International Journal of Research and Review
[Indexed, Peer-Reviewed Journal]
Volume 12; Issue: 12; December 2025
Website: www.ijrrjournal.com
E-ISSN: 2349-9788; P-ISSN: 2454-2237

Research Paper

Spatial Multi-Criteria Assessment of Wind-Energy Feasibility in Gorontalo Province

Sudarmantao Hasan[1], Fitryane Lihawa[2], Lanto Moh. Kamil Amali[3]

[1,2]Population and Environmental Studies Program, Postgraduate Program, Gorontalo State University, Gorontalo, Indonesia.
[3]Electrical Engineering Study Program, Faculty of Engineering, Gorontalo State University, Gorontalo, Indonesia

Corresponding Author: Fitryane Lihawa

DOI: https://doi.org/10.52403/ijrr.20251260

ABSTRACT

Wind energy is a key pathway for Indonesia's renewable energy transition, but provincial planning remains limited. This study uses a multi-criteria GIS approach to assess the wind- power potential of Gorontalo Province. The method includes factors such as wind speed, terrain, land cover, forest status, hazard exposure, roads, and proximity to the transmission network. It is then verified against the Provincial Spatial Plan (RTRW 2024). Wind speeds of 4–6.5 m/s, combined with optimal terrain and land cover, yield 12,743.36 ha of suitable and 113.8 ha of very suitable land before policy constraints. After RTRW integration, these fall to about 7,300 ha and 63.97 ha, revealing the impact of zoning and the need for policy alignment. Top development areas are Kwandang–Anggrek–Monano, West Gorontalo City, and Tibawa–Batudaa. Grid proximity and slope are key, with only 6.65% of the province within 1 km of transmission lines. Gorontalo offers feasible, policy-compliant zones for medium-scale wind development, provided grid upgrades and inter-agency coordination improve. These findings provide a replicable spatial-planning model for regions expanding wind energy.

Keywords: *Wind energy; GIS-based suitability analysis; renewable energy planning; spatial multi-criteria evaluation; Gorontalo Province*

INTRODUCTION

The global energy sector drives nearly 75% of anthropogenic greenhouse gas emissions, making it central to climate mitigation (Ge et al., 2024). As climate challenges intensify, nations are rapidly shifting to renewables to cut fossil fuel use and ensure energy security. Indonesia, one of the largest emerging economies and a Paris Agreement signatory has pledged to reduce domestic emissions by 29% and, with international support, by up to 41% by 2030 (Armstrong, 1931). The National Energy Plan (RUEN) sets these ambitious renewable targets. However, despite a technical wind potential of 154.6 GW, only 152.3 MW had been realized by 2023 (Kementerian ESDM, 2022), highlighting a gap between policy and implementation. Wind energy development strongly supports key Sustainable Development Goals: SDG 7, SDG 8, SDG 11, and SDG 13 (UNDP, 2023). Assessments show Indonesia's wind resources are strongest in coastal and highland areas. Gorontalo Province in northern Sulawesi is notable, with coastal wind speeds of 4–6.5 m/s at 50 meters (Global Wind Atlas; BMKG). Although this potential is recognized in the Regional Energy Plan (RUED, 2019), the province lacks wind farms. This disconnect emphasizes the need for integrated spatial assessment to guide provincial wind energy planning.

Although interest in spatially informed renewable energy planning is growing, several challenges remain. A key issue is the lack of comprehensive, province-wide spatial assessments that integrate technical wind parameters, environmental constraints, infrastructure readiness, and land-use regulations. Without a robust spatial framework, decision-makers cannot reliably identify feasible locations for wind development or verify alignment with existing plans, such as the Provincial Spatial Plan (BAPPEDA, 2023). Wind energy infrastructure also often intersects with socially or ecologically sensitive areas if planning does not use multi-criteria analysis. Previous studies in Indonesia highlight similar deficiencies: inconsistent methodologies, limited spatial coverage, and insufficient data constrain effective planning (Said, Akil, & Muzakir, 2019; Kusweanto & Jebatu, 2024; Suci & Muhamad, 2024).

A second challenge is the limited integration of wind resource assessments with policy frameworks. Policies at various levels promote renewable energy, but technical assessments often overlook zoning rules, protected areas, and long-term land-use plans. As a result, feasible areas may still fall within restricted zones, leading to delays, higher costs, or infeasible proposals. In Gorontalo, promising wind corridors often overlap complex land classifications, so coordinated planning across sectors and administrations is required.

