

Evaluating Regional Digital Development in Indonesia Using Entropy-TOPSIS: A Data-Driven Decision Support Approach

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ABSTRACT

Regional disparities in digital development remain a significant challenge in Indonesia, requiring a multidimensional assessment of connectivity, device access, and telecommunications infrastructure. These disparities highlight the need for systematic approaches that can compare provincial conditions using consistent and measurable indicators. This study evaluated and ranked digital development across 38 Indonesian provinces using a data-driven decision-support approach. Secondary data for 2024 were analyzed using an integrated Entropy-TOPSIS framework. Five initial criteria were considered, and correlation-based screening was applied to reduce potential information redundancy, resulting in four final criteria: internet access, computer ownership, mobile phone ownership, and 4G/LTE share. The Entropy method assigned the highest objective weight to computer ownership (51.11%), followed by internet access (19.77%), mobile phone ownership (16.75%), and 4G/LTE share (12.37%). These weights reflect the relative information diversity of the indicators across provinces and provide a data-driven basis for the subsequent ranking process. TOPSIS ranked DKI Jakarta first, with a closeness coefficient of 0.9988, followed by DI Yogyakarta (0.7966), Kalimantan Timur (0.7721), and Kepulauan Riau (0.7691), whereas Papua Pegunungan recorded the lowest score (0.0096). The results reveal considerable variation in provincial digital development, particularly in the distribution of access to digital devices and connectivity. Sensitivity analysis indicated strong ranking stability across alternative weighting scenarios, with Spearman's rank correlation coefficients ranging from 0.9350 to 0.9980. This consistency suggests that the provincial ranking structure remained relatively stable under the alternative weighting configurations examined. The findings also indicate that evaluating digital development solely through connectivity indicators may not adequately represent differences in access to digital devices and supporting infrastructure. The proposed framework provides decision-support information for identifying regional disparities, comparing provincial conditions, and informing more targeted digital development policies. The resulting rankings can help policymakers identify provinces that may require further assessment and more focused interventions based on their respective digital development conditions. Future research may extend this framework by incorporating additional indicators, such as digital literacy, affordability, service quality, and digital economic participation, as well as longitudinal data to examine changes in regional digital development over time.

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1. Introduction

Digital development has become an important component of modern development strategies, supported by the expansion of internet connectivity, digital devices, and telecommunications infrastructure. Advances in information and communication technologies (ICTs) have facilitated access to information, public services, education, economic activities, and social participation. However, these developments have also revealed persistent disparities in ICT adoption and infrastructure between and within countries (Ayanso *et al.*, 2014). Such disparities are particularly relevant to Indonesia, where archipelagic geography and socioeconomic heterogeneity contribute to uneven conditions for digital transformation. Previous studies have documented spatial differences in digital development, with stronger performance in metropolitan and western regions and comparatively weaker conditions in rural and eastern areas (Kartiasih *et al.*, 2022). Research on Indonesia's Digital Society Index has also identified regional differences in digital development, including the concentration of digital progress in Java and the comparatively limited advancement of several eastern regions (Jaya *et al.*, 2024). These conditions highlight the need to assess digital development at the provincial level by considering connectivity, access to digital devices, and telecommunications infrastructure.

