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Harnessing the Potential of the Blue Economy in Central Java: Mapping, Strategic Development, and Macroeconomic Analysis

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Abstract. This study pioneers the mapping and analysis of the blue economy's potential across the 35 regencies/municipalities of Central Java by constructing a novel Blue Economy Index (BEI). Notably, this research is among the first in Indonesia to build the BEI using granular satellite data and digital sensor information, and to apply the Two-Step System GMM approach to dynamically analyze the factors influencing its development. This combination provides unprecedented sub-national detail and robust insights into effective policy levers. The findings reveal significant disparities among the southern coastal, northern coastal, and non-coastal areas. The southern coastal regions exhibit higher BEI values compared to their northern coastal and non-coastal counterparts, which fall below the average. Results from the Two-Step System GMM regression analysis indicate that internet usage, infrastructure, and the COVID-19 period exert significant effects on the BEI. Specifically, infrastructure development, proxied by Nighttime Light (NTL), demonstrates a negative impact on the BEI, suggesting that environmentally unsustainable infrastructure may undermine the sustainability of the blue economy. Meanwhile, access to digital technology through internet usage plays a crucial role in fostering inclusive blue economy growth. Based on these findings, the proposed policy recommendations include optimizing environmentally friendly infrastructure development, leveraging digital technology to expand market access, and strengthening the resilience of the blue economy through Adaptive-Responsive-Innovative (ARI) crisis policies. Consequently, the development of the blue economy in Central Java is expected to enhance the sustainable welfare of coastal communities while fully optimizing the potential of coastal areas.

Keyword: Blue Economy, Big Data, Central Java, Two-Step System GMM, Blue Economy Index

1. Introduction

The Blue Economy is a sustainability-oriented economic concept that harnesses marine resources wisely while taking into account economic, social, and environmental dimensions in the long run (World Bank & UN DESA, 2017). This concept has become a strategic focus for Indonesia's development, particularly in achieving the vision of Indonesia Emas 2045. The development of the blue economy is regarded as a source of inclusive and sustainable growth, as it generates substantial economic and social benefits while serving as a game changer in Indonesia's development agenda.

Central Java Province, with a coastline stretching 971.52 kilometers across 17 regencies, is among the regions with the greatest blue economy potential in Indonesia. Its marine area covers 1.7 million hectares and encompasses 45 small islands, making it a strategic zone for the development of the fisheries sector. Various key fishery commodities—such as catfish (Clarias), tilapia (Oreochromis), milkfish (Chanos chanos), seaweed, and vannamei shrimp (Litopenaeus vannamei)—play a crucial role in providing high-protein food, creating employment opportunities, and increasing foreign exchange earnings.

The fisheries sector in Central Java holds a strategic role in national economic development. The provincial government has set a target to develop this sector into one that is self-reliant, advanced, and resilient. According to the vision of the Central Java Marine and Fisheries Office, marine and fisheries development is directed toward realizing sovereignty, sustainability, and the welfare of coastal communities and fisheries actors. Ultimately, this development is expected to improve community welfare, generate employment, and promote a fisheries sector that is both independent and competitive.

Despite the immense potential of the blue economy and fisheries sector in Central Java, coastal communities have not fully benefited from its development. This is reflected in the fact that 12.5 percent of Central Java’s poverty is concentrated in coastal areas, highlighting a gap between vast economic potential and the welfare of coastal populations. In principle, sustainable marine resource management should drive inclusive economic growth; however, this has not yet been fully achieved in the coastal regions of Central Java (World Bank & UN DESA, 2017)

Despite the immense potential, a significant gap persists between the blue economy's promise and the welfare of coastal communities in Central Java. A primary reason for this disconnect is a critical research gap in how the blue economy is measured and analyzed at a sub-national level. Previous studies on Indonesia's blue economy have predominantly relied on conventional, aggregated national statistics. Such data often masks significant local disparities and fails to provide the granular, real-time insights necessary for effective, evidence-based policymaking at the regency and municipal levels. This limitation makes it difficult to identify specific areas that are underperforming or the precise factors driving success.

This study directly addresses this gap in two fundamental ways. First, it pioneers the use of big data, including satellite imagery and digital sensors, to construct a comprehensive Blue Economy Index (BEI) for all 35 regencies/municipalities in Central Java. This approach overcomes the limitations of traditional secondary data by offering a more detailed and dynamic mapping of blue economy potential. Second, much of the existing research employs static analytical models that fail to capture the complex, dynamic, and potentially endogenous relationships between macroeconomic factors and blue economy performance. To fill this methodological gap, this study utilizes a Two-Step System GMM approach. This dynamic panel data model is specifically chosen for its ability to address issues of endogeneity and persistence over time, thereby providing more robust and reliable insights into the true drivers of the blue economy.

