

Sustainability analysis of fisheries and marine resource development in Indonesia's blue economy framework

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Abstract. Yusuf M, Riana AD, Rusneni, Salawali WA, Eddiwan. 2025. Sustainability analysis of fisheries and marine resource development in Indonesia's blue economy framework. *Biodiversitas* 26: 3634-3646. Indonesia possesses vast and rich marine and fisheries resources. These resources play a critical role in ensuring national food security, driving economic growth, generating employment, and improving the welfare of coastal communities. However, the intensive utilization of marine resources must be accompanied by cautious and measurable management. Hence, evaluating the level of sustainability in fisheries and marine development is a vital and urgent necessity that cannot be overlooked. This study aims to analyze the level of sustainability in fisheries and marine development, as well as the factors that influence its sustainability. The research was conducted from August to November 2024. This study employed a quantitative approach using a survey research design. The data consisted of both primary and secondary sources, collected through survey questionnaires and desktop studies. The data analysis was carried out using the Multi-Dimensional Scaling – Rapid Appraisal for Fisheries (MDS RAPFISH) method. The research findings indicate that the sustainability index for the ecological dimension is 44.32 (unsustainable), the economic dimension is 37.75 (unsustainable), and the social dimension is 39.78 (unsustainable). Thus, the overall level of sustainability in fisheries and marine development in Indonesia is categorized as unsustainable, with an average index score of 40.62. The study also identified three key attributes that significantly influence the sustainability of fisheries and marine development in Indonesia: (i) the presence of key species (coral reefs, sea turtles, whales, tuna, sharks, and mangroves) with an Root Means Square (RMS) value of 4.88; (ii) investment in Indonesia's maritime sector with an RMS value of 3.56; and (iii) the level of participation in decision-making processes with an RMS value of 3.91.

Keywords: Fisheries, index, marine, MDS, RAPFISH

INTRODUCTION

Sustainable development has become a mainstream global development paradigm over the past few decades (Ferreira et al. 2021). According to Hajian and Kashani (2021), sustainable development is understood as a form of development that harmonizes economic growth, social equity, and the sustainability of natural and environmental resources, aiming to meet present needs without compromising the ability of future generations to meet their own (Mahesh and Aithal 2024). On the other hand, Yusuf et al. (2024) assert that the blue economy has emerged as both a framework and a business model for sustainable development. The blue economy as an economic development concept that promotes the sustainable use of ocean resources, encompassing various ocean-dependent economic activities such as tourism, maritime transport, energy, and fisheries (Martínez-Vázquez et al. 2021). This concept supports sustainable growth in the maritime sector by recognizing the ocean as a driving force of the global economy, with significant potential for innovation and growth (Duarte et al. 2021).

Integrating the blue economy framework into national economic development presents a strategic opportunity to strengthen the role of the maritime sector in a country's economy (Renaldo et al. 2024). By prioritizing the maritime sector within national development policies, countries can optimize marine resources to enhance national income, attract investment, and strengthen their position in global markets (Okafor-Yarwood et al. 2020). Research by Yusuf et al. (2024) reveals that the integration of the blue economy into regional economic planning in South Sulawesi has significantly increased overall regional output by IDR 2.882 trillion especially through growth in the fisheries sector. This includes the expansion of fisheries-related industries such as cold storage, ice factories, and food and beverage processing.

The blue economy is recognized as a key priority in the *Rencana Pembangunan Jangka Menengah Nasional* (RPJMN) in Indonesia, aligned with efforts to achieve self-sufficiency in food, energy, and water. Institutionally, the RPJMN offers a legal framework and implementation guidelines for the blue economy targeting ministries, agencies, regional governments, and civil society. In the fisheries sector, the government has enacted Indonesian Government Regulation (PP) No. 11 of 2023 on Measured

Fishing as part of the blue economy implementation (Trenggono 2023). Additionally, the Ministry of National Development Planning (Bappenas) has developed the Indonesia Blue Economy Roadmap, building on the Blue Economy Development Framework for Indonesia's Economic Transformation (OECD 2021). The government, through Bappenas and the Ministry of Finance, has also formulated a Blue Financing Instrument Development Guide to drive economic transformation toward "Indonesia Emas 2045", targeting a 15% Gross Domestic Product (GDP) contribution from the maritime sector (Bappenas 2023).

Nevertheless, the integration of sustainable development remains uneven across Indonesia. Numerous regions and Fisheries Management Areas (*Wilayah Pengelolaan Perikanan/WPP*) have yet to incorporate blue economy principles into their regional development plans (Khoiriyah 2024). This reflects a disconnect between Indonesia's vast marine resource potential and the suboptimal implementation of policies aimed at achieving sustainability goals. Many regions and WPPs continue to face critical challenges such as overfishing, destructive fishing practices, and illegal fishing, which have severely degraded marine ecosystems (Hamzah 2022). Despite Indonesia's abundant marine resources particularly in the fisheries sector their utilization has been largely uninnovative and has not significantly contributed to national economic recovery (Rosyadi et al. 2018). Currently, the maritime sector contributes only around 7.9% to Indonesia's national GDP annually.

These conditions indicate that the development of marine resources particularly fisheries has not fully addressed critical aspects that could sustainably improve the welfare of fishers and coastal communities (Bhatnagar and Kumar 2024). The suboptimal utilization of marine resources is also reflected in the limited infrastructure on small islands, which restricts accessibility and hampers the development of local fisheries potential (Masaya and Yasumoto 2018). In this context, the blue economy approach becomes essential to address these challenges, emphasizing the integration of marine and fisheries-based development with sustainable environmental management (Khoiriyah 2024). For this reason, this study is of critical importance as it aims to evaluate the sustainability level of development in the fisheries and marine sectors, identify the factors influencing their sustainability, and provide future-oriented management recommendations.

MATERIALS AND METHODS

The research method was conducted in this study is a quantitative approach using a survey-based design. This method is considered appropriate for rapidly obtaining respondent assessments regarding the level of fisheries and marine development in Indonesia. The sustainability assessment of fisheries and marine development is based on three key indicators: ecological, economic, and social. These indicators are grounded in the concept of sustainable development, which integrates environmental, economic,

and social dimensions to achieve long-term well-being (Organization for Economic Cooperation and Development/OECD 2021). Each dimension comprises a set of attributes evaluated to comprehensively measure the level of sustainability, with a sustainability index score ranging from 0% to 100% (Ardiansyah et al. 2024). Each attribute is assessed using ordinal-scaled evaluation criteria. The following section presents the attributes and their respective evaluation criteria based on the identified indicators. The details are as in Tables 1, 2 and 3.

