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Sustainability Evaluation of Regency Development in Peatland Areas of Riau Province, Indonesia

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Abstract: The sustainable development of peatland ecosystems is imperative due to their susceptibility to climate change. This study evaluates the sustainability of regency development in the peatland areas of Riau Province, Indonesia, utilizing the rapid appraisal technique combined with the Rapfish multidimensional scaling (MDS) algorithm. Critical attributes influencing sustainability were identified, including the Gross Regional Domestic Product (GRDP) in the agriculture, forestry, and fisheries sectors, unemployment rates, GRDP growth rates, investment levels, poverty rates, population growth, deforestation rates, waste management practices, environmental conservation efforts, community involvement, local wisdom, occurrence of peat fires, and groundwater level stations. The findings indicate that the sustainability status of regencies in peatland areas predominantly falls between less and moderately sustainable. Consequently, an urgent need exists to accelerate the implementation of new development paradigms, such as green and low-carbon development strategies, to achieve sustainable development goals in peatland regions effectively. Enhanced policies and practices are required to address the identified sustainability dimensions, fostering resilience and promoting long-term ecological balance.

Keywords: Peatland; Rapfish; Regional development; Sustainability evaluation

1. Introduction

The concept of sustainable development is a universally recognized principle guiding development initiatives at various levels, including regional, national, and local scales (Gore, 2015). Emphasizing the preservation of natural resources and the environment is crucial for meeting present needs, while safeguarding those of future generations and ensuring the sustained availability of goods and services over the long term (Fauzi, 2021). The goals of sustainable development highlight the significance of not only meeting human needs, such as alleviating hunger and inequality, but also emphasizing the importance of conserving water, soil, and other ecosystems (Plummer, 2005; Ríos-Osorio et al., 2013). Currently, there is an increasing emphasis on peat or wetland ecosystems because of the rising impacts of climate change and global warming (Humpenöder et al., 2020; Joosten, 2015). Peatlands are natural ecosystems of significant importance, celebrated for their biodiversity, climate regulation, and essential role in supporting nearby livelihoods (Harsono, 2012). These ecosystems deliver essential services to local populations, including the preservation of air and water quality, provisioning of both timber and non-timber forest resources, and fostering local fish populations for sustenance (Dommain et al., 2016; Harrison, 2013; Thornton, 2017). In addition to their role as environmental buffers, peatlands serve as sources of various commodities, such as timber, vegetation, and fauna, including fish and birds (Noor, 2016). Importantly, forests, particularly peatlands, act as substantial carbon reservoirs, with estimates suggesting that Indonesia's peat carbon stocks range from 13.6 to 57.4 Gt (Page et al., 2011; Warren et al., 2017). Consequently, peatlands play a pivotal role in mitigating the impacts of climate crises (Barbier & Burgess, 2024).

The drainage of peatlands for various economic development endeavors has significant implications for environmental degradation, as it releases the carbon stored within these ecosystems. The destruction of peatlands accounts for 10% of greenhouse gas emissions, with CO_2 emissions from dried peat estimated to contribute 1.3 $GgCO_2$ annually, representing 5.6% of worldwide CO_2 emissions (IUCN, 2017). Extensive draining of peatlands and recurrent fires are the primary contributors to greenhouse gas emissions, including carbon dioxide (CO_2), methane (CH_4), and nitrogen oxides (N_2O). Forest and land fires, particularly in peatlands, positioned the forestry/land sector as the principal emitter of emissions in Indonesia from 2000 to 2020 (source: https://signsmart.menlhk.go.id/v2.1/app/). Peatland fires not only pose environmental threats but also have profound impacts on health, social, and economic dimensions (Hein et al., 2022; Kiely et al., 2021). The short- and medium-term economic benefits of utilizing organic soils or peatlands are currently prioritized over the environmental benefits of their conservation (Ferré et al., 2019).

The sustainability of peatland ecosystems highlights the need to prioritize the research question: How is the sustainability of regencies in peatland areas? Various research endeavors focused on the evaluation and assessment of sustainability in peatlands have been conducted, often using a sectoral approach. For instance, studies have explored sustainable development in peat areas for palm oil plantations (Rahmawati et al., 2019), the sustainability status of rice farming on peatlands (Barchia et al., 2021), and peatland management for sustainable agriculture (Nursyamsi et al., 2015). Moreover, research conducted within a regional context has examined peatland utilization and its impact on changes in land-use functions (Hermanns et al., 2017), as well as sustainability in the ecological dimension of peatlands (Zulkarnaini et al., 2022). However, few studies have investigated sustainability in peat areas from a regional perspective, particularly at the regency level. Many studies that have measured sustainability have been conducted at the provincial level (Adetama et al., 2023; Rahma et al., 2019). Measuring sustainability at the local level, especially in regencies, is still a challenge owing to the complexity of preparing sustainability indicators, complicated methods for measuring sustainability, and lack of resource capacity and data availability at the local level (Rendrarpoetri et al., 2024). Given this limitation, it is important to develop an approach that is easy to use and apply to evaluate sustainability at the regency level, especially in peatland areas. The main objective of this study is to evaluate regional sustainability in peatland areas, which can further assist in making more fundamental policy decisions in the future. MDS analysis with the Rapfish algorithm method is easy to use and can be applied to quickly evaluate the sustainability status of regency in peatland areas.

2. Literature Review

Sustainability is a multidimensional concept that includes the economic, social, and environmental aspects that must be considered and integrated (Pollesch & Dale, 2016). Sustainability evaluation can be developed using a variety of approaches, depending on the objectives, scale, and scope of the study (Büyüközkan & Karabulut, 2018). Creating reliable and comprehensive sustainability indicators for peatlands is complex because of the diverse ecosystem services they provide and the different stressors they face (Rydin & Jeglum, 2010).

In the peatland context, sustainability studies can be found in the sectoral approach. In the agricultural sector, studies show that rice farming has the highest sustainability score in degraded peatlands, followed by oil palm and rubber (Surahman et al., 2018). To achieve productive and sustainable land, peatland management should be implemented and integrated with effective water management, soil amelioration, and fertilization (Nursyamsi et al., 2015). Strategies considered for enabling short-term agricultural utilization of degraded peatlands in a relatively sustainable manner include improvements in soil fertility and suitability for agriculture, infrastructure related to peatland agriculture, institutional capacity, innovation technology and dissemination, farmer knowledge in sustainable peatland agriculture, and plant productivity (Surahman et al., 2019). Unsustainable resource extraction in neotropical peatlands could lead to a high-cost economy (Hidalgo Pizango et al., 2022).

The sustainability index is used to measure the progress of sustainability achieved by a region (Rendrarpoetri et al., 2024). The research conducted by Rahma et al. (2019) investigated how economic, social, and environmental factors could be integrated into regional sustainable development indicators using a new composite index. The weighted combinations of economic, social, and environmental aspects provide a balanced perspective that contributes to sustainability. The index could be used as a simple indicator for policymakers, both at the provincial and national levels, to assess the implementation of economic, social, and environmental dimensions of sustainable development in the regions. Adetama et al. (2023) stated that, in the agricultural sector, conditions vary in terms of sustainability at the provincial level. The existing evaluation of the Business as Usual (BAU) development concept with low carbon shows conditions ranging from less sustainable to quite sustainable in each province. In this study, including a new dimension for sustainability evaluation, it was the low-carbon dimension. Peat decomposition and peat fires are closely related to emissions from peatlands (Fawzi et al., 2024). Research on the sustainability of regional development at the local or regency level is rare in Indonesia. Therefore, this study aims to capture the sustainability of development by evaluating sustainability at the regency level, combining the concepts of sustainability with a focus on peatland areas.

3. Methodology

The study area is located in Riau Province. Riau Province is one of the top priority areas for peatland restoration in Indonesia. With an area of approximately 9,026,360 ha, more than half of the Riau Province's area of 4.97 million ha (55.09%) is peatland. It has been mapped to 59 KHG (Peat Hidrological Unit) in 9 regencies: Bengkalis, Siak, Kepulauan Meranti, Kampar, Pelalawan, Indragiri Hulu, Indragiri Hilir, Rokan Hulu, and Rokan Hilir (Figure 1).