Several studies have addressed these obstacles using Geographic Information Systems (GIS) and multi-criteria decision analysis (MCDA). In Jeneponto, researchers identified potential wind farm locations using seven spatial parameters but did not integrate them with regional policies, thereby reducing their relevance (Said, Akil, & Muzakir, 2019). Studies in Semarang and Pandeglang used parameters like wind speed, slope, elevation, land use, and infrastructure accessibility to map suitability zones (Kusweanto & Jebatu, 2024; Suci & Muhamad, 2024). Although valuable, these works focus mainly on physical–technical factors rather than governance or policy compliance.

International literature highlights the value of models integrating policy and legal aspects. Placide & Lollchund (2024) created a fuzzy-logic GIS model for wind siting in Burundi, demonstrating multi-criteria integration for data-limited settings. Dimitriou et al. (2025) applied these techniques for offshore wind in Greece, showing methodological adaptability. Thresholds such as wind speed (≥5 m/s), turbine spacing, and grid proximity remain central (Eftekhari et al., 2022; Denholm et al., 2009). These works affirm that robust spatial assessments must combine biophysical, infrastructural, and governance factors.

Despite these contributions, several gaps persist in Indonesia. Most studies do not adopt a province-wide perspective to account for variability in wind resources and land use. Policy integration is also missing, yet it is crucial for legal and long-term wind development. Prior analyses do not triangulate spatial results, policy frameworks, and stakeholder insights. This reduces their operational feasibility. These gaps show the need for research that unites technical, spatial, and institutional aspects.

This study presents Gorontalo's first province-wide GIS-based wind-suitability assessment. It combines eight spatial parameters—wind speed, slope, elevation, land cover, forest status, road and grid proximity, and seismic hazard—with policy tools like the RTRW (2024) and RUED (2019). A Sequential Explanatory Mixed Methods design is used, starting with quantitative spatial modeling and then validating with policy and expert insights. The research is novel for its multidisciplinary approach. It combines biophysical, legal, and institutional analyses to identify candidate sites that align with the rules and real-world cases. The study expects that Gorontalo has spatial clusters that meet technical and regulatory criteria for wind power. By mapping and validating suitable areas, the study provides planners and investors with clear, policy-compliant information for wind energy planning in Indonesia.

MATERIALS & METHODS

This study employed a Sequential Explanatory Mixed Methods design to systematically evaluate the spatial feasibility of wind power development in Gorontalo Province. The methodological strategy was grounded in Geographic Information Systems (GIS), multi-criteria spatial analysis, and qualitative policy triangulation. This integrated approach was selected to ensure that the identification of suitable wind-power sites reflected not only technical criteria but also environmental constraints and institutional frameworks, consistent with recommendations from earlier GIS-based wind assessments (Díaz-Cuevas, 2018; Gavériaux et al., 2019; Placide & Lollchund, 2024). The methodology consisted of four major stages: defining the research location and timeline; applying a mixed-methods research design; collecting and processing spatial and non-spatial datasets; and conducting multi-criteria spatial analysis followed by validation using qualitative sources.

The research was conducted in Gorontalo Province, located between 0°19′–0°57′ N and 121°23′–125°14′ E, a region characterized by coastal wind speeds of 4–6.5 m/s at 50 meters above ground level, according to the Global Wind Atlas and BMKG. The province lacks operating wind power infrastructure despite holding significant wind energy potential. Field and secondary data collection was undertaken from May to October 2025, encompassing proposal refinement, acquisition of spatial datasets, stakeholder communication, and implementation of both GIS and qualitative analytical phases. These stages aligned with methodological recommendations for renewable energy spatial planning, which highlight the importance of combining temporal sequencing and iterative verification (Rehman et al., 2020; Razeghi et al., 2023).

A mixed-methods approach was selected to capture both the quantitative spatial characteristics and the qualitative institutional conditions shaping wind energy development. Quantitatively, the study used a spatial GIS framework to identify areas that met technical and environmental suitability criteria. This quantitative phase incorporated descriptive, exploratory, and spatial-analytic procedures, reflecting the need for systematic classification of wind resources, terrain, land cover, and hazard conditions. The qualitative phase followed sequentially and consisted of thematic analysis of interviews and policy documents, including National Energy Plan (RUEN), Regional Energy Plan (RUED), Regional Spatial Planning (RTRW), the Medium-Term Development Plan (RPJMD), and sectoral environmental regulations. This sequencing is consistent with a Sequential Explanatory Design, in which quantitative outputs guide qualitative interpretation and validation (Creswell, cited in methodological literature). The use of mixed methods reflects similar approaches in international renewable-energy siting research, where technical outputs are strengthened through institutional and policy triangulation (Dimitriou et al., 2025).