The scoring and evaluation criteria for each indicator are derived from a range of established sources that have been widely used to assess the sustainability of fisheries and marine development. These include the FAO Technical Guidelines for Responsible Fisheries No.8 (Nadiarti et al. 2021), Ecosystem Approach to Fisheries Management (EAFM) (FAO 2019), Sustainable Ocean Economy Country Diagnostics of Indonesia (OECD 2021), Indonesia's Blue Economy Index (IBEI) (BEDI 2024), Rapid Appraisal for Fisheries (RAPFISH) code of Conduct for Responsible Fisheries/CCRF (FAO 1999), and Oceans for Prosperity (World Bank 2021). The assessed aspects encompass biological, technical, economic, and social dimensions to ensure a holistic approach to sustainability (Rema 2022). These methodologies integrate ecological and socio-economic factors through parameter scoring and weighting, as demonstrated by factor analysis techniques (Ramadhini and Sihombing 2019). The integration of these methods enables a comprehensive assessment of fishery conditions, including analyses such as population parameter estimations and Spawning Potential Ratio (SPR) based on length metrics, which are essential for sustainable stock management (Wujdi et al. 2020). Furthermore, the evaluation process employs sensitivity analysis and multi-criteria scoring to identify key indicators with the most significant influence on system resilience (Ardiansyah et al. 2024).

Data collection methods

The data collection methods were conducted in this study consist of: (i) desktop research and (ii) survey-based methods. The desktop research approach was utilized to collect secondary data from various Indonesian official sources, including the Ministry of National Development Planning (*Badan Perencanaan Pembangunan Nasional/Bappenas*), the Ministry of Marine Affairs and Fisheries (*Kementerian Kelautan dan Perikanan/KKP*), the Ministry of Environment and Forestry (*Kementerian Lingkungan Hidup dan Kehutanan/KLHK*), the Investment Coordinating Board (*Badan Koordinasi Penanaman Modal/BKPM*), and the National Research and Innovation Agency (*Badan Riset dan Inovasi Nasional/BRIN*). Additionally, this method was used to gather data from previous studies related to the Multi-Dimensional Scaling (MDS) RAPFISH analysis for the marine and fisheries sector. The collected secondary data were used to assess fixed indicators, while the survey method was employed to evaluate opinion-based or unfixed attributes, as detailed in Table 4.

Table 1. Attributes and scoring of the ecology indicator

Ecology indicators	Scoring	Criteria	Sources
Marine biodiversity	0,1,2,3	[0] low/bad, [1] moderate, [2] high/good, [3] very high/good	C
Coral reef health	0,1,2,3	[0] damaged <30% (good), [1] damaged 30-50%, [2] damaged 50-70%, [3] damaged >70% (bad)	
Oversfishing rate (Maximum Sustainable Yield/MSY)	0,1,2,3	[0] under TAC (good), [1] equal to/close to TAC, [2] above TAC, [3] approaching MSY (bad)	A
Marine conservation	0,1,2,3	[0] very low <10% conservation target (bad), [1] low 10-30% conservation target, [2] moderate 30-50% conservation target, [3] high >50% conservation target (good)	B
Marine pollution (marine debris)	0,1,2,3	[0] low 10% from the plastic waste produced (good), [1] moderate 10-29%, [2] high 30-50%, [3] very high >50% (bad)	C
Presence of key species (coral reefs, sea turtles, whales, tuna, sharks, and mangroves)	0,1,2,3	[0] >50% endangered (bad), [1] 30-50% endangered (moderate), [2] <30% endangered (good), [3] <10% endangered (good)	B
Indonesia's economy Blue Index (IBEI)	0,1,2,3	[0] very low <30 (bad), [1] low 30-50 (bad), [2] moderate 50-80, [3] high >80 (good)	C
Climate Resilient Development Index	0,1,2	[0] low/bad (many climate change impacts (ROB floods, coral bleaching), [1] moderate, [2] high (good)	C
Seawater Quality Index (<i>Indeks Kualitas Air Laut</i> /IKAL)	0,1,2,3,4	[0] very low: IKAL<25 (bad), [1] low: 25≤IKAL<50, [2] moderate: 50≤IKAL<70, [3] good: 70≤IKAL<90, [4] very good: 90 ≤IKAL ≤100	C
Mangrove conditions	0,1,2,3	[0] damaged <10% (good), [1] damaged 10-30% (moderate), [2] damaged 30-50%, [3] damaged >50% (bad)	B
Seagrass condition	0,1,2	[0] covered ≤ 29,9% (poor/bad) [1] covered 30-59,9% (moderate), [2] covered <60% (good)	B
Ocean Health Index (OHI)	0,1,2,3,4	[0] score 0 - 20 (very bad), [1] score 21 - 40 (bad), [2] score 41 - 60 (moderate), [3] score 61 - 80 (good), [4] score 81 - 100 (very good)	C

Source: A: Technical Guidelines for Responsible Fisheries (FAO 1999), B: Ecosystem Approach to Fisheries Management (EAFM) (FAO 2021) and C: Indonesia's Blue Economy Index (BEDI 2024)

Table 2. Attributes and scoring of the economy sustainability

Economy indicators	Scoring	Criteria	Sources
Fisheries sector's contribution to GDP	0,1,2,3,4	[0] very low <3% (bad), [1] low 3-5%, [2] moderate 5-10%, [3] high 10-20%, [4] very high >20% (good)	A/C
Marine tourism contribution to GDP	0,1,2,3,4	[0] very low <3% (bad), [1] low 3-5%, [2] moderate 5-10%, [3] high 10-20%, [4] very high >20% (good)	A/C
Marine renewable energy contribution to GDP	0,1,2,3,4	[0] very low <3% (bad), [1] low 3-5%, [2] moderate 5-10%, [3] high 10-20%, [4] very high >20% (good)	A/C
Maritime transportation contribution to GDP	0,1,2,3,4	[0] very low <3% (bad), [1] low 3-5%, [2] moderate 5-10%, [3] high 10-20%, [4] very high >20% (good)	A/C
Maritime sector contribution to GDP	0,1,2,3,4	[0] very low <10% (bad), [1] low 10-15%, [2] moderate 15-20%, [3] high 20-30%, [4] very high >30% (good)	A/C
Export value of marine products	0,1,2,3,4	[0] very low <1% (bad), [1] low 1-3%, [2] moderate 3-5% [3] high >5-10%, [4] very high >10% (good)	A/C
Investment of Indonesia's maritime sector	0,1,2,3	[0] very low <5% from potential of the maritime economy (bad), [1] low 5-10%, [2] moderate 10-30%, [3] high >30 (good)	A/C
Diversification of marine products	0,1,2,3	[0] undeveloped (bad), [1] low developed, [2] moderately developed, [3] highly developed (good)	B
Income of workers in the marine fisheries sector /fishermen	0,1,2,3,4	[0] very low <1M per month (bad), [1] low 1,1-3M per month, [2] moderate 3-5M per month, [3] high 5-10M per month, [4] very high >10M per month (good)	B
Income of workers in the marine tourism sector	0,1,2,3,4	[0] very low <1M per month (bad), [1] low 1,1-3M per month, [2] moderate 3-5M per month, [3] high 5-10M per month, [4] very high >10M per month (good)	B
Income of workers in the marine oil and gas mining technician sector	0,1,2,3,4	[0] very low <1M per month (bad), [1] low 1,1-3M per month, [2] moderate 3-5M per month, [3] high 5-10M per month, [4] very high >10M per month (good)	B
Income of employees in the sea transport sector of Crew Ship	0,1,2,3,4	[0] very low <1M per month (bad), [1] low 1,1-3M per month, [2] moderate 3-5M per month, [3] high 5-10M per month, [4] very high >10M per month (good)	B