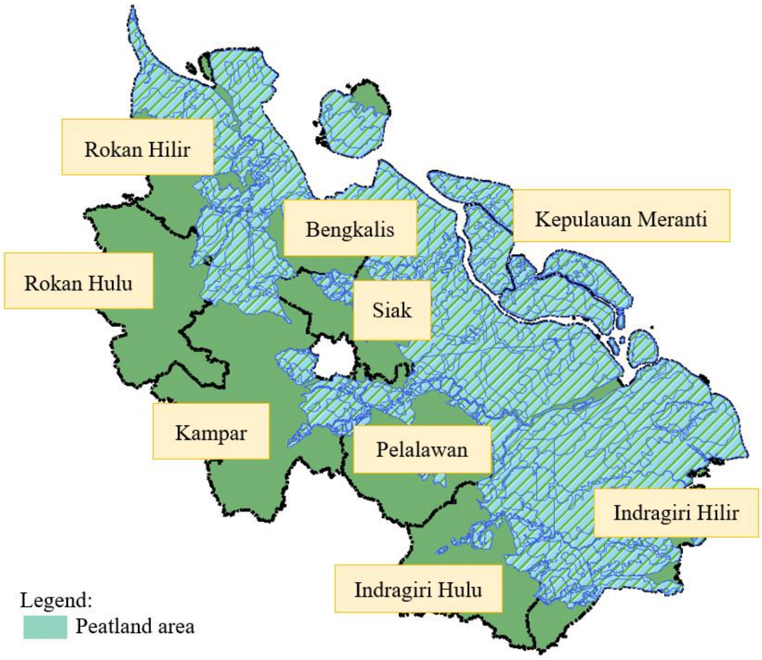


Figure 1. Map of study area

This study used the rapid appraisal method along with the Rapfish algorithm to assess the sustainability of sustainable development (Pitcher et al., 2013). Rapid Appraisal (Rap) is a multidisciplinary technique used to assess comparative sustainability based on various easily scored attributes (Fauzi & Anna, 2002). The rapid appraisal method, combined with the Rapfish algorithm, has been utilized in several studies to assess sustainability status across various domains. Examples include evaluating low-carbon sustainability in the rice agriculture sector (Adetama et al., 2023), assessing sustainability in the Bengawan Solo watershed (Rendrarpoetri et al., 2024), examining the sustainability of tourism villages (Nurhayati et al., 2021), assessing the status of fisheries sustainability (Saifullah bin Aziz et al., 2024), and analyzing the sustainability of coral reef ecosystems (Yasir Haya & Fujii, 2020). However, there is limited research that specifically examines the sustainability of regional development in peat areas using a Rapfish analysis tool.

3.1 MDS

MDS has been adopted in this study using the Rapfish algorithm with the software R. Utilizing the Rapfish method for sustainability analysis requires specific conditions to ensure accurate measurement, scoring determination, and interpretation of the results (Fauzi, 2019). This requirement is crucial for minimizing potential errors during the analysis process. Scoring determination in this study draws upon peer review scoring, gray literature, and expert judgment. The sustainability analysis in this study involved several stages (Figure 2). This algorithm arranges units on a spectrum from "bad" to "good" by transforming multidimensional statistics (involving units of analysis with a set of attributes) into lower dimensions while maintaining the "distance" properties between the analyzed cases. The process involves: 1) Identifying attributes for each dimension (economics, social, ecological, institutional, and low-carbon); 2) Assessing each attribute on an ordinal scale based on sustainability criteria for each factor and performing ordination analysis using the MDS method; 3) Compiling the sustainability status of development.

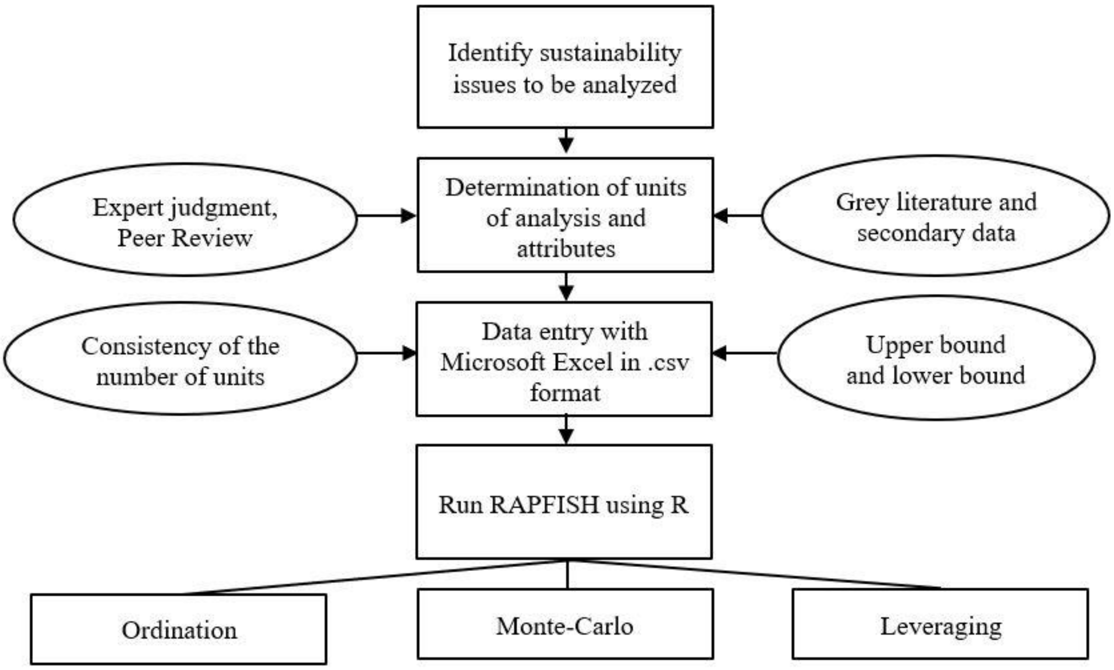


Figure 2. Stages of Rapfish analysis

A score was assigned to each attribute in each dimension to reflect the sustainability conditions of the dimension under examination. The scoring range was established based on the criteria derived from field observations and secondary data analysis. Each dimension encompasses several attributes sourced from the literature, research, and other resources. Each attribute received a score, indicating the sustainability conditions of the dimension under scrutiny. Primary data were derived from peer reviews and expert judgments, while secondary data covering the period from 2015 to 2020 were sourced from the Central Bureau of Statistics of the Republic of Indonesia, the Mangrove and Peatland Restoration Agency of the Republic of Indonesia, the Ministry of Finance of the Republic of Indonesia, the Ministry of Environment and Forestry of the Republic of Indonesia, the Nature Conservation Agency of Riau Province, and the Department of Environment and Forestry of Riau Province.

Each attribute was assigned a score representing the sustainable conditions of sustainable development within the studied dimensions. The scoring system adopted the 2013 version of Rapfish scoring, which ranges from 0 to 10 (Pitcher et al., 2013). In this study, five dimensions are considered: economics, social, ecological, institutional, and low-carbon, each with particular dimensions and attributes detailed in Table 1.

Table 1. List of dimensions and attributes

Dimension	Attribute	Description	Scoring	Data Sources	References
Economics	GRDP per Capita	The average of GRDP per capita (in thousand Rupiah).	0-2 = ≤ 60,000; 3-4 = 60,001 – 90,000; 5-6 = 90,001 – 120,000; 7-8 = 120,001 – 150,000; 9-10 = ≥ 150,001	Central Bureau of Statistics	Liang et al. (2017); Shi et al. (2019)
	GRDP Growth Rate	The average of GRDP growth rate.	0-2 = ≤ 0; 3-4 = 0.01 – 1.5; 5-6 = 1.51 – 3; 7-8 = 3.01 – 4.5; 9-10 = ≥ 4.51	Central Bureau of Statistics	Adetama et al. (2023); Rahma et al. (2019)
	Unemployment Rate	The average of open unemployment rate.	0-2 = ≤ 8.01; 3-4 = 7.01 – 8; 5-6 = 6.01 – 7; 7-8 = 5.01 – 6; 9-10 = ≥ 5	Central Bureau of Statistics	Adetama et al. (2023); Rahma et al. (2019)
	GRDP in the Agriculture, Forestry and Fisheries sector	The average of GRDP in the Agriculture, Forestry and Fisheries sector (in thousand Rupiah).	0-2 = ≤ 6,000; 3-4 = 6,001 – 9,000; 5-6 = 9,001 – 12,000; 7-8 = 12,001 – 15,000; 9-10 = ≥ 15,001	Central Bureau of Statistics	Adetama et al. (2023); Hély & Antoni (2019)
	Investment	The average of domestic and foreign investment (PMDN and PMA in billion Rupiah).	0-2 = ≤ 1,000; 3-4 = 1,001 – 2,500; 5-6 = 2,501 – 4,000; 7-8 = 4,001 – 5,500; 9-10 = ≥ 5,500.1	Central Bureau of Statistics	Liang et al. (2017)

