Modeling Economic Resilience of Indonesian Provinces Using PCA and K-Means to Support Regional Development Policy Optimization

K A A'la[1] and B C Thalita[1,*]

[1] Department of Mathematics, Actuarial Science Study Program, Universitas Brawijaya, Malang City, East Java, Indonesia

*Corresponding author's email: bellacindy@student.ub.ac.id

Abstract. In Indonesia's post-decentralization era, assessing regional economic resilience is critical to promoting inclusive development. This study constructs a composite resilience index using seven indicators Human Development Index (HDI), Open Unemployment Rate, GRDP per capita, Gini Ratio, Economic Growth, Capital Expenditure, and Own-Source Revenue (OSR) across 34 provinces from 2020–2024. Principal Component Analysis (PCA) and K-Means clustering are applied to identify resilience patterns and classify provinces into high, moderate, and low resilience categories. The findings reveal significant interprovincial disparities. Provinces such as DKI Jakarta (HDI: 81.65), Bali (HDI: 76.54), and DI Yogyakarta (HDI: 80.22) consistently demonstrate high resilience, supported by low unemployment (e.g., Jakarta: 5.78%) and robust fiscal capacity (e.g., OSR share: Jakarta 58.29%). In contrast, Papua and West Papua exhibit lower resilience scores, characterized by HDI below 65, limited OSR below 15%, and economic growth volatility. Correlation analysis indicates a strong positive association between HDI and fiscal indicators ($r = 0.82$), while OLS regression confirms OSR and Capital Expenditure as significant predictors of resilience ($p < 0.05$). Spatial mapping highlights geographic clustering of resilience, with Western Indonesia outperforming the Eastern region—underscoring persistent spatial inequalities. These findings reinforce the necessity for regionally differentiated policies. The study recommends enhancing fiscal autonomy, investing in human capital, and integrating Fintech-based financial inclusion, especially for lagging regions. The study recommends boosting fiscal autonomy, investing in human capital, and leveraging Fintech for inclusive growth. This framework supports evidence-based policies aligned with Indonesia's SDG and post-2024 development goals.

Keyword: Fiscal Capacity, K-Means Clustering, PCA, Regional Economic Resilience, Spatial Mapping

1. Introduction

In the wake of Indonesia's decentralization reforms, regional economic resilience has emerged as a critical lens through which the performance of local governance is assessed particularly in fostering inclusive development across the country's geographically dispersed and socioeconomically varied regions. This transition from centralized to decentralized governance has granted provincial governments greater autonomy over budget allocation, infrastructure planning, and development priorities, positioning them as pivotal agents in advancing economic progress and enhancing public service delivery. [1]. As demonstrated by Shi and Lu [2], Fintech enhances economic resilience by

promoting industrial upgrading, reducing information asymmetry, and fostering technological innovation, thus enabling regions to proactively adapt to structural shocks and long-term uncertainties.

This study responds to the pressing need for a systematic evaluation of Indonesia's regional economic resilience through a comprehensive, data-driven approach [3]. By utilizing secondary data from BPS covering 34 provinces from 2020 to 2024, the study examines seven key indicators representing economic, social, and fiscal dimensions: Human Development Index (HDI), Open Unemployment Rate, GRDP per capita, Gini Ratio, Economic Growth Rate, Capital Expenditure, and Own-Source Revenue (OSR). These variables are selected not only for their relevance in reflecting development outcomes but also for their statistical robustness in measuring interprovincial variation supported by recent findings on fiscal capacity and inclusive regional convergence and policy synergies in support of resilience [4][5].

Building on this foundation, the present study employs a multivariate analytical approach that incorporates Pearson correlation, Ordinary Least Squares (OLS) regression, Principal Component Analysis (PCA), and K-Means clustering to examine variations in regional resilience and to categorize provincial typologies throughout Indonesia. PCA serves as a tool for dimensionality reduction and for uncovering latent constructs of resilience, allowing the analysis to capture the deeper structure within interconnected socio-economic and fiscal indicators [6]. Following this, K-Means clustering is employed to group provinces into categories of high, moderate, and low resilience, supporting data-driven policy interventions that reflect the diverse development capacities across regions. This integrative methodological approach allows for the effective translation of complex data into practical insights, fostering more targeted and context-sensitive policy design [7].

To effectively illustrate and interpret these differences, spatial mapping is incorporated as a key element of the analysis. This visual approach helps reveal regional patterns and resilience clusters, shedding light on areas where vulnerabilities or strengths are geographically concentrated. This mapping approach is crucial for contextualizing the results within Indonesia's spatial development framework and supports geographically differentiated policy interventions. Previous studies have emphasized the value of spatial econometrics and GIS-based approaches in assessing regional disparities and informing targeted development strategies [8][9].

Preliminary findings reveal considerable disparities in resilience profiles among provinces. Provinces such as DKI Jakarta, Bali, and DI Yogyakarta consistently exhibit high economic and social resilience, characterized by strong HDI scores, relatively low unemployment, and robust fiscal capacity [10][11]. Conversely, provinces in Eastern Indonesia particularly Papua and West Papua continue to face structural challenges, including lower HDI, fiscal constraints, and infrastructural deficits, echoing prior studies on regional inequality and governance outcomes in post-decentralized Indonesia [12]. By introducing a novel composite index and spatially grounded segmentation, this research contributes to both academic knowledge and practical policymaking, particularly in support of Indonesia's Sustainable Development Goals and post-2024 national development roadmap.