Spatial multi-criteria analysis formed the core of the quantitative methodology. The analytical workflow began with collecting spatial datasets representing wind speed, elevation, slope, land use, forest area status, distance to roads, distance to electrical transmission infrastructure, and earthquake hazard. Data sources included NASA satellite products, BIG topographic and administrative layers, Meteorology, Climatology, and Geophysics Agency (BMKG) wind data, the Global Wind Atlas, and local datasets from ESDM, Regional Development Planning Agency (BAPPEDA), State Electricity Company (PLN), and Regional Environmental

Agency (DLH). These datasets were processed into structured spatial layers, forming the analytical base maps for GIS operations. The reliance on authoritative spatial datasets aligns with established practices in wind-farm siting research (Denholm et al., 2009; Eftekhari et al., 2022).

Each spatial layer was converted into a classified thematic map using reclassification techniques. For instance, wind speed values were categorized according to feasibility thresholds, with speeds of 4–5 m/s or higher considered suitable based on prior empirical work (Ifkirne et al., 2022; BMKG). Slope values were reclassified to distinguish terrain with an inclination of less than 15%, reflecting globally accepted suitability thresholds for wind-turbine infrastructure (Islam et al., 2022). Elevation, land cover, forest-use classifications, and infrastructure distances were similarly transformed into ordinal suitability scales. Hazard layers, especially earthquake susceptibility provided by BNPB (2022–2026), were integrated to exclude high-risk zones. All reclassification schemes were informed by methodological precedents in multi-criteria renewable-energy assessments (Gavériaux et al., 2019; Rehman et al., 2020).

Following reclassification, exclusion buffers were applied to remove legally restricted or technically incompatible zones. Buffers were created around settlements, conservation forests, water bodies, and areas exceeding hazard thresholds. Road buffers ensured the feasibility of turbine access, consistent with infrastructure requirements for blade and tower transportation. Similarly, buffer zones were created around electrical transmission lines in accordance with regional grid planning documented in Electricity Supply Business Plan (RUPTL). These exclusion criteria reflect the environmental and infrastructural considerations emphasized by Denholm et al. (2009) and subsequent GIS-based siting studies. The reclassified and buffered layers were combined using a weighted overlay. The overlay produced composite suitability maps that classified land into three categories: highly suitable, suitable, and unsuitable.

Table 1. Criteria and Classification of Feasibility of Wind Power Plant Locations

Criteria	Original Data Range	Score Scale	Description
Wind Speed (m/s)	< 3.0	1	Not Suitable
	3.1–4.0	2	Less Suitable
	4.1–5.0	3	Moderately Suitable
	5.1–6.0	4	Suitable
	≥ 6	5	Optimal
Elevation / Topography (m a.s.l.)	1501–2000	1	Not Suitable
	1001–1500	2	Less Suitable
	501–1000	3	Moderately Suitable
	201–500	4	Suitable
	0–200	5	Optimal
Slope (%)	> 45	1	Not Suitable
	25.1–45	2	Less Suitable
	15.1–25	3	Moderately Suitable
	8.1–15	4	Suitable
	0–8	5	Optimal
Distance to Transmission Network (km)	≥ 3	1	Not Suitable
	2.1–3	2	Less Suitable
	1.1–2	3	Moderately Suitable
	0.51–1	4	Suitable
	≤ 0.5	5	Optimal
Land Use	Protected forest / settlement	1	Not Suitable

	Rice field / plantation	2	Less Suitable
	Shrub / dryland agriculture	3	Moderately Suitable
	Bare land / grassland	4	Suitable
	Open land without vegetation	5	Optimal
Earthquake Hazard (g)	> 0.80	1	Not Suitable
	0.60–0.80	2	Less Suitable
	0.40–0.60	3	Moderately Suitable
	0.20–0.40	4	Suitable
	< 0.20	5	Very Suitable
Distance from Road (km)	> 3 km	1	Not Suitable (solid access)
	2.01–3 km	2	Less Suitable (solid access)
	1.01–2 km	3	Moderately Suitable
	0.51–1 km	4	Suitable
	≤ 0.5 km	5	Optimal (easy access)
Forest Area Status	Conservation areas (KSA, HI, CA)	1	Not Suitable
	Limited production forest	2	Less Suitable
	Permanent production forest	3	Moderately Suitable
	Convertible production forest	4	Suitable
	Non-forest area (APL)	5	Optimal

Data analysis used ArcGIS 10.8/Pro to run map algebra operations and produce final suitability zonations. Spatial operations included raster conversion, resampling, weighted overlays, and cartographic visualization. The analysis resulted in a full provincial-scale suitability map. Importantly, the methodology incorporated a subsequent overlay with the latest Provincial Spatial Plan (RTRW 2024-2045) to ensure policy compliance, consistent with literature highlighting the significance of land-use regulations in determining renewable-energy feasibility (Prasetyo, 2022; BAPPEDA, 2023). This integration allowed the study to differentiate between technically feasible sites and those permissible under legal and zoning constraints.