Dimension	Attribute	Description	Scoring	Data Sources	References
	Regional Fiscal Capacity Index (IKFD)	The average of regional fiscal independence index.	0-2 = ≤ 0.5; 3-4 = 0.51 – 1; 5-6 = 1.01 – 1.5; 7-8 = 1.51 – 2; 9-10 = ≥ 2.01	Ministry of Finance of the Republic of Indonesia	Balynskaya & Vasilyeva (2017); Liuta et al. (2015)
Social	Human Development Index (HDI)	The average of Human Development Index (HDI).	0-2 = ≤ 66; 3-4 = 66.01 – 68; 5-6 = 68.01 – 70; 7-8 = 70.01 – 72; 9-10 = ≥ 72.01	Central Bureau of Statistics	Adetama et al. (2023); Rahma et al. (2019); Zulkarnaini et al. (2020)
	Gini Ratio	The average of Gini Ratio.	0-2 = ≥ 0.311; 3-4 = 0.301 – 0.31; 5-6 = 0.291 – 0.30; 7-8 = 0.281 – 0.29; 9-10 = ≤ 0.28	Central Bureau of Statistics	Rahma et al. (2019)
	Poverty	The average of poverty percentage.	0-2 = ≥ 15.01; 3-4 = 12.01 – 15; 5-6 = 9.01 – 12; 7-8 = 6.01 – 9; 9-10 = 0 – 6	Central Bureau of Statistics	Adetama et al. (2023); Rahma et al. (2019)
	Population growth rate	The average of population growth rate.	0-2 = ≥ 2.11; 3-4 = 1.41 – 2.1; 5-6 = 0.71 – 1.4; 7-8 = 0.01 – 0.7; 9-10 = 0	Central Bureau of Statistics	Adetama et al. (2023)
	Sufficient sanitation	The average percentage of households with access to adequate sanitation.	0-2 = ≤ 62; 3-4 = 62.01 – 72; 5-6 = 72.01 – 82; 7-8 = 82.01 – 92; 9-10 = ≥ 92.01	Central Bureau of Statistics	Rendrarpoetri et al. (2024)
	Crime	The average percentage of villages/kelurahan experiencing crime incidents.	0-2 = ≥ 60,01; 3-4 = 50.01 – 60; 5-6 = 40.01 – 50; 7-8 = 30.01 – 40; 9-10 = ≤ 30	Central Bureau of Statistics	Strezov et al. (2017)
Ecological	Natural disasters	The average percentage of villages/kelurahan experiencing natural disasters.	0-2 = ≥ 50,01; 3-4 = 45.01 – 50; 5-6 = 40.01 – 45; 7-8 = 35.01 – 40; 9-10 = ≤ 35	Central Bureau of Statistics	Adetama et al. (2023); Pravitasari et al. (2018)
	Environmental Pollution	The average percentage of villages/kelurahan experiencing environmental pollution.	0-2 = ≥ 25,01; 3-4 = 20.01 – 25; 5-6 = 15.01 – 20; 7-8 = 10.01 – 15; 9-10 = 0 – 10	Central Bureau of Statistics	Liang et al. (2017); Strezov et al. (2017)
	Deforestation	The percentage of gross deforestation.	0-2 = ≥ 10,01; 3-4 = 7.51 – 10; 5-6 = 5.01 – 7.5; 7-8 = 2.51 – 5; 9-10 = 0 – 2.5	Ministry of Environment and Forestry	Liang et al. (2017)
	Biodiversity	The presence of conservation areas, flora, and fauna.	0-2 = No conservation area; 3-4 = 1 – 3 conservation area, a little variation of flora and fauna; 5-6 = 1 – 3 conservation area, more variation of flora and fauna; 7-8 = > 3 conservation area, a little variation of flora and fauna; 9-10 = > 3 conservation area, more variation of flora and fauna.	Nature Conservation Agency of Riau Province	Adetama et al. (2023); Strezov et al. (2017)
	Waste management	The average percentage of waste management activity in villages/kelurahan.	0-2 = ≤ 5; 3-4 = 5.01 – 7.5; 5-6 = 7.51 – 10; 7-8 = 10.01 – 12.5; 9-10 = ≥ 12.51	Central Bureau of Statistics	Liang et al. (2017); Paoli et al. (2022)
	Critical land	The average percentage of critical land area relative to the total area of the regency.	0-2 = ≥ 50,01; 3-4 = 40.01 – 50; 5-6 = 30.01 – 40; 7-8 = 20.01 – 30; 9-10 = 0 – 20	Central Bureau of Statistics	Liang et al. (2017); Strezov et al. (2017)
Institutional	Social forestry	Percentage of villages/kelurahan that have social forestry program.	0-2 = ≤ 1; 3-4 = 1.01 – 2; 5-6 = 2.01 – 3; 7-8 = 3.01 – 4; 9-10 = ≥ 4.01	Central Bureau of Statistics	Gunawan & Afriyanti (2019)
	Local wisdom related to the Environment	Percentage of villages/kelurahan that have local wisdom relate to environment.	0-2 = ≤ 8; 3-4 = 8.01 – 16; 5-6 = 16.01 – 24; 7-8 = 24.01 – 32; 9-10 = ≥ 32.01	Central Bureau of Statistics	Kamal et al. (2023); Osawa, (2023)
	Environmental Conservation	Percentage of villages/kelurahan that have environmental	0-2 = ≤ 20; 3-4 = 20.01 – 30; 5-6 = 30.01 – 40; 7-8 = 40.01 – 50; 9-10 = ≥ 50.01	Central Bureau of Statistics	Seifollahi-Aghmiuni et al. (2019)

Dimension	Attribute	Description	Scoring	Data Sources	References
		conservation activity.			
	Community participation	Percentage citizen participation on community in villages/kelurahan.	0-2 = ≤ 60; 3-4 = 60.01 – 70; 5-6 = 70.01 – 80; 7-8 = 80.01 – 90; 9-10 = ≥ 90.01	Central Bureau of Statistics	Syafrizal & Resdati (2020)
	Peat restoration interventions	Percentage of restoration interventions in villages within Peat Hidrological Unit (KHG).	0-2 = ≤ 10; 3-4 = 10.01 – 20; 5-6 = 20.01 – 30; 7-8 = 30.01 – 40; 9-10 = ≥ 40.01	Mangrove and Peatland Restoration Agency	Humpenöder et al. (2020); Lestari et al. (2023)
	Local regulations related to the environment	Availability of local government regulation about environment.	0-2 = No; 3-4 = Available, but inadequate; 5-6 = Available, but less effective; 7-8 = Effective; 9-10 = Very effective	Department of Environment and Forestry of Riau Province	Ekardt et al. (2020); Lees et al. (2023); Ratamäki et al. (2019)
Low-carbon	Peat fires	The average of estimated emissions from peat fires (in GgCO2e).	0-2 = ≥ 13,000.01; 3-4 = 9,000.01 – 13,000; 5-6 = 5,000.01 – 9,000; 7-8 = 1,000.01 – 5,000; 9-10 = ≤ 1,000	Mangrove and Peatland Restoration Agency; Ministry of Environment and Forestry	Febria et al. (2021); Rengasamy & Parish (2021); Uda et al. (2017)
	Peat decomposition	The average of estimated emissions from peat decomposition (in GgCO2e).	0-2 = ≥ 35,000.01; 3-4 = 25,000.01 – 35,000; 5-6 = 15,000.01 – 25,000; 7-8 = 5,000.01 – 15,000; 9-10 = ≤ 5,000	Mangrove and Peatland Restoration Agency; Ministry of Environment and Forestry	Fawzi et al., (2024); Leng et al. (2019); Liu et al. (2020)
	Waste volume	The average of potential waste volume (in tons).	0-2 = ≥ 140,000.01; 3-4 = 100,000.01 – 140,000; 5-6 = 60,000.01 – 100,000; 7-8 = 20,000.01 – 60,000; 9-10 = ≤ 20,000	Department of Environment and Forestry of Riau Province	Liang et al. (2017)
	Groundwater Level Station (TMAT)	The number of groundwater level monitoring stations.	0-2 = ≤ 3; 3-4 = 4 – 6; 5-6 = 7 – 9; 7-8 = 10 – 12; 9-10 = ≥ 13	Mangrove and Peatland Restoration Agency	Khodyko (2020); Omar et al. (2022); Wakhid (2018)
	Canal blocking	The ratio of canal blocking constructed in villages.	0-2 = ≤ 0.5; 3-4 = 0.51– 2; 5-6 = 2.01 – 3.5; 7-8 = 3.51 – 5; 9-10 = ≥ 5.01	Mangrove and Peatland Restoration Agency	Ritzema et al. (2014)
	Adoption of low-carbon technologies	The level of low carbon technology adoption in peatland.	0-2 = No; 3-4 = Few, hard to adopt; 5-6 = Few, easy to adopt; 7-8 = More, hard to adopt; 9-10 = More, easy to adopt	Mangrove and Peatland Restoration Agency; Department of Environment and Forestry of Riau Province	Adetama et al. (2023)

The calculated scores form the ordination for each dimension. Rapfish assigns scores on a scale of 0 to 100 for each sustainability dimension. The ordination scores obtained from the Rapfish analysis were classified into four categories: unsustainable, less sustainable, moderately sustainable, and sustainable. This categorizes the index value and sustainability status into four categories, as outlined in Table 2.

Table 2. Index value categories and sustainability status (Kavanagh & Pitcher, 2004)

Index Value	Category
0 – 25	Unsustainable
25.01 – 50	Less sustainable
50.01 – 75	Moderately sustainable
75.01 – 100	Sustainable

3.2 Monte-Carlo Analysis

The goodness of fit indicators for the Rapfish analysis model can be evaluated using Monte-Carlo analysis in the R program. The purpose of this analysis was to identify the sources of diversity errors. Monte-Carlo analysis is a statistical simulation method to evaluate the effects of random error on a process, and to estimate the 'true' value of a statistic of interest (Kavanagh et al., 2004). Random errors from computer random number generators are added to the phenomena under test (like a roulette table), and a 'scatter' plot and other statistics are generated. The Monte-Carlo graph illustrates that a wider distribution of dots indicates greater disturbance, whereas a narrower distribution suggests a lower disturbance. It is important to note that errors in Rapfish can arise from various factors (Fauzi, 2019; Pitcher et al., 2013), including inaccuracies in determining variable scores, incomplete convergence in MDS, and the possibility that the variables employed may not be suitable for the constructed theme. In this study, the R program was set to a 95% confidence level with 100 iterations.