Regional digital disparities extend beyond differences in internet access. Evidence from Indonesia indicates that disparities persist between western and eastern regions and between urban and rural areas, even as national ICT development progresses (Kartiasih *et al.*, 2022; Ramadhanti & Astuti, 2022). Provincial-level assessments are therefore important for monitoring the digital divide and informing regional development strategies (Ratna Wati *et al.*, 2024). Moreover, access to digital technologies does not necessarily eliminate inequality, because differences in the ability to benefit from these technologies may reinforce existing disadvantages (Heeks, 2022). A meaningful assessment of regional digital development should consequently consider not only connectivity but also device availability and supporting infrastructure. This multidimensional perspective provides a basis for identifying differences in provincial digital conditions that may not be apparent from a single indicator. Single-indicator approaches may be insufficient to capture the multidimensional nature of digital development because measures such as internet penetration alone can overlook disparities in device access, infrastructure, and digital capabilities (Sharp, 2023). Recent studies have therefore applied multidimensional and composite assessment frameworks to examine digital transformation and regional disparities (González-Rodríguez & Díaz-Fernández, 2025; Guo *et al.*, 2024; Valaskova *et al.*, 2025). Multi-criteria decision-making approaches are relevant to this task because they integrate indicators with different measurement characteristics into a unified evaluation framework (Su *et al.*, 2022). Such approaches allow provincial conditions to be compared across several dimensions rather than relying exclusively on internet connectivity. The integration of Entropy and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) offers a multi-criteria framework for evaluating regional digital development. Entropy determines criterion weights based on the distribution and diversity of information in the observed data, reducing reliance on subjective weighting decisions (Robles-Algarín *et al.*, 2024). TOPSIS ranks alternatives according to their relative distances from positive and negative ideal solutions (Fahmi *et al.*, 2023). Previous research has applied Entropy-TOPSIS to composite digital economy assessments (Ge & Wu, 2022), while other applications have demonstrated its use in evaluating digital development through multiple indicators (Liu *et al.*, 2024). Combining the two methods provides a systematic means of deriving data-based criterion weights and ranking provinces according to their relative performance across the selected indicators. Although previous studies have examined the multidimensional nature of digital inequality and its relationship with regional and socioeconomic disparities (Kartiasih *et al.*, 2022; Vassilakopoulou & Hustad, 2021), further assessment is needed to integrate connectivity, device ownership, mobile phone ownership, and 4G/LTE infrastructure within a unified framework for comparing all 38 Indonesian provinces. The study also incorporates correlation-based criterion screening before weighting and evaluates ranking stability under alternative weighting scenarios. These components are intended to address potential information redundancy among indicators and examine the extent to which provincial rankings remain consistent when criterion weights change. The resulting approach combines criterion screening, Entropy weighting, TOPSIS ranking, and multi-scenario sensitivity analysis within a single assessment procedure. This study aims to evaluate and rank digital development across 38 Indonesian provinces using secondary data for 2024 from BPS-Statistics Indonesia and an integrated Entropy-TOPSIS framework. Its contributions are fourfold: providing a multidimensional assessment of provincial digital

conditions, deriving criterion weights objectively from the data, generating comparative provincial rankings for decision-support purposes, and examining ranking stability under alternative weighting scenarios. The resulting assessment is intended to support the identification of regional disparities and inform the consideration of more targeted digital development strategies across Indonesia.

2. Methodology

2.1 Research Design and Data

This study employed a quantitative cross-sectional research design to evaluate regional digital development across Indonesia using a multi-criteria decision-making approach. The unit of analysis consisted of all 38 Indonesian provinces, which were treated as alternatives in the decision model. Secondary data for 2024 were obtained from BPS-Statistics Indonesia, primarily from the *Telecommunication Statistics in Indonesia 2024* publication and related provincial statistical tables. Because all 38 provinces were included, no sampling procedure was required, enabling a nationwide comparison based on a consistent reference year. Five initial criteria were selected to represent complementary aspects of regional digital development: household internet access (C1), household computer ownership (C2), mobile phone ownership (C3), computer usage (C4), and 4G/LTE network availability (C5). Criteria C1–C4 were expressed as percentages based on the corresponding BPS indicators. Criterion C5 was derived from provincial data on villages/urban wards according to the type of cellular signal received at locations with Base Transceiver Stations (BTS). The proportion of 4G/LTE availability for province (i) was calculated as:

$$C5_i = \frac{4G/LTE_i}{4G/LTE_i + 3G_i + 2.5G_i + NoSignal_i} \times 100 \quad (1)$$

All five initial criteria were specified as benefit criteria, meaning that higher values represented more favorable digital conditions. Before the multi-criteria analysis, the dataset was examined for completeness, numerical consistency, and missing values. The resulting dataset contained complete observations for all 38 provinces. Data preprocessing, statistical analysis, Entropy-TOPSIS computation, robustness assessment, and visualization were conducted using Python in the Google Colab environment.