2. Research Method

2.1. Conceptual Framework

Based on the literature review, the conceptual framework proposed in this study is as follows:

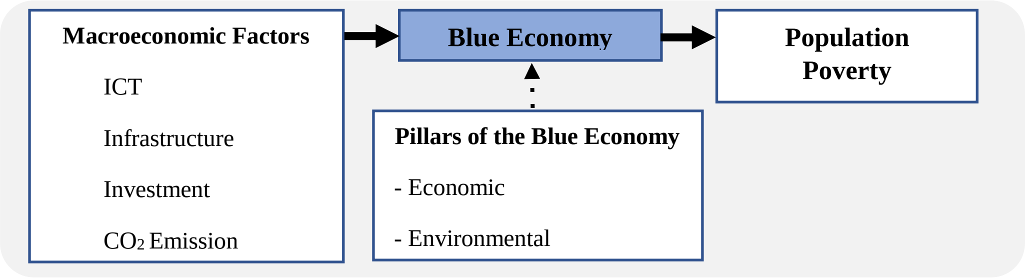


Figure 1. Conceptual Framework of the Study.

2.2. Data Sources and Operational Variables

This research employs secondary data and big data, covering 35 regencies/municipalities in Central Java for the period 2019–2023, with the research variables presented in Appendix 1. Secondary data were obtained from statistical publications by Statistics Indonesia (BPS) and the Ministry of Marine Affairs and Fisheries (Kemen-KKP). Other data were derived from satellite imagery processing and digital sensing results (Appendices 3 to 6), which enable monitoring of environmental conditions such as the number of marine tourism sites, mangrove forest area, and CO$_2$ emissions.

2.3. Measurement of the Blue Economy Index (BEI)

a. Constructing the framework and determining variables

The BEI developed in this study is based on three dimensions of the blue economy: Economic (E), Environmental (L), and Social (S) pillars (Appendix 2).

The selection of variables for the BEI, particularly the Environmental (L) pillar, was governed by the principles of data availability and spatial granularity at the regency/municipality level. While a comprehensive measure of marine ecosystem health would ideally include factors like water quality and biodiversity metrics, the Environmental pillar was constructed using three robust, measurable indicators: waste management capacity (OL), critical coastal ecosystem health (LM), and general environmental quality (TP). This selection ensures a focused measure of human impact and natural resource protection, representing the most accessible and verifiable environmental data points available through both conventional and big data sources for this specific geographic scale. Future research, as data availability improves, can incorporate more indicators.

The selection of variables for the BEI, particularly the Environmental (L) pillar, was strategically governed by two factors: ecological importance and data granularity at the regency/municipality level. While an ideal BEI would include comprehensive indicators like water quality and biodiversity, the chosen variables (waste management capacity (OL), critical coastal ecosystem health (LM), and general environmental quality (TP)) serve as robust, verifiable proxies for measuring human impact and natural resource protection where sub-national data is scarce. We acknowledge that this limits the scope to key verifiable inputs but ensures the index remains a practical, policy-relevant tool for Central Java's local governments.

b. Data normalization

Data normalization was conducted since the variables used to construct the BEI have different measurement units. The method applied is min-max normalization, which transforms each indicator value into a scale ranging from 0 to 1 using the following formula:

$$l_k^t = \frac{x_k^t-(x_k)}{(x_{kmax})-(x_{kmin})},\ k = 1,2,\ldots.,10; t = 1,2,\ldots,9 \quad (1)$$

Where:

l_k^t : Normalized value of indicator k in year t

(x_{kmax}) : Maximum value of indicator k

x_k^t : Original value of indicator k in year t

(x_{kmin}) : Minimum value of indicator k

c. Weighting and aggregation process

The weighting process was carried out to derive the BEI and its sub-indices. This study applies the equal weighting method.

$$\underline{IEB_t} = \frac{\underline{SIE_t}+\underline{SIL_t}+\underline{SIS_t}}{3} \quad (2)$$

$$\underline{SIE_t} = \frac{\sum_{i=1}^{4} SIE_{it}}{4}; \underline{SIL_t} = \frac{\sum_{i=1}^{3} SIL_{it}}{3}; \underline{SIS_t} = \frac{\sum_{i=1}^{4} SIS_{it}}{4}$$

Where:

$\underline{IEB_t}$: Average Blue Economy Index in year t

SIE_{it}: Economic index of region i in year t

$\underline{SIE_t}$: Average economic sub-index in year t

SIL_{it}: Environmental index of region i in year t

$\underline{SIL_t}$: Average environmental sub-index in year t

SIS_{it}: Social index of region i in year t

$\underline{SIS_t}$: Average social sub-index in year t

d. Data Analysis and Econometric Model

The analytical techniques employed in this study consist of both descriptive and inferential analysis. Descriptive analysis was conducted using tables and thematic maps, while inferential analysis utilized an econometric regression model with panel data. Data processing was carried out using R, Python, and ArcGIS software.