3.3 Leverage Analysis

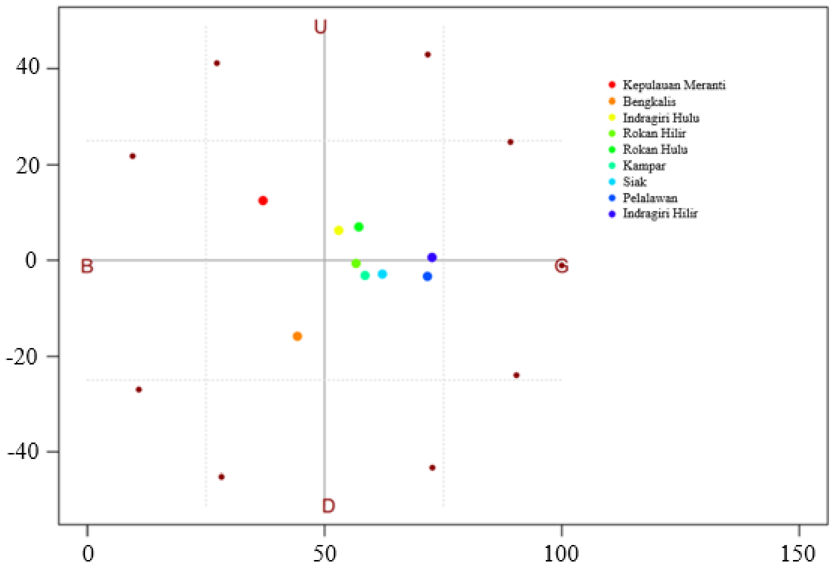
The objective of this analysis is to identify the predominant variables and explore any changes in ordination (from bad to good), as each variable is removed individually. This process ensured that the constructed variables accurately represented the themes and dimensions evaluated. Essentially, leverage also serves as a sensitivity analysis, where the length of the bar indicates the extent of influence the variable has on bad-to-good ordination, and the numerical value represents the percentage difference if the variable is excluded from the ordination position. If an attribute's status accurately reflects the status of the unit being assessed, it should contribute equally to the final outcome. In Rapfish, leverage values typically range from 2% to 6%, as determined by the change in Root Mean Square (RMS) (Kavanagh et al., 2004). No one attribute should dominate if a truly multivariate situation exists, and a rough rule of thumb is that the ordination score should not be influenced by more than 8% in any one or two attributes. Sustainability status should be determined by attributes with high leverage values.

4. Results and Discussion

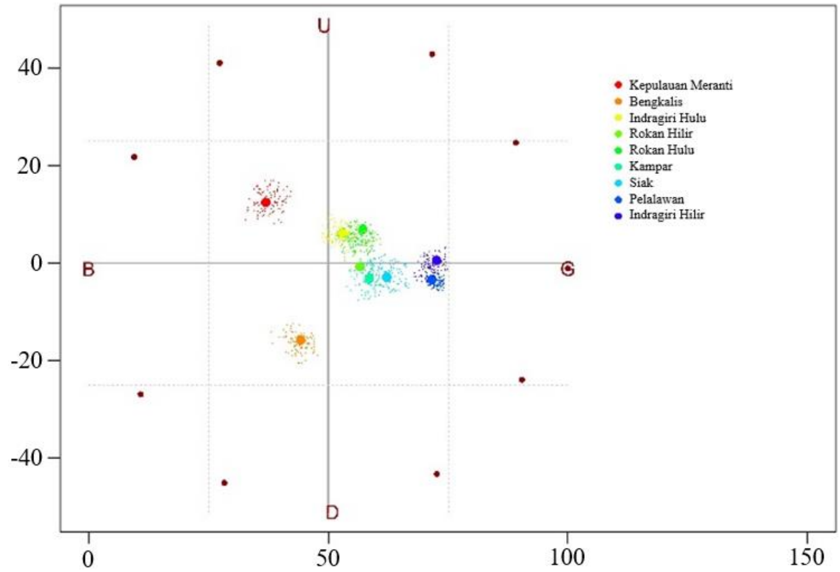
The results of the rapid appraisal analysis utilizing the Rapfish MDS method were conducted in nine regencies on peatland areas in Riau Province. Through this analysis, insights into attributes sensitive to sustainability were gleaned across five dimensions: economic, social, ecological, institutional, and low-carbon. The output encompasses MDS ordination analysis, leverage analysis, Monte-Carlo analysis, and the results of the five dimensions presented through the sustainability kite diagram and radar diagram. The analysis of each dimension is detailed below.

4.1 Economic Dimension

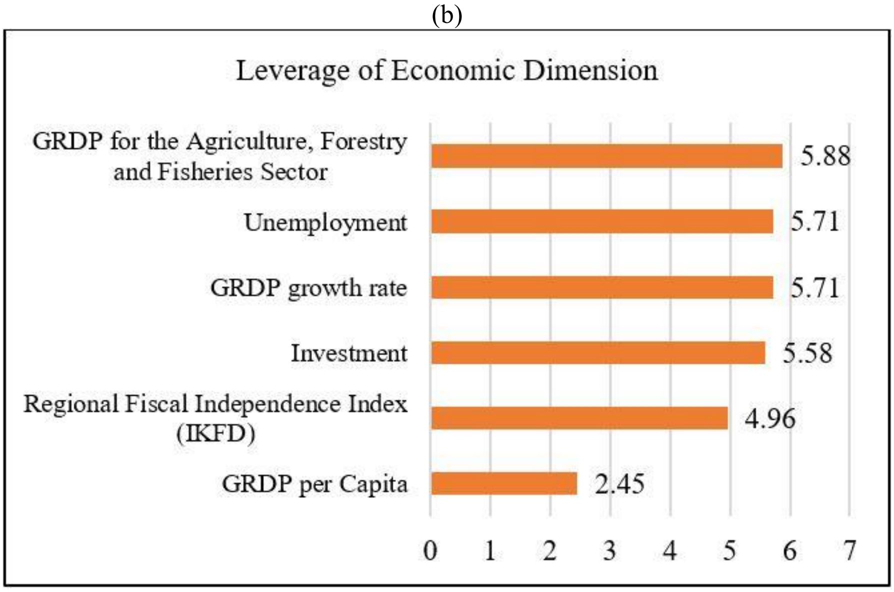
The analysis results on the economic dimension showed a range of diversity, with score values falling between 36.94 and 72.60. The multidimensional ordination of the economic dimension ranges from less sustainable to moderately sustainable (Subgraph (a) of Figure 3). Two regencies, Kepulauan Meranti (36.94) and Bengkalis (44.25), are situated in the red and orange dots, respectively, indicating less sustainable ordination. The remaining seven regencies are positioned as green and blue dots, denoting sustainable ordination levels. These regencies included Indragiri Hulu (52.97), Rokan Hilir (56.62), Rokan Hulu (57.21), Kampar (58.50), Siak (62.17), Pelalawan (71.60), and Indragiri Hilir (72.60).



(a)



(b)



(c)

Figure 3. (a) MDS ordination, (b) Monte-Carlo ordination, and (c) Leverage of economic dimension

The subsequent analysis of the economic dimension involves uncertainty analysis using Monte-Carlo analysis of the uniform distribution type with 100 iterations. A Monte-Carlo analysis was conducted to identify the sources of diversity errors. The results of the Monte-Carlo ordination analysis indicated that ordination did not change significantly (Subgraph (b) of Figure 3). The sustainability score for regional development closely resembles the results of the MDS ordination analysis, as evidenced by the proximity of the Monte-Carlo analysis result points to the MDS analysis result points. This suggests minimal errors in attribute score generation, stable repetition processes in the MDS analysis, and few errors in the data input. Furthermore, Monte-Carlo analysis results revealed a spread of units that clustered tightly around the initial score and were dispersed. Notably, in the blue points representing Indragiri Hilir and Pelalawan, the spread accumulated close to the initial score, indicating minimal disruption in these regencies concerning the economic dimension. Conversely, in the red dot representing Kepulauan Meranti, the spread appeared relatively wide from the initial score, signifying a significant disturbance in this regency related to the economic dimension.

In addition to ordination and Monte-Carlo, Rapfish analysis also involves leveraging. Leveraging primarily identifies the dominant attribute that determines ordination. Leveraging calculations assess changes in ordination (from bad to good positions) when individual attributes are excluded. Based on the results of the leverage analysis, four attributes were identified as having nearly equal contributions to determining the sustainability status of regional development regencies on peatland areas, specifically the economic dimension, with scores ranging from 5.58 to 5.88 (refer to subgraph (c) of Figure 3). These attributes include GRDP in the Agriculture, Forestry, and Fisheries Sectors, unemployment rate, GRDP growth rate, and investment (foreign and domestic investment).