2.2 Criterion Screening and Entropy Weighting

Before weighting, Pearson correlation analysis was conducted to identify potential redundancy among the initial criteria and reduce the risk of double counting conceptually overlapping information. Computer ownership (C2) and computer usage (C4) exhibited a very high correlation ($r=0.948$); therefore, C4 was excluded from the final decision matrix, while C2 was retained to represent household-level computer availability. Internet access (C1) and mobile phone ownership (C3) were also strongly correlated ($r=0.935$). However, both criteria were retained because they represent distinct operational dimensions: household internet connectivity and individual access to mobile communication devices, respectively. Consequently, the final decision matrix consisted of four criteria: C1, C2, C3, and C5. The Entropy method was applied to determine objective criterion weights based on the information diversity contained in the provincial data. For each criterion (j), the original observations were transformed into proportional values as follows:

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

where (x_{ij}) denotes the value of province (i) for criterion (j), and (m) represents the number of provinces. The Entropy value for each criterion was calculated as:

$$e_j = -k \sum_{i=1}^m p_{ij} \ln(p_{ij}), \quad k = \frac{1}{\ln(m)} \quad (3)$$

The degree of diversification was then obtained as:

$$d_j = 1 - e_j \quad (4)$$

The objective weight of criterion (j) was calculated as:

$$w_j = \frac{d_j}{\sum_{j=1}^n d_j} \quad (5)$$

A criterion exhibiting greater information diversity across provinces receives a relatively larger Entropy weight. These weights represent the discriminatory information contained in each criterion and should not be interpreted as causal effects on regional digital development.

2.3 TOPSIS Ranking and Robustness Analysis

The Entropy-derived weights were integrated into the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) to rank the 38 provinces. The final decision matrix was normalized using vector normalization:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^m x_{ij}^2}} \quad (6)$$

The weighted normalized decision matrix was subsequently obtained as:

$$v_{ij} = w_j r_{ij} \quad (7)$$

Because all four criteria were defined as benefit criteria, the positive and negative ideal solutions were determined as:

$$A^+ = \{\max_i v_{ij}\}, \quad A^- = \{\min_i v_{ij}\} \quad (8)$$

The Euclidean distances of each province from the positive and negative ideal solutions were calculated as:

$$D_i^+ = \sqrt{\sum_{j=1}^n (v_{ij} - v_j^+)^2} \quad (9)$$

And

$$D_i^- = \sqrt{\sum_{j=1}^n (v_{ij} - v_j^-)^2} \quad (10)$$

The TOPSIS closeness coefficient was then calculated as:

$$CC_i = \frac{D_i^-}{D_i^+ + D_i^-} \quad (11)$$

A higher (CC_i) indicates that a province is relatively closer to the positive ideal solution and therefore receives a higher regional digital development ranking. Ranking robustness was evaluated through a multi-scenario sensitivity analysis comparing the baseline Entropy-weighted model with five alternative weighting schemes. These consisted of an equal-weighting scenario, assigning a weight of 0.25 to each criterion, and four criterion-dominant scenarios in which C1, C2, C3, or C5 received a weight of 0.40, while each remaining criterion received a weight of 0.20. Ranking consistency between the baseline model and each alternative scenario was evaluated using Spearman's rank correlation coefficient. All computational procedures were

implemented in Python, using Pandas and NumPy for data processing and numerical computation, SciPy for rank-correlation analysis, and Matplotlib for graphical visualization.

3. Results

3.1 Descriptive Statistics and Criterion Screening

Before screening the criteria for further analysis, descriptive statistics were calculated to examine the distribution, central tendency, and variability of the five initial digital development criteria across the 38 Indonesian provinces. The analysis included the mean, standard deviation (SD), minimum, median, and maximum values to provide an overview of the overall data distribution and the extent of differences among provinces. These statistical measures also helped identify criteria with substantial variation, which may be relevant to understanding disparities in digital development. The descriptive results serve as an initial basis for evaluating the characteristics of each criterion before proceeding to the subsequent analytical stages. The results are presented in Table 1.

Table 1. Descriptive Statistics of the Initial Digital Development Criteria

Criterion	Mean	SD	Min	Median	Max
C1 – Internet Access (%)	87.20	16.39	12.15	91.20	98.18
C2 – Computer Ownership (%)	18.89	6.67	2.31	17.88	39.33
C3 – Mobile Phone Ownership (%)	66.75	12.26	15.76	68.18	83.90
C4 – Computer Usage (%)	10.67	4.05	1.16	9.98	22.24
C5 – 4G/LTE Share (%)	87.29	14.02	33.33	90.75	100.00

Source: Authors' calculations based on BPS-Statistics Indonesia (2024) data.