2. Research Method

2.1. Source and Data Collecting

This study uses secondary data sourced from official provincial publications issued by the Central Statistics Agency (Badan Pusat Statistik/BPS). The dataset covers 34 provinces in Indonesia from 2020 to 2024, allowing for a consistent cross-sectional and longitudinal analysis of regional economic resilience. This study analyzes the economic resilience of provinces in Indonesia from 2020 to 2024, focusing on seven key quantitative indicators: Human Development Index (HDI), Open Unemployment Rate, Gross Regional Domestic Product (GRDP) per capita (based on constant prices), Gini Ratio, Economic Growth Rate (GRDP), Capital Expenditure, and Local Revenue (PAD). All of these indicators are numerical; HDI (0-1) summarizes education, health, and income, OUR (percentage) measures the proportion of the labor force seeking employment, GRDP per capita (constant monetary units) reflects real income levels, Gini Ratio (0-1) evaluates income inequality, and GRDP Growth Rate

(percentage) indicates the pace of economic expansion. Additionally, Capital Expenditure and Provincial Revenue are monetary variables representing government spending and provincial income.

The single categorical variable used is the province name, which serves as a unique identifier for data organization. This analysis will be conducted using Python in the Google Colab environment, leveraging the pandas library for data manipulation and scikit-learn for statistical modeling. To enrich the analysis with a spatial dimension, provincial administrative boundary data in GeoJSON format will be integrated. By combining this geographic information with socioeconomic indicators, spatial visualizations will be created using geospatial Python libraries such as Geopandas, Folium, or Plotly. These maps will effectively illustrate the distribution of economic resilience indicators, highlight disparities between regions, and provide useful data for policy formulation. Through this integrated approach that combines statistical analysis with geospatial visualization, a comprehensive and intuitive understanding of the economic resilience of Indonesia's provinces is expected.

2.2. Preprocessing

In the early stages of this research, organizing and cleaning secondary data obtained from the Central Bureau of Statistics (BPS) for 2020 to 2024 was the main focus. This phase is essential to ensure the accuracy and validity of the subsequent analysis. The main concern in data cleaning is handling missing values and outlier data. Data found to be inconsistent or corrupted will be deleted or repopulated using scientifically proven methods, to prevent potential bias or errors in the research results. Once the data is clean, a scale transformation will be applied to homogenize the ranges of all variables. One approach used is min-max normalization, which converts indicator values to the range [0,1][13].

$$X' = \frac{X - min(X)}{max(X) - min(X)}, \tag{1}$$

As another option, z-score standardization can be applied. This method serves to transform each variable so that the mean becomes 0 and the standard deviation 1, based on the formula ($Z = (X - \underline{X})/s$). This approach has high significance, especially if multivariate techniques such as Principal Component Analysis (PCA) will be utilized, where scale consistency between variables is essential.

2.3. Descriptive Statistics & Correlation

The next step in this study was to calculate descriptive statistics for each of the cleaned key indicators. This included analyzing the Human Development Index (HDI), Open Unemployment Rate (OPT), Gross Regional Domestic Product (GRDP) per capita, Gini Ratio, economic growth, capital expenditure, and Regional Original Revenue (PAD) for each province. By calculating metrics such as mean, median, standard deviation, range, and quartiles, a basic understanding of the distribution and variability of each indicator's data will be obtained. This will provide a crucial initial overview of the characteristics of each variable before proceeding to a more in-depth analysis [13] . This summarized analysis of the initial data will help identify common patterns, understand how the data is spread out, and find any extreme values that may need further examination. After this stage, the Pearson correlation coefficient between each pair of indicators will be calculated. This is done to find out how strong and in which direction a linear relationship exists between the various variables under study [14]. The Pearson correlation formula is:

$$r = \frac{\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n} (x_i - \bar{x})^2 \sum_{i=1}^{n} (y_i - \bar{y})^2}}, \tag{2}$$

Descriptive statistical analysis and Pearson correlation calculations will provide a thorough initial understanding of the nature of the data and the relationships between variables. The correlation coefficient (r) value between -1 and 1 has a special meaning: the closer the r number is to 1 or -1, the stronger the linear relationship between the variables. Conversely, an r value close to 0 indicates a very

weak or no linear relationship. This initial understanding is crucial before proceeding to more in-depth analysis.

2.4. Formation of the Economic Resilience Index (PCA)

The Economic Resilience Index was formed using Principal Component Analysis (PCA) to reduce the seven indicators to a single composite index. PCA produces orthogonal linear combinations that capture the greatest variance in the data [15]. Mathematically, the first principal component (PC1) is selected as the Economic Resilience Index because it contains the highest proportion of total variance. PC1 is formulated as a combination of standardized variables:

$$PC_1 = a_1 Z_{HDI} + a_2 Z_{GRDP} + \ldots a_7 Z_{OSR}, \quad (3)$$

where a_i is the weight (loading) of the eigenvector determined to maximize the variance of the linear composite. Thus, the Economic Resilience Index is a linear composite score that integrates information from the seven indicators. This transformation effectively reduces the original correlated variables into a new "clean" (uncorrelated) variable that is easier to interpret.

2.5. Cluster Analysis

Cluster analysis was applied to group provinces with similar economic resilience characteristics. One of the methods used was K-Means clustering (a non-hierarchical partitioning method). K-Means clusters data into k clusters such that the intra-cluster distance is minimal. The commonly used distance measure is the Euclidean distance[16]:

$$d_{ij} = \sqrt{\sum_{k=1}^{p} (x_{ik} - x_{jk})^2}, \quad (4)$$

where x_{ik} is the value of the kth variable in object iii. The iterative K-Means algorithm assigns provinces to the cluster with the nearest centroid and updates the centroid until it stabilizes. The number of clusters (k) is determined through supporting methods (e.g., silhouette method or elbow plot in SSE). Additionally, hierarchical clustering (e.g., agglomerative clustering with Ward linkage) can be used, producing a dendrogram that shows the grouping structure based on data similarity. Cluster analysis results identify groups of provinces with similar economic resilience profiles, useful for regional segmentation policies.

