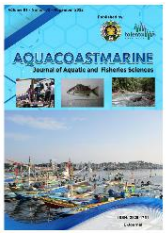
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Assessing the marine economic performance of coastal provinces in Indonesia

Pengukuran kinerja ekonomi kelautan di provinsi pesisir Indonesia

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ABSTRACT

The marine economy plays a strategic role in supporting sustainable development. Although the marine economy contributes significantly to economic growth, spatial disparities are manifested in the unevenness of utilization and performance of marine economy across different provinces in Indonesia. The lack of a standardized and comparable measurement framework at the subnational level constrains evidence-based policymaking. Therefore, this study aims to develop a comparable assessment of marine economic performance in coastal areas at the provincial level. Marine economic performance was assessed using Grey Relational Analysis that measures the proximity of provincial performance patterns to an ideal reference condition. This assessment was conducted on coastal provinces with high marine economic intensity, as previously identified through clustering analysis. Assessment of performance showed significant spatial and temporal heterogeneity. North Maluku, Bali, and Maluku were among the provinces that consistently maintained high performance levels, driven by effective and efficient resource utilization and also diversified economic structures. The results also show a complementary relationship between fisheries and marine tourism, where primary sectors support the development of tertiary sectors. The findings emphasize the importance of a spatially sensitive approach in evaluating marine-based economic systems, and the framework supports identification of regional priorities and advancement of sustainable development.

Keyword: Cluster analysis; Coastal regions; Grey Relational Analysis; Marine economy; Regional performance

ABSTRAK

Ekonomi kelautan berperan strategis dalam mendukung pembangunan berkelanjutan. Meskipun ekonomi kelautan memberikan kontribusi signifikan terhadap pertumbuhan ekonomi di Indoneisa, disparitas spasial termanifestasi dalam ketidakmerataan pemanfaatan dan kinerja ekonomi kelautan di berbagai wilayah. Kurangnya kerangka pengukuran yang terstandarisasi dan sebanding di tingkat provinsi membatasi pembuatan kebijakan berbasis bukti. Oleh karena itu, studi ini bertujuan untuk mengembangkan penilaian yang sebanding terhadap kinerja ekonomi kelautan di daerah pesisir pada tingkat provinsi. Kinerja ekonomi kelautan dinilai menggunakan *Grey Relational Analysis* yang mengukur kedekatan pola kinerja provinsi dengan kondisi referensi ideal. Penilaian ini dilakukan pada provinsi-provinsi pesisir dengan intensitas ekonomi kelautan yang tinggi, seperti yang telah diidentifikasi sebelumnya melalui analisis pengelompokan. Hasil penilaian kinerja menunjukkan heterogenitas spasial dan temporal yang signifikan. Maluku Utara, Bali, dan Maluku termasuk di antara provinsi-provinsi yang secara konsisten mempertahankan tingkat kinerja yang tinggi, didorong oleh pemanfaatan sumber daya yang efektif dan efisien serta struktur ekonomi yang terdiversifikasi. Hasil penelitian juga menunjukkan hubungan komplementer antara perikanan dan pariwisata bahari, di mana sektor primer mendukung pengembangan sektor tersier. Temuan ini menekankan pentingnya pendekatan yang berbasis karakteristik wilayah dalam mengevaluasi sistem ekonomi berbasis kelautan, kerangka kerja tersebut mendukung identifikasi prioritas ekonomi wilayah dan pembangunan yang berkelanjutan.

Keyword: Analisis pengelompokan; Ekonomi kelautan; *Grey Relational Analysis*; Kinerja wilayah; Wilayah pesisir

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1. Introduction

The marine economy is an important pillar of global and national economic development, especially for coastal and archipelagic nations. Over the past decade, this sector has gained substantial attention for role in economic development and job creation also the social and ecological sustainability of coastal areas (Hasan et al., 2018; Lindsay et al., 2020; Zhang et al., 2023). Sustainable marine economic development is also regarded as a strategic pathway to improve regional competitiveness through efficient and responsible utilization of marine resources (Han & Cao, 2024; Yu et al., 2024; Zhang & Chen, 2022). Thus, the enhancement of the marine economy may play a significant role here as well from not only economic growth perspective but also inclusive and sustainable regional development.

As the largest archipelagic nation in the world, Indonesia is a country with enormous economic potential in marine biological resources supported by vast marine areas, long coastline and strategic geographical position inside coral triangle. According to data from the Coordinating Ministry for Maritime Affairs and Investment (Kemenkomarves) and Statistics Indonesia (BPS), Indonesia's maritime gross domestic product (GDP) reached IDR 1,290.2 trillion in 2021, contributing an average of approximately 7.71% to national GDP during the period 2017–2021. In addition, fisheries GDP, as the largest sub-sector of marine economy, accounted for an average of IDR 262.3 trillion, or approximately 2.66% annually, over the period 2017–2024. While these numbers show relatively stable contribution at the national level, they do not capture regional disparities in marine economic potential across provinces.

Measuring marine economic performance at the subnational scale presents significant methodological challenges. The absence of a representative statistical framework has been identified as a key constraint in evidence-based decision-making within the marine economy sector (Colgan, 2013). In addition, limitations in the availability of consistent and standardized data also a major barrier to the comparative assessment of marine economic contributions across regions. These challenges become more pronounced when performance measurement occurs in regions with considerable geographical variability and also different economic capacities. In the Indonesian context, such measurement challenges are also reflected in the implementation of blue economy policies. The ministry of marine affairs and fisheries (MMAF) of Indonesia, has emphasized that the blue economy aims to ensure the sustainable use of marine resources. However, the assessment of the economic and environmental effects of these policies still needs quantifiable indicators with coherent data across regions, especially at subnational scale (Trenggono et al., 2025).