Among these, the GRDP attribute of the Agriculture, Forestry, and Fisheries Sectors emerged as the most influential attribute on economic sustainability ordination, with a score of 5.88. This score indicates the percentage difference if the GRDP attribute of the Agriculture, Forestry, and Fisheries Sectors is excluded from the ordination position, illustrating that the sustainability ordination position would change by nearly 5.88 percent.

The GRDP generated by the Agriculture, Forestry, and Fisheries Sector serves as the primary pillar of the regency's economic framework in the peatland area of Riau Province, contributing an average of 23.63% to Riau's overall GRDP. Regencies heavily reliant on primary economic activities include the Indragiri Hulu, Indragiri Hilir, Rokan Hulu, Rokan Hilir, Kampar, and Kepulauan Meranti. In contrast, for Pelalawan and Siak, the agriculture, forestry, and fisheries sectors ranked second in contribution, following the processing and manufacturing sectors. Meanwhile, Bengkalis's economic structure is predominantly shaped by the contribution of the mining sector, particularly in the oil and gas subsectors.

Another significant attribute that influences the ordination of the economic dimension is the unemployment rate. The leveraging analysis revealed a score of 5.715 for the unemployment rate attribute, indicating that its exclusion would result in a 5.715% change in ordination. Across regencies in the peatland area of Riau Province, the average unemployment rate remains below double. Bengkalis exhibits the highest percentage at 9.54%, surpassing the provincial average unemployment rate of 6.66%. Conversely, Indragiri Hulu has the lowest unemployment rate among the regencies, at 4.82%.

The third attribute that influences the leverage of the economic dimension is the growth rate of GRDP. Although the leverage score for the GRDP growth rate attribute differs only slightly from that of the open unemployment rate, with a mere difference of 0.002 points, it underscores the significance of the GRDP growth rate attribute in ensuring economic sustainability. Across regencies in Riau Province during the 2015-2020 period, the average GRDP growth rate was 1.52%, with the highest rates achieved by Rokan Hulu, Indragiri Hilir, and Pelalawan. However, Bengkalis experienced a negative GRDP growth rate, making it the regency with the lowest GRDP growth rate in Riau Province. This decline in GRDP growth in Bengkalis is attributed to its heavy reliance on the oil and gas sector. Thus, diversification of value-added sources is imperative to ensure the sustainability of regional development within the economic dimension.

Investment is another factor that significantly influences economic sustainability. In the leveraging analysis, the investment attribute attained a score of 5.58. Throughout the 2015-2020 period, Riau Province consistently ranked among the top ten provinces in Indonesia in terms of domestic investment (PMDN) and foreign investment (PMA). In 2020, Riau Province secured the 6th position nationally for both PMDN and PMA investments and stood out as the leading province on Sumatra Island, with a total investment value of 49.64 trillion rupiah. The highest realized investment values in Riau Province during the same period were observed in sectors such as food crops, plantations, animal husbandry, chemical and pharmaceutical industries, and the food industry. Investments in the palm oil industry and other plantation sectors, including the rubber and pulp sectors, also played a significant role. Major companies in these sectors are expanding their operations or investing to enhance their production and efficiency. Pelalawan, Bengkalis, and Indragiri Hilir emerged as regencies with the highest average PMDN and PMA realization values in Riau Province from 2015 to 2020, whereas Kepulauan Meranti and Rokan Hilir had the lowest averages. To foster a more conducive and attractive investment climate, local governments must address various aspects, such as regulatory improvements, infrastructure enhancement, the provision of appealing incentives for investors, and more serious attention to environmental and social concerns.

4.2 Social Dimension

The analysis of the social dimension revealed a diverse sustainability status, with two regencies exhibiting a less sustainable status and seven regencies demonstrating a moderate sustainable status (see subgraph (a) of Figure 4). Specifically, Kepulauan Meranti scored 30.18, whereas Rokan Hulu scored 48.96. Conversely, the remaining seven regencies showed a moderately sustainable status, with scores ranging from 55.95 to 71.39. Bengkalis achieved the highest score in the social dimension, with a score of 71.39, classifying it as a sustainable regency in the social dimension.

Error detection for attribute diversity and unit analysis within the social dimension were conducted using the Monte-Carlo method with a uniform distribution type, involving 100 iterations. The results of Monte-Carlo ordination analysis revealed minimal changes in ordination (Subgraph (b) of Figure 4). The sustainability score for the social dimension of regional development closely aligns with the MDS ordination results. This is evident from the close proximity of the Monte-Carlo analysis result points to the MDS analysis result points, indicating few errors in attribute score generation, stable repetition processes in the MDS analysis, and minimal errors in the data input. Notably, in the blue points representing Bengkalis and Siak, the spread accumulated close to the initial score, suggesting minimal disturbance in these units within the social dimension. Conversely, the red dot representing Kepulauan Meranti exhibits a relatively wide spread from the initial score, indicating a significant disturbance in the social dimension within this regency.

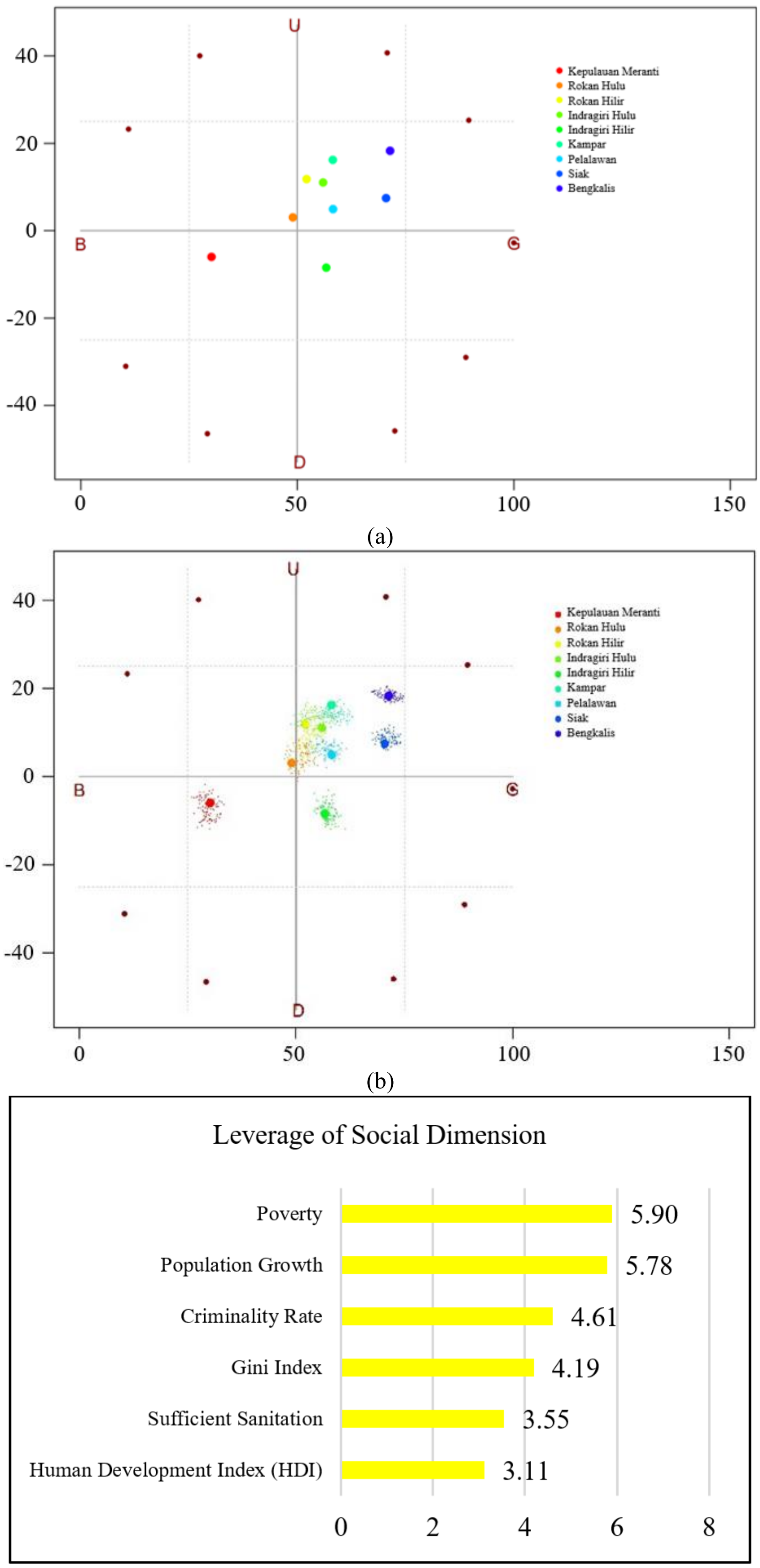
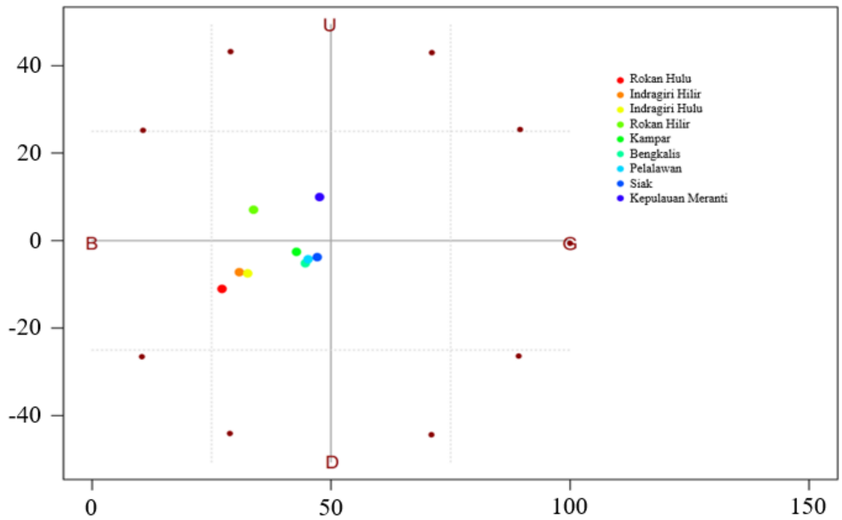