The qualitative phase validated spatial results and assessed institutional readiness. Semi-structured interviews were conducted with key stakeholders, including energy planners, spatial planning officials, and local agencies. Policy documents such as RUEN, RUED, RTRW, and RPJMD were analyzed to assess governance alignment and policy feasibility. Data triangulation was then performed to synthesize findings from spatial analysis, regulatory frameworks, and stakeholder insights. This triangulation process strengthened the study by reconciling technical outputs with real-world planning conditions and aligning with methodological recommendations in the multi-criteria energy planning literature (Gavériaux et al., 2019; Razeghi et al., 2023).

Validation procedures included both spatial and policy-oriented checks. Spatial validation involved field observations at selected locations to confirm land-cover accuracy, access-road feasibility, and topographic consistency. Photographic documentation and GPS logging were used to cross-verify map outputs. Policy validation ensured that identified zones complied with regulations outlined in the RTRW, including cultivation area and designated energy-development zones. These validation steps strengthened the operational feasibility of the proposed wind-energy sites and aligned with best practices in renewable-energy spatial analysis (Dimitriou et al., 2025).

Overall, this methodology integrates quantitative spatial modeling and qualitative institutional validation to produce robust, policy-aligned wind-energy suitability zones. By employing a province-wide GIS approach grounded in established renewable-energy siting literature, the study provides a replicable framework for identifying technically feasible, environmentally sound, and institutionally compliant wind-energy development sites in emerging regions. The approach not only contributes to methodological advancements in wind-farm siting but also supports evidence-based planning for renewable-energy expansion at the provincial scale.

RESULT

The results of this study present a comprehensive, province-wide assessment of the feasibility of wind-power development in Gorontalo Province through multi-criteria GIS analysis. The findings integrate technical, environmental, and policy-based spatial constraints to produce suitability classifications at multiple levels. Administrative Map of Gorontalo Province shown in Figure 1.

Figure 1. Administrative Map of Gorontalo Province

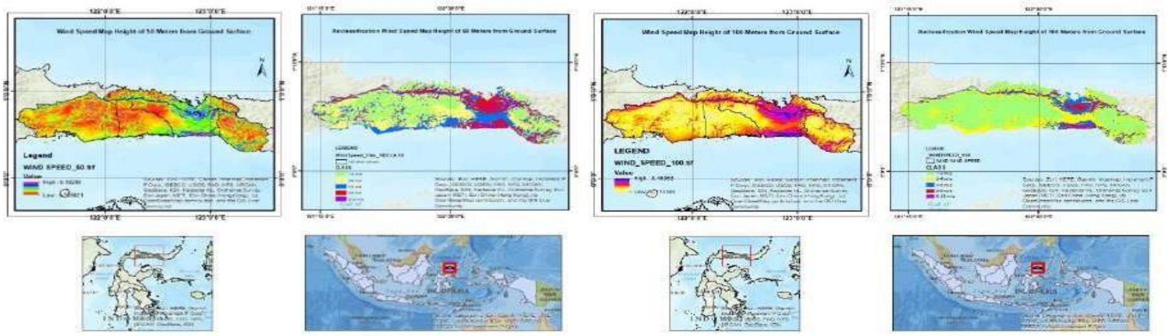
Description of Gorontalo Province

Wind speed represents the core determinant of wind farm feasibility. Reclassification results (Figure 2a and Figure 2b) show that wind speeds in Gorontalo range from 3–7 m/s, with ≥4 m/s serving as a minimum threshold for feasibility and ≥5 m/s representing optimal feasibility conditions. High-potential zones (≥6 m/s) are found primarily along the northern and southern coasts. A total of 15.72% of the province, equivalent to 189,023 ha, meets or exceeds the ≥5 m/s threshold. Removing wind-speed restrictions would significantly expand the feasible zones, but such an approach would violate established turbine performance requirements.

Spatial Criterion Maps and Foundational Layers

Wind Speed Distribution

Wind speed represents the core determinant of wind farm feasibility. Reclassification results (Figure 2a and Figure 2b) show that wind speeds in Gorontalo range from 3–7 m/s, with ≥4 m/s serving as a minimum threshold for feasibility and ≥5 m/s representing optimal feasibility conditions. High-potential zones (≥6 m/s) are found primarily along the northern and southern coasts. A total of 15.72% of the province, equivalent to 189,023 ha, meets or exceeds the ≥5 m/s threshold. Removal of wind-speed restrictions would significantly expand feasible zones, but such an approach would violate established turbine performance requirements.