Source: A: Indonesia's Blue Economy Index (BEDI 2024), B: Sustainable Ocean Economy Country Diagnostics of Indonesia (OCED 2021), and C: Oceans for Prosperity (World Bank 2021)

Table 3. Attributes and scoring of the social sustainability

Social indicators	Scoring	Criteria	Sources
Poverty level	0,1,2,3	[0] low/good <10%, [1] moderate 10-20%, [2] high/bad 20-30% [3] very high/bad >30%	A/B
Unemployment rate	0,1,2,3	[0] low/good <10%, [1] moderate 10-20%, [2] high/bad 20-30% [3] very high/bad >30%	B
Fish consumption rate	0,1,2,3	[0] low/bad <30 kg per capita, [1] moderate 31-50 kg per capita [2] high/good 60-80 kg per capita, [3] very high/good >80 kg per capita	B
Access to marine resources	0,1,2	[0] low access/bad, [1] moderate, [2] easily accessible/good	A
Participation rate in decision making	0,1,2	[0] low partition/bad, [1] medium/moderate, [2] high/good	B
Involvement of social organizations in marine resources management	0,1,2	[0] low/bad, [1] medium/moderate, [2] high/good	B
Coastal community education level	0,1,2	[0] low/bad is generally elementary, [1] medium is generally middle school and high school, [2] high/good is generally higher education (Diploma/Undergraduate)	B
Awareness of marine conservation	0,1,2	[0] low/bad, [1] medium/moderate, [2] high/good	B
Local community empowerment	0,1,2	[0] low/bad, [1] medium/moderate, [2] high/good	B
Gender equality in marine management	0,1,2	[0] low/bad, [1] medium/moderate, [2] high/good	B
Sustainability of local traditions and culture (recognition of customary rights)	0,1,2	[0] low/bad, [1] medium/moderate, [2] high/good	A/B
Potential of social conflict	0,1,2	[0] low/bad, [1] medium/moderate, [2] high/good	A/B

Source: A: Indonesia's Blue Economy Index (BEDI 2024) and B: Oceans for Prosperity (World Bank 2021)

The survey method was conducted among expert respondents, consisting of policymakers, academics and scientists in the field of fisheries and marine affairs, seasoned practitioners with decades of experience, and representatives from Non-Government Organizations (NGOs) working in the fisheries and marine sector. A total of seven experts (specialists) participated in the survey, comprising: two national-level policymakers (Director Generals from the Indonesian Ministry of Marine Affairs and Fisheries), two university-based academics, two industry practitioners, and one representative from an NGO. This classification of expert respondents follows Yusuf et al. (2021), who define experts in three categories: (i) those considered experts by virtue of their decision-making positions; (ii) those regarded as experts due to their academic knowledge; and (iii) those recognized as experts based on their specialized professional experience, such as private sector executives, NGO directors, and similar roles.

Data analysis method

The data analysis method used in this study is the MDS RAPFISH analysis method. The MDS RAPFISH method is a technique used to analyze and evaluate the quality of natural resources, particularly in fisheries management (Yusuf et al. 2021). This method was developed to provide a systematic approach to evaluating the sustainability of fisheries in a particular region by combining both quantitative and qualitative assessments (Kholil and Dewi 2014). This allows decision-makers or researchers to assess and compare various factors that affect the sustainability of fisheries ecosystems, including ecological, social, and

economic aspects.

This method provides a visual representation in the form of a two-dimensional map that illustrates the relative positions of different fishery management units based on relevant parameters (Johnson and James 2023). In MDS RAPFISH, the objects refer to various aspects of the fisheries being evaluated, such as policies, social aspects, environmental conditions, and other technical parameters that influence the sustainability of fisheries and marine resource utilization. The MDS process works by mapping these objects into a two-dimensional (or three-dimensional) space, where the distance between objects reflects their degree of similarity or difference based on the analyzed data. Therefore, this method is highly useful for illustrating the complex relationships among the various factors influencing the condition of a system, in this case, the fisheries ecosystem (Cinner and McClanahan 2020).

The MDS RAPFISH uses an index-based sustainability assessment that is constructed based on expert judgment. In RAPFISH, experts provide assessments of relevant criteria or indicators by scoring them according to their perceived sustainability level. The first step in MDS RAPFISH is to determine the indicators or criteria used to assess the sustainability of fisheries. These indicators encompass various aspects, ranging from ecosystem conditions (e.g., habitat quality and fish populations) to socio-economic aspects (such as community well-being and existing policies). Next, the scale and assessment index for each indicator are established, and they are organized into a proximity matrix that depicts the level of similarity or difference between indicators.