2.6. Spatial Mapping

As a final step, the analysis results will be integrated into Indonesia's spatial thematic map to provide a visual representation of the geographical distribution of economic resilience between provinces. Economic Resilience Index data and clustering results will be linked to regional administrative boundaries (shapefile files) using Geographic Information System (GIS) software, such as ArcGIS or QGIS. To effectively visualize these findings, choropleth maps will be created for each province. These maps will use color variations or gradients to represent specific index levels or cluster categories. This approach facilitates the identification of spatial patterns, such as whether provinces with high economic resilience are concentrated in western Indonesia, or if other distribution patterns emerge. These maps are designed with strong cartographic principles, using the WGS84 (EPSG:4326) geographic coordinate projection. That way, the accuracy of the geographical location on the map is maintained both when displayed digitally and in printed form. This precision is crucial for the accurate application of analysis results in contexts such as regional planning, development of underdeveloped areas, and the formulation of location-based economic policies. This map will be an effective visual information delivery medium for both government officials and ordinary citizens [17][18].

3. Result and Discussion

3.1. Descriptive Statistics

Descriptive statistical analysis of provincial economic resilience in Indonesia during the period 2020 to 2024 shows significant regional variations in seven key indicators. These indicators include the Human Development Index (HDI), Open Unemployment Rate, Regional Domestic Product (RDP) per capita, Gini Ratio, economic growth rate (RDP growth), Capital Expenditure, and Local Government Revenue (LGR). Specifically, the average HDI stands at 72.23 with a standard deviation of 3.71. This figure reflects a considerable disparity in human well-being levels across provinces. Meanwhile, the average open unemployment rate stood at 5.10%, but with substantial variation, reaching up to 10.95% in some regions. This indicates that unemployment remains a serious challenge in a number of provinces.

Per capita GRDP shows a very wide distribution, with values ranging from a minimum of around Rp 20 million to a maximum of over Rp 340 million per year (in constant prices). This distribution highlights the striking economic inequality between regions. Similarly, both Capital Expenditure and Regional Original Revenue (PAD) show extreme values. PAD, in particular, ranges from hundreds of millions to hundreds of trillions of rupiah, indicating significant disparities in fiscal capacity among provinces. These findings underscore that many regions in Indonesia still face significant challenges related to fiscal capacity and economic development. Therefore, more adaptive and targeted policy interventions are needed to promote equitable progress across all regions.

3.2. Correlation Among Variables

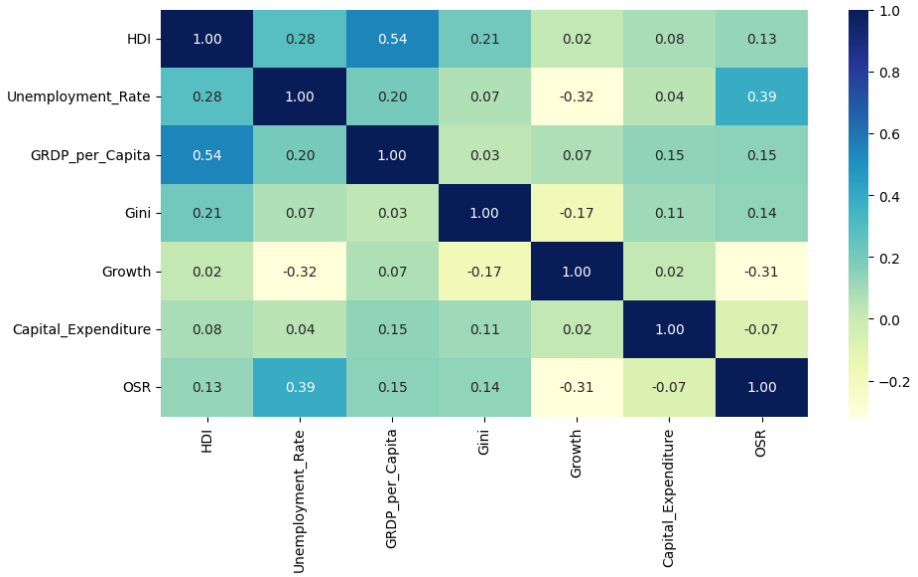

Figure 1. Pearson correlation matrix of economic indicators

The Pearson correlation analysis reveals significant relationships among key regional development indicators. The Human Development Index (HDI) shows a moderate positive correlation of +0.54 with GRDP per capita, indicating that provinces with higher per capita income tend to achieve better human development outcomes. The analysis shows that regions with high economic productivity generally have better access to education, healthcare and basic public facilities. However, an interesting pattern was found with regard to the Human Development Index (HDI). Although positively correlated (+0.28) with the unemployment rate, this relationship is weak and seemingly contradictory - indicating that a region's economic progress is not always followed by optimal employment, especially for informal or low-skilled workers. Meanwhile, the correlation between HDI and regional own-source revenue (PAD) is

positive but very weak (+0.13), suggesting that the fiscal capacity of the region makes only a limited contribution to the achievement of social development. Surprisingly, HDI shows a positive correlation (+0.21) with income inequality (Gini ratio), contrary to conventional economic theory that human development should reduce inequality. This may indicate that in some regions, improvements in human development do not necessarily coincide with income equality, revealing that development outcomes may not be evenly distributed across different population groups.