Figure 4. (a) MDS ordination, (b) Monte-Carlo ordination, and (c) Leverage of social dimension

Within the social dimension, poverty and the rate of population growth emerged as the two attributes that exerted the most significant influence on sustainability. Poverty stands out as the most influential attribute with a score of 5.90, indicating that the omission of the poverty percentage attribute would result in a 5.90 percent change in the sustainability ordination position (see subgraph (c) of Figure 4). Poverty warrants special attention from the government, given its significant implications for sustainable development, particularly in regency areas. According to the Central Bureau of Statistics data, the average percentage of impoverished individuals in Riau Province from 2015 to 2020 was 7.58%. While this figure remains below the national average of 10.13%, three regencies in Riau Province recorded average poverty percentages exceeding 10%: Kepulauan Meranti (28.99%), Rokan Hulu (10.80%), and Pelalawan (10.31%). Conversely, Siak reported the lowest percentage of impoverished individuals, with an average value of 5.43%. Poverty represents a complex and multidimensional challenge that remains the primary focus of development goals, particularly in regions with peatland areas. The prevalence of poverty, particularly in rural areas, underscores the urgency of poverty alleviation efforts within developmental agendas.

The second attribute that influences the ordination of the social dimension is the rate of population growth. Controlling population growth is crucial for preventing imbalances that can impact welfare. This directly affects the availability of basic facilities, employment opportunities, and other essential infrastructure. Leveraging the population growth rate attribute in this study's social dimension analysis yielded a score of 5.78. This indicates that omitting the population growth rate attribute results in a 5.78 percent change in the sustainability ordination position. Population growth rates vary annually in each regency. On average, Kepulauan Meranti experiences the highest population growth rate, with an average increase of 2.37%, while Indragiri Hilir is the only regency with a negative average population growth rate of -0.85%.

4.3 Ecological Dimension



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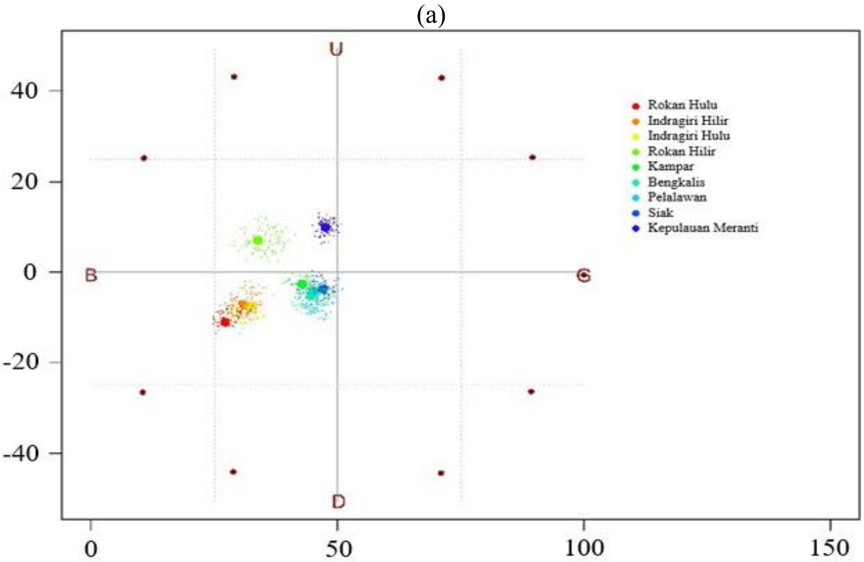

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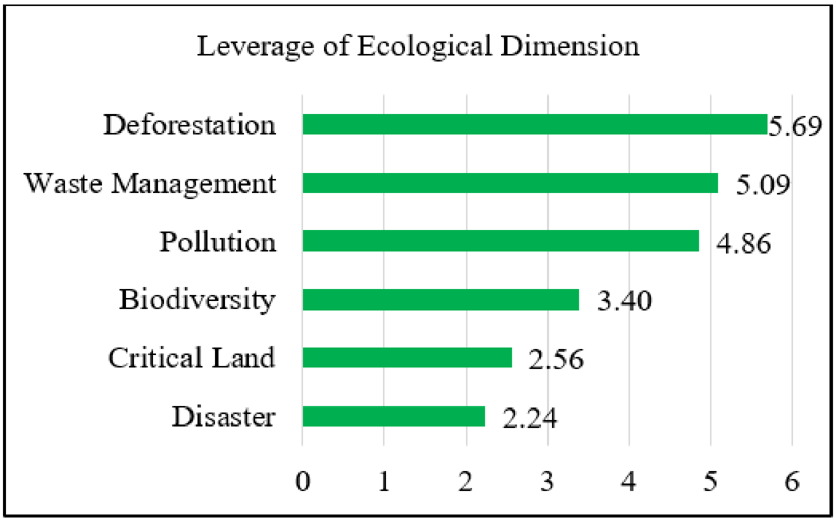


(c)

Figure 5. (a) MDS ordination, (b) Monte-Carlo ordination, and (c) Leverage of ecological dimension

The analysis of the sustainability status of regional development within the ecological dimension revealed a consistent ordination of sustainability status within the same quadrant across all regencies in peatland areas (Subgraph (a) of Figure 5). All regencies are positioned in the less sustainable ordination category, with scores ranging from 27.18 to 47.57. Rokan Hulu attains the lowest sustainability score within the ecological dimension, scoring 27.18, whereas Kepulauan Meranti achieves the highest sustainability score among the regencies, scoring 47.57.

Monte-Carlo analysis revealed a dense distribution around the initial score of the blue dot in the Kepulauan Meranti, suggesting minimal disturbance in this regency within the ecological dimension. Conversely, the red dot representing Rokan Hulu exhibited a relatively wide spread from the initial score, indicating a significant disturbance in the ecological dimension (Subgraph (b) of Figure 5).

Additionally, the results of the leverage analysis revealed that the most influential attribute affecting the ecological dimension was deforestation (Subgraph (c) of Figure 5). Deforestation obtained a score of 5.69, indicating that omitting the deforestation attribute would result in a 5.69 percent change in the sustainability ordination position within the ecological dimension. Changes in forest cover occur because of various factors, such as forest conversion for non-forestry development, deforestation, encroachment, and fire. Analysis of data changes during the 2015-2020 period indicates that the Indragiri Hilir has a notably high deforestation rate, accounting for 29,258.07 hectares, or 15.41% of the deforestation area in Riau Province. Another attribute that influences the ecological dimension is waste management. On average, Siak leads waste processing activities, accounting for 14.89%, followed by Bengkalis at 10.97%, and Pelalawan at 10.17%. Both deforestation and waste management are critical considerations in sustainable development, given their close correlation with peatland management dynamics.

4.4 Institutional Dimension

In the institutional dimension, sustainability status varies across regencies. Bengkalis attains a score of 77.60, indicating a highly sustainable status within the institutional dimension. Two regencies, Kepulauan Meranti with a score of 71.36, and Siak with a score of 65.33, achieved a moderate sustainable status. Conversely, six regencies fell into the less sustainable score category: Pelalawan (44.05), Rokan Hulu (40.15), Indragiri Hilir (37.12), Kampar (36.12), Indragiri Hulu (30.29), and Rokan Hilir (25.42) (Subgraph (a) of Figure 6).

Monte-Carlo analysis results indicate the spread of units that accumulate tightly and are distributed. In Bengkalis, the blue dot exhibits tightly concentrated scatter around the initial score, suggesting minimal interference in this unit within the institutional dimension. Conversely, the red dot representing Rokan Hulu demonstrates a wider spread from the initial score, indicating a significant disturbance in the institutional dimension (Subgraph (b) of Figure 6).