Table 1 presents the descriptive statistics for the five initial digital development criteria across the 38 Indonesian provinces. Internet access (C1) had a mean of 87.20%, with values ranging from 12.15% to 98.18%, indicating substantial variation in household internet access across provinces. Computer ownership (C2) had a considerably lower mean of 18.89%, whereas mobile phone ownership (C3) averaged 66.75%. Computer usage (C4) recorded the lowest mean, at 10.67%. Meanwhile, the mean 4G/LTE share (C5) was 87.29%, although provincial values ranged from 33.33% to 100.00%. Overall, the descriptive statistics show that relatively high average levels of internet access and 4G/LTE availability coexist with substantial provincial variation, particularly in computer ownership and computer usage.

Table 2. Pearson Correlation Matrix of the Initial Digital Development Criteria

Criterion	C1	C2	C3	C4	C5
C1	1.000	0.600	0.935	0.605	0.810
C2	0.600	1.000	0.773	0.948	0.452
C3	0.935	0.773	1.000	0.734	0.680
C4	0.605	0.948	0.734	1.000	0.490
C5	0.810	0.452	0.680	0.490	1.000

Source: Authors' calculations using Python based on BPS-Statistics Indonesia (2024) data.

Before applying the Entropy-TOPSIS procedure, Pearson correlation analysis was conducted to identify potential redundancy among the initial criteria. As shown in Table 2, computer ownership (C2) and computer usage (C4) exhibited a strong positive correlation ($r = 0.948$). Because these indicators capture related aspects of household computer access and use, retaining both could introduce overlapping information into the decision model. Therefore, C4 was excluded, while C2 was retained to represent household computer ownership. Internet access (C1) and mobile phone ownership (C3) also exhibited a strong positive correlation ($r = 0.935$). Nevertheless, both criteria were retained because they represent conceptually distinct dimensions of digital development. C1 captures household-level internet access, whereas C3 represents mobile phone ownership. Accordingly, the final decision matrix comprised four benefit criteria: internet access (C1), computer ownership (C2), mobile phone ownership (C3), and 4G/LTE share (C5).

3.2 Entropy-Based Criterion Weighting

Following criterion screening, the Entropy method was applied to calculate the objective weights of the four retained criteria. The resulting entropy values, diversification degrees, and weights are presented in Table 3.

Table 3. Entropy-Based Weights of Digital Development Criteria

Criterion	Entropy	Diversification	Weight	Weight (%)
C1 – Internet Access	0.9934	0.0066	0.1977	19.77
C2 – Computer Ownership	0.9828	0.0172	0.5111	51.11
C3 – Mobile Phone Ownership	0.9944	0.0056	0.1675	16.75
C5 – 4G/LTE Share	0.9958	0.0042	0.1237	12.37

Source: Authors' calculations using Python based on BPS-Statistics Indonesia (2024) data.

Computer ownership (C2) received the highest Entropy weight, at 51.11%, followed by internet access (C1) at 19.77%, mobile phone ownership (C3) at 16.75%, and 4G/LTE share (C5) at 12.37%. The relatively high weight assigned to C2 reflects its greater information diversity across provinces compared with the other retained criteria. In the Entropy method, a criterion receives a higher weight when its observed distribution provides greater discriminatory information within the dataset; this weight should not be interpreted as evidence of a causal influence on digital development. Figure 1 illustrates the relative weights assigned to the four criteria in the Entropy-TOPSIS model.