The unemployment rate has a moderately negative correlation with economic growth (-0.32), highlighting that provinces experiencing stronger economic expansion tend to have lower unemployment levels. However, this relationship may not be fully linear, as regional economies vary widely in structure and dominant sectors. A notable finding is the positive correlation between unemployment and OSR (+0.39), which implies that provinces with higher fiscal revenues may still struggle to create sufficient employment opportunities, possibly due to reliance on capital-intensive or non-labor-intensive sectors. Furthermore, GRDP per capita exhibits weak correlations with other variables such as OSR (+0.15) and capital expenditure (+0.15), suggesting that higher income levels do not automatically translate into increased fiscal capacity or public spending. Similarly, capital expenditure appears largely uncorrelated with other development dimensions, with very weak correlations such as +0.08 with HDI and -0.07 with OSR, indicating a potential disconnect between public investment and development outcomes in several regions. Economic growth also shows a negative correlation with OSR (-0.31), which may reflect the situation in newly developing or resource-based provinces where economic expansion has yet to translate into a broader fiscal base. Beyond the direct indicators, the analysis also revealed a negative correlation of -0.17 between economic growth and the Gini ratio. The observed pattern reveals an interesting fact: economic growth does not necessarily reduce social inequality in the study areas. The results of the correlation analysis show the complexity of regional development that involves various interrelated aspects. There is no single dominant factor, but rather a combination of economic conditions, social circumstances, and regional fiscal capacity that determine the success of development. These findings underscore the importance of an integrated approach to development policy formulation. Local governments need to design strategies that spur balanced economic growth, strengthen social equity programs, improve local institutional capacity and build long-term regional resilience.

3.3. Principal Component Analysis

This research develops a comprehensive measure to assess regional economic resilience through the application of Principal Component Analysis (PCA). Seven development indicators are the focus of the analysis, including the Human Development Index, unemployment rate, gross regional domestic product per capita, level of income inequality, economic growth rate, capital expenditure budget, and realization of local revenue. The PCA method was chosen based on its ability to simplify the structure of multivariate data while maintaining most of the original information diversity. The calculation results show that the first principal component successfully explains the percentage of data variation that fluctuates between observation periods, starting from 44.10 percent (2020), decreasing to 34.17 percent (2021), then increasing again to 44.83 percent (2022). Similar fluctuation patterns were observed in 2023 with an achievement of 41.56 percent and in 2024 at 36.68 percent, indicating structural dynamics in regional economic resilience during the study period. Although these values do not reach 50%, they are considered sufficient given the diversity and scale differences among the variables used.The resulting index was then normalized into a 0–100 scale, referred to as the Economic Resilience Index. Based on this index, it is evident that provinces with strong economic structures and robust fiscal capacities consistently ranked higher, although notable shifts in ranking occurred from year to year.

Table 1. Top three provinces based on the Economic Resilience Index, 2020–2024

Year	Rank 1	Index_100	Rank 2	Index_100	Rank 3	Index_100
2020	DKI Jakarta	100	West Java	70.63	Banten	60.78

2021	West Java	100	DKI Jakarta	89.5	East Java	70.89
2022	DKI Jakarta	100	West Java	49.3	East Kalimantan	46.74
2023	North Maluku	100	East Nusa Tengggara	95.8	West Kalimantan	93.84
2024	DKI Jakarta	100	West Java	53.34	Riau Islands	45.33

The economic resilience rankings of Indonesia's provinces have shown significant dynamics over the period 2020 to 2024, reflecting the evolving economic landscape and the impact of strategic policies. In 2020, DKI Jakarta topped the rankings with a perfect index score of 100, followed by West Java (70.63) and Banten (60.78). The western region of Java, which consists of three leading provinces, has consistently performed the best in terms of infrastructure, economic scale and institutional capacity. 2021 saw a significant change when West Java overtook DKI Jakarta with a perfect score of 100, while DKI Jakarta and East Java achieved 89.50 and 70.89 respectively. This shift indicates an improvement in the performance of the economic and fiscal sectors in West Java. The year 2022 shows more complex dynamics. Although DKI Jakarta again leads with a score of 100, West Java experiences a drastic decline to 49.30. Meanwhile, East Kalimantan emerges as a new contender in third place with a score of 46.74, strongly suspected to be the result of increased investment and infrastructure development to welcome its status as the country's capital city candidate. The most surprising development occurs in 2023 when North Maluku unexpectedly tops the list with a score of 100, followed by East Nusa Tenggara (95.80) and West Kalimantan (93.84). This surge in the performance of provinces that were previously in the middle class requires an in-depth study to distinguish whether the improvement is fundamental or temporary. The year 2024 marks the return of DKI Jakarta to the top spot (100), with West Java holding on to second place albeit with a lower score (53.34), and Riau Islands making a mark as a newcomer in third place (45.33). Riau Islands' emergence was supported by significant improvements in the GRDP per capita and regional revenue indicators. Overall, the annual ranking fluctuations reveal the dynamic nature of regional economic resilience that is influenced by various factors, including sectoral developments, fiscal capacity, and regional policies. The findings emphasize the need for continuous monitoring systems and development approaches that are adaptive to each region's specific conditions.