Empirical literature on the marine economy in Indonesia has thus far been dominated by sectoral and locally focused approaches. Existing studies generally are focused only on certain subsectors or commodities, without integrating cross-sectoral linkages into a comprehensive framework for measuring marine economic performance at the provincial level (Mulyanie, 2023; Suhana et al., 2023). Marine economic activities in

Indonesia also exhibit high spatial heterogeneity, which means that some coastal areas with high marine economic intensity have very advanced marine economies (Diantara et al., 2025). This condition emphasises the need for measurement approaches that are capable of capturing differences in marine economic intensity across provinces. However, as yet there is no empirical study that has provided a simple and comparable measurement of marine economic performance at the provincial level within Indonesia. This gap in the literature indicates the need for a measurement approach that focuses on core economic aspects, particularly the scale, structure, and efficiency of the marine economy, as a basis for assessing interregional performance. This is expected to give a better representation of marine economic performance as well as assist with the creation of policies that are more sensitive to regional characteristics.

This paper aims to develop an approach for measuring marine economic performance at the provincial level in Indonesia. High marine economic intensity provinces are identified in particular, and the comprehensive evaluation of performance is carried out for this group of provinces. It is anticipated that this will offer an empirical basis for designing more accurate and region-specific policy on marine economic development.

2. Methods

2.1. Identification of coastal provinces with high marine economic intensity

As an archipelagic country, all provinces in Indonesia are classified as coastal regions. Based on Village Potential Statistics published by BPS (2018, 2021, and 2024), the proportion of coastal areas exhibits substantial variation across provinces, ranging from less than 1% to approximately 85%. In addition, the intensity of marine economic activities varies considerably across regions, partly reflecting the fact that some provinces exhibit minimal marine economic activity, while in others such activities are not adequately captured or publicly documented in official statistics. Therefore, to ensure an objective and statistically valid selection, this study first identifies provinces with relatively high marine economic intensity prior to conducting the assessment of marine economic performance.

This study employed secondary data from all provinces in Indonesia covering the period 2019–2023. In addition to data availability, the selected period was chosen so that the results of the assessment can be interpreted as an achievement of short-term regional development. In Indonesia, short-term regional development is typically evaluated within a five-year cycle (Rahma et al., 2019). To identify provinces with high marine economic intensity, cluster analysis based on the k-medoids algorithm was applied. In general, economic intensity is defined as the ratio between the utilization of economic resources and economic output at a given level of activity (Tao, 2022). Based on this definition, three sector-specific indicators were established, along with an additional indicator representing the extent of coastal areas within each province (**Table 1**). Median values over the 2019–2023 period were used in order to reduce the influence of outliers and data anomalies.

Table 1. Marine economic intensity indicators

Indicator	Code	Operational Definition	Unit	Source
Marine capture fisheries and aquaculture intensity	mtfish	Ratio of the production value of marine capture fisheries, marine aquaculture, and brackish-water aquaculture to total fisheries output	Percent	MMAF
Marine transport intensity	mtransp	Contribution of marine transport to provincial gross regional domestic product (GRDP)	Percent	BPS
Marine tourism intensity	mtourism	Ratio of marine tourism arrivals to total tourist visits	Percent	BPS
Coastal area representation	coastreg	Percentage of coastal villages within province	Percent	BPS

Note: All indicators were calculated at the provincial level.

The k-medoids method was selected due to its robustness to extreme values compared to the k-means algorithm, as it employs medoids as cluster centers that are less sensitive to outliers (Azmi & Al., 2023). The Partitioning Around Medoids (PAM) algorithm minimizes the total distance between data points and medoids through an iterative process until convergence is achieved. Several studies have indicated that k-medoids produces more stable and representative partitions in the context of complex socio-economic data (Jarupunphol et al., 2025).

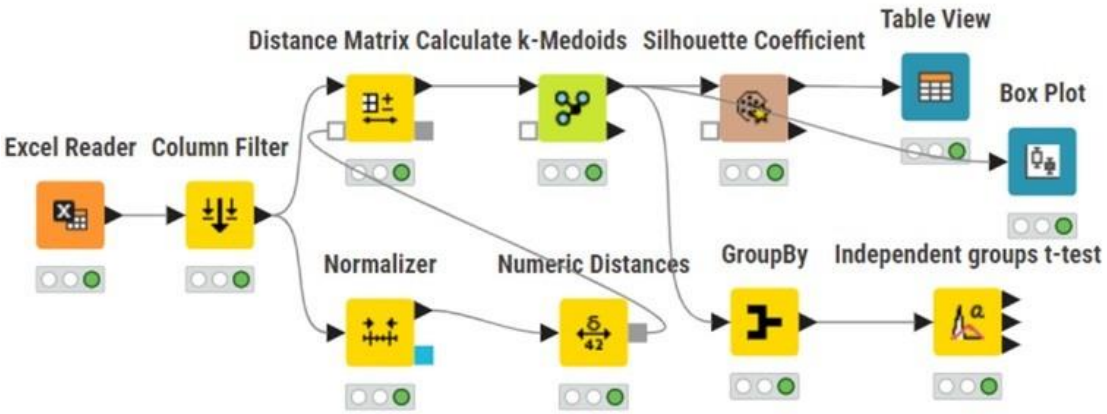


Figure 1. Workflow of the k-medoids clustering procedure implemented using the KNIME Analytics

The clustering procedure was implemented using the KNIME Analytics Platform, following the workflow illustrated in Figure 1. Prior to clustering, all variables were normalized to ensure comparability across different measurement scales. For distance measurement, the Euclidean distance metric was selected due to its computational efficiency and its ability to form compact clusters that are geometrically interpretable (Prasad et al., 2023). After clusters were formed using the k-medoids algorithm, cluster validity was assessed using the Silhouette coefficient, inter-cluster difference tests, and box plot analysis.