The econometric method applied in this study is Dynamic Panel Regression with the Generalized Method of Moments (GMM) approach. This method was chosen because static panel regression models such as the Fixed Effects Model (FEM) tend to produce biased and inconsistent estimators in cases where the dynamics of variables over time are present (Arellano & Bond, 1991). The use of GMM helps mitigate issues related to heteroskedasticity, autocorrelation, and endogeneity.

The GMM procedure was implemented using the two-step system approach, due to the limited number of observations and time periods, as well as the weak instrument problem associated with the difference procedure (Hwang & Sun, 2018). The GMM model in this study incorporates the lag of the Blue Economy Index (BEI) as an explanatory variable and applies instrumental variable techniques to address potential endogeneity caused by bidirectional causality between the BEI and other endogenous variables.

The specification of the Dynamic Panel-Data estimation model with the Two-Step System Generalized Method of Moments (Two-Step System GMM) is formulated as follows:

$$IEB_{i,t} = \alpha + \beta_1 LIEB_{i,t-1} + \beta_2 LPOV_{i,t} + \beta_3 LNET_{i,t} + \quad (3)$$

$$+\beta_4 LNTL_{i,t} + \beta_5 LPMTB_{i,t} + \beta_6 LCO_{i,t} + \beta_7 COVID_{i,t} + \mu_{i,t} + \sigma_{i,t} + \varepsilon_{i,t}$$

Where:

$IEB_{i,t}$: Blue Economy Index for region *i* in year *t*

$IEB_{i,t-1}$: Lagged Blue Economy Index

$POV_{i,t}$: Poverty level

$NET_{i,t}$: Internet usage (ICT)

$NTL_{i,t}$: Infrastructure (proxied by Nighttime Light)

$PMTB_{i,t}$: Investment

$CO_{i,t}$: CO_2 emissions

$COVID_{i,t}$: COVID-19 dummy variable

μ_i : Region-specific effect

σ_t : Time-specific effect

$\varepsilon_{i,t}$: Error term

3. Result and Discussion

3.1 *Descriptive Analysis*

The poverty rate across districts and municipalities in Central Java Province in 2023 exhibits substantial variation, reflecting diverse socio-economic disparities among regions. Kebumen Regency recorded the highest proportion of poor residents, whereas several municipalities such as Salatiga and Magelang reported relatively low poverty levels. This inequality not only reflects differences in access to resources and economic opportunities but also highlights various structural factors influencing community welfare at the local level.