Table 4. Data collection methods and data sources

Atributtes	Data source
Marine biodiversity	BKKHI (2024)
Coral reef health	BRIN (2020)
Over fishing rate (MSY)	KKP (2024a)
Marine Conservation	KKP (2024b)
Marine Pollution (marine debris)	DCA (2024)
Presence of key species (coral reefs, sea turtles, whales, tuna, sharks, and mangroves)	Survey (2025)
Indonesia’s Economy Blue Index (IBEI)	BEDI (2024)
Climate Resilient Development Index	Bappenas (2023)
Seawater Quality Index (IKAL)	KLHK (2024)
Mangrove Conditions	FWI (2019)
Seagrass Condition	BRIN (2021)
Ocean Health Index (OHI)	OHI (2024a)
Fisheries sector’s contribution to GDP	BPS (2024a)
Marine tourism contribution to GDP	BPS (2024a)
Marine renewable energy contribution to GDP	BPS (2024a)
Maritime transportation contribution to GDP	BPS (2024a)
Maritime sector contribution to GDP	BPS (2024a)
Export value of marine products	BPS (2024b)
Investment of Indonesia’s maritime sector	BPS (2024b)
Diversification of marine products	Survey (2025)
Income of workers in the marine fisheries sector /fishermen	Survey (2025)
Income of workers in the marine tourism sector	Survey (2025)
Income of workers in the marine oil and gas mining technician sector	Survey (2025)
Income of employees in the sea transport sector of Crew Ship	Survey (2025)
Poverty level	BPS (2024b)
Unemployment rate	BPS (2024c)
Fish consumption rate	Survey (2025)
Access to marine resources	Survey (2025)
Participation rate in decision making	Survey (2025)
Involvement of social organizations in marine Resources management	Survey (2025)
Coastal community education level	Survey (2025)
Awareness of marine conservation	Survey (2025)
Local community empowerment	Survey (2025)
Gender equality in marine management	Survey (2025)
Sustainability of local traditions and culture (recognition of customary rights)	Survey (2025)
Potential of social conflict	Survey (2025)

Table 5. Sustainability criteria

Ordination Index	Criteria
0-25	Unsustainable
25.1-50	Less sustainable
50.1-75	Quite sustainable
75.1-100	Sustainable

Subsequently, the MDS analysis is conducted, where MDS works by transforming the proximity matrix into two-dimensional coordinates using an iterative technique. The algorithm used in MDS aims to minimize the difference between distances calculated based on the proximity matrix and the distances projected onto the two-dimensional map. The result of this calculation is a map that illustrates the relative positions of various management units or

sustainability factors within the two-dimensional map space.

The basic process in MDS involves calculating the distance between points that represent objects in an n-dimensional space (typically n = 2 for 2D visualization). The basic formula for calculating the Euclidean distance between two points in multi-dimensional space, following Mitchell and Thomas (2022), is as follows:

$$d_{ij} = \sqrt{\sum_{k=1}^n (x_{ik} - x_{jk})^2}$$

Where: d_{ij} is the Euclidean distance between two points i and j ; x_{ik} and x_{jk} are the coordinates of the i -th and j -th points in the k -th dimension; n is the number of dimensions in the space (for 2D, $n=2$).

The commonly used stress function in MDS is:

$$Stress = \sqrt{\frac{\sum_{i < j} (d_{ij} - \hat{d}_{ij})^2}{\sum_{i < j} \hat{d}_{ij}^2}}$$

Where: d_{ij} is the observed distance (from the proximity matrix); \hat{d}_{ij} is the estimated distance between points i and j in the two-dimensional space; The summation runs over all pairs of points (i, j).

The goal of the MDS algorithm is to adjust the positions of the points in two-dimensional space in such a way that the calculated distances (\hat{d}_{ij}) are as close as possible to the original distances (d_{ij}) in the proximity matrix, thereby minimizing the stress function. Furthermore, the results of the analysis in the form of a sustainability ordination index are estimated with sustainability criteria according to Fauzi (2019), as shown in the Table 5.

RESULTS AND DISCUSSION

Validation model

Model validation is the process used to ensure that the model developed in research or analysis accurately represents the phenomenon or system being studied. This process aims to test the reliability and accuracy of the model in reflecting the reality or data used to build it. Model validation is crucial to ensure that the predictions, decisions, or outcomes generated by the model can be trusted and applied in practical settings (Sargent 2020). Model validation is essential to ensure that the results are valid and reliable, forming a solid basis for decision-making. Various approaches and techniques are employed in model validation, including conceptual model validity, operational validity, and data validity (Thum et al. 2024).

Model validation becomes particularly important in determining whether the results obtained sufficiently represent the real world, allowing the model to be deemed valid or not. A model is considered valid if it meets the model validation criteria, which include: a maximum stress value of 0.20-0.25, an R-squared value above 0.8, and the difference between the Monte Carlo value and the

ordination sustainability value not exceeding 5.0. The indicators of model validity are detailed in Table 6.

In MDS modelling, the stress value is used to assess how well the model maps the original data into lower dimensions without losing important information (George et al. 2021). Based on the analysis results, the stress value ranges from 0.1325 to 0.1361, or approximately 13%, indicating that the pressure on the model is relatively low, under 20%. This suggests that the model is quite good and can be accepted as a predictor. This is consistent with George et al. (2021), who stated that a tolerable stress value is <20%, Di Leo and Sardanelli (2020), who suggested that a very good stress value is <0.25. Furthermore, according to Yusuf et al. (2021), the smaller the stress value, the better the model, indicating that the monotonous relationship between inequality and disparity is improving and that the configuration map criteria formed are becoming more accurate. Conversely, the higher the stress value, the greater the mismatch between the data and the measurement, implying more errors or incompatibility. According to Vakili and Jahangiri (2018), the stress value is an indicator of model validity that reflects the level of strain on the model. The stress value measures how well the distances calculated based on the proximity matrix or the relationships between objects in multi-dimensional space align with the distances projected in a lower-dimensional space, such as a two- or three-dimensional space. In addition to the stress value indicator, validity indicators based on the R-Squared value are also used, as shown in Table 7.

In addition to stress values, model validation is also carried out using the R-Square (R²) value approach. According to Keller (2020), the R-Squared or the coefficient of determination, is a statistical measure used to evaluate how well a model can explain the variation in observed data. Based on the analysis results, the R-squared value ranges from 0.9520 to 0.9525, or approximately 95%. This indicates that the model explains the data well, with 95% of the variation accounted for by the model and only around 5% unexplained. Therefore, the model is quite good and valid for use as a predictor. As stated by Kutner et al. (2020), an R² value >0.8 (80%) is considered excellent for explaining data. Similarly, Chatterjee and Hadi (2006) noted that an R² value >0.7 indicates a strong model that effectively explains the data. This is in accordance with Chicco et al. (2021), the R-squared provides information about the extent to which the independent variables in the model can explain the dependent variable. R-Squared is a value between 0 and 1 that measures the proportion of variance in the dependent data (the variable being

explained) that can be explained by the model (Shao and Tu 2021). The R² value is calculated based on the comparison between the variance explained by the model and the total variance present in the data (Hastie et al. 2020). The model validity indicator also uses the Monte Carlo value, which is the same as the ordination value, as shown in the following Table 8.