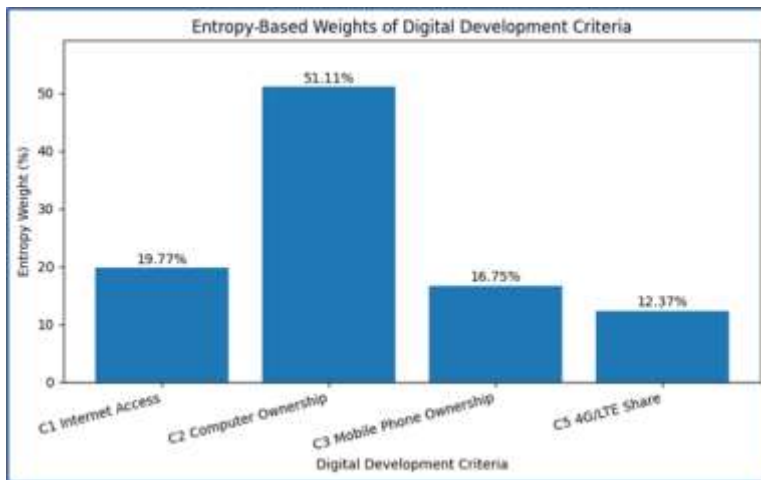


Figure 1. Entropy-Based Weights of the Final Digital Development Criteria

3.3 Entropy-TOPSIS Ranking of Regional Digital Development

The Entropy-derived weights were incorporated into TOPSIS to calculate the closeness coefficient for each of the 38 provinces. Higher coefficients indicate that a province is relatively closer to the positive ideal solution across the four retained criteria. Table 4 presents the five highest-ranked and five lowest-ranked provinces.

Table 4. Top and Bottom Provincial Rankings Based on Entropy-TOPSIS

Rank	Province	TOPSIS Score
1	DKI Jakarta	0.9988
2	DI Yogyakarta	0.7966
3	Kalimantan Timur	0.7721
4	Kep. Riau	0.7691
5	Bali	0.6739
34	Nusa Tenggara Timur	0.3184
35	Nusa Tenggara Barat	0.3155

36	Lampung	0.3033
37	Papua Tengah	0.1602
38	Papua Pegunungan	0.0096

Source: Authors' calculations using Python based on BPS-Statistics Indonesia (2024) data.

DKI Jakarta ranked first, with a TOPSIS score of 0.9988, followed by DI Yogyakarta (0.7966), Kalimantan Timur (0.7721), and Kepulauan Riau (0.7691). Bali completed the top five, with a score of 0.6739. At the lower end of the ranking, Papua Pegunungan recorded the lowest score (0.0096), preceded by Papua Tengah (0.1602), Lampung (0.3033), Nusa Tenggara Barat (0.3155), and Nusa Tenggara Timur (0.3184). These results reveal substantial differences in provincial digital development as measured by internet access, computer ownership, mobile phone ownership, and 4G/LTE availability. The ranking represents relative performance against the ideal solution defined by the selected criteria and their Entropy-derived weights. It should therefore be interpreted as a comparative assessment of the included indicators rather than a comprehensive measure of every dimension of digital development. Figure 2 presents the TOPSIS scores for all 38 provinces.

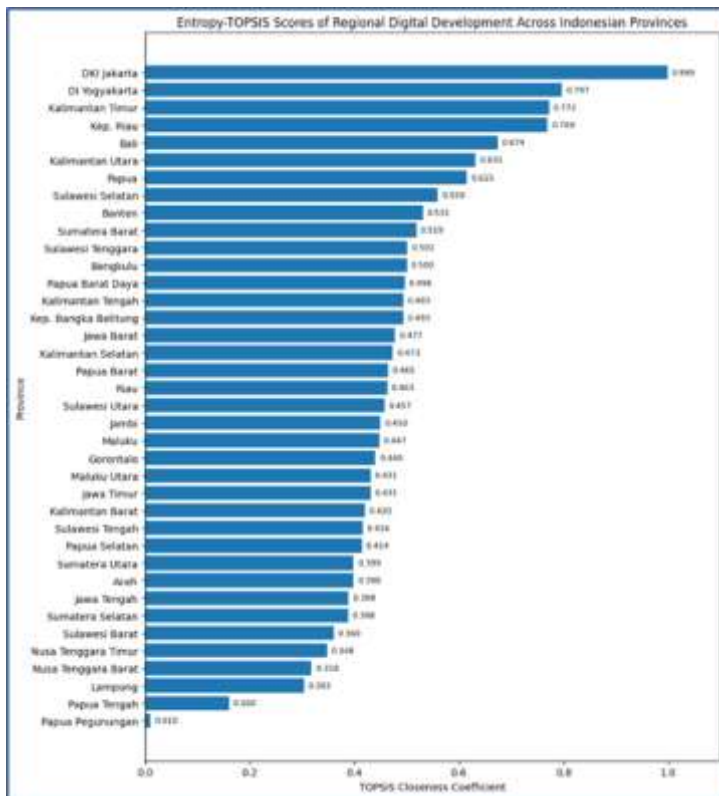


Figure 2. Entropy-TOPSIS Scores of Regional Digital Development Across Indonesian Provinces