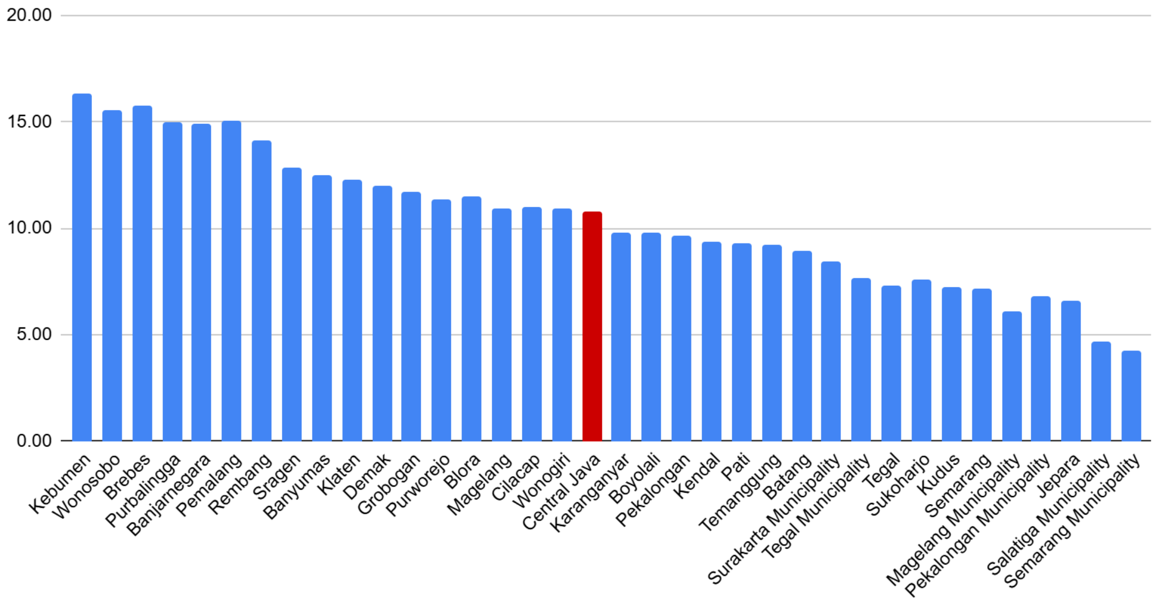
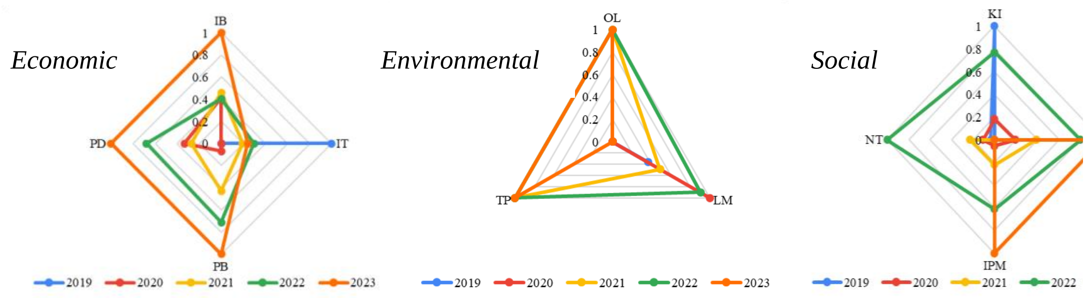


Figure 2. Poverty Rate of Districts/Municipalities in Central Java Province, 2023

The economic pillar of the blue economy is represented by the variables of Aquaculture Production (IB), Capture Fisheries Production (IT), Marine Tourism Activities (PB), and Fisheries Gross Regional Domestic Product (PD). Overall, IB has emerged as the fastest-growing sector, while IT has remained low and stagnant. PB experienced a decline, particularly during the COVID-19 pandemic, whereas PD remained stable, albeit not yet optimal. Future challenges lie in enhancing the marine tourism and capture fisheries sectors, which continue to lag behind, while sustaining the rapid growth of aquaculture.

The environmental pillar is represented by the variables of Percentage of Villages with Waste Management Mechanisms (OL), Mangrove Forest Area (LM), and Percentage of Villages Without Air, Marine, or Other Pollution (TP). On average, the extent of mangrove forests has fluctuated annually. Mangroves play a crucial role in maintaining coastal ecosystem balance and contribute to the sustainability of marine resources. OL has increased, indicating stronger efforts in waste management at the village level. In contrast, LM has remained relatively stable, though with a slight decline in 2020. Meanwhile, TP experienced a sharp decline in 2020 but gradually recovered in subsequent years. Collectively, these variables illustrate both the challenges and continuous efforts undertaken to preserve environmental balance and ecological sustainability.

The social pillar is represented by Fish Consumption Calorie Intake (KI), Monthly Per Capita Expenditure (PM), Human Development Index (HDI), and the Number of Fishers and Aquaculture Farmers (NT). KI and NT exhibited considerable fluctuations, with declines in certain years reflecting dynamics in consumption patterns and fisher engagement in the fisheries sector. Conversely, HDI and PM demonstrated stable and upward trends each year, indicating improvements in living standards and community welfare. This pattern reflects persistent challenges in the marine and fisheries sector, yet also highlights ongoing efforts to enhance social well-being.


Economic

Environmental

Social

Figure 3. Radar Diagram of Sub-Index Indicators, 2019–2023 (Normalized Data)

Furthermore, the percentage of internet usage (NET) showed a substantial increase from 2019 to 2023. The NTL variable (proxy for infrastructure development) also recorded steady annual growth, whereas PM (proxy for investment) displayed a fluctuating pattern (Appendix 7).

3.2 Results of the Blue Economy Index in Districts/Municipalities of Central Java

One of the primary objectives of this study is to identify and map the potential of the blue economy across 35 districts and municipalities in Central Java through the measurement of the Blue Economy Index (IEB). During the 2019–2023 period, the IEB exhibited a consistent upward trend. In 2019, the index value stood at 0.32, which increased to 0.36 in 2023. This indicates a steady improvement in productivity and the blue economy climate in Central Java.

