysis outcomes are considered sufficient to estimate the index value of sustainability.

The research results suggest that the Mangrove Ecosystem RapMangrove model can be an adequate estimator of the sustainability index value for the management of the Mangrove Ecosystem in Tebing Tinggi. This can have significant implications for renewable energy production as the model can assist in sustainable management practice. By understanding the spatial distribution and carbon stocks of mangrove forests, as well as their potential for renewable energy production, managers and policymakers can make informed decisions on the sustainable use and conservation of these ecosystems. Furthermore, mangrove forest ecosystems have the potential to provide a significant source of renewable energy, including biomass, biogas, and biofuels. The utilization of these sources of energy can help to reduce carbon emissions, promote sustainable development, and support the livelihoods of local communities. This study also highlights the potential for integrated management approaches that balance the socio-economic needs of local communities with conservation objectives (Iqbal, 2020).

4. CONCLUSION

The study revealed the indicators that determine the sustainability of the management of mangrove forests in Tebing Tinggi, Meranti, Riau. Economic analysis showed that the use of mangroves could boost the income of the people. However, social analysis revealed poor education level of the community and negligible participation of the community in the management of mangrove ecosystems. On the other hand, access to mangrove ecosystems was high. According to the Rap-Mangrove analysis, the multidimensional index of mangrove ecosystem management was 50.16 on a sustainability scale of 0-100, signifying sufficiently sustainability. Three dimensions, i.e., ecological, socio-cultural, and legal-institutional were moderately sustainable, while economic and technology dimensions were less sustainable. Thus, the RapMangrove approach could aid in policymaking for sustainable mangrove forest management by encouraging biodiversity in mangrove ecosystems, enforcing laws and creating alternative livelihoods.

This study is valuable in both theory and practice as it establishes a knowledge base regarding the environmental conditions of mangrove ecosystems based on ecological, economic, socio-cultural, legal/institutional, and technological factors. It provides scientific insight into the factors that impact the environmental health of these ecosystems, and contributes to the development of sustainable management policies. Furthermore, this research is intended to serve as a resource for policymakers and stakeholders to inform their decisions regarding the sustainable management of these ecosystems. It is recommended that in order to create more comprehensive policy formulations, detailed data and information, including economic evaluations of mangrove ecosystem resources, are necessary. This will enable policymakers to make informed decisions about the management of mangrove ecosystems in Tebing Tinggi, Riau, Indonesia.

REFERENCES

Alder, J., Pitcher, T.J., Preikshot, D., Kaschner, K., Ferriss, B. (2000), How good is good? A rapid appraisal technique for evaluation of the sustainability status of fisheries of the North Atlantic. Fisheries Centre Research Reports, 8(2), 136-182.

Alongi, D. (2009), The Energetics of Mangrove Forests. Germany: Springer Science and Business Media.

Boer, M., Pratiwi, N. (2016), Pengelolaan ekosistem mangrove di Taman nasional sembilang kabupaten banyuasin provinsi Sumatera Selatan. Jurnal Ilmu dan Teknologi Kelautan Tropis, 7(2), 703-714.

Clarke, K.R. (1993), Non□parametric multivariate analyses of changes in community structure. Australian Journal of Ecology, 18(1), 117-143.

Dahdouh-Guebas, F., Friess, D.A., Lovelock, C.E., Connolly, R.M., Feller, I.C., Rogers, K., Cannicci, S. (2022), Cross-cutting research themes for future mangrove forest research. Nature Plants, 8(10), 1131-1135.

Das, S.C., Das, S., Tah, J. (2022), Mangrove ecosystems and their services. In: Mangroves: Biodiversity, Livelihoods and Conservation. Singapore: Springer Nature Singapore. p139-152.

Fatonah, S., Hamidy, R., Mulyadi, A., Efriyeldi, E. (2021), Floristic composition and stand structure of mangrove forests with varying vegetation conditions in Sungai Apit, Siak, Riau, Indonesia. Biodiversitas Journal of Biological Diversity, 22(9), 3972-3983.