Based on the analysis results, as shown in Table 8, the difference between the Monte Carlo value and the sustainability ordination value ranges from 0.2424 to 0.3688, or less than 1.0%. Therefore, this value is very small and is considered valid, making the model suitable for use as a predictor. According to Velikova et al. (2024) that Monte Carlo validation is a method used to validate models by simulating a large number of random samples to assess the accuracy, reliability, and robustness of the model. This technique involves using Monte Carlo simulations to generate various possible outcomes based on varying inputs in the model, and then examining how the model responds to these variations (Saltelli et al. 2020; Chen and Yu 2023). This allows for evaluating how well the model can handle uncertainty and variability in the data or conditions encountered (McGray and Washington 2021; Simini and Andreu 2022). According to Yusuf et al. (2021), Monte Carlo validation in MDS RAPFISH is done by examining the difference between the Monte Carlo value and the sustainability ordination value, where this difference should not exceed 5.0%. If the difference exceeds 5.0%, the model is considered invalid and cannot be used as a predictor.

Table 6. Validation model based on stress value

Dimension	Stress value	Criteria	Validation
Ecology	0.1325	0-0.2 (Valid)	Valid
Economy	0.1361		Valid
Social	0.1330	>0.2 (invalid)	Valid

Source: Mukherjee et al. (2018) and Data analysis of MDS RAPFISH Modification (2025)

Table 7. Validation model based on R-Squared value

Dimension	R Squared	Criteria	Validation
Ecology	0.9520	0.6-1.0 (Valid)	Valid
Economy	0.9525		Valid
Social	0.9525	<0.6 (invalid)	Valid

Sources: Mukherjee et al. (2018) and Data analysis of MDS RAPFISH Modification (2025)

Table 8. Validation model based on difference of Monte Carlo and Ordination Value

Dimension	Monte Carlo value	Ordination value	Difference	Criteria	Validation
Ecology	44.6906	44.3218	0.3688	0-5.0% (Valid)	Valid
Economy	37.9902	37.7478	0.2424		Valid
Social	40.0745	39.7837	0.2908	>5% (invalid)	Valid

Sources: Mukherjee et al. (2018) and Data analysis of MDS RAPFISH Modification (2025)

Thus, based on these three validity indicators stress value, R-squared value, and the difference between the Monte Carlo value and the sustainability ordination value it can be concluded that the model produced is quite good, valid, and can be used as a predictor for the sustainability of fisheries and marine management and development in Indonesia. Additionally, sensitive factors influencing this sustainability have been identified.

Ecology sustainability

Ecological sustainability in fisheries and marine development is a crucial aspect that needs to be addressed. Several studies have shown the negative impacts of unsustainable fishing practices on marine ecosystems. Illegal and excessive fishing has led to a decline in fish stocks and habitat degradation (Aceves-Bueno et al. 2021; Svolkinas et al. 2023). In addition, climate change and ocean acidification also impose additional pressures on marine ecosystems (Rai 2021; Anikwe and Ife 2023). To achieve ecological sustainability, a paradigm shift is needed from managing individual species to managing ecosystems as a whole. Integrating fisheries management with conservation through an Ecosystem-Based Fisheries Management (EBFM) approach becomes essential (Rees et al. 2020). Collaboration between various stakeholders, including fishermen, scientists, and policymakers, is also necessary (Pita et al. 2020). Effective monitoring and evaluation, as well as the development of alternative livelihoods for coastal communities, are key to achieving ecologically sustainable fisheries and marine development (Zhang et al. 2024). The level of ecological sustainability in fisheries and marine management in Indonesia is depicted by the sustainability ordination values, as shown in Figure 1.

The MDS RAPFISH analysis results show that the ecological sustainability index is 44.32, indicating an unsustainable status. As stated by Yusuf et al. (2021), an ordination value of less than 50 is categorized as unsustainable. The lack of ecological sustainability in Indonesia's fisheries and marine development highlights a serious threat to these resources. High fishing pressure, particularly from Illegal, Unreported, and Unregulated (IUU) fishing, is one of the primary factors contributing to the low sustainability of fisheries and marine ecosystems in Indonesia. For this reason, one of the main programs for marine and fisheries development is the measured fishing program which is one of the main national programs in the 2025-2029 RPJMN. The program implements a blue economy in the capture fisheries sector through scalable fisheries that includes post-production and quota setting per catch fleet (Hamzah 2022).

The IUU fishing is a significant global issue that threatens marine ecosystems, food security, and economic stability. Estimates suggest that IUU fishing accounts for 11-26 million tonnes of fish annually, valued between \$10 billion and \$23.5 billion (Mackay et al. 2020). This practice severely hampers the sustainable management of marine resources, with developing countries being the most at risk. For instance, in West Africa, total estimated catches are 40% higher than reported catches. To combat IUU fishing,

various approaches have been proposed and implemented. These include trade measures (Ma 2020), improved monitoring and enforcement through international collaboration (Desai and Shambaugh 2021). The same is also true in Norway which has a strong fishery, offshore energy (oil and gas) and aquaculture sectors. However, there is an imbalance between the exploitation and conservation of marine resources. Exploitation often conflicts with efforts to preserve marine ecosystems. Deep sea mining has become controversial due to its high ecological risks, despite the promise of economic benefits (Buonocore et al. 2020). The Blue Economy encompasses diverse sectors such as living and non-living resources, renewable energy, port activities, shipbuilding, and infrastructure, all of which necessitate careful management to ensure sustainability and minimize environmental impact (Gouvea and Gutierrez 2023).

Additionally, engaging with stakeholders to understand their perspectives and develop sustainable practices is crucial, as demonstrated by Svolkinas et al. (2023) in their study in the Caspian Sea region. Ultimately, addressing IUU fishing requires a multifaceted approach involving improved governance, international cooperation, and innovative technologies to ensure the long-term sustainability of marine ecosystems and fisheries (Donlan et al. 2020). The pressure on fisheries and marine resources is illustrated in Figure 2, where the attribute "presence of key species" (including coral reefs, sea turtles, whales, tuna, sharks, and mangroves) emerges as the most sensitive attribute in the ecological sustainability of marine resources in Indonesia.

The MDS RAPFISH analysis reveals that the attribute of "the presence of key species" including coral reefs, mangroves, sea turtles, whales, tuna, and sharks is a critical factor with high sensitivity in the ecological sustainability of fisheries and marine ecosystems in Indonesia. Coral reefs currently serve as crucial, yet increasingly threatened, habitats for various fish species. Several studies emphasize the importance of interconnectivity between coral reefs and other habitats, such as mangrove forests and seagrass beds, which function as protective buffers for coral reef ecosystems (Anton et al. 2020).