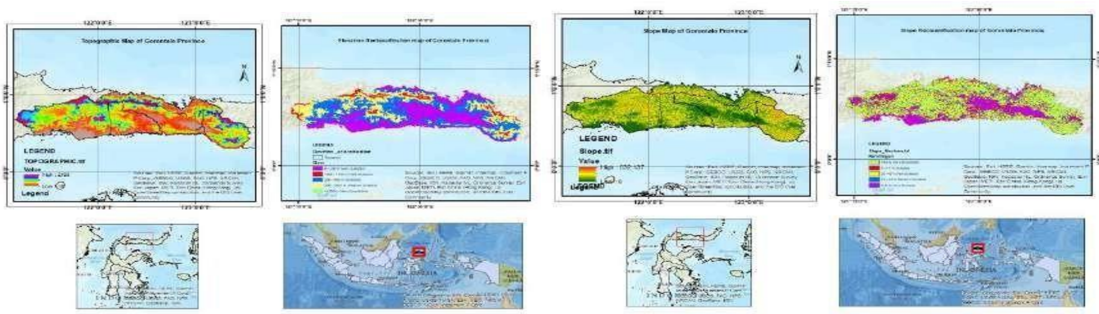


(a) (b)

Figure 2. Wind Speed Map & Reclassification Map; (a) Height of 50 Meters from Ground Surface; (b) Height of 100 Meters from Ground Surface;

Elevation and Slope

Elevation reclassification (Figure 3a and Figure 3b) indicates that mid-altitude regions possess higher suitability. These areas offer relatively stable terrain and avoid excessive turbulence effects associated with steep elevation gradients. Slope reclassification (Figure 4) identifies areas with an inclination of <15% as most suitable, consistent with international standards. Flat and moderately sloped terrain dominates Gorontalo's interior lowlands, particularly in the central and coastal regions, creating favorable conditions for the construction of turbine foundations and access roads.



(a) (b)

Figure 3. Topographic Map of Gorontalo Province & Reclassification map of Gorontalo Province; (a) Elevation reclassification Map; (b) Slope reclassification Map

Land Cover

Land cover (Figure 4) was reclassified according to suitability. Shrubs, open land, and mixed agriculture were categorized as the most feasible for development due to low conflict potential. Settlements, wetlands, and dense forest areas were classified as unsuitable. This classification helps avoid high-ecological-impact zones.

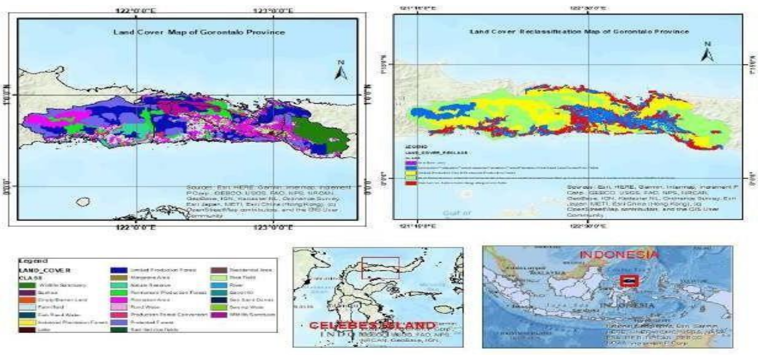


Figure 4. Land Cover Map & Reclassification Map of Gorontalo Province

Forest Area Status

Forest status analysis (Figure 5) divides areas into protected and non-protected zones. Protected forest zones received a score of 0, indicating they were entirely excluded from potential development. Non-protected zones received a score of 1 and were included in the weighted overlay.