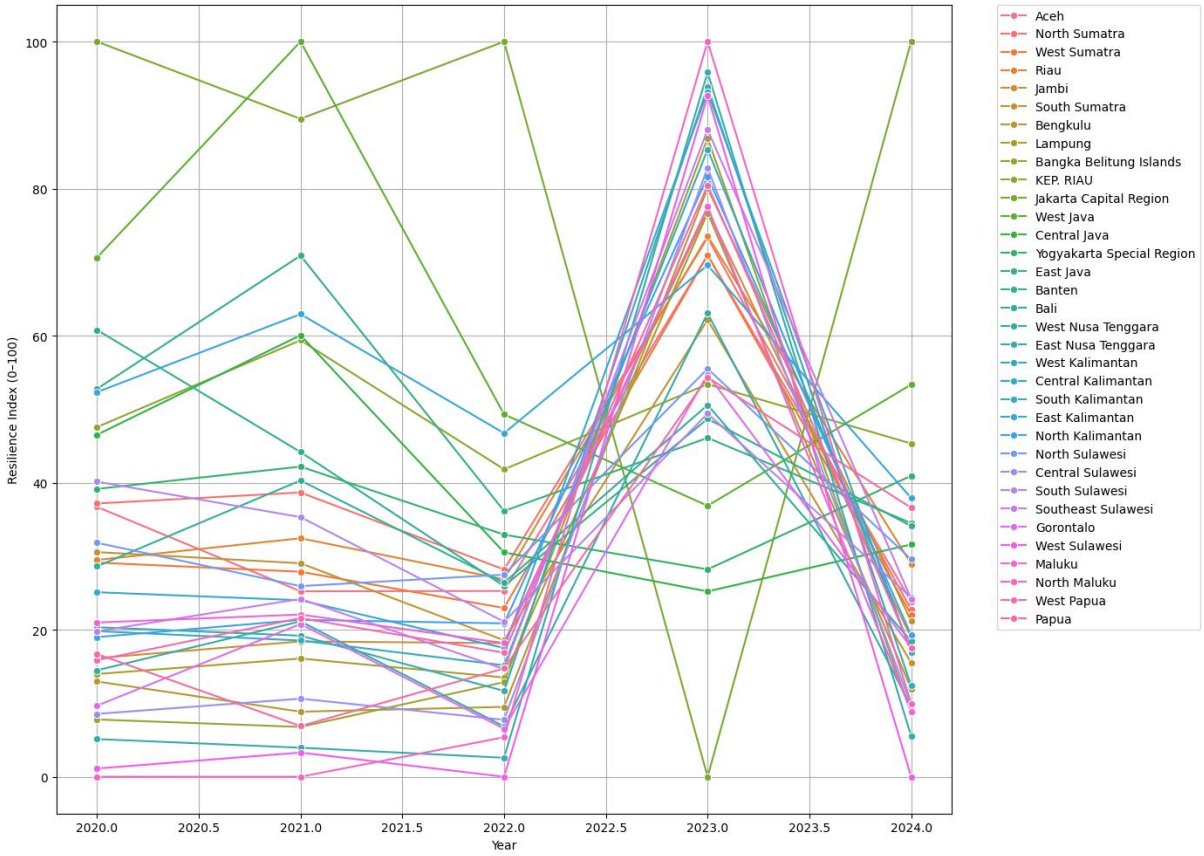

Figure 2. Trend of Economic Resilience Index across provinces

The development pattern of the economic resilience index of Indonesia's provinces over the past five years shows significant fluctuations. Provinces with a large economic scale such as DKI Jakarta, West Java and East Java do tend to dominate the top rankings, but with dynamics that change every year. DKI Jakarta, for example, lost its top position in 2021 and 2023, but managed to bounce back in 2024, indicating strong economic fundamentals. On the other hand, West Java, which reached its peak in 2021, experienced a sharp decline the following year and has not shown any significant recovery until 2024. The year 2023 is a special period where almost all provinces recorded a considerable increase in scores, regardless of their previous position. This phenomenon suggests the impact of a comprehensive national policy or program. However, the nature of this improvement turned out to be temporary, as evidenced by the decline again in 2024.

Eastern provinces such as Papua, West Papua and some parts of Sulawesi have consistently ranked lower, although they have shown some improvement. This highlights two fundamental problems: first, that improvements are temporary and unsustainable; second, that structural disparities between regions persist. The jump in the index in 2023 reflects short-term policy effects rather than deep economic transformation. This finding emphasizes the need for a more consistent policy approach that matches the characteristics of each region, as well as a monitoring system that is able to capture the dynamics of change in real-time. Regional economic development requires a long-term strategy that focuses not only on growth, but also on equity and sustainability. The aim is to better align development planning with the unique capacities and challenges faced by each province.