2.2. Analysis of marine economic performance

To measure marine economic performance across provinces, the Grey Relational Analysis (GRA) method was applied. GRA is a component of Grey System Theory, which was developed by Deng in 1982. This method has been widely employed in the context of Multiple Attribute Decision Making (MADM), particularly in situations characterized by incomplete or uncertain data (Kuo et al., 2008). The application of GRA was relevant in the Indonesian context due to limitations on data availability at the provincial level. In particular, comprehensive indicators commonly used in similar studies are not fully available, including marine GRDP, the separation of economic values between offshore and onshore activities within regional accounts, data on human resources in the marine sector, marine-related secondary economic activities, marine research and development (R&D), and other related indicators. In this respect, GRA, as part of Grey System Theory, is capable of processing such data limitations without requiring complete datasets as typically assumed in classical statistical approaches (Liu, 2025). However, it should be noted that GRA results are sensitive to data quality and indicator selection, and therefore should be interpreted as a relative assessment of system performance rather than a causal evaluation.

Table 2. Indicators of marine economic performance

Dimension/indicator	Code (preference)	Operational definition (unit)	Reference	Data source
Economic scale				
Fisheries GRDP	fgrdp (+)	Contribution of fisheries to GRDP (Percent)	(1)(2)	MMAF
Marine transport GRDP	mtransp (+)	Contribution of marine transport to GRDP (Percent)	(1)(2)	MMAF
Economic structure				
Primary activity	mprimary (-)	Percentage of villages whose main source of income is marine capture fisheries and brackish-water aquaculture (Percent)	(1)(2)	BPS
Tertiary activity	mtourism (+)	Ratio of marine tourism arrivals to total tourist visits (Percent)	(1)(2)	BPS
Economic efficiency				
Marine capture fisheries labor productivity	mcaptf (+)	Volume of marine capture fisheries production per marine fisher (Ton per person)	(3)(2)	MMAF
Marine aquaculture land productivity	mcultf (+)	Volume of marine and brackish-water aquaculture production per aquaculture area (Ton per hectare)	(3)	MMAF

Note: A positive sign (+) indicates that a higher indicator value reflects better performance, while a negative sign (–) indicates that a lower value reflects better performance. References: (1) (Zhang et al., 2023); (2) (Cheng et al., 2023); (3) (Liu et al., 2022).

This study adopted three main dimensions, adapted from Cheng et al. (2023) and Liu et al. (2022), to measure marine economic performance, namely economic scale, economic structure, and economic efficiency (Table 2).. The scale dimension represented growth and contributions to employment creation, the structure dimension reflected the degree of diversification and the transition from primary to tertiary sectors, while the efficiency dimension described the productivity of marine resource utilization (Cheng et al., 2023; Liu et al., 2022; Zhang et al., 2023). Within the economic structure dimension, the indicator *mprimary* was assigned a negative (–) sign, as excessive dependence on primary sectors may reduce ecosystem sustainability (Geng et al., 2024; Khan & Emon, 2024), whereas the *tourism* indicator was assigned a positive (+) sign to represent diversification toward tertiary-sector activities (Murphy et al., 2021). To ensure intertemporal comparability between the observation years (2019 and 2023), data were normalized using a fixed reference scale approach (Hessel et al., 2020). In addition, a winsorizing procedure based on the 5th percentile (P5) and the 95th percentile (P95) was applied to mitigate the influence of extreme values without altering the underlying distributional structure of the data (Akilli & Atıl, 2020).

After data preprocessing, the initial step in GRA was the grey relational generating process. This process was conducted to transform the raw data $\mathcal{X}_{ij}$, as defined in Table 2, into a dimensionless and linearly comparable form The next step involved the calculation of the Grey Relational Coefficient (GRC), denoted as ξ_{ij}, which measured the degree of closeness between each provincial indicator value and the reference sequence, a procedure widely adopted in marine-related multi-criteria evaluations using Grey Relational Analysis (Ju-Yong et al., 2019), denoted as $\mathcal{X}_{ij}^{*}$. Based on the preference direction of each indicator, the following normalization formulas were applied. If a higher indicator value represented better performance, the normalization was defined as:

$$\mathcal{X}_{ij}^{*} = \frac{\mathcal{X}_{ij} - min_i\, \mathcal{X}_{ij}}{max_i\, \mathcal{X}_{ij} - min_i\, \mathcal{X}_{ij}} \quad (1)$$

If a lower indicator value represented better performance, the normalization was defined as:

$$\mathcal{X}_{ij}^{*} = \frac{max_i\, \mathcal{X}_{ij} - \mathcal{X}_{ij}}{max_i\, \mathcal{X}_{ij} - min_i\, \mathcal{X}_{ij}} \quad (2)$$

After all indicators were normalized, a reference sequence X_0, was constructed to represent the ideal performance condition. The reference sequence was defined as:

$$X_0 = \{x_{0j}\} = \{1,1,\ldots.,1\} \quad (3)$$

A value of 1 indicated that the corresponding indicator had achieved its optimal performance level. Consequently, the closer a province was to this reference sequence, the better its overall marine economic performance. The next step involved the calculation of the Grey Relational Coefficient (GRC), denoted as ξ_{ij}, which measured the degree of closeness between each provincial indicator value and the reference sequence (Li et al., 2019). The GRC was calculated as:

$$\xi_{ij} = \frac{\Delta_{min} + \zeta \Delta_{max}}{\Delta_{ij} + \zeta \Delta_{max}} \quad (4)$$

where $\Delta_{ij} = \left| x_{0j} - \mathcal{X}'_{ij} \right|$ represented the absolute difference between the reference value and the normalized indicator value; Δ_{min} and Δ_{max} denoted the minimum and maximum values of Δ_{ij} across all provinces and indicators, respectively; and; $\zeta\ \epsilon[0,1]$ was the distinguishing coefficient, which was commonly set at 0.5 (Liu, 2025). A higher value of ξ_{ij}, indicated that the marine economic indicator *j* of province *i* was closer to the ideal condition.