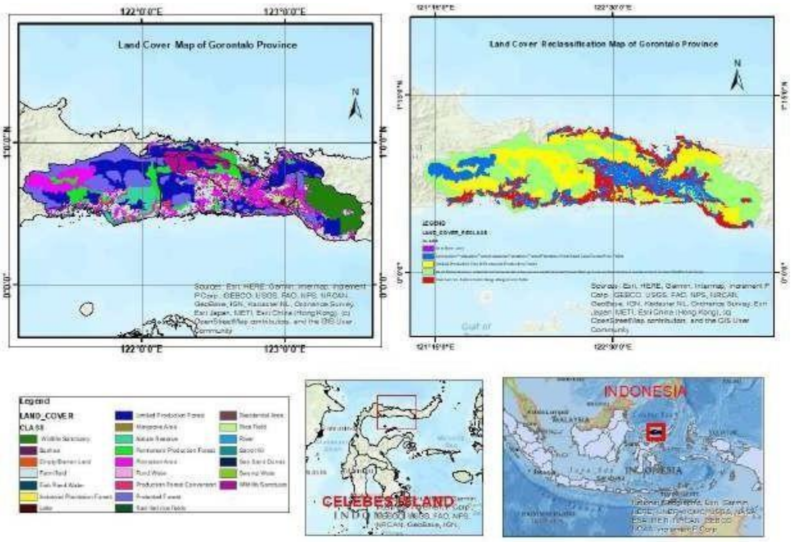


Figure 5. Forest Area Map & Reclassification Map of Gorontalo Province

Distance to Road Infrastructure

Road distance analysis (Figure 6) shows that suitability increases with proximity to roads meeting turbine-transport criteria. Buffers account for road widths>4 m and turning radii>30 m, ensuring that selected areas can accommodate the logistical requirements of turbine blade and tower delivery.

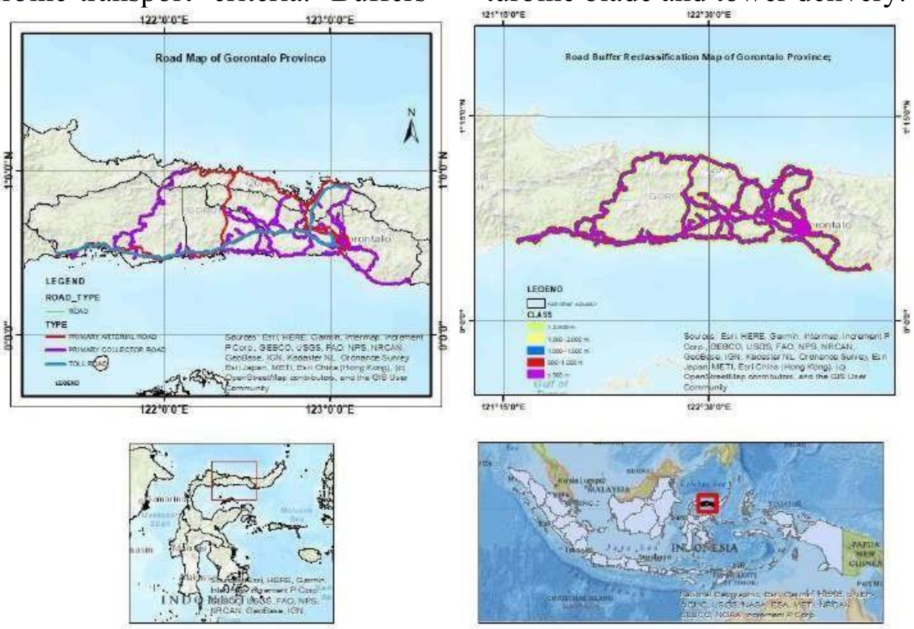


Figure 6. Road Buffer Map & Reclassification Map

Electricity Grid Proximity

Transmission grid buffers (Figures 7) classify areas near 70–150 kV SUTT lines as more suitable due to reduced transmission losses and lower infrastructure costs. Only 6.65% of Gorontalo is located within ≤1 km of transmission infrastructure. Removing grid constraints increases the feasible area by 329.4%, confirming grid proximity as the dominant limiting factor.