3.4. Province Profile (Spider Chart)

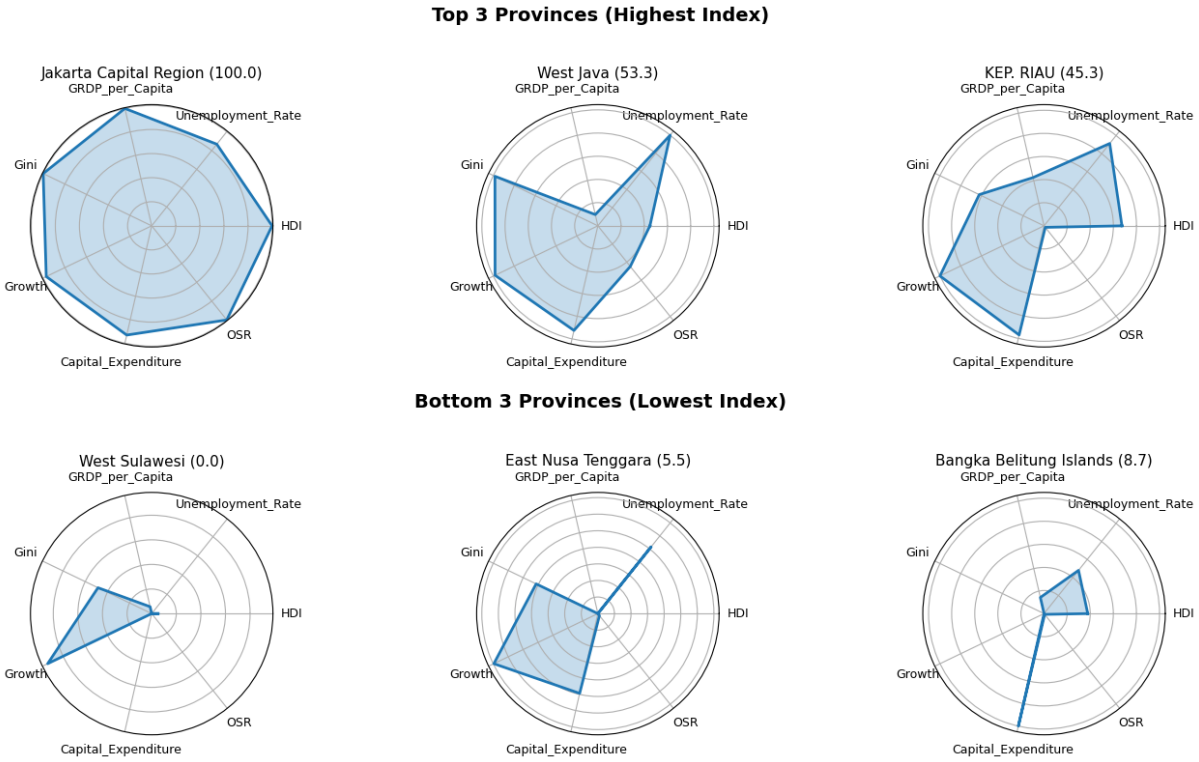

Figure 3. Top and bottom 3 provinces – Economic Resilience Index 2024

The spider charts above display the normalized performance profiles of the three lowest-ranking provinces in the 2024 Economic Resilience Index: East Nusa Tenggara, Sulawesi Barat, and Bangka Belitung Islands. Each chart represents seven key indicators HDI, Unemployment Rate, GRDP per Capita, Gini Ratio, Economic Growth, Capital Expenditure, and Own-Source Revenue (OSR) scaled between 0 and 1. The resulting visualization clearly shows significant disparities in economic resilience. The development gap is not only evident between the best and worst performing provinces, but also among the regions with low economic resilience themselves. This reveals the fact that regional economic weaknesses can stem from a variety of different structural problems. West Sulawesi, with an index score of zero, exhibits very serious limitations in all aspects of the indicator. The province's spider diagram visualization displays an almost flat pattern, reflecting fundamental weaknesses in various areas of development, fiscal constraints and complex social problems.

In contrast, East Nusa Tenggara shows an uneven development pattern. The province has recorded good achievements in terms of income equality and economic growth, but is still very behind in terms of HDI, PAD, and employment. This imbalance indicates that progress in certain sectors has not been able to drive overall improvements in development. Meanwhile, Bangka Belitung Islands presents a more stable profile with moderate achievements in HDI and GRDP per capita. However, the province still faces challenges in economic growth and fiscal capacity. In contrast to West Sulawesi, Bangka Belitung's radar diagram shows a more balanced shape, suggesting opportunities for further improvement. Overall, these findings show that the issue of regional economic resilience is multidimensional. Each region faces unique challenges that require different approaches to address, emphasizing the importance of location-specific and comprehensive policies to strengthen regional economic resilience. Each province faces a unique combination of constraints. Therefore, development policies must be tailored specifically to their respective regional profiles, targeting specific weaknesses rather than assuming uniform causes behind low index values.

3.5. Cluster Results

In the analysis of provincial economic resilience, four clusters were identified as the most effective grouping. This determination was made using both the Elbow method and the Silhouette Score

method.The Elbow method clearly showed an "elbow point" at k=4, indicating that adding more clusters beyond this point did not significantly reduce inertia. Similarly, the Silhouette Score reached its highest point at approximately 0.58 for four clusters, which suggests that the resulting clusters are both internally cohesive and well-separated from one another. Therefore, four clusters are considered to best represent the structure of interprovincial economic resilience.

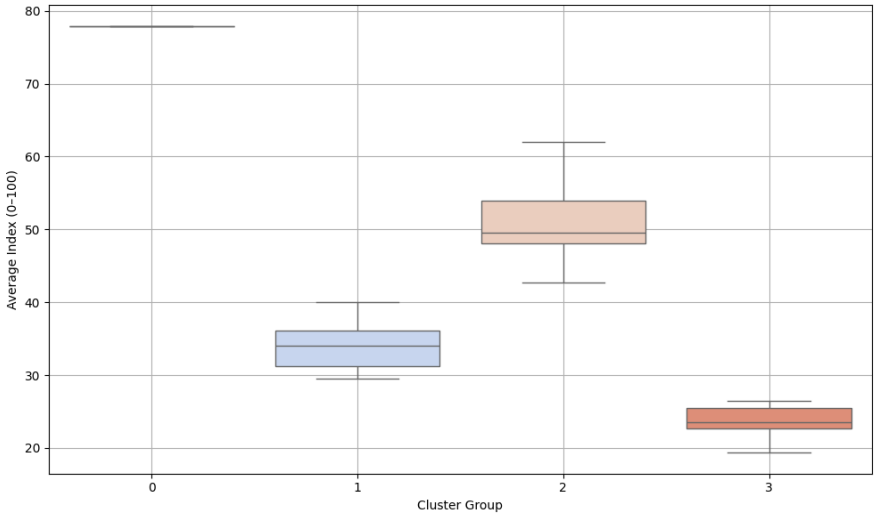

Figure 4. Provincial clustering based on average Economic Resilience Index

After the clusters were formed, an in-depth statistical analysis was conducted to understand the characteristics of each group. Cluster 3 was identified as the cluster with provinces that had the highest economic resilience, marked by an index value above 70 and a very consistent distribution, indicating strong stability. Meanwhile, Cluster 1 comprises provinces with relatively high indices but showing more varied value distributions, indicating strong economic resilience despite stability not being evenly distributed across all aspects. The majority of provinces are grouped in Cluster 0, which shows a medium index, generally ranging from 30 to 40. Finally, Cluster 2 encompasses provinces with the lowest indices, consistently below 30, highlighting the most severe development challenges and significant structural lag.