Subsequently, the Grey Relational Grade (GRG) was computed as an aggregate measure of overall marine economic performance for each province. The GRG was calculated as:

$$GRG_i = \sum_{j=1}^{n} \omega_j \,.\, \xi_{ij} \quad (5)$$

where ω_j denoted the weight of indicator *j*. In this study, equal weights were assigned across dimensions in order to eliminate subjectivity in the weighting scheme and to enhance intertemporal stability. As each dimension contained an equal number of indicators, the weight assigned to each indicator was set at $1/6$. A higher GRG value indicated that a province exhibited more stable performance and was closer to the ideal marine economic condition.

For sensitivity analysis, indicator weights were also calculated using the entropy weight method (EWM). EWM is a statistical technique used to determine indicator weights objectively based on the amount of information contained in the data (Deng et al., 2020; Z. Wang et al., 2024). This method is commonly applied in multi-criteria analysis to ensure that indicator weights reflect actual data variation rather than subjective judgment.

3. Results and Discussion

3.1. Clustering results of marine economic intensity provinces

The clustering process resulted in two distinct provincial groups with a clear separation structure, as indicated by an average silhouette coefficient of 0.44 for both clusters (**Table 3**). In social, economic, and regional studies, silhouette coefficients below 0.5 are commonly accepted as satisfactory (Buchadas et al., 2022; Lee et al., 2024; Wan et al., 2025). To address this issue, researchers systematically enhance the silhouette coefficient with inter-cluster disparity tests and boxplot visualizations. Inter-cluster difference tests provide formal statistical confirmation that the clusters identified are uniquely different from one another (Rozova et al., 2021; Wan et al., 2025). Based on the t-statistics obtained from these tests (**Table 3**), the results indicate statistically significant differences for three of the four primary indicators, namely marine capture and brackish aquaculture intensity, marine tourism intensity, and the proportion of coastal area.

Table 3. Clustering results using the k-medoids method and inter-cluster difference tests

Indicator	t-statistic	p-value
Marine capture fisheries and aquaculture intensity (mtfish)	8.734***	0.000
Marine transport intensity (mtransp)	–0.358	0.724
Marine tourism intensity (mtourism)	3.450***	0.002
Coastal area representation (coastreg)	4.489***	0.000

Note: Silhouette coefficient: Cluster 1 = 0.33; Cluster 2 = 0.60; Overall = 0.44. Values represent independent samples t-test results comparing Cluster 1 and Cluster 2. *** indicates significance at the 1% level.

Boxplots are a fundamental visualisation of the distribution that highlights within-cluster differences and between-cluster separation (Agoub & Kada, 2021; Jin et al., 2022; Rozova et al., 2021). The boxplot visualization (Figure 2) further reinforces the distinction between the two clusters, with Cluster 1 consistently exhibiting higher median values across most indicators compared to Cluster 2. A total of 20 provinces were classified into Cluster 1 (**Figure 3**), indicating relatively high marine economic intensity. These provinces were subsequently selected for further analysis using GRA. Overall, the clustering results provide a robust empirical basis for understanding spatial variation in marine economic intensity and for focusing subsequent performance evaluation on provinces with stronger marine economic engagement.

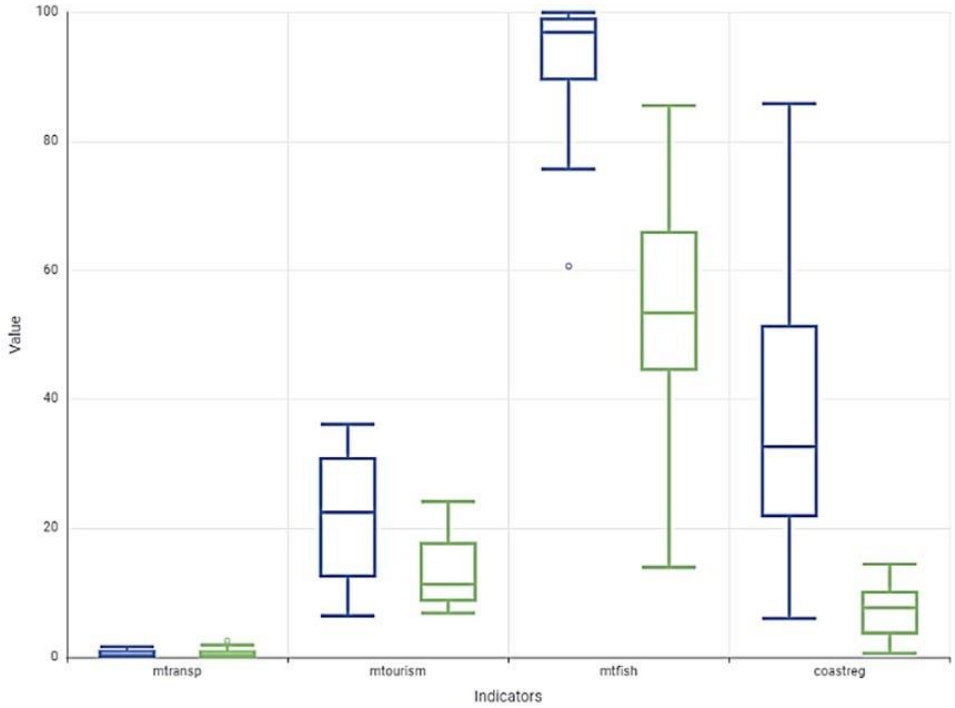


Figure 2. Box plots of marine economic intensity indicators for the two clusters. Blue boxes represent Cluster 1, while green boxes represent Cluster 2.