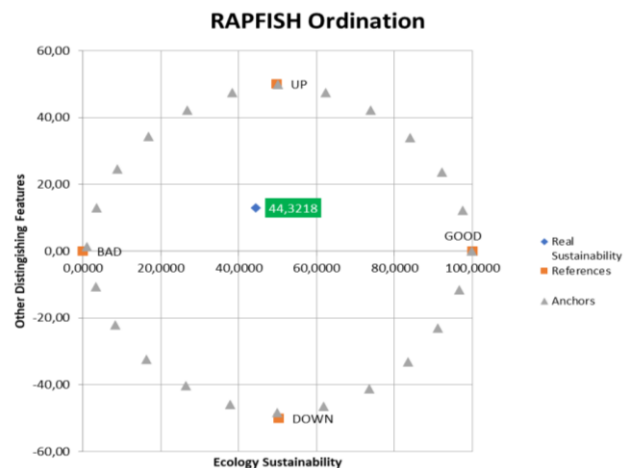


Figure 1. RAPFISH ordination of ecology sustainability

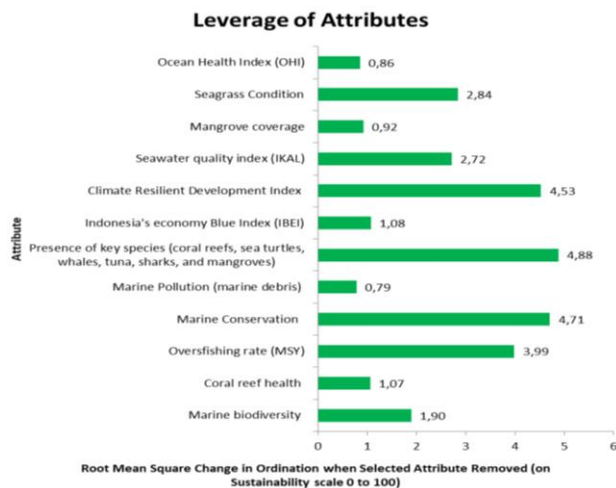


Figure 2. Leverage of attribute of ecology sustainability

In addition to coral reef ecosystems, mangrove ecosystems also play a highly strategic role in maintaining the health of marine ecosystems (Seemann et al. 2018). Furthermore, Sherman et al. (2019) highlight that sharks and rays are key functional components of coral reef ecosystems, with nearly two-thirds of shark and ray species associated with coral reefs currently facing the threat of extinction. Notably, reef sharks serve as key indicators of marine ecosystem health (Desbiens et al. 2021).

The presence of key species such as coral reefs, turtles, whales, tuna, sharks, and mangrove ecosystems has a strategic and substantial link with the Sustainable Development Goal (SDG) 14: Life Below Water. SDG 14 aims to promote the conservation and sustainable use of marine resources, and the existence of these key species serves as a vital indicator of the overall health of marine ecosystems. SDG Target 14.2, which focuses on protecting marine and coastal ecosystems, highlights the essential roles of coral reefs, seagrass beds, and mangroves as carbon sinks, coastal protectors, and critical habitats for various marine species. SDG Target 14.4 addresses overfishing, particularly in relation to tuna and sharks, which are economically valuable yet highly vulnerable to overexploitation and non-selective fishing practices. SDG Target 14.5 calls for the conservation of at least 10% of marine and coastal areas, where the protection of species such as sea turtles, whales, and sharks contributes directly to the achievement of Marine Protected Area (MPA) targets. SDG Target 14.c emphasizes the implementation of international law, as reflected in the United Nations Convention on the Law of the Sea (UNCLOS), including the protection of whales and the management of migratory tuna species through multilateral mechanisms such as the Indian Ocean Tuna Commission (IOTC) and the International Whaling Commission (IWC), which foster international cooperation.

Economy sustainability

Economic sustainability in the fisheries and marine sector means ensuring that marine resources are used efficiently, while considering the natural regeneration

capacity and the well-being of communities dependent on this sector. In this context, sustainability focuses not only on short-term economic growth but also on long-term welfare, involving wise management of the available natural resources (FAO 2020). Sustainably managed fisheries can provide stable income for coastal communities, create jobs, and enhance food security for populations relying on fish as a primary protein source. The level of economic sustainability in the management of fisheries and marine resources in Indonesia is depicted by the sustainability ordination values, as shown in Figure 3.

The MDS RAPFISH analysis results show that the economic sustainability index is 37.75, indicating an unsustainable status. According to Fauzi (2019), ordination values are divided into four categories: 0-25 is categorized as unsustainable, 25.1-50 as less sustainable, 50.1-75 as moderately sustainable, and 75.1-100 as sustainable. The low economic sustainability index in fisheries and marine development in Indonesia is clearly reflected in the very low contribution of the marine and fisheries sector.

The fisheries and marine sector play a significant role in the local economy, especially in coastal areas and remote islands. In many developing countries, including Indonesia, fisheries are a primary source of livelihood for millions of fishermen and their families, who depend on catches to meet daily living needs. Moreover, fisheries also contribute to exports and the national economy through trade in fish and fishery products (Cinner and McClanahan 2020). Therefore, economic sustainability in this sector is crucial to ensure that the economic benefits derived are not only enjoyed today but can also be passed on to future generations. Based on data from BPS in 2024, it is known that the contribution of the fisheries sector is only around 2.54%, with the GDP of the fisheries sector at Current Market Prices (*Atas Dasar Harga Berlaku/ADHB*) amounting to IDR 407 trillion (USD 35.7 billion). The contribution of the fisheries sector to national GDP is still relatively small compared to the abundant natural resources potential. One of the main factors contributing to the low contribution of the fisheries sector to national GDP is the small and traditional scale of fisheries operations. According to data from the Indonesian Ministry of Marine Affairs and Fisheries (KKP 2024c), most fisheries operations in Indonesia are small-scale or traditional, with approximately 96% of 2.1 million fisheries enterprises being micro-scale operations. This limits production capacity and competitiveness in both domestic and international markets.

In addition to the scale of operations, the lack of investment also contributes to the low contribution of the fisheries sector to national GDP, ultimately reflecting the low level of economic sustainability in the fisheries and marine sectors in Indonesia. Investment in the fisheries sector in Indonesia remains very low. Data from the Investment Coordinating Board (BKPM 2022) shows that from 2014 to 2021, the realized investment in Domestic Investment (*Penanaman Modal Dalam Negeri/PMDN*) in the fisheries sector was only IDR 2.24 trillion, or about 0.09% of total national investment. Meanwhile, Foreign Direct Investment (*Penanaman Modal Asing/PMA*) during

the same period was only about USD 334 million. Investment factors also emerge as a key sensitive attribute in the economic sustainability of fisheries and marine development in Indonesia, as shown in the leverage attribute analysis results, illustrated in Figure 4.