3.4 Sensitivity and Robustness Analysis

Sensitivity analysis was conducted to examine the stability of the baseline Entropy-TOPSIS ranking under alternative criterion-weighting schemes. Five alternative scenarios were evaluated: equal weighting and four scenarios in which one criterion received a dominant weight. Spearman's rank correlation coefficient was used to compare the ranking under each alternative scenario with the baseline ranking. The results are presented in Table 5.

Table 5. Sensitivity Analysis of the Entropy-TOPSIS Ranking

Scenario	Spearman's	p-value
Equal Weight	0.9836	< 0.001
C1 Dominant	0.9698	< 0.001
C2 Dominant	0.9980	< 0.001
C3 Dominant	0.9656	< 0.001
C5 Dominant	0.9350	< 0.001

Source: Authors' calculations using Python based on BPS-Statistics Indonesia (2024) data.

The results show strong positive rank correlations across all five alternative weighting scenarios, with Spearman's ranging from 0.9350 to 0.9980. The C2-dominant scenario produced the highest agreement with the baseline ranking ($\rho = 0.9980$), whereas the C5-dominant scenario produced the lowest correlation ($\rho = 0.9350$). The equal-weight scenario also showed strong agreement with the baseline ranking ($\rho = 0.9836$). These findings indicate that the relative ordering of provinces remained highly consistent under the alternative weighting configurations examined. However, the differences in correlation coefficients suggest that the degree of ranking stability varied depending on which criterion received greater emphasis. The results support the robustness of the ranking to the specific weighting scenarios tested, but they do not establish that the ranking would remain unchanged under all possible weighting schemes or alternative indicator selections. Figure 3 illustrates the results of the sensitivity analysis.

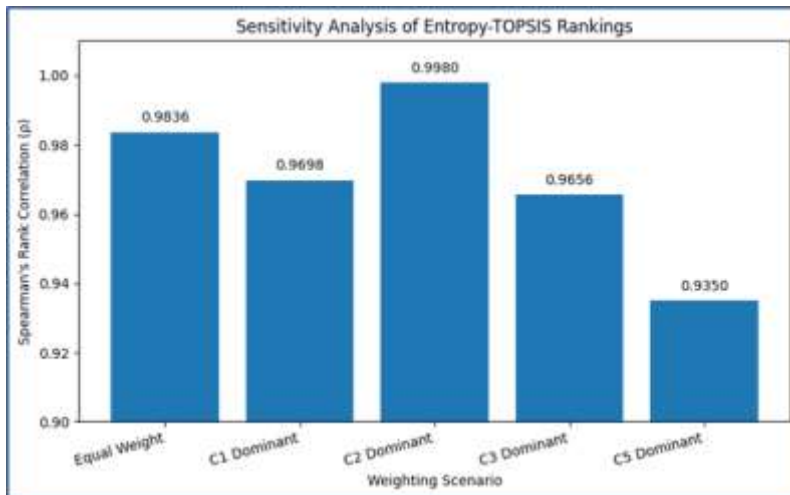


Figure 3. Sensitivity Analysis of Provincial Rankings Under Alternative Weighting Scenarios