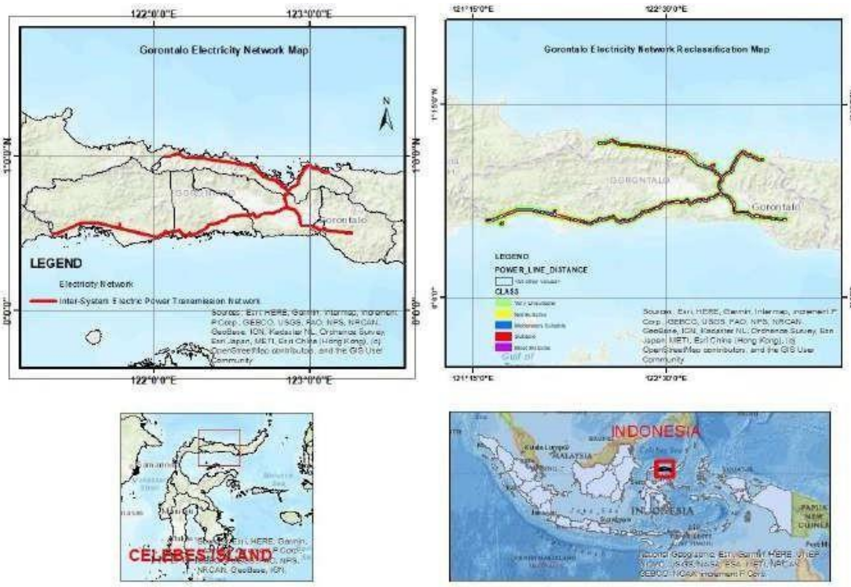


Figure 7. Gorontalo Electricity Network Map & Reclassification Map

Earthquake Hazard

Earthquake hazard values were reclassified using thresholds found in Figure 8. High-risk seismic zones were assigned the lowest suitability values. This ensures structural feasibility, given wind towers' sensitivity to ground acceleration.

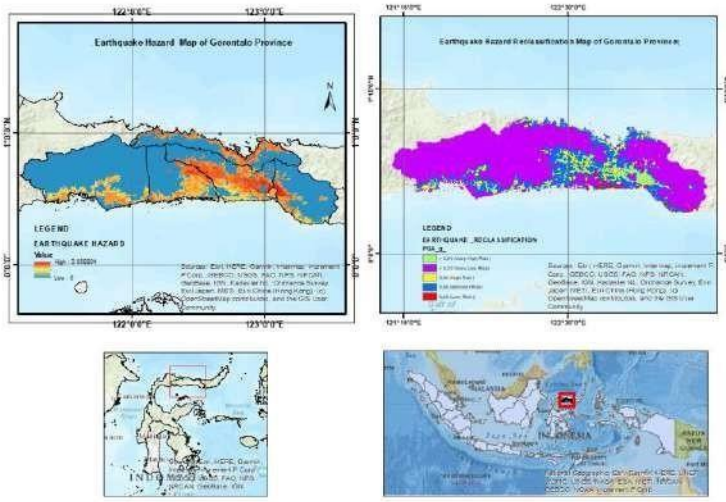


Figure 8. Earthquake Hazard & Reclassification Map

Multi-Criteria Weighted Overlay

The weighted overlay integrates eight spatial criteria: wind speed, slope, elevation, land cover, forest status, road distance, grid distance, and seismic hazard. Each criterion contributed equally to the final composite index. Tables 1 and 2 show the multi-criteria suitability output. The overlay produced three primary categories: unsuitable, suitable, and very suitable (Figures 10-11). The composite suitability map demonstrates a clear clustering of feasible sites, particularly in the northern and central provinces.

Table 1. Multi-Criteria Overlay Formation

Factor	Preference Direction	Weight (%)	Reclassification Criteria (1–5 suitability scale)
Wind speed	Higher wind speeds are preferred	30	≥6 m s⁻¹ = 5; 5–<6 m s⁻¹ = 4; 4–<5 m s⁻¹ = 3; <4 m s⁻¹ = 2; <3 m s⁻¹ = 1
Slope (terrain steepness)	Gentler slopes are preferred	12	0–5% = 5; >5–15% = 4; 15–25% = 3; >25–40% = 2; >40% = 1
Distance to transmission grid	Shorter distances are preferred	12	0–0.5 km = 5; >0.5–1 km = 4; 1–1.5 km = 3; 1.5–2 km = 2; >2 km = 1
Distance to road network	Shorter distances are preferred	10	0–0.5 km = 5; >0.5–1 km = 4; 1–1.5 km = 3; 1.5–2 km = 2; >2 km = 1
Land cover type	Open areas/agriculture preferred over forests/settlements	8	Open/bare land = 5; Plantation/agroforest = 4; Shrubland = 3; Secondary Forest = 2; Built-up areas = 1
Topography (elevation)	Moderate elevation preferred for logistics and wind stability	10	0–200 m = 5; >200–500 m = 4; 500–1000 m = 3; >1000 m = 2
Forest-area status	Non-forest > production forest > protected areas	10	Non-forest (APL) = 5; Convertible production forest (HPK) = 4; Permanent production forest (HPT) = 3; Conservation areas (KSA, KPA, HII, CA, national parks, nature reserves) = 1
Seismic hazard	Lower hazard levels are preferred	8	Very low = 5; Low = 4; Moderate = 3; High = 2; Very high = 1

Source: Denholm, P., et al. (2009); Ifkirne, S., et al. (2022); Islam, M., et al. (2022); Gavériaux, M., et al. (2019); Placide, L., & Lollchund, M. (2024); Rehman, S., et al. (2020)