A key attribute of economic sustainability in fisheries and marine development in Indonesia is investment in the maritime sector with the highest sensitivity value (Root Means Square/RMS=3.56). This shows that investment is a key factor in maintaining the sustainability of the fisheries economy and marine development. The fisheries and marine sector are a strategic sector for the economies of archipelagic countries such as Indonesia. As a country with a large maritime area, Indonesia has enormous potential for marine resources. However, to take full advantage of this potential, investment is required.

Investment in the maritime sector is crucial because it can accelerate the development of infrastructure, technology, human resource capacity, and improve the management of marine natural resources (Ma 2020). In many developing countries, the fisheries and marine sectors play a significant role in the economy, whether in creating jobs, boosting exports, or supporting food security (Edgar et al. 2018). Therefore, investment in the maritime sector is key to sustainable fisheries and marine development.

In Indonesia, many coastal areas still lack basic infrastructure, such as fishing ports, fish processing facilities, and distribution networks for fish products (Bappenas 2020). This leads to inefficiencies in distributing fish catches, delays in market access, and reduced competitiveness of Indonesian fish products in international markets. Investment in modern technology is also a critical factor in the fisheries and marine sectors. Many fishermen in developing countries, including Indonesia, still rely on traditional fishing technology and methods, which reduce production efficiency. With more advanced technology, such as more efficient fishing vessels, environmentally friendly fishing gear, and satellite-based fish stock monitoring systems, the fisheries sector can optimize catches and ensure the sustainability of marine resources (Tversky and Lee 2024).

Investment is also needed to address the issue of IUU (illegal, unreported, and unregulated) fishing, which remains a significant challenge in global fisheries management. Investment in satellite-based monitoring systems or Vessel Monitoring Systems (VMS) can help track fishing activities in areas that are far from surveillance. With the right investment, Indonesia can reduce IUU fishing levels, protect marine resources, and increase the income from legitimate fisheries (FAO 2020).

Social sustainability

Social sustainability is one of the key pillars in the development of the fisheries and marine sector in Indonesia. Given the sector's significant role in the lives of millions of Indonesians, particularly those living in coastal areas and small islands, fisheries and marine development must not only address economic and ecological aspects but also meet the social needs of communities dependent on marine natural resources. Therefore, social sustainability in

the context of fisheries and marine development focuses on the fair management of natural resources, improving the quality of life for coastal communities, and ensuring equitable distribution of the benefits of this sector's development across all levels of society. The level of social sustainability in the management of fisheries and marine resources in Indonesia is depicted by the sustainability ordination values, as shown in Figure 5.

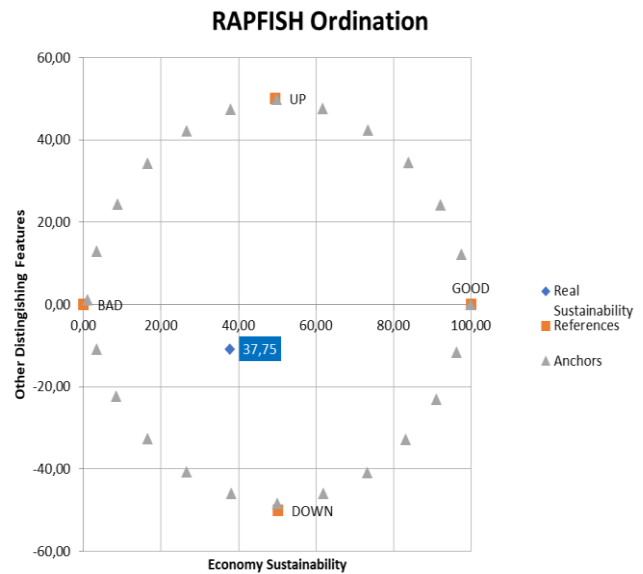


Figure 3. RAPFISH ordination of economy sustainability

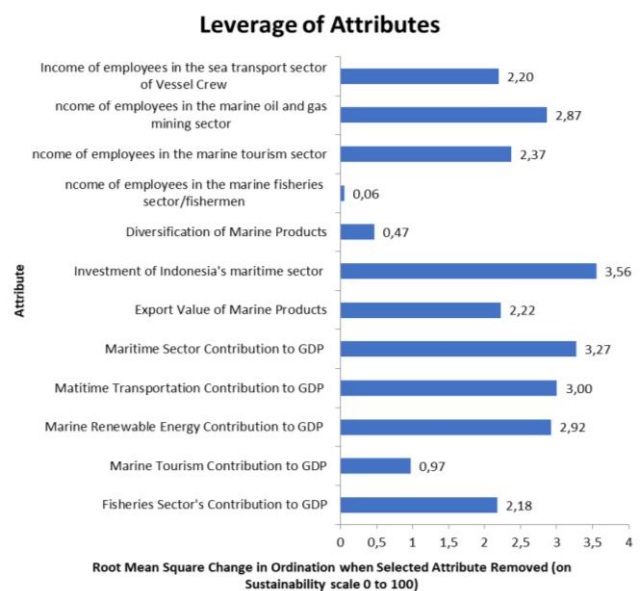


Figure 4. Leverage of attribute of economy sustainability

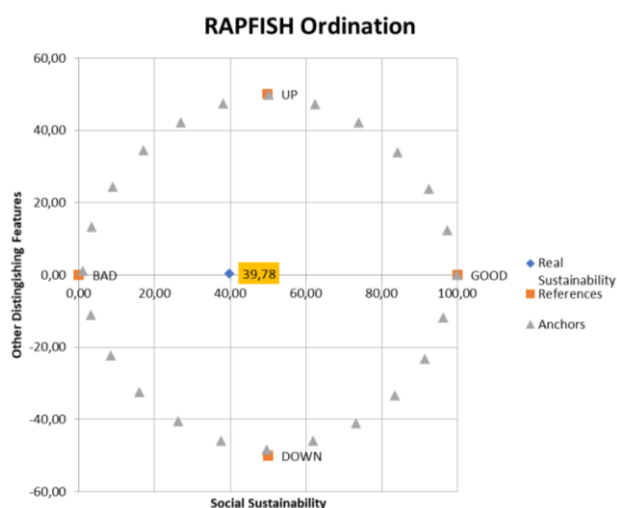


Figure 5. RAPFISH ordination of social sustainability

The MDS RAPFISH analysis results show that the economic sustainability index is 39.78, indicating an unsustainable status. According to Stephenson et al. (2018), ordination values are divided into two categories: less than 50 is categorized as unsustainable, and above 50 is categorized as sustainable. Social sustainability in fisheries and marine development in Indonesia faces significant challenges that hinder the achievement of equitable and sustainable development goals. Although the fisheries and marine sectors are crucial to Indonesia's economy, with millions of people depending on marine resources for their livelihoods, social sustainability in this sector remains relatively low.