4. Discussion

The findings reveal substantial disparities in digital development across Indonesian provinces. DKI Jakarta achieved the highest Entropy-TOPSIS score (0.9988), followed by DI Yogyakarta (0.7966), Kalimantan Timur (0.7721), and Kepulauan Riau (0.7691), whereas Papua Tengah (0.1602) and Papua Pegunungan (0.0096) occupied the lowest positions. These differences indicate that provincial digital development is uneven when assessed through a combination of internet access, computer ownership, mobile phone ownership, and 4G/LTE availability. The ranking provides a comparative view of provincial conditions based on these four indicators, rather than a comprehensive assessment of every dimension of digital transformation. The Entropy analysis assigned the highest weight to computer ownership (C2), at 51.11%, indicating that this criterion contained the greatest discriminatory information among the four retained indicators. In the context of this study, variation in household computer ownership therefore contributed substantially to differentiating provincial digital development profiles. However, this weight reflects the distribution of the observed data rather than a causal relationship between computer ownership

and digital development. It should consequently be interpreted as a feature of the weighting method and the dataset, not as evidence that computer ownership alone determines a province's digital development level. From a regional policy perspective, the findings suggest that digital development assessments should consider multiple dimensions rather than relying exclusively on internet connectivity or mobile network availability. Provinces with lower composite scores may warrant further examination of device access, connectivity conditions, and supporting infrastructure to identify the dimensions most relevant to their circumstances. The Entropy-TOPSIS framework can provide preliminary decision-support information by comparing provincial conditions and highlighting potential priorities for further assessment. Nevertheless, selecting specific interventions requires additional evidence on local needs, implementation constraints, affordability, and other contextual factors not directly examined in this study. The sensitivity analysis provides additional evidence regarding the consistency of the provincial ranking. Spearman's rank correlation coefficients ranged from 0.9350 to 0.9980 across the five alternative weighting scenarios, with all reported correlations statistically significant. The high positive correlations indicate that the relative ordering of provinces remained largely consistent when the criterion weights were modified under the scenarios examined. However, this result does not establish that the ranking is invariant to all possible weighting schemes, changes in the selected indicators, or differences in the underlying data. The robustness finding should therefore be understood within the scope of the sensitivity tests conducted. Several limitations should be considered when interpreting these findings. First, the assessment uses cross-sectional data for 2024 and therefore does not capture changes in provincial digital development over time. Second, the analysis is based on four retained indicators following correlation-based screening, meaning that dimensions such as digital literacy, affordability, service quality, and actual participation in digital activities are not directly represented. Third, the Entropy weights depend on the variation observed in the selected dataset, while the TOPSIS scores express relative performance against the ideal solutions defined by the model. Future research could address these limitations by incorporating additional indicators, analyzing multiple years, and comparing alternative weighting and ranking methods. Such extensions would help assess whether the observed provincial patterns persist over time and under different model specifications.

5. Conclusion

This study developed a data-driven decision-support framework for evaluating regional digital development across 38 Indonesian provinces using secondary data for 2024 and the Entropy-TOPSIS method. Five initial indicators were examined, followed by correlation-based screening to reduce potential information redundancy. Computer usage (C4) was excluded because of its high correlation with computer ownership (C2), leaving four criteria for the final assessment: internet access (C1), computer ownership (C2), mobile phone ownership (C3), and 4G/LTE share (C5). The Entropy method assigned the highest weight to computer ownership (51.11%), followed by internet access (19.77%), mobile phone ownership (16.75%), and 4G/LTE share (12.37%). These weights reflect the relative discriminatory information provided by the indicators across provinces. The TOPSIS ranking revealed substantial disparities in regional digital development. DKI Jakarta achieved the highest closeness coefficient (0.9988), followed by DI Yogyakarta (0.7966), Kalimantan Timur (0.7721), and Kepulauan Riau (0.7691), whereas Papua Tengah (0.1602) and Papua Pegunungan (0.0096) ranked lowest. Sensitivity analysis showed strong positive rank correlations across the alternative weighting scenarios, ranging from 0.9350 to 0.9980 ($p < 0.001$). These findings indicate that the relative ordering of provinces remained largely consistent under the weighting configurations examined. Overall, integrating criterion screening, Entropy weighting, TOPSIS ranking, and sensitivity analysis provides a systematic approach for comparing provincial digital development conditions. The resulting rankings can help policymakers identify regional disparities and determine where further assessment of connectivity, digital device access, and telecommunications infrastructure may be warranted. However, the findings represent a comparative assessment based on the selected indicators rather than a comprehensive measure of digital transformation. Future research could incorporate additional dimensions, including digital literacy, affordability, service quality, cybersecurity readiness, and digital economic participation, as well as multi-year data to examine changes in regional digital development over time.

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