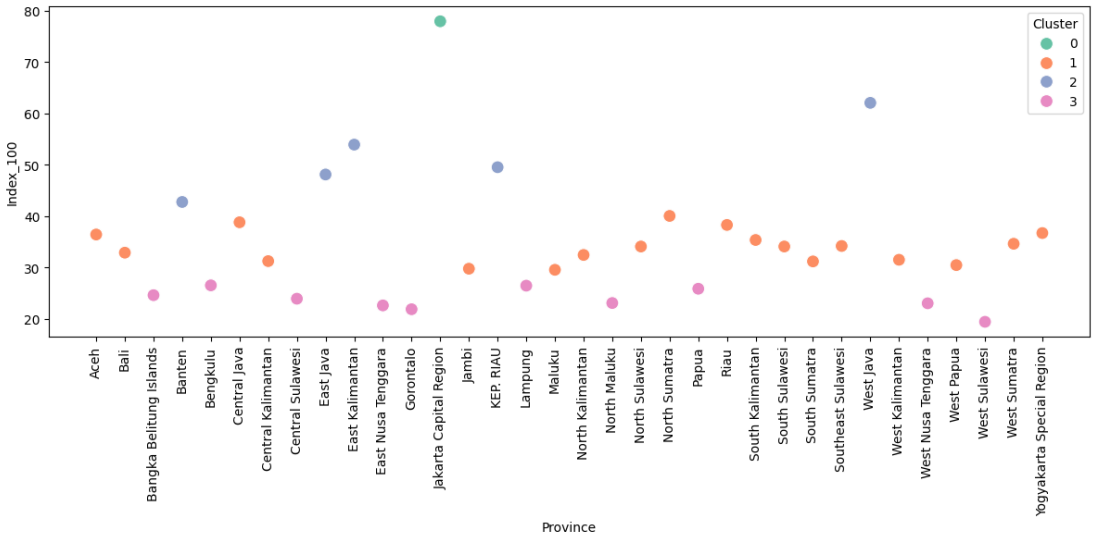

Figure 5. Cluster Distribution Based on Index_100 per Province

Building upon the detailed statistical analysis of each cluster, figure 4, which illustrates the Provincial Clustering Based on Average Economic Resilience Index, visually confirms the distinct groupings. The scatterplot effectively demonstrates the presence of four differentiated clusters, each representing a unique level of economic resilience among provinces. Specifically, provinces in Cluster 3 (highlighted in light green), such as Gorontalo, stand out with the highest index values, visually reinforcing their strong economic stability. Cluster 1 (depicted in orange), encompassing provinces like Aceh and Lampung, exhibits a range of generally high, albeit more varied, index values, indicating a robust economic foundation with differing degrees of consistency. The majority of provinces, including Jakarta Capital Region and Riau, fall into Cluster 0 (shown in blue), which visually confirms their intermediate economic resilience. Conversely, Cluster 2 (represented by light purple) clearly contains provinces with the lowest index values, such as West Sumatera and West Java, thereby visually emphasizing their significant developmental challenges and structural disadvantages.

3.6. Spatial Mapping

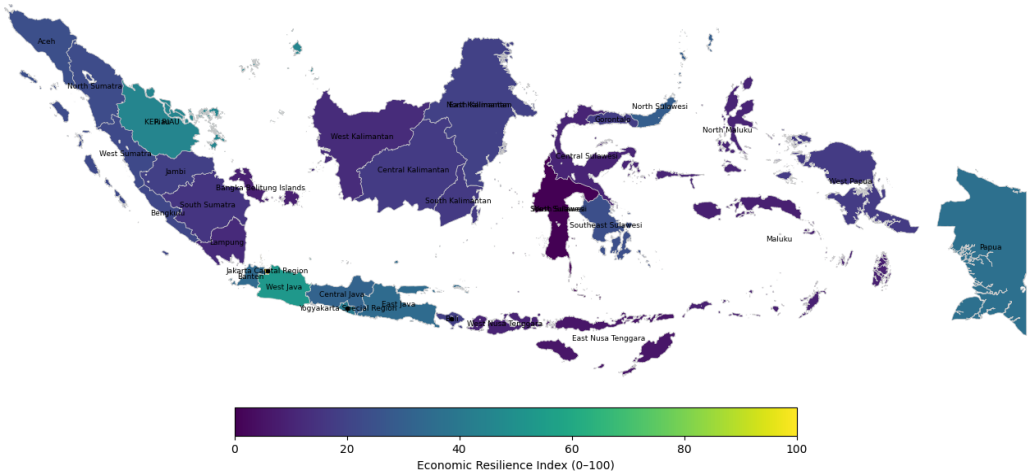

Figure 6. Economic Resilience Index by Province – Indonesia, 2024

The map shows the 2024 Provincial Economic Resilience Index in Indonesia in choropleth form, with a color scale ranging from purple (low value) to bright yellow (high value). Each province is colored based on its Index_100 value, which indicates its relative economic resilience. Provinces such as West Java, Central Java, and East Java appear to have higher indices (green-yellow colors), indicating better economic resilience compared to other provinces. Conversely, regions such as West Sulawesi, East Nusa Tenggara, and South Papua are in the purple color range, indicating lower economic resilience indices. The map also includes province names, although some provinces in island regions or with small areas (such as Bali, Jakarta Capital Region, and Yogyakarta Special Region) are marked with dots and additional text to clarify their locations. The entire Indonesian territory from Aceh to Papua is fully displayed, reflecting the national scope of this economic resilience data. With a clear color scale at the bottom and properly placed labels, this map provides an informative and easy-to-understand visual representation of the differences in economic resilience levels among provinces in Indonesia in 2024.