Data from the Indonesian Ministry of Marine Affairs and Fisheries (*Kementerian Kelautan dan Perikanan/KKP*) show that more than 10 million Indonesians rely directly on the fisheries sector as their primary source of income, including fishermen, aquaculture entrepreneurs, and workers in the fish processing industry (FAO 2020). Therefore, the development of this sector must enhance the social welfare of coastal communities, many of whom are traditional fishermen and other vulnerable groups. Although Indonesia has vast potential in the fisheries sector, the majority of fishermen in the country operate on a small scale and have limited access to capital, technology, and markets (Purnomo et al. 2024). Additionally, many traditional fishermen live in poverty and have limited access to healthcare, education, and basic infrastructure. Thus, social sustainability in the development of the fisheries and marine sector is crucial to addressing social inequality and improving the quality of life for coastal communities.

Several factors contribute to this low level of social sustainability, including unequal access to resources, limited infrastructure, an inability to manage the impacts of climate change, and the prevalence of illegal fishing practices that threaten the welfare of traditional fishermen and coastal communities. To enhance social sustainability in fisheries and marine development, Indonesia needs to implement more inclusive and equitable policies,

particularly concerning the level of community (fishermen) participation in decision-making processes. Several factors are quite sensitive related to the social aspects in marine and fisheries development as shown in the leverage attribute analysis results, illustrated in Figure 6.

The leverage attribute analysis for social sustainability in fisheries and marine development in Indonesia shows that the level of community (fishermen) participation in decision-making is the most sensitive attribute. Community involvement is particularly important, as coastal communities and fishermen are the actors most directly connected to marine and fisheries resources. Therefore, they should be part of decision-making processes related to the management of these natural resources.

In many cases, involving fishermen in resource management can improve the effectiveness of policies and support the achievement of sustainable development goals in the fisheries sector. Research by Cinner and McClanahan (2020) indicates that when fishermen are involved in management processes, whether in decision-making about catch quotas or the establishment of marine protected areas, they are more likely to support the policies and comply with the existing regulations. This study also found that communities engaged in community-based management are better able to adapt to climate change and maintain the sustainability of fish stocks in their waters.

Research by Johnson and James (2023) further suggests that fisheries sustainability can be achieved more effectively when fishermen are involved in resource planning and management. Communities that are involved in decision-making have a better understanding of the importance of conservation and are more aware of the long-term impacts of resource exploitation. Researchers also noted that policies designed with community participation are easier to accept and more likely to be adhered to by fishermen.

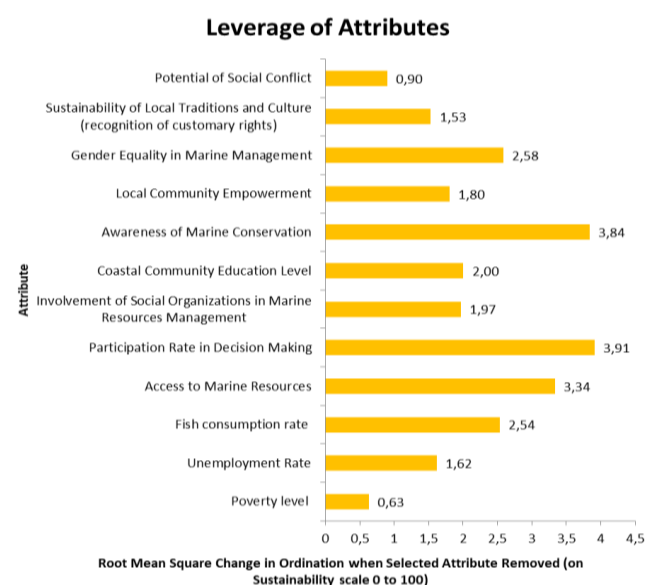


Figure 6. Leverage of attribute of social sustainability

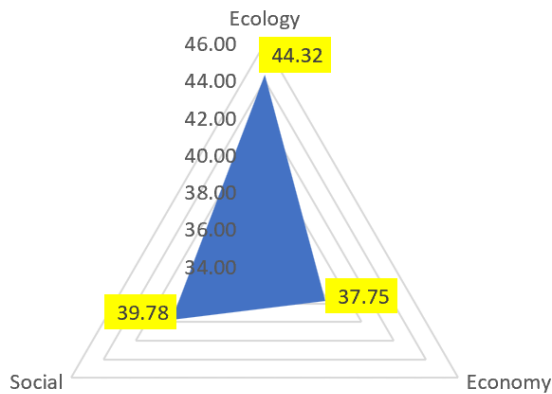


Figure 7. Trade-off of the sustainability dimension of Indonesia's fisheries and marine development

Multi-dimensional aspect

Sustainable fisheries and marine development require the integration of three key dimensions: ecological, economic, and social. While these dimensions are interdependent, in practice, they often lead to trade-offs situations, where achieving progress in one dimension may come at the expense of another (OECD 2021). These trade-offs represent a fundamental challenge in marine resource management, particularly in developing countries where economic and social pressures are intense. An overview of the 3-dimensional trade-offs of the sustainability of Indonesia's fisheries and marine development, as shown in the following Figure 7.

Trade-offs among ecological, economic, and social dimensions are inevitable in the pursuit of sustainable fisheries and marine development. The key challenge lies in managing and balancing these dimensions through evidence-based policies, participatory approaches, and adaptive management tools. A deeper understanding of these trade-offs enables the formulation of policies that are not only ecologically sound but also economically viable and socially just ensuring long-term sustainability.

In conclusion, the research findings indicate that the sustainability index for the ecological dimension is 44.32 (unsustainable), the economic dimension is 37.75 (unsustainable), and the social dimension is 39.78 (unsustainable). Thus, the overall level of sustainability in fisheries and marine development in Indonesia is categorized as unsustainable, with an average index score of 40.62. The study also identified three key attributes that significantly influence the sustainability of fisheries and marine development in Indonesia: (i) the presence of key species (coral reefs, sea turtles, whales, tuna, sharks, and mangroves) with an RMS value of 4.88; (ii) investment in Indonesia's maritime sector with an RMS value of 3.56; and (iii) the level of participation in decision-making processes with an RMS value of 3.91. To enhance the sustainability of fisheries and marine development in Indonesia, several key development strategies are recommended: (i) a strategy to improve ecosystem and environmental health by expanding conservation areas and strengthening the monitoring of marine protected areas; (ii)

a strategy to increase investment in the maritime sector, particularly in fisheries and supporting infrastructure, by streamlining licensing procedures for investment in the fisheries and marine sectors; and (iii) a strategy to strengthen community involvement in the management of marine and fishery resources by increasing public outreach (public consultations) and ensuring community participation from the planning stage through to program evaluation.

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