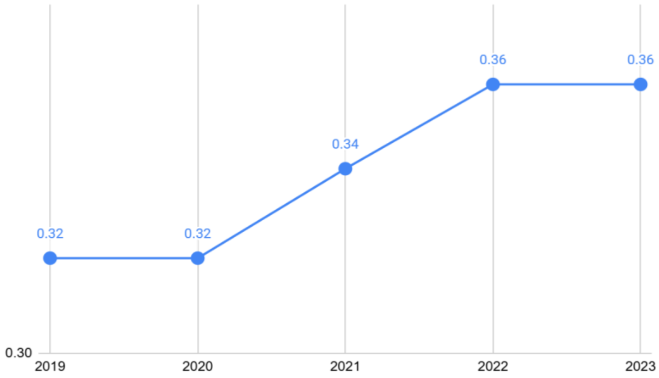


Figure 4. Average Blue Economy Index of Central Java, 2019–2023

In general, the IEB of Central Java demonstrates a positive trend, with notable increases in several districts and municipalities over the 2019–2023 period. However, significant disparities persist across regions, suggesting that the potential of the blue economy in certain areas has not been fully optimized. This highlights the need for development strategies that are more tailored to the specific characteristics of each locality to ensure balanced progress.

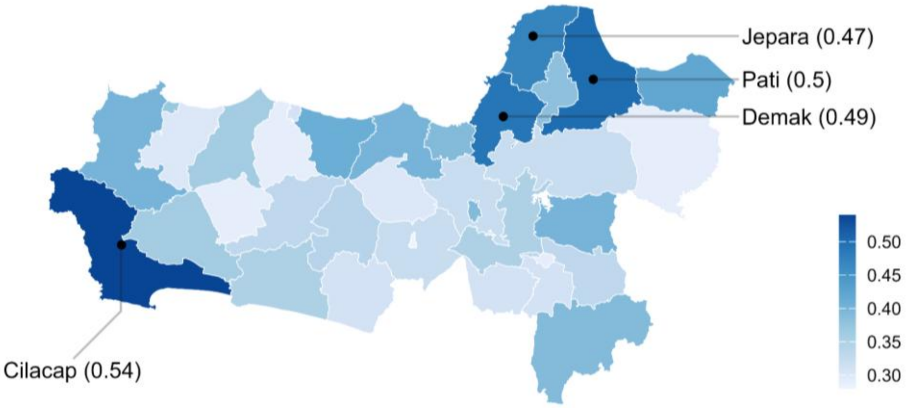


Figure 5. Blue Economy Index Map of Central Java, 2023

Cilacap Regency consistently recorded the highest IEB with a positive trend throughout 2019–2023. Its strategic geographical location as a key coastal regency is one of the main factors contributing to its strong performance. Similarly, Demak Regency also exhibited relatively high IEB values, albeit with some fluctuations, reflecting stability in the management of its blue economy sector. Conversely, several regencies reported lower IEB values. For instance, Tegal Regency recorded the lowest index in 2019, but showed improvement by 2023 due to initiatives in strengthening the blue economy sector, although its value remained below the provincial average.

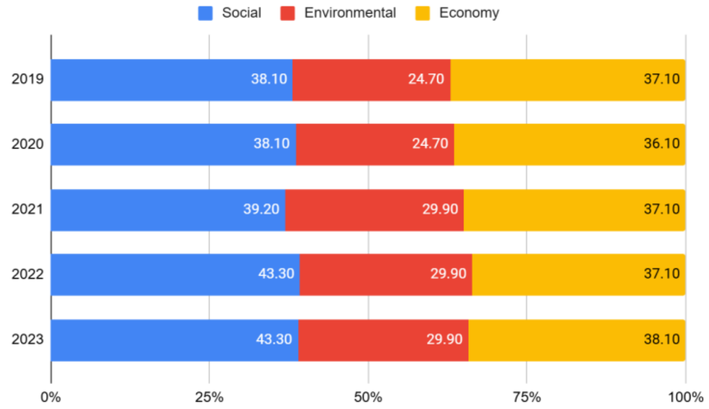


Figure 6. Percentage Distribution of IEB Sub-Index Values, 2019–2023

The IEB sub-indices in Central Java are predominantly driven by the social pillar, which experienced substantial growth during 2019–2023. This reflects an increasing emphasis on social factors such as unemployment, internet access, and human development. Meanwhile, the environmental dimension also exhibited a steady increase, indicating greater awareness of environmental sustainability. By contrast, the economic dimension showed a fluctuating pattern, underscoring the critical role of economic activities in supporting the development of the blue economy in Central Java.