The environmental preservation attribute has the greatest influence compared to other attributes within the institutional dimension, with a score of 4.95 (Subgraph (c) of Figure 6). Environmental preservation initiatives play a pivotal role in enhancing the sustainability of peatland ecosystems by mitigating the risks of peatland and forest fires, curbing land subsidence and erosion, reducing greenhouse gas emissions, and restoring the hydrological functions of peatlands. Kepulauan Meranti leads to environmental preservation activities, with 50.49% of villages engaging in such endeavors. Besides environmental preservation, attributes such as community participation and local wisdom concerning the environment also contribute significantly to the sustainability of the institutional dimension across regencies in peatland areas.

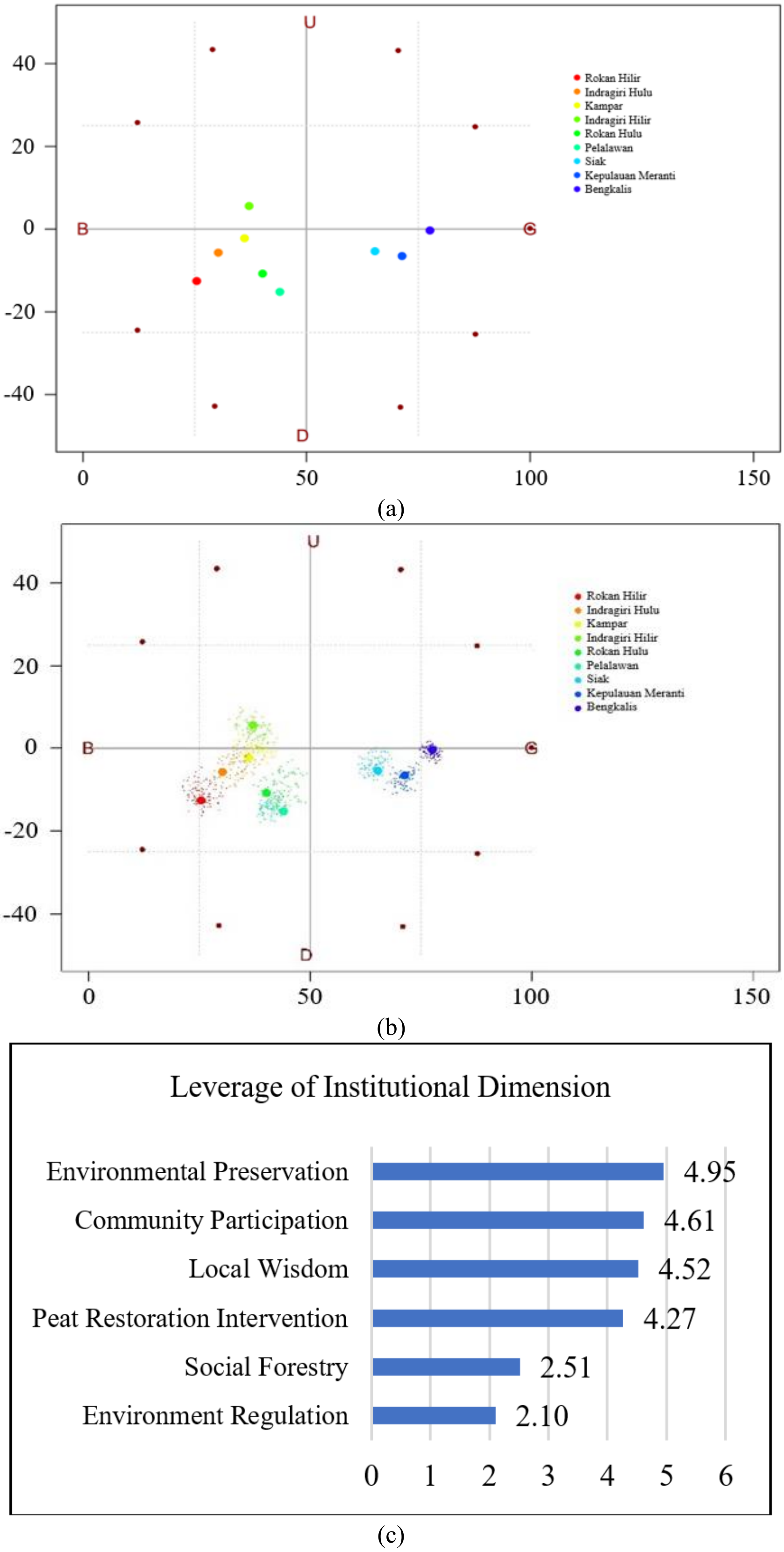
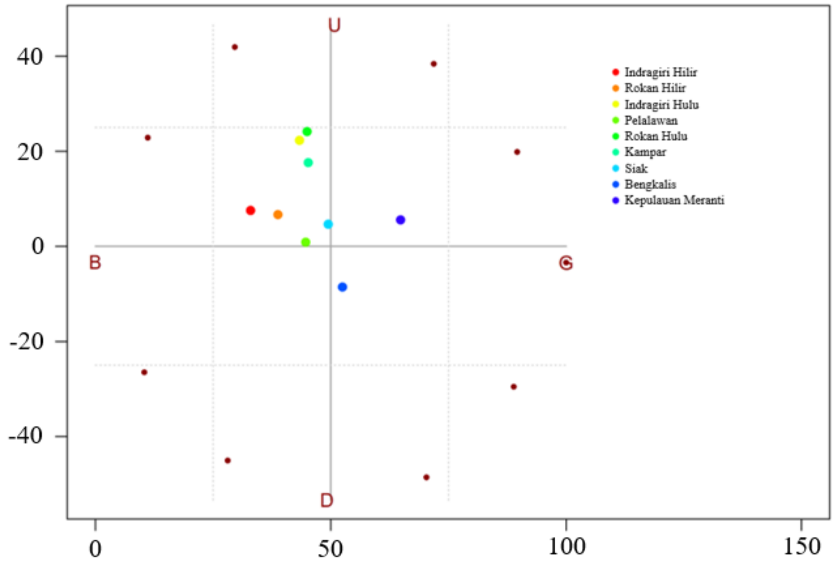


Figure 6. (a) MDS ordination, (b) Monte-Carlo ordination, and (c) Leverage of institutional dimension

4.5 Low-Carbon Dimension



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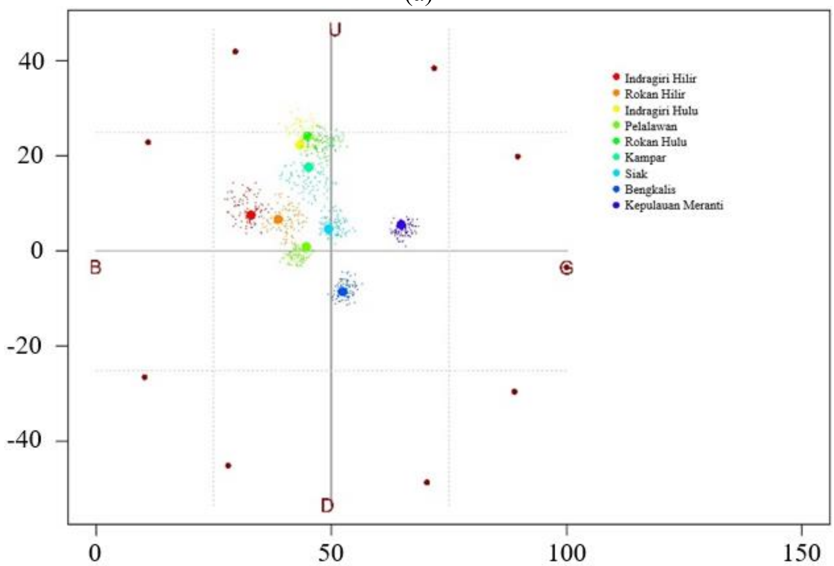

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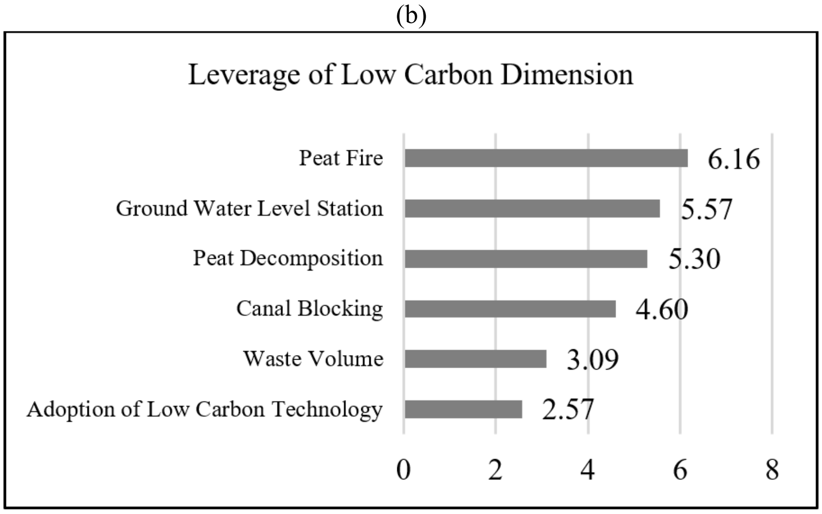


(c)

Figure 7. (a) MDS ordination, (b) Monte-Carlo ordination, and (c) Leverage of low-carbon dimension

In the low-carbon dimension, seven regencies attained less sustainable status, with scores ranging from 32.94 to 49.44. The Indragiri Hilir scored the lowest at 32.94, followed by the Rokan Hilir (38.78), Indragiri Hulu (43.34), Pelalawan (44.66), Rokan Hulu (44.95), Kampar (45.18), and Siak (49.44). Meanwhile, two regencies fell into the category of moderate sustainability: Bengkalis (52.47) and Kepulauan Meranti (64.81) (Subgraph (a) of Figure 7).