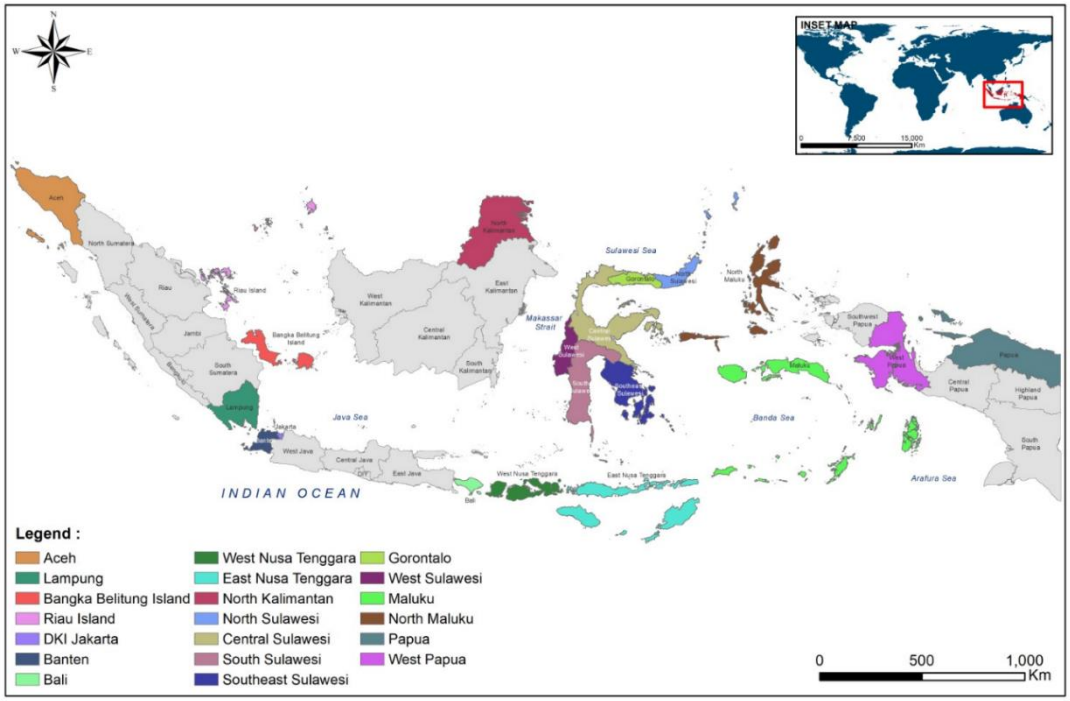


Figure 3. Spatial distribution of provinces with high marine economic intensity in Indonesia. Colored provinces represent Cluster 1 (high marine economic intensity), while grey provinces indicate Cluster 2.

3.2. Marine economic performance based on GRA

GRA was used to assess composite marine economic performance at the provincial level by measuring the proximity of each province's performance pattern to an ideal reference condition (Liu, 2025). Thus, selecting provinces with high marine economic intensity (cluster 1) ensures that the analysis captures meaningful variation among relevant indicators, while reducing structural bias from provinces with low or insignificant marine economic activity. The GRG, represented as the MEPI, for 2019 ranged from 0.45 in Central Sulawesi to 0.73 in North Maluku, with an average value of 0.55 (Table 4). North Maluku ranked highest in 2019, followed by Maluku, North Sulawesi, and North Kalimantan. These provinces exhibited relatively balanced marine economic structures, characterized by strong marine transport contributions and lower dependence on primary extraction activities. In contrast, Central Sulawesi displayed the lowest proximity to the ideal condition, reflecting weak performance in marine transport activities (*mtransp)*, tertiary marine economic activities, and capture fisheries productivity.

Across dimensions, the economic scale highlighted the importance of fisheries and marine transport contributions to regional economies. Fisheries GRDP reached its highest value in Maluku, indicating the central role of fisheries in supporting local economic activity. As a result, fisheries not only generate income but also create employment along the value chain, from harvesting and processing to distribution, while fulfilling food security and the livelihoods of coastal communities (Kalinowski et al., 2018; Ridzuan et al., 2022). Meanwhile, marine transport GRDP was highest in North Sulawesi, reflecting the strategic role of maritime logistics in inter-island connectivity. The maritime sector is considered as a key driver of regional economic growth and employment. At the global level, seaports compose approximately 80 percent of merchandise trade by volume, which shows their importance in economic systems (Amdaoud et al., 2022). At the regional level, port activities also contribute to job creation. Studies conducted in Europe suggest that every one million tons of port throughput can generate between 400 and 600 jobs in surrounding areas (Ahmad et al., 2021). These findings suggest that Maluku and North Sulawesi deserve to be ranked second and third in performance because of their important role as a contributing province both in fisheries and marine transport.

The economic structure revealed varying degrees of dependence on primary marine activities. Provinces such as Lampung and Bali demonstrated low dependence on primary activities, indicating greater diversification toward secondary and tertiary marine sectors. In contrast, provinces with high dependence on primary activities often exhibited lower overall performance, reflecting structural vulnerability. This vulnerability occurs through several associated mechanisms, including low value-added production and an inability to achieve economies of scale (Park & Seo, 2016), as well as resource depletion and environmental degradation (Karim & Islam, 2022; Mondal et al., 2024).