3.7. Policy Recommendations for Strengthening Regional Economic Resilience

Based on an analysis of provincial economic resilience in Indonesia during the period 2020–2024, which includes descriptive statistical studies, inter-indicator correlations, principal component analysis (PCA), as well as spatial mapping and inter-regional clustering, it can be concluded that there are significant

disparities between provinces in terms of human development, fiscal capacity, economic growth, and income inequality. Findings such as the weak correlation between capital expenditure and social indicators, persistent high income inequality despite improvements in the Human Development Index (HDI), and low regional revenue (PAD) and gross regional domestic product (GRDP) per capita in most eastern Indonesian regions highlight the need for more systematic and context-specific policy interventions. The following are a series of policy recommendations designed to address these complexities, with reference to relevant national development regulations and documents:

1. Fiscal Synergy Between Central and Local Governments : Strengthen fiscal coordination between central and regional governments in accordance with Law No. 1/2022 on Fiscal Relations between Central and Local Governments (HKPD) to enhance efficiency and equitable resource distribution . The use of General Allocation Funds (DAU) and Special Allocation Funds (DAK) must be optimized so that all provinces have adequate fiscal capacity to fulfill basic public service obligations, as mandated by Law No. 23/2014 on Regional Government . For instance, the central government must allocate sufficient performance-based transfers to reduce fiscal disparities and ensure minimum service standards across provinces[19][20][21].
2. Investment in Infrastructure and Basic Services: Prioritize infrastructure investment, especially in lagging, outermost, and frontier regions, to expand access to education, healthcare, housing, clean water, sanitation, and electricity . Enhance both physical infrastructure (roads, bridges, electricity) and digital infrastructure (telecommunication and internet networks) to support domestic market integration and digital economy development . This aligns with the RPJMN (National Medium-Term Development Plan) principle of "leaving no one behind" (SDG principle) and supports equitable improvements in quality of life [22].
3. Development of New Economic Growth Centers : Promote the establishment of new economic growth centers outside Java (e.g., industrial zones, tourism areas, or strategic investment locations) to foster regional development and employment. Bappenas identifies two development corridors: a growth corridor for new economic hubs, and a distribution corridor to strengthen the surrounding support regions . Regulatory and fiscal incentives (e.g., investment facilitation, targeted subsidies) must be provided to encourage knowledge and economic spillovers from developed to developing provinces. This strategy aligns with the RPJMN 2020–2024 agenda for developing "new economic centers" to reduce inter-regional disparities [23][24]
4. Empowering Local Potential and Human Resources : Encourage the development of local economic sectors based on regional strengths (e.g., agriculture, fisheries, tourism, mining) with support in technology and market access . Villages should be empowered to develop local superior products as engines of rural and regional economies. Simultaneously, vocational education and skills training must be aligned with regional industrial needs . For example, strengthen cooperation between vocational schools and industries to cultivate sector-specific skills. This is in line with the Equitable Development Policy (KPE), which emphasizes land, opportunity, and human resources development as pillars for reducing inequality [25][26]
5. Special Support for Lagging and Vulnerable Provinces : Implement affirmative policies for provinces with the lowest economic resilience index scores (e.g., Papua, East Nusa Tenggara, Maluku). Local governments should optimize the use of Presidential Regulation No. 63/2020 on the designation of disadvantaged regions for 2020–2024, which targets improvements in HDI and poverty reduction across 62 disadvantaged districts . Programs include integrated village development, basic service expansion, and investment incentives in remote or border areas . These efforts reflect the "no one left behind" SDG commitment to inclusive national development[27][28].

The findings demonstrate that sound fiscal allocation, investment in social and economic infrastructure, and effective multilevel policy coordination are essential to reduce disparities and

enhance national economic resilience. These policy directions should be supported by key national regulations such as Law No. 23/2014 (on Regional Governance), Law No. 1/2022 (HKPD), and the RPJMN 2020–2024, ensuring long-term sustainability and impact across all provinces .

4. Conclusion

The comprehensive analysis of Indonesia's provincial economic resilience from 2020 to 2024 definitively highlights the persistent and profound disparities across the archipelago. The research unequivocally demonstrates that a multifaceted approach is critical to fostering equitable and sustainable development. The significant variations in human development, fiscal capacity, economic growth, and income equality underscore the urgent need for targeted and adaptive policy interventions. The limited correlation between capital expenditure and social indicators, the enduring challenge of income inequality despite advancements in the Human Development Index, and the consistently low Own-Source Revenue and Gross Regional Domestic Product per capita in many eastern Indonesian regions are not merely statistical observations; they are clear indicators of structural weaknesses that demand immediate attention. Achieving true national economic resilience necessitates a concerted and integrated effort, ensuring that fiscal allocations are strategically deployed, investments in both social and economic infrastructure are prioritized, and multi-level policy coordination is seamless and effective. This will undoubtedly lead to a more balanced and robust economic landscape for all provinces in Indonesia.

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