3.3 Regression Results

3.3.1 Unit-Root Test

Stationarity testing (unit-root) was conducted to ensure the reliability of the model and to avoid spurious regression (Maddala & Wu, 1999) (Appendix 14).

3.3.2 System GMM Regression Results

To examine the relationship between the blue economy and poverty levels, as well as to identify the macroeconomic determinants influencing the blue economy in Central Java, modeling was carried out using the System GMM regression method. This approach was chosen due to its ability to address endogeneity issues, account for variable dynamics, and incorporate heterogeneity across regions. The Blue Economy Index (IEB1) was employed as the dependent variable, while independent variables such as poverty rate, infrastructure networks, and other economic factors were included simultaneously to obtain more robust estimates. The model estimation results are presented in Table 1.

The estimation results reveal that several variables exert a significant influence on IEB. The lagged value of IEB (L1.IEB1) shows a significant positive coefficient, indicating that the blue economy performance in the previous period affects the outcomes in the subsequent period. Specifically, a one-unit increase in the lagged IEB (L1.IEB1) raises the current IEB1 by 1.030 units, ceteris paribus. This finding underscores the critical role of policy continuity and sustainability efforts in maintaining the growth momentum of the blue economy.

Table 1. System GMM Regression Results

Dependen: IEB1	**Coeff.**	**Std. Err**
L1. IEB1	1.030***	0.140

Dependen: IEB1	**Coeff.**	**Std. Err**
LPOV	-0.078	0.065
LNET	0.156***	0.035
LNTL	-0.056*	0.029
LPMTB	0.001	0.011
LCO	0.822	1.282
COVID	-0.038*	0.019
Diagnostic test:		
AR(1) p-value	0.005	
AR(2) p-value	0.625	
Sargan p-value	0.094	
Hansen p-value	0.056	
Obs.	175	
No. of Group (Region)	5	

Note: The GMM estimation was performed with robust standard errors using the *xtabond2* syntax in Stata (Hwang & Sun, 2018). The Arellano-Bond AR(1) test indicates the presence of first-order autocorrelation (reject H0), while the AR(2) test suggests no second-order autocorrelation (fail to reject H0), confirming that the dynamic model is statistically valid. The Hansen test, with a p-value greater than 0.05, implies that the instruments are uncorrelated with the standard errors and therefore valid for use. The Sargan test results indicate no overidentification issues across all model estimations. The p-values are based on two-tailed tests, where *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

The logarithm of internet usage (LNET) exhibits a significant positive effect on the Blue Economy Index (IEB). A 1% increase in internet users raises the IEB by 0.156%, *ceteris paribus*. This finding indicates that greater access to and adoption of digital technologies are crucial in supporting blue economy activities, consistent with the studies of Bahrini & Qaffas (2019) and Bhattacharya & Dash (2020).

In contrast, the logarithm of nighttime lights (LNTL) demonstrates a significant negative effect. A 1% increase in NTL reduces the IEB by 0.056%, *ceteris paribus*. This suggests that infrastructure expansion contributes to a decline in IEB. In line with Andrade-Núñez & Aide (2020), infrastructure development is generally accompanied by environmental degradation, which in turn adversely impacts the blue economy where environmental sustainability is a central consideration.

Finally, the COVID-19 pandemic (COVID) had a significant negative impact on the blue economy, reducing its performance in Central Java by 0.038%, *ceteris paribus*. Social restrictions, supply chain disruptions, declines in marine tourism, and limited access during the pandemic led to reduced activities in blue economy-related sectors (Eugui et al., 2021).

3.3.3 Model Selection and Robustness Checks

A series of diagnostic tests were conducted to determine the most appropriate model specification and to assess robustness (Appendix 13).

To address the potential interpretive bias arising from the limited set of environmental indicators, a dedicated robustness check was performed. We re-estimated the Two-Step System GMM model using an alternative Blue Economy Index that excluded the entire environmental sub-index (L). The resulting coefficients for our primary determinants (Internet Usage, Infrastructure) remained statistically significant and consistent in direction and magnitude (The Nighttime Light (NTL) variable serves as an unbiased proxy for infrastructure, as it is derived from independent remote sensing data and has been empirically proven to exhibit a strong correlation with economic activity, regional development, and infrastructure across multiple cross-country studies (Henderson et al., 2012; Chen & Nordhaus, 2011; Wang et al., 2021; Kuncoro et al., 2023). This confirms that while the environmental pillar is foundational to the blue economy concept, the significant macro-determinants of the overall BEI are robust to potential measurement limitations within the environmental sub-index.