Table 2. Multi-Criteria Overlay Output

No.	Administrative Region	Identified Locations	Suitability Category
1	**Gorontalo Regency**	Tibawa District: Labanu Village; Isimu Utara Village Tibawa District: Labanu, Buhu, Iloponu, Botumoputi, Isimu Utara, Mootilango, Baruwila, Bandua Villages (including Bua, Barakati, Iluta, Dunggala); Bandua Beach Village (Buhutadaa)	Very Suitable Suitable
2	**North Gorontalo Regency**	Monano District: Tolitehuyu Village Monano District: Dunu Village; most villages in Anggrek District (Ilangata, Putiana, Popalo, Tolango, Tutuwoto); Kwandang District (Molingkapoto, Leboto, Mootinelo, Alata Karya, Posso Villages)	Very Suitable Suitable
3	**Gorontalo City**	West City District: Dembe, Lekobalo, Bulotio, Pilolodaa, Tenda Subdistricts; Hulonthalangi District (Pohe) West City District: Dembe, Lekobalo, Tenilo, Bulila, Pilolodaa; Hulonthalangi District: Dunggalala, Pohe, Siendeng, Tenda; Kota Selatan District: Leato Selatan, Botu, Talumolo, Leato Selatan II	Very Suitable Suitable
4	**Bone Bolango Regency**	Botupingge District: Timbulolo Village; Bunta and Tanah Putih Areas	Suitable
5	**Boalemo Regency**	Bolihutuo Village; Tapadaa, Dulangeya, Botumoito, Potanga, Lamu, and Bongo Nol	Suitable

Source: Overlay results, 2025

(a) **(b)**

Figure 10. Feasibility Map of PLTB Development Locations; (a) Gorontalo Regency and North Gorontalo Regency; (b) Gorontalo City and Bone Bolango Regency

Figure 11. Feasibility Map of Wind Power Plant Development Locations in Gorontalo Province

3.5 Wind Power Plant (WPP) Suitability Zonation

Pre-Regional Spatial Planning results show that 12,743.36 ha fall into the "Suitable" category, while 113.8 ha fall into the "Very Suitable" category. These areas exhibit optimal combinations of wind speed, low slope, non-protected land cover, proximity to a grid, and low seismic risk. Following integration with the Regional Spatial Planning 2024, these figures decrease to approximately 7,300 ha of "Suitable" land and 63.97 ha of "Very Suitable" land. This reduction reflects legal zoning constraints. Priority locations for wind power development include: (1) Kwandang–Anggrek–Monano (North Gorontalo), (2) West Gorontalo City, and (3) Tibawa–Batudaa (Gorontalo Regency). Integration with Regional Spatial Planning confirms that all high-priority zones fall within Cultivation Area or compatible strategic areas. These zones do not intersect protected forests or other restricted-use designations. Regional Spatial Planning constraint maps further refine spatial outputs by eliminating legally incompatible zones. Compliance with Regional Spatial Planning ensures long-term policy feasibility for WPP development (Table 3).

Table 3. The feasibility of the location for the construction of a PLTB is based on the Gorontalo Province Regional Spatial Planning

No.	Administrative Region	Identified Locations	Suitability Category
1	**Gorontalo Regency**	Tibawa District: Labanu Village, North Isimu Tibawa District: Labanu, Buhu, Iloponu, Botumoputi, North Isimu, Mootilango, Tridarma Villages; Bandua District (Bua, Barakati, Iluta, Dunggala, Pilobuhuta Villages); Tabongo District (Tabongo Timur); Limboto Barat District (Ombulo, Padengo, and Haya-Haya Villages)	Very Suitable Suitable
2	**North Gorontalo Regency**	Anggrek District: Ilangata, Putiana, Tolango, Tutuwoto Villages; Kwandang District: Molingkapoto, Leboto, Mootinelo, Alata Karya, Posso, Masuru, Ombulo Data, Dambalo	Suitable
3	**Gorontalo City**	West Gorontalo District: Dembe, Lekobalo, Bulotio, Pilolodaa, Tenda Subdistricts; Hulonthalangi District (Pohe) West Gorontalo District: Dembe, Lekobalo, Tenilo, Bulila, Pilolodaa; Hulonthalangi District: Dunggalala, Pohe, Tenda; South Gorontalo District: Leato Selatan, Botu, Talumolo, Leato Utara	Very Suitable Suitable

4	**Bone Bolango Regency**	Botupingge District: Timbulolo Village, Bunta and Tanah Putih Areas; Suwawa Selatan District: Pancuran and Libungo Villages	Suitable
5	**Boalemo Regency**	Dulangeya Village; Hutamaro, Botumoito, Potanga, Lamu, and Lahumbo Villages	Suitable

Source: Overlay results, 2025