Fauzi, A. (2005), Pemodelan Sumber Daya Perikanan Dan Kelautan Untuk Analisis Kebijakan. Jakarta: Gramedia Pustaka.

Iqbal, M.H. (2020), Valuing ecosystem services of Sundarbans Mangrove forest: Approach of choice experiment. Global Ecology and Conservation, 24, e01273.

Kavanagh, P. (2001), Rapid Appraisal of Fisheries (RAPFISH) Project. Colombia: Fisheries Center University of British Columbia.

Kavanagh, P., Pitcher, T.J. (2004), Implementing Microsoft Excel Software for Rapfish: A Technique for the Rapid Appraisal of Fisheries Status. Canada: Fisheries Centre Research, University of British Columbia.

Kumari, P., Pathak, B. (2023), Effect of climate change and urbanization on Mangrove ecosystem. In: Climate Change and Urban Environment Sustainability. Singapore: Springer Nature Singapore. p293-301.

Macreadie, P.I., Costa, M.D., Atwood, T.B., Friess, D.A., Kelleway, J.J., Kennedy, H., Duarte, C.M. (2021), Blue carbon as a natural climate solution. Nature Reviews Earth and Environment, 2(12), 826-839.

Maharyudi, P. (2006), Model Pengelolaan Sumberdaya Hutan Berkelanjutan di Wilayah Perbatasan Kalimantan Barat, Disertasi. Bogor: Institut Pertanian Bogor.

Mukhlisi, H.L., Purnaweni, H. (2014), Status keberlanjutan pengelolaan hutan Mangrove di desa sidodadi kecamatan Padang cermin kabupaten pesawaran provinsi Lampung. Jurnal Geografi, 11(1), 58-70.

Mulyadi, A. (2017), Mangrove di Kampus Universitas Riau Dumai. Pekanbaru: UR Press.

Numbere, A.O. (2020), Utilization of the mangrove forest for sustainable renewable energy production. Progress in Petrochemical Science, 3(3), 324-329.

Onyena, A.P., Sam, K. (2020), A review of the threat of oil exploitation to mangrove ecosystem: Insights from Niger Delta, Nigeria. Global Ecology and Conservation, 22, e00961.

Pattimahu, D.V., Kusmana, C., Harjomidjojo, H., Darusman, D. (2010), Analisis nilai keberlanjutan pengelolaan ekosistem hutan mangrove di Kabupaten Seram Bagian Barat, Maluku. Forum Pascasarjana, 33(4), 239-249.

Pitcher, T.J. (1999), Rapfish, A Rapid Appraisal Technique for Fisheries, and its Application to the Code of Conduct for Responsible Fisheries, FAO Fisheries Circular, 947(47). Italy: FAO.

Pitcher, T.J., Preikshot, D. (2001), RAPFISH: A rapid appraisal technique to evaluate the sustainability status of fisheries. Fisheries Research, 49(3), 255-270.

Preikshot, D., Nsiku, E., Pitcher, T., Pauly, D. (1998), An interdisciplinary evaluation of the status and health of African lake fisheries using a rapid appraisal technique. Journal of Fish Biology, 53, 381-393.

Santoso, N.N. (2018), Status keberlanjutan pengelolaan ekosistem mangrove di wilayah pesisir desa akuni kecamatan tinanggea kabupaten konawe selatan sustainability management status of Mangrove ecosystem in coastal area of Akuni village District of Tinanggea, South Konawe. Jurnal Silvikultur Tropika, 9(1), 44-52.

Suwarno, J., Kartodiharjo, H., Pramudya, B., Rachman, S. (2011), Pengembangan kebijakan pengelolaan berkelanjutan DAS ciliwung hulu kabupaten Bogor. Jurnal Analisis Kebijakan Kehutanan, 8(2), 115-131.

Young, F.W. (2001), Multidimensional Scaling: History, Theory and Application. New York: Erlbaum.

Zhu, J.J., Yan, B. (2022), Blue carbon sink function and carbon neutrality potential of mangroves. Science of the Total Environment, 822, 153438.