3.4 Discussion

The findings of this study, which covers 35 districts and municipalities in Central Java, highlight the presence of spatial variation in the Blue Economy Index (IEB), particularly between the northern, southern, and non-coastal regions. The southern coastal region consistently recorded higher IEB values compared to the northern coast. In 2023, the southern coastal area reached an average IEB of 0.37, while the northern coast registered 0.40. These differences are also reflected in the trends from 2019 to 2023, where the southern coastal region consistently outperformed the northern coastal region.

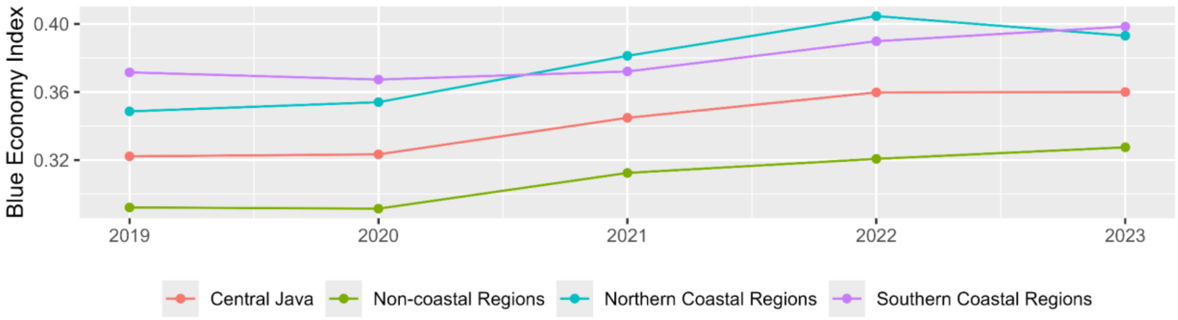


Figure 7. IEB Trends by Geographic Region

The IEB results reveal significant variations across regions. The southern coastal areas tend to consistently achieve higher values compared to other regions, while the non-coastal areas generally record lower values. The differentiated contributions of each sub-index underscore the need for an integrated approach. Blue economy development cannot rely solely on a single dimension but instead requires a balanced strategy with targeted interventions based on the specific characteristics of each region to ensure inclusive and sustainable growth.

The expansion of information and communication technologies has proven to enhance blue economy outcomes in Central Java, as evidenced by the significantly positive effect of LNET. Regions with broader internet access tend to be better equipped to optimize technology in managing marine resources, whether in the context of fishing (Muhyun et al., 2022), seafood trade (Hamzah et al., 2018), tourism (Pranita, 2022), or environmental management (Simbolon et al., 2022).

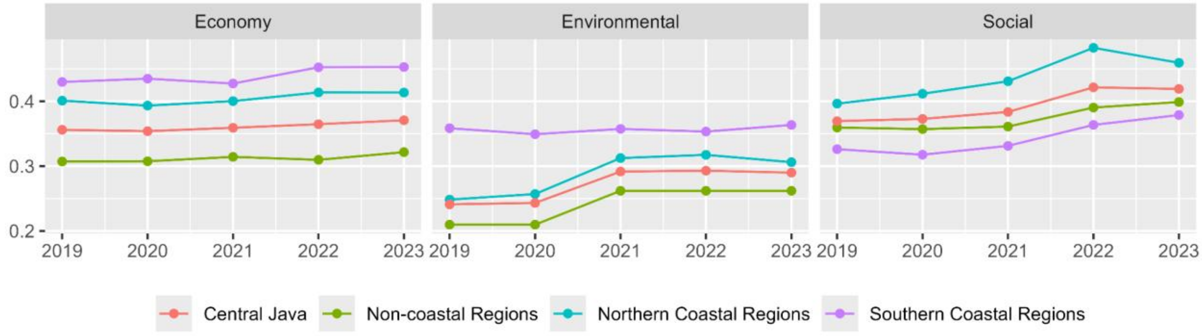


Figure 8. Sub-Index Trends of IEB by Geographic Region

Infrastructure development, proxied by LNTL, contributes negatively. This finding suggests that although infrastructure is important, its orientation has not fully supported the blue economy sector, as it is primarily directed toward industrial and commercial activities unrelated to the maritime economy, and often exacerbates coastal environmental degradation (rapid urbanization and ecosystem decline) (Andrade-Núñez & Aide, 2020). Therefore, more strategically planned infrastructure development is required.