The Monte-Carlo analysis results regarding the low-carbon dimension depict a dense distribution around the initial score of the blue dot for the Kepulauan Meranti. This finding suggests minimal interference in this regency concerning the low-carbon dimension. Conversely, the red point representing Indragiri Hilir exhibits a wide spread from the initial score, indicating a significant disturbance in the low-carbon dimension (Subgraph (b) of Figure 7).

Within a low-carbon context, the utilization of peat fires stands out as the most influential factor in determining regional development sustainability, surpassing other attributes. With a score of 6.16, the peat fire attribute is the most influential factor in sustainability ordination, signifying that its elimination would result in a 6.16 percent alteration in the position of low-carbon sustainability (Subgraph (c) of Figure 7). The emissions stemming from peat fires constitute the primary source of emissions in the forestry sector (https://signsmart.menlhk.go.id/v2.1/app/). Other attributes that influence the low-carbon dimension are the groundwater level station (5.57) and peat decomposition (5.30). These two factors are also linked to the emission levels from activities on peatland. The notion of green economy advancement is closely linked to the low-carbon dimension, given that one of the fundamental principles of a green economy is the reduction of greenhouse gas emissions.

Green and low-carbon economic development serves as a foundation for sustainable development in Indonesia, striving to strike a balance between economic, social, and environmental progress through efforts to minimize greenhouse gas emissions and reduce the exploitation of natural resources. This initiative aligns with Indonesia's pledge to curtail emissions by 2030, aiming for a reduction of 31.89% with domestic resources and 43.20% with international support to enhance the nationally determined contribution (ENDC).

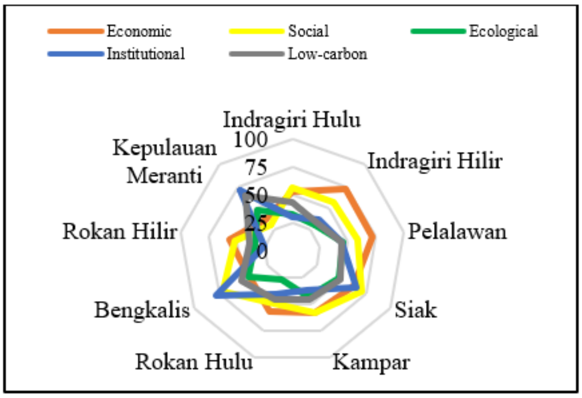
4.6 Multi-Dimensional Analysis

The multi-dimensional analysis results encompass the economic, social, ecological, institutional, and low-carbon dimensions. In the economic dimension, most regencies fall into the moderate sustainable category, with two regencies classified as less sustainable. Similarly, in the social dimension, the majority of regencies also exhibited moderate sustainable, with two regencies categorized as less sustainable. However, in the ecological dimension, all regencies were classified as less sustainable. In terms of the institutional dimension, sustainability status varies, with some regencies showing moderate sustainable, others less sustainable, and the remainder categorized as sustainable. Regarding the low-carbon dimension, most regencies have a less sustainable status, with some even being moderate sustainable. A summary of the sustainability status is presented in Table 3.

Table 3. Sustainability status of each regency by dimension

Regency	Sustainability Status				
	Economics	**Social**	**Ecological**	**Institutional**	**Low-Carbon**
Indragiri Hulu	Moderate	Moderate	Less	Less	Less
Indragiri Hilir	Moderate	Moderate	Less	Less	Less
Pelalawan	Moderate	Moderate	Less	Less	Less
Siak	Moderate	Moderate	Less	Moderate	Less
Kampar	Moderate	Moderate	Less	Less	Less
Rokan Hulu	Moderate	Less	Less	Less	Less
Bengkalis	Less	Moderate	Less	Sustain	Moderate
Rokan Hilir	Moderate	Moderate	Less	Less	Less
Kepulauan Meranti	Less	Less	Less	Moderate	Moderate

The sustainability analysis also generated radar and kite diagrams illustrating the interplay between the five dimensions (economic, social, ecological, institutional, and low-carbon) and the sustainability status of the nine regencies. In the radar diagram, the sustainability dimensions in each regency are depicted by their distance from the radar core, with deeper positions indicating a poorer sustainability status (Subgraph (a) of Figure 8). Across the economic and social dimensions, regencies are predominantly situated in the less sustainable and moderately sustainable quadrants, with a dominant distribution in the moderately sustainable category. In contrast, all regencies fell within the less sustainable quadrant in the ecological dimension. The institutional and low-carbon dimensions exhibit more varied distributions, with the dominant trend leaning towards a less sustainable status, except for Bengkalis, which falls within sustainable in the institutional dimension. The kite diagram reveals that the scores for the ecological and low-carbon dimensions are closer to the core, indicating a poorer sustainability status compared to other dimensions. Notably, only one regency demonstrated a sustainable condition in the institutional dimension (Subgraph (b) of Figure 8). In the ecological dimension, all regencies exhibit a less sustainable status, despite Riau Province's commitment to implementing green and low-carbon economic development paradigms. Consequently, there is a crucial need for further analysis of ecological and environmental risks, along with their governance strategies, particularly at the local level in peatland areas.



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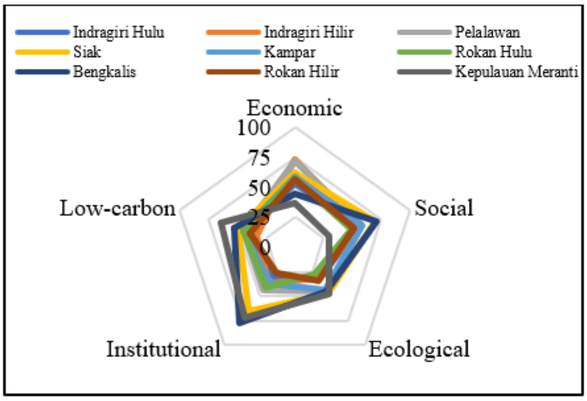

(b)

Figure 8. (a) Radar diagram of sustainability and (b) Kite diagram of sustainability

The results show that sustainability status in the regional context of peatland areas varies between less sustainable, moderate, and sustainable. The economic and social dimensions show better conditions than the ecological, institutional, and low-carbon dimensions. The use of the low-carbon dimension in sustainability evaluation supports the study conducted by Adetama et al. (2023), where separating the low-carbon dimension from the ecological dimension provides a specific picture of the leverage factors affecting sustainability in the low-carbon dimension. One paradigm that supports sustainable development is low-carbon development. This study provides an overview of the different focuses of efforts to improve sustainability dimension scores in each regency in peatland areas. However, overall improvements are required in the ecological, institutional, and low-carbon dimensions.

These findings can provide recommendations to decision makers on how to plan sustainable regional development in peatland areas. The priority should be to improve sustainability in the dimensions with lower scores while maintaining the dimensions that are already more sustainable. This study can be replicated in contexts and areas with similar characteristics. One limitation of this study was the incomplete years of analysis due to data limitations. Further verification is needed regarding the estimated emissions from peat fires and peat decomposition to minimize potential bias in the conclusions.

5. Conclusions

The findings from the study utilizing the rapid appraisal method with the Rapfish algorithm underscore the unsustainable condition of development in regency in peatland areas in Riau Province. Sustainability status across dimensions varies from less to moderately sustainable in each regency, with only one regency demonstrating sustainable in the institutional dimension. The economic dimension, characterized by attributes such as GRDP for the agriculture, forestry, and fisheries sectors, unemployment, GRDP rate, and investment, has emerged as particularly sensitive and influential on regency development in peat areas. Similarly, the social (poverty and population growth), ecological (deforestation and waste management), institutional (environmental preservation, community participation, and local wisdom), and low-carbon (peat fire and groundwater level stations) dimensions play significant roles. Omitting these attributes could have adverse effects on sustainability status. Failure to address multidimensional sustainability considerations could hinder anticipated development outcomes. Therefore, governments must implement innovative policies for sustainable development, such as transitioning to green and low-carbon economic models. This is essential for reconciling the trade-off between economic growth and environmental conservation, particularly in high-risk peatland areas.

Author Contributions

Conceptualization, A.P.F. and A.F.; methodology, A.P.F. & A.F.; software, A.P.F. & A.F.; validation, A.F., B.J., and E.R.; data curation, A.P.F. & A.F.; writing—original draft preparation, A.P.F; writing—review and editing, A.P.F., A.F., B.J., and E.R.; supervision, A.F., B.J., and E.R. All authors have read and agreed to the published version of the manuscript.

Data Availability

The data used to support the research findings are available from the corresponding author upon request.

Conflicts of Interest

The authors declare no conflict of interest.

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