Tabel 4. Results of GRA for marine economic performance in 2019

Province	Grey Relational Coefficient (GRC)						GRG (MEPI)
	fgrdp	mtransp	mprimary	mtourism	mcaptf	mcultf	
North Maluku	0.53	0.82	0.74	0.71	0.58	0.98	0.73
Maluku	1.00	0.76	0.49	0.92	0.38	0.56	0.68
North Sulawesi	0.52	1.00	0.65	0.46	0.56	0.90	0.68
North Kalimantan	0.59	0.97	0.78	0.45	0.42	0.45	0.61
DKI Jakarta	0.33	0.38	0.92	0.36	1.00	0.51	0.58
Papua	0.48	0.70	0.70	0.49	0.42	0.65	0.57
Riau Islands	0.37	0.66	0.33	1.00	0.59	0.47	0.57
Lampung	0.49	0.37	1.00	0.40	0.63	0.45	0.56
East Nusa Tenggara	0.46	0.37	0.84	0.33	0.34	1.00	0.56
Bangka Belitung Islands	0.52	0.51	0.56	0.77	0.43	0.47	0.54
Gorontalo	0.68	0.37	0.60	0.34	0.74	0.46	0.53
Bali	0.43	0.34	1.00	0.36	0.45	0.59	0.53
Banten	0.33	0.33	0.95	0.48	0.53	0.45	0.51
South Sulawesi	0.60	0.38	0.69	0.34	0.47	0.48	0.49
Southeast Sulawesi	0.84	0.36	0.46	0.43	0.38	0.47	0.49
West Papua	0.49	0.48	0.54	0.37	0.55	0.50	0.49
West Nusa Tenggara	0.44	0.36	0.86	0.37	0.39	0.49	0.49
West Sulawesi	0.74	0.35	0.68	0.33	0.34	0.45	0.48
Aceh	0.45	0.35	0.83	0.45	0.38	0.45	0.48
Central Sulawesi	0.46	0.35	0.68	0.33	0.40	0.49	0.45
Mean	0.54	0.51	0.71	0.49	0.50	0.56	0.55

Note: fgrdp= Fisheries GRDP; mtransp= Marine transport GRDP; mprimary= Primary activity; mtourism= Tertiary activity; mcaptf= Marine capture fisheries labor productivity; mcultf= Marine aquaculture land productivity; GRG (MEPI)= Marine economic performance index.

The efficiency dimension further highlighted disparities in resource utilization, with Jakarta demonstrating high capture fisheries productivity, while several eastern provinces faced productivity constraints linked to limited capacity and access to modern fishing inputs. Marine economic efficiency is determined by a complex and interconnected set of factors operating across multiple scales and dimensions. The mechanisms lead to high marine economic efficiency are usually subject to some hot conditions, including geographical advantages and abundant natural endowments (Wang et al., 2021; Zhang & Wang, 2024), sufficient human capital endowment (An et al., 2022), and adequate as well as well-allocated capital investment (Hà, 2024; Matekenya & Ncwadi, 2022). These patterns reflect Jakarta's productivity due to greater resource endowments and capacity, whereas the constraints posed on eastern provinces signal that reduced access to skills, capital and modern fishing technologies are impeding their efficiency.

The MEPI values for 2023 (Table 5) ranged from 0.43 in West Papua to 0.73 in North Maluku, with an average of 0.54, slightly lower than the 2019 average. North Maluku continued to exhibit strong performance driven by high efficiency in capture fisheries and aquaculture productivity. Bali's improved ranking reflected strong structural diversification, particularly through marine tourism, while Maluku remained strongly supported by fisheries-based economic scale. In contrast, West Papua, Central Sulawesi, and DKI Jakarta occupied the lowest ranks, reflecting generally weak performance across multiple indicators.

From a dimensional perspective, the economic scale showed continued resilience of fisheries-based economies, particularly in Maluku, where fisheries GRDP remained the strongest contributor in the post-pandemic period. Marine transport activities remained most prominent in North Sulawesi, underscoring the role of maritime logistics in regional supply chains. However, relatively low marine transport contributions in provinces such as Bali and Central Sulawesi suggest that logistics infrastructure remains underutilized as a growth driver.

The economic structure revealed continued diversification in several provinces. Bali, Lampung, and Banten demonstrated low dependence on primary marine activities, indicating a shift toward tertiary sectors. High marine tourism values in the Bangka Belitung Islands and Bali confirm the importance of marine tourism as a key driver of marine economic performance. However, the sustainability of tourism-driven marine economic performance in provinces such as Bali and Lampung remains contingent on effective management of coastal carrying capacity and mitigation of cumulative environmental pressures, including habitat degradation, waste accumulation, and intensified coastal use (Kamil et al., 2022).

Table 5. Results of GRA for marine economic performance in 2023

Province	Grey Relational Coefficient (GRC)						GRG (MEPI)
	fgrdp	mtransp	mprimary	mtourism	mcaptf	mcultf	
North Maluku	0.43	0.51	0.72	0.69	1.00	1.00	0.73
Bali	0.44	0.34	1.00	0.99	0.38	0.98	0.69
Maluku	1.00	0.69	0.40	0.82	0.46	0.42	0.63
Lampung	0.48	0.38	0.99	0.64	0.64	0.33	0.58
North Sulawesi	0.52	1.00	0.66	0.46	0.41	0.33	0.56
Bangka Belitung Islands	0.52	0.52	0.52	1.00	0.40	0.34	0.55
Papua	0.67	0.90	0.35	0.50	0.52	0.34	0.55
North Kalimantan	0.63	0.90	0.70	0.33	0.33	0.34	0.54
West Sulawesi	0.84	0.35	0.70	0.60	0.39	0.34	0.53
Aceh	0.48	0.34	0.82	0.79	0.42	0.33	0.53
East Nusa Tenggara	0.49	0.37	0.85	0.66	0.33	0.48	0.53
Gorontalo	0.71	0.37	0.58	0.74	0.45	0.34	0.53
West Nusa Tenggara	0.44	0.37	0.85	0.70	0.39	0.37	0.52
Southeast Sulawesi	0.99	0.35	0.47	0.50	0.37	0.35	0.50
Banten	0.33	0.33	0.99	0.59	0.34	0.34	0.49
Riau Islands	0.36	0.60	0.33	0.78	0.42	0.44	0.49
South Sulawesi	0.62	0.37	0.67	0.42	0.39	0.36	0.47
DKI Jakarta	0.33	0.39	0.89	0.35	0.36	0.40	0.45
Central Sulawesi	0.40	0.33	0.62	0.48	0.51	0.36	0.45
West Papua	0.41	0.38	0.48	0.53	0.45	0.33	0.43
Mean	0.55	0.49	0.68	0.63	0.45	0.43	0.54

Note: fgrdp= Fisheries GRDP; mtransp= Marine transport GRDP; mprimary= Primary activity; mtourism= Tertiary activity; mcaptf= Marine capture fisheries labor productivity; mcultf= Marine aquaculture land productivity; GRG (MEPI)= Marine economic performance index.

An additional and notable finding from the economic structure dimension, consistent across both 2019 and 2023, is that provinces such as Maluku and the Riau Islands exhibited high dependence on primary marine economic activities while simultaneously achieving high values for the *mtourism* indicator. This pattern indicates the persistence of positive marine tourism performance despite continued reliance on fisheries-based activities, reflecting a complementary relationship between primary marine livelihoods and tourism-oriented development, as observed in island-based marine tourism governance contexts (Solihin et al., 2020). Such a configuration reflects structural coexistence between primary and tertiary sectors, as described by Cheng et al.(2023). In the contexts of the Riau Islands and Maluku, fisheries activities serve as a socio-ecological foundation for marine tourism development, allowing both sectors to evolve in a complementary rather than substitutive manner, as observed in locations such as Banda Neira in Maluku Province and Bintan in the Riau Islands (Andini et al., 2024; Mira et al., 2017).

The efficiency performance highlighted persistent disparities in resource productivity. North Maluku continued to exhibit the highest capture fisheries and aquaculture productivity, while provinces such as East Nusa Tenggara and North Kalimantan recorded relatively low capture fisheries productivity. These disparities may be associated with structural constraints, such as limited access to modern fishing technology, low capital investment, and weak supporting infrastructure, which have been recognised as major barriers to achieving gains in fishery productivity (Ali et al., 2023; Wasik et al., 2024). Furthermore, environmental pressures such as overfishing, habitat degradation, and climate change may further reduce fish stock availability and productivity, particularly in vulnerable regions (Cheung et al., 2024; Osemwegie et al., 2021). These challenges are likely more pronounced in East Nusa Tenggara, which is both vulnerable to natural hazards and climate-related challenges, potentially affecting fisheries stability. Meanwhile, in North Kalimantan, the dominance of extractive industries, particularly mining, might inhibit not only fisheries development but productivity as well.

Examining changes over time provides important insights into the dynamics and resilience of provincial marine economic systems. Table 6 presents changes in MEPI between 2019 and 2023. Bali recorded the largest increase, primarily driven by structural diversification toward tertiary marine economic activities. Similar improvements were observed in Lampung, Bangka Belitung Islands, West Sulawesi, Aceh, and West Nusa Tenggara. The improvement observed in these provinces suggests that marine tourism plays a catalytic role in shifting marine economies from extraction-based structures toward service- and value-added development pathways, consistent with the blue economy literature emphasizing structural diversification as a key driver of balanced and sustainable marine economic performance (Reddy & Sailesh, 2024; Santoso, 2025).

Table 6. Changes in marine economic performance index (MEPI) between 2019 and 2023

Province	MEPI 2019	Rank 2019	MEPI 2023	Rank 2023	ΔMEPI
Bali	0.53	12	0.69	2	0.16
West Sulawesi	0.48	18	0.53	9	0.05
Aceh	0.48	19	0.53	10	0.05
West Nusa Tenggara	0.49	17	0.52	13	0.03
Lampung	0.56	8	0.58	4	0.02
Southeast Sulawesi	0.49	15	0.50	14	0.01
Bangka Belitung Islands	0.54	10	0.55	6	0.01
Central Sulawesi	0.45	20	0.45	19	0.00
Gorontalo	0.53	11	0.53	12	0.00
North Maluku	0.73	1	0.73	1	0.00
South Sulawesi	0.49	14	0.47	17	-0.02
Banten	0.51	13	0.49	15	-0.02
East Nusa Tenggara	0.56	9	0.53	11	-0.02
Papua	0.57	6	0.55	7	-0.03
Maluku	0.68	2	0.63	3	-0.05
West Papua	0.49	16	0.43	20	-0.06
North Kalimantan	0.61	4	0.54	8	-0.07
Riau Islands	0.57	7	0.49	16	-0.08
North Sulawesi	0.68	3	0.56	5	-0.12
DKI Jakarta	0.58	5	0.45	18	-0.13

Note: ΔMEPI represents the change in marine economic performance index between 2019 and 2023. Positive values indicate improvement, while negative values indicate decline.

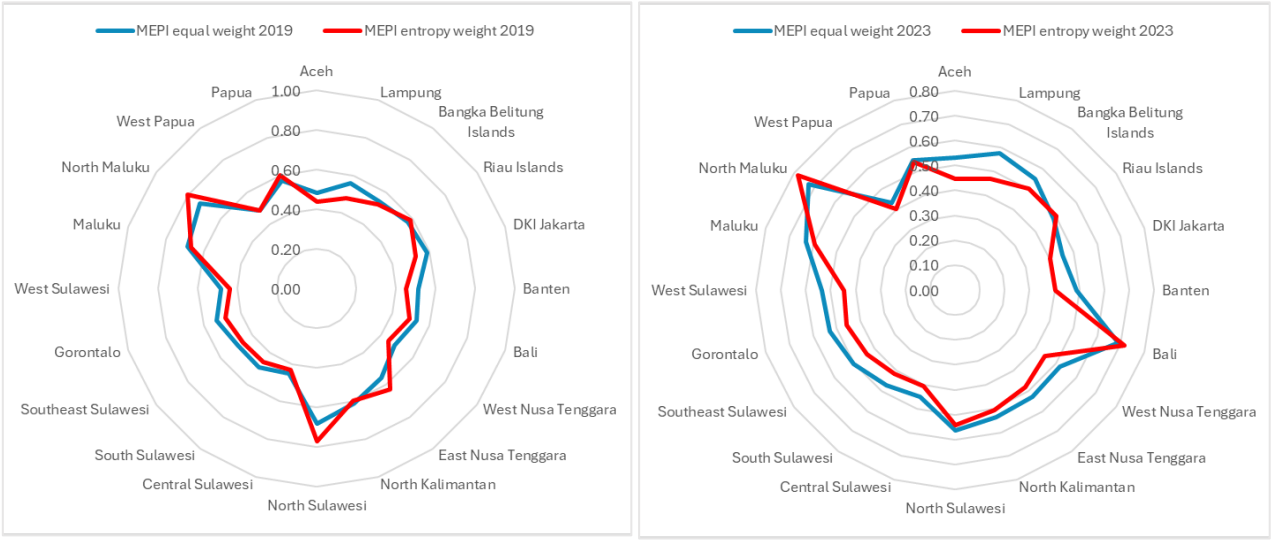


Figure 4. Comparison of marine economic performance index (MEPI) based on equal weight and entropy weight in 2019 (left) and 2023 (right).

Conversely, several provinces experienced declining performance. DKI Jakarta experienced the sharpest decline, largely associated with reduced capture fisheries productivity and shrinking aquaculture areas, consistent with intense coastal land conversion and urbanization pressures (Fedriansya & Rahman, 2025; Januari et al., 2024). East Nusa Tenggara remained in the lower performance group. In the context of East Nusa Tenggara, proximity of marine economic performance to the ideal condition remains closely linked to the sustainability of coastal and marine ecosystems, particularly within conservation areas such as the Savu Sea National Marine Park. Persistent pressures from overfishing, marine pollution, and climate change underscore the critical role of participatory and ecosystem-based governance in maintaining long-term marine economic performance in the region (Paulus et al., 2023). Similar sustainability challenges are also evident in provinces such as West Papua and parts of Maluku, where trade-offs between marine resource utilization and ecosystem conservation continue to shape economic outcomes.

A shift in performance drivers over time was observed. In 2019, proximity to ideal conditions was more closely related to economies of scale, while in 2023, structural balance and efficiency played a more prominent role. This transition to efficiency- and sustainability-oriented marine economic development is consistent with

recent evidence of high-quality marine economic growth (An et al., 2022) and the orientation of Indonesia's blue economy policy (Trenggono et al., 2025). In this context, North Maluku consistently maintained its highest performance across both periods, reflecting a stable and balanced marine economic system. To assess the robustness of the index, a sensitivity analysis comparing equal weight and entropy-based weighting schemes was conducted. As shown in Figure 4, alternative weighting approaches produced only minor differences in MEPI values and did not alter the relative performance patterns across provinces in either year. This finding confirms that the constructed index is robust to variations in weighting methodology.

4. Conclusion

Marine economic performance, measured using the Marine Economic Performance Index (MEPI), was evaluated across 20 coastal provinces with high marine economic intensity. The results show significant spatial and temporal heterogeneity. Provinces such as North Maluku, Bali, and Maluku consistently achieved high performance, supported by efficient resource utilization and diversified economic structures. On the other hand, provinces such as DKI Jakarta, Central Sulawesi, and West Papua performed weaker performance due to persistent imbalances across multiple dimensions.

A comparison between 2019 and 2023 indicates that, although average performance remained relatively stable, the underlying performance mechanism shifted over time. Earlier performance was heavily dependent on production scale, especially fisheries output, while more recent performance reflects enhanced efficiency and structural balance. This shift suggests a transition from extraction-oriented activities toward more value-added and sustainability-oriented marine economic systems.

Another structural aspect shows the coexistence of primary and tertiary marine sectors. Provinces such as Maluku and the Riau Islands demonstrate that fisheries-based activities can serve as a socio-ecological foundation for marine tourism development, enabling a complementary rather than substitutive relationship between sectors. This configuration highlights the value of coastal development strategies that integrate existing resource-based livelihoods with efforts to promote diversification.

Overall, underscore the need for a spatial-sensitive perspective on marine economic performance. Although the province-level data are limited, the suggested approach provides a practical basis for comparative assessment. From a policy perspective, the results support the formulation of region-specific development strategies (based on structural diversity and governance capacity) that ensure sustainability in coastal and marine resource use.

Further research will expand this analysis to the coupling relationship between marine economic performance and regional development dynamics. It will emphasize interaction between marine economic performance and regional development indicators across economic, social, and environmental dimensions. This type of analysis is expected to deepen understanding of sectoral integration within coastal regions and to support the formulation of sustainable regional development policies in coastal areas.

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