The COVID-19 crisis significantly reduced blue economy performance in Central Java across multiple dimensions. This global crisis adversely affected demand in the fisheries and tourism sectors (Bhattacharya & Dash, 2020; Haque, 2020). Nonetheless, it also generated environmental benefits through reductions in marine, air, and water emissions due to the decline in economic activity (Sharma & Sharma, 2020).

The finding that infrastructure development, proxied by Nighttime Light (NTL), demonstrates a significant negative impact on the Blue Economy Index (BEI) in Central Java warrants critical examination. While infrastructure is generally expected to be a positive driver of economic growth, this counter-intuitive result suggests that the type and location of current infrastructure development are detrimental to long-term blue economy sustainability. This finding is likely rooted in two key contextual factors specific to Central Java's coastal development. First, the majority of recent infrastructure investment—such as coastal roads, industrial parks, and land reclamation projects—has been primarily land-oriented and focused on short-term economic gains, often neglecting marine protection measures. Second, and more critically, this development frequently results in environmental degradation, including the destruction of critical coastal ecosystems like mangroves and coral reefs for port expansion or pollution from increased industrial activity. As our BEI incorporates environmental sustainability, this destructive infrastructure growth undermines the long-term value of the blue economy, leading to the observed negative coefficient.

3.5 Limitations and Future Research

While the utilization of big data—specifically, satellite imagery for mapping resources like Mangrove Forest Area (LM)—provided the necessary sub-regional granularity, it is important to acknowledge its limitations. Proxies derived from remote sensing data, such as mangrove areas, represent physical presence but cannot fully capture ecological quality, biodiversity loss, or the degree of ecosystem functionality. Similarly, the Nighttime Light (NTL) proxy for infrastructure, while effective for measuring physical development, may not perfectly align with the specific infrastructure directly supporting blue economy activities. This reliance on proxy indicators for environmental and infrastructure metrics necessitates cautious interpretation and underscores the need for continuous on-the-ground validation in future studies.

4. Conclusion

This study demonstrates a consistent increase in the Blue Economy Index (BEI), indicating the presence of sustainable blue economy growth in Central Java. The southern coastal region shows higher BEI performance compared to the northern coastal region, while non-coastal areas generally remain below the average. These findings highlight the need for more targeted blue economy development strategies, without neglecting the northern coastal region as part of sustainable blue economy planning.

Furthermore, the variables of internet usage (LNET), infrastructure proxied by nighttime light (LNTL), and the COVID-19 period were found to have significant effects on the BEI. While the increasing use of the internet contributes positively, infrastructure development exhibited a negative effect, suggesting a potential imbalance between physical development and blue economy principles. The negative impact of infrastructure requires further exploration to ensure that development policies are aligned with the sustainability principles of the blue economy.

To ensure the sustainable development of the blue economy in Central Java, the study recommends a four-pronged approach. First, optimization in coastal regions (especially the north) is crucial, focusing on strengthening sustainable fisheries, ecotourism, and marine conservation area management. Second, infrastructure development must be carefully integrated with blue economy support, ensuring that new ports, roads, or public facilities in both northern and southern coastal areas do not compromise critical resources like marine ecosystems, coral reefs, or mangroves, while simultaneously modernizing fishing vessels and production facilities (Central Java Provincial Government, 2024). Third, digitalization of the blue economy needs to be advanced by improving access to technology and digital literacy to expand market opportunities and enable active contributions from all actors. Finally, strengthening the resilience of the blue economy is essential, using the ARI (Adaptive–Responsive–Innovative) framework to prepare for and address crises, starting with the household level as the foundational economic driver to minimize adverse impacts during turbulent times.

The novelty of this research is demonstrated through the development and spatial application of the Blue Economy Index (BEI) at the provincial level, incorporating digital and infrastructural dimensions into the evaluation of blue economy performance. This approach has rarely been explored in previous Indonesian regional studies. Despite these contributions, this study acknowledges several limitations, particularly the relatively narrow scope of environmental indicators, which may not fully capture the ecological complexity of coastal and marine systems.

Future research is encouraged to refine the BEI framework by incorporating more comprehensive ecological indicators (e.g., coastal water quality, biodiversity indices), adopting spatial econometric or machine learning models to capture complex spatial dependencies and nonlinear relationships, and extending the analysis to other provinces or national-level comparisons. Such advancements would deepen the understanding of the digital–infrastructure–environment nexus in supporting a sustainable blue economy.

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