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Explainable Entropy-TOPSIS for Digital Infrastructure Prioritization Across Indonesian Island Groups

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ABSTRACT

Indonesia's national internet penetration has continued to increase, reaching 80.66% in 2025, equivalent to 229,428,417 connected people from a total population of 284,438,900. However, this national achievement does not fully represent regional equality in digital infrastructure readiness. This study proposes an Explainable Entropy-TOPSIS framework to develop a Regional Digital Infrastructure Priority Index (RDIPI) across six Indonesian island groups using APJII 2025 indicators. Internet penetration, regional contribution, and ISP distribution are treated as raw input indicators, whereas access gap, ISP supply gap, and demand-supply shortage are used as final priority-oriented criteria. Demand-supply shortage is operationalized as a proxy of regional imbalance, where positive values indicate that internet-user contribution exceeds ISP representation. The entropy results show that demand-supply shortage is the dominant criterion with a weight of 0.8192, followed by ISP supply gap = 0.1292 and access gap = 0.0517. The TOPSIS results rank Sumatra as the highest priority with an RDIPI score of 0.9840, followed by Maluku-Papua = 0.5226, Sulawesi = 0.3699, Kalimantan = 0.2422, Bali-Nusa Tenggara = 0.2013, and Java = 0.0000. The proposed framework provides an explainable decision-support approach for targeted broadband expansion and digital inclusion planning.

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1. INTRODUCTION

Digital infrastructure has become a critical foundation for national transformation because internet connectivity enables digital public services, online education, e-commerce, financial technology, artificial intelligence-based services, and data-driven economic participation. In Indonesia, the urgency of digital infrastructure development is strongly related to the country's geographical structure, which consists of major island groups with different levels of population concentration, connectivity readiness, economic activity, and market attractiveness. The 2025 APJII survey shows that Indonesia reached an internet penetration rate of 80.66%, equivalent to 229,428,417 connected people from a total population of 284,438,900 [1]. However, this national figure does not fully represent regional equality because internet penetration and user contribution remain uneven across island groups. The term regional contribution in this study refers to the share of each island group in Indonesia's national internet-user population. The 2025 APJII data show that Java recorded the highest penetration and contribution, with 84.69% penetration and 58.14% national contribution, while Maluku-Papua recorded 69.26% penetration and only 3.71% national contribution [1]. These differences indicate that digital infrastructure policy should not rely only on national-level indicators, but should also consider regional access gaps, user concentration, and infrastructure-support needs.

The role of Internet Service Providers (ISPs) is central to regional infrastructure development. APJII's ISP segmentation survey in 2025 involved 300 active ISP members and used self-administered responses with non-probability sampling [2]. The survey indicates that ISP distribution remains highly concentrated in Java, where the sample proportion reached 71.67%, compared with Sumatra at 14.67%, Kalimantan at 4.67%, Sulawesi at 4.32%, Bali-Nusa Tenggara at 4.00%, and Maluku-Papua at only 0.67% [2]. This distribution suggests a demand-supply imbalance because some regions have a higher need for connectivity expansion than their ISP representation would suggest. The 2024 ISP Market Profile also confirms that ISP actors are mostly Internet Service Provider license holders, while 20.74% were classified as ISP and local fixed-network providers [3]. This condition is important because local ISP capacity can directly influence service expansion, affordability, and last-mile connectivity in underserved regions. The APJII ISP segmentation and ISP Market Profile reports therefore provide complementary evidence for describing both demand-side and supply-side conditions.

Previous studies have emphasized that digital infrastructure and regional inequality are closely connected. Kartiasih et al. [4] showed that Indonesia's regional digital development inequality is associated with socioeconomic characteristics and spatial patterns. Jaya et al. [5] demonstrated the importance of monitoring the spatiotemporal distribution and clustering of Indonesia's Digital Society Index. Widjaja et al. [6] proposed a GIS-based spatial recommendation model for identifying internet infrastructure needs in Indonesia. Related studies also show that digital infrastructure can influence enterprise digital transformation, entrepreneurial orientation, digital divide patterns, broadband expansion, and regional productivity [7]-[10]. These studies provide strong evidence that digital development should be analyzed regionally. Nevertheless, the practical decision problem faced by industry associations and public stakeholders is not only how to describe disparity, but how to translate official survey indicators into a transparent priority order for intervention.

From a methodological perspective, multi-criteria decision-making is suitable because the available APJII data are aggregated indicators rather than raw transaction-level or respondent-level datasets. Entropy weighting determines objective criterion weights based on information variability, while TOPSIS ranks alternatives according to their closeness to an ideal solution. Recent studies have applied entropy-weighted TOPSIS to evaluate digital trade, digital economy development, digital village development, regional digital industry, urban resilience, and productive forces [11]-[18]. However, the novelty of this study is not the use of Entropy-TOPSIS alone. Its novelty lies in the operationalization of APJII survey indicators into an explainable digital infrastructure priority index that links access inequality, ISP scarcity, and underserved demand in a single decision-support model.

Based on these gaps, this study proposes an explainable Entropy-TOPSIS framework for prioritizing digital infrastructure development across Indonesian island groups. Explainability in this study is not limited to displaying entropy weights. It includes a traceable transformation from raw APJII indicators to priority-oriented criteria, transparent criterion weighting, RDIPI closeness computation, identification of the dominant driver behind each ranking, and sensitivity checking under an alternative weighting scheme. This approach differs from previous studies because it converts APJII survey indicators into a practical decision-support output that can guide infrastructure prioritization while still explaining why one island group is prioritized over another.

The objective of this study is to develop a data-driven and explainable priority model for digital infrastructure development across Indonesia's major island groups. Specifically, this study aims to: (1) construct a regional decision matrix from APJII internet penetration and ISP segmentation indicators; (2) calculate objective criterion weights using the entropy method; (3) rank Indonesian island groups using TOPSIS; and (4) interpret the results to support APJII, ISPs, policymakers, and the public. The main contribution of this study is threefold. First, it introduces a reproducible decision-support framework based on official APJII survey indicators. Second, it integrates digital access, regional contribution, and ISP distribution into one priority model. Third, it provides actionable insight for more equitable connectivity planning.

2. METHOD

This study applies a quantitative decision-support design to prioritize digital infrastructure development across Indonesian island groups. The unit of analysis consists of six major Indonesian island groups: Sumatra, Java, Kalimantan, Sulawesi, Bali-Nusa Tenggara, and Maluku-Papua. This aggregation was selected because the available APJII data provide consistent penetration, contribution, and ISP distribution indicators at the island-group level.

The research data were obtained from three APJII sources. The first source is the 2025 APJII internet penetration highlight report, which provides national internet penetration trends from 2018 to 2025, the 2025 national penetration rate of 80.66%, and 229,428,417 connected people from a total population of 284,438,900 [1]. The same report provides internet penetration and national contribution by island group, which are used as demand-side indicators in this study [1]. The second source is the 2025 APJII ISP segmentation survey, which involved 300 active APJII ISP members, used self-administered responses, and applied non-probability sampling [2]. This report provides the ISP sample distribution across the six island groups and is used as the supply-side indicator [2]. The third source is the 2024 APJII ISP Market Profile, which is used as supporting evidence regarding ISP characteristics, including survey methodology, licensing composition, and local fixed-network ISP representation [3].

The research procedure consists of six sequential stages: data acquisition, indicator construction, decision matrix formation, entropy weighting, TOPSIS ranking, and explainability-based interpretation. First, APJII indicators were extracted and reorganized into a structured dataset based on six Indonesian island groups. Second, three APJII indicators, namely internet penetration, regional contribution, and ISP distribution, were treated as raw input indicators. These raw indicators were then transformed into three final priority-oriented criteria used in the Entropy-TOPSIS computation: access gap, ISP supply gap, and demand-supply shortage. Access gap was derived from internet penetration, ISP supply gap was derived from ISP distribution, and demand-supply shortage was derived from the imbalance between regional internet-user contribution and ISP distribution. Third, the decision matrix was constructed using the six island groups as alternatives and the three priority-oriented criteria as evaluation variables. Fourth, entropy weighting was applied to calculate objective criterion weights based on information variability. Fifth, TOPSIS was used to calculate the Regional Digital Infrastructure Priority Index (RDIPI). Sixth, the ranking result was interpreted through criterion contribution and sensitivity testing to ensure that the output was not only numerical but also explainable and useful for decision-making. Entropy-based weighting and TOPSIS were selected because they are widely used in recent digital economy, digital village, regional development, and explainable decision-support studies [11]-[18].

The relationship between the raw APJII indicators and the derived priority-oriented criteria is summarized in Table 1.

Table 1. Raw Indicators and Priority-Oriented Criteria

Data Component	Raw Input Indicator	Derived Priority Criterion	Source	Analytical Function
Digital access	Internet penetration	Access gap (100 - penetration)	APJII [1]	Indicates remaining access need; higher value means stronger intervention priority.
Supply readiness	ISP distribution	ISP supply gap (100 - ISP distribution)	APJII ISP [2]	Indicates limited ISP presence at the island-group level.
Market imbalance	Regional contribution and ISP distribution	Demand-supply shortage max(contribution - ISP distribution, 0)	APJII [1] and ISP [2]	Proxy for underserved demand when user contribution exceeds ISP representation.

The priority-oriented criteria were derived from the raw APJII indicators using the following equations:

$$G_i = 100 - P_i \quad (1)$$
$$S_i = 100 - I_i \quad (2)$$
$$M_i = Max\,(C_i - I_i, 0) \quad (3)$$

where G_i the access gap, P_i is the internet penetration rate, S_i is the ISP supply gap, I_i is the ISP distribution proportion, M_i is the demand-supply shortage, and C_i is the national internet-user contribution of island group i. The demand-supply shortage is a directional proxy indicator: a positive value indicates that the regional internet-user contribution exceeds ISP representation, whereas zero indicates that ISP representation is not lower than the contribution share.

The overall research procedure of the proposed decision-support model is illustrated in Figure 1.

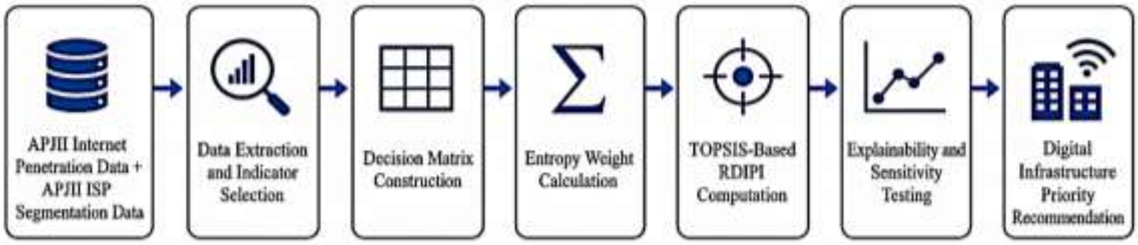

Figure 1. Research procedure of the proposed decision-support model.

Entropy weighting was used to determine objective criterion weights. Let $X = x_{ij}$ be the decision matrix, where x_{ij} is the value of alternative i on criterion j. The normalized proportion p_{ij} is calculated as:

$$p_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \quad (4)$$

The entropy value of criterion j is:

$$e_j = -k \sum_{i=1}^{m} p_{ij} \ln(p_{ij}) \quad (5)$$

Where:

$$k = \frac{1}{\ln(m)} \quad (6)$$

The Diversification degree is calculated as:

$$d_j = 1 - e_j \quad (7)$$

The final entropy weight is:

$$w_j = \frac{d_j}{\sum_{j-1}^{n} d_j} \quad (8)$$

where w_j represents the objective weight of criterion j. A criterion with greater variation across island groups receives a higher weight because it has stronger discriminatory power.
After the weights were obtained, TOPSIS was applied to calculate RDIPI. The normalized decision matrix is computed as:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \quad (9)$$

The weighted normalized matrix is:

$$V_{ij} = w_j r_{ij} \quad (10)$$

The positive ideal solution $A^+ = (v_1^+, v_2^+, v_3^+, \dots, v_n^+)$ and negative ideal solution $A^- = (v_1^-, v_2^-, v_3^-, \dots, v_n^-)$ are defined. The distance of each alternative from the positive and negative ideal solutions is calculated as:

$$D_i^+ = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^+)^2} \quad (11)$$

$$D_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2} \quad (12)$$

The RDIPI score is obtained using the TOPSIS closeness coefficient:

$$RDIPI_i = C_i = \frac{D_i^-}{D_i^+ + D_i^-} \quad (13)$$

A higher $RDIPI_i$ indicates a higher priority for digital infrastructure intervention.

The testing procedure was conducted using ranking consistency analysis. The main model uses entropy-derived weights, while the comparison scenario uses equal weights across all criteria. If the ranking order remains stable under both weighting scenarios, the result is considered robust. In addition, explainability analysis was conducted by observing the dominant criteria that influenced each island group's RDIPI score. This step is important because the objective of this study is not only to produce a ranking but also to provide interpretable decision support for APJII, ISPs, policymakers, and the public.

The detailed computational flow of the Entropy-TOPSIS procedure is shown in Figure 2.

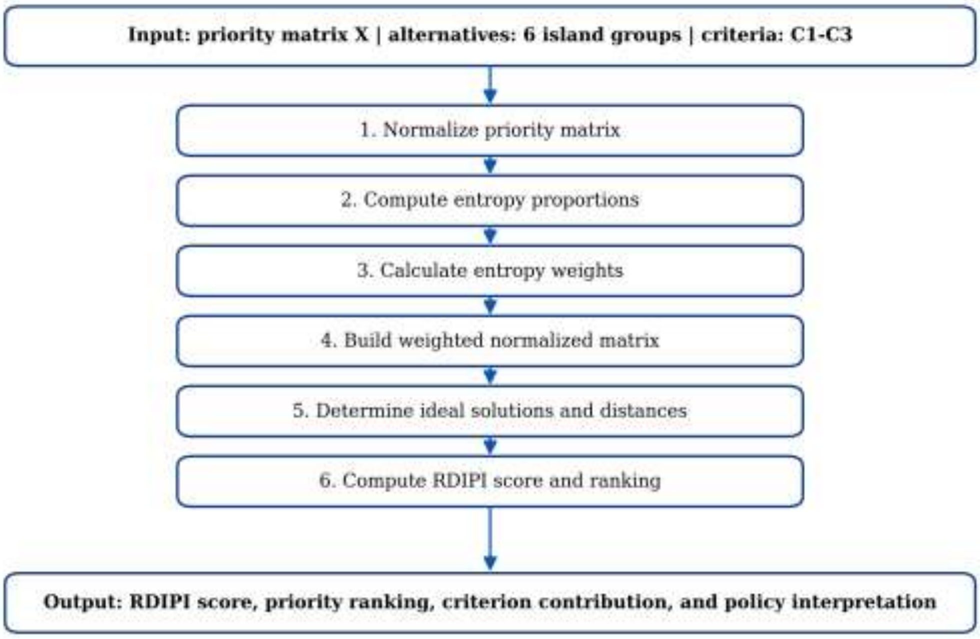

Figure 2. Entropy-TOPSIS computation flow.

This methodological design ensures that the analysis is consistent with the available data. Since the APJII data used in this study are aggregated survey indicators, the proposed Entropy-TOPSIS framework is more appropriate than predictive deep learning or regression models that require raw longitudinal data. The final output is expected to support evidence-based digital infrastructure planning by identifying which island groups require stronger intervention and which factors explain their priority status.

3. RESULTS AND DISCUSSION

3.1. National Internet Penetration Overview

The APJII 2025 survey shows that Indonesia's internet penetration reached 80.66%, representing 229,428,417 connected people from a total population of 284,438,900. The national penetration trend also increased from 64.80% in 2018 to 80.66% in 2025, indicating continuous growth in digital access. Table 2 summarizes the national penetration trend used as contextual evidence for the regional priority analysis.

Table 2. National Internet Penetration Trend

Year	Internet Penetration (%)
2018	64.80
2020	73.70
2022	77.01
2023	78.19
2024	79.50
2025	80.66

The trend indicates that internet access in Indonesia has reached a relatively mature national level. However, the national average does not fully describe regional inequality. Some island groups show high penetration and strong ISP presence, while others still experience lower access and limited provider representation. Therefore, the priority analysis should focus not only on national growth but also on regional infrastructure imbalance.

3.2. Decision Matrix Construction

The decision matrix was constructed from APJII's island-group indicators. The original indicators consist of internet penetration, regional contribution, and ISP distribution. These indicators were transformed into priority-oriented criteria: access gap, ISP supply gap, and demand-supply shortage.

The access gap, ISP supply gap, and demand-supply shortage were calculated using Equations (1)-(3). The demand-supply shortage is directional because this study aims to identify underserved regions: a positive value indicates that internet-user contribution is higher than ISP representation, while a zero value means that ISP representation is not lower than the user contribution share. Table 3 presents the initial decision matrix used to assess digital infrastructure priorities across six island groups in Indonesia. The transformed criteria emphasize infrastructure deficiencies rather than existing digital performance, allowing regions with larger access gaps, limited ISP availability, and stronger demand-supply imbalances to receive higher priority values. The results reveal substantial regional disparities, particularly in Maluku-Papua, Sulawesi, and Sumatra, while Java demonstrates comparatively stronger infrastructure conditions.

Table 3. Decision matrix for Digital Infrastructure Prioritization

Island Group	Penetration (%)	Contribution (%)	ISP Distribution (%)	Access Gap	ISP Supply Gap	Demand-Supply Shortage
Sumatra	77.12	20.51	14.67	22.88	85.33	5.84
Java	84.69	58.14	71.67	15.31	28.33	0.00
Kalimantan	78.72	6.05	4.67	21.28	95.33	1.38
Sulawesi	71.64	6.46	4.32	28.36	95.68	2.14
Bali-Nusa Tenggara	76.86	5.13	4.00	23.14	96.00	1.13
Maluku-Papua	69.26	3.71	0.67	30.74	99.33	3.04

The matrix shows three important patterns. First, Java has the strongest existing digital position, with the highest penetration and the largest ISP distribution. Second, Maluku-Papua has the largest access gap and the lowest ISP distribution. Third, Sumatra shows the strongest demand-supply shortage because its internet-user contribution is higher than its ISP distribution. These patterns confirm that infrastructure prioritization should consider both access inequality and provider availability.

3.3. Entropy Weight Results

The entropy method was applied to calculate the objective weight of each priority criterion. The weight indicates how strongly each criterion differentiates the six island groups. Table 4 summarizes the objective criterion weights generated using the entropy weighting method. The results indicate that demand-supply shortage contributes the greatest discriminatory information among the evaluated regions, with an entropy weight of 0.8192, followed by ISP supply gap at 0.1292 and access gap at 0.0517. Consequently, the regional prioritization process is primarily influenced by the imbalance between internet-user demand and ISP representation rather than by penetration differences alone.

Table 4. Entropy Weight Results

Criterion	Entropy Value	Diversification Degree	Entropy Weight
Access Gap	0.9873	0.0127	0.0517
ISP Supply Gap	0.9682	0.0318	0.1292
Demand-Supply Shortage	0.7981	0.2019	0.8192

The entropy result shows that demand-supply shortage has the highest weight, 0.8192. This means that the largest source of differentiation among island groups is not merely penetration inequality, but the imbalance between internet-user contribution and ISP representation. The second largest weight is ISP supply gap, while access gap receives the smallest weight because penetration differences among island groups are relatively less varied than demand-supply shortage.

This result is significant for APJII because it shows that priority mapping should not only ask which region has the lowest penetration. It should also identify where the distribution of ISP actors is not proportional to the regional internet-user base. From a policy perspective, this finding supports a more targeted infrastructure strategy.

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3.4. TOPSIS-Based RDIPI Ranking

After the entropy weights were obtained, TOPSIS was used to calculate the Regional Digital Infrastructure Priority Index (RDIPI). A higher RDIPI score indicates a stronger priority for digital infrastructure intervention. Table 5 presents the final Regional Digital Infrastructure Priority Index (RDIPI) ranking derived from the entropy-weighted TOPSIS analysis. Sumatra achieves the highest RDIPI score of 0.9840 and is therefore classified as a Very High priority region, primarily because of its substantial demand-supply shortage. Maluku-Papua ranks second due to its severe access and ISP supply gaps, whereas Java obtains the lowest RDIPI score because of its relatively strong penetration level and ISP availability. The ranking demonstrates that infrastructure intervention priorities are determined by the combined effects of accessibility, provider availability, and regional demand-supply imbalance.

Table 5. TOPSIS-Based RDIPI Ranking

Rank	Island Group	(D^+)	(D^-)	RDIPI Score	Priority Category
1	Sumatra	0.0109	0.6701	0.9840	Very High
2	Maluku-Papua	0.3208	0.3512	0.5226	High
3	Sulawesi	0.4240	0.2488	0.3699	Moderate
4	Kalimantan	0.5111	0.1633	0.2422	Low
5	Bali-Nusa Tenggara	0.5397	0.1360	0.2013	Low
6	Java	0.6707	0.0000	0.0000	Maintenance Priority

Figure 3 visualizes the RDIPI priority ranking and makes the relative distance between island groups easier to interpret.

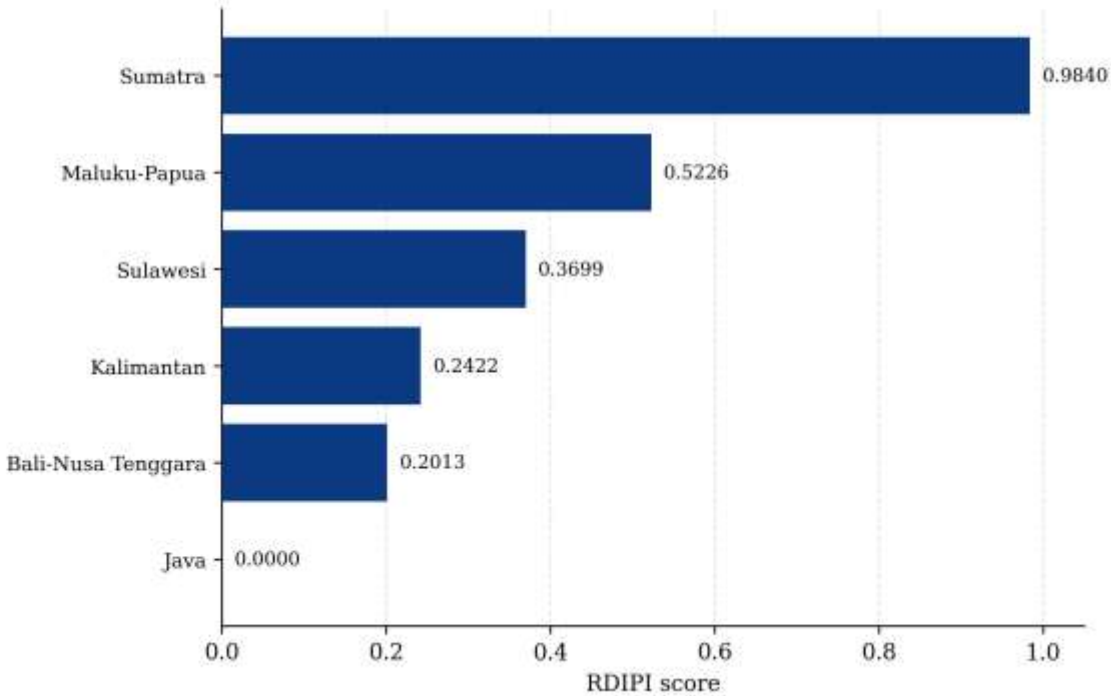

Figure 3. RDIPI priority ranking across Indonesian island groups.
Source: computed from APJII 2025 penetration, contribution, and ISP distribution indicators.

The TOPSIS result places Sumatra as the highest-priority island group. This result may appear counterintuitive because Maluku-Papua has the lowest penetration and the lowest ISP distribution. However, the entropy-weighted model gives the largest weight to demand-supply shortage, and Sumatra has the highest shortage value because its internet-user contribution reaches 20.51%, while its ISP distribution is only 14.67%. This produces a shortage value of 5.84, the largest among all island groups, indicating strong user demand that is not yet matched by proportional ISP representation.

Maluku-Papua ranks second because it has the largest access gap and the lowest ISP distribution. Although these indicators reflect a critical digital inclusion issue, its national internet-user contribution is only 3.71%, resulting in a lower demand-supply shortage than Sumatra. Therefore, Maluku-Papua remains a high-priority inclusion region, while Sumatra becomes the highest-priority intervention region in the combined RDIPI model.

Sulawesi ranks third with a moderate RDIPI score. The region has lower penetration than Sumatra and Kalimantan and also has limited ISP distribution. This indicates that Sulawesi requires targeted infrastructure expansion, especially in areas where local access and provider availability remain uneven.

Java receives the lowest intervention-priority score. This does not mean that Java is unimportant. Rather, the result indicates that Java already has the strongest penetration, the largest national contribution, and the highest ISP representation. Therefore, Java should be treated as a maintenance and service-quality region, while other regions require stronger inclusion-oriented intervention.

3.5. Sensitivity Testing

A sensitivity test was conducted by comparing the entropy-weighted ranking with an equal-weight scenario. The purpose was to examine whether the final ranking was stable when the weighting scheme changed. Table 6 reports the equal-weight RDIPI scores and their ranking consistency compared with the main entropy-weighted model.

Table 6. Sensitivity Test Using Equal Weighting

Rank	Island Group	Equal-Weight RDIPI	Ranking Consistency
1	Sumatra	0.8542	Stable
2	Maluku-Papua	0.6050	Stable
3	Sulawesi	0.4845	Stable
4	Kalimantan	0.3725	Stable
5	Bali-Nusa Tenggara	0.3606	Stable
6	Java	0.0000	Stable

The sensitivity test shows that the ranking order remains unchanged under equal weighting. This provides initial evidence of ranking stability, although it should not be interpreted as a complete robustness proof. Although the RDIPI scores change, the priority structure remains consistent: Sumatra is the highest-priority region, followed by Maluku-Papua and Sulawesi. Java remains the lowest intervention-priority region because its ISP representation is already stronger than its demand-supply shortage condition.

4. CONCLUSION

This study developed an Explainable Entropy-TOPSIS framework to prioritize digital infrastructure development across six Indonesian island groups using APJII 2025 aggregated indicators. The final priority-oriented criteria consist of access gap, ISP supply gap, and demand-supply shortage. The entropy results show that demand-supply shortage has the dominant weight of 0.8192, followed by ISP supply gap = 0.1292 and access gap = 0.0517. Based on the TOPSIS computation, the RDIPI ranking is Sumatra = 0.9840, Maluku-Papua = 0.5226, Sulawesi = 0.3699, Kalimantan = 0.2422, Bali-Nusa Tenggara = 0.2013, and Java = 0.0000. Sumatra ranks first not because it has the lowest penetration, but because it has the largest positive demand-supply shortage: its internet-user contribution is 20.51%, while its ISP distribution is 14.67%. Maluku-Papua remains the second priority because it has the largest access gap and the lowest ISP distribution, but its lower contribution share produces a smaller shortage value than Sumatra.

These findings confirm that digital infrastructure priority should be interpreted as a combined decision-support index, not as a single-indicator ranking or an official APJII infrastructure score. The proposed RDIPI model can help APJII, ISPs, and policymakers translate survey indicators into an explainable priority map for broadband expansion, last-mile connectivity, and digital inclusion planning. Future research should extend this framework using province-level or district-level data, internet speed, affordability, service quality, digital literacy, and GIS-based visualization to produce a more comprehensive digital infrastructure decision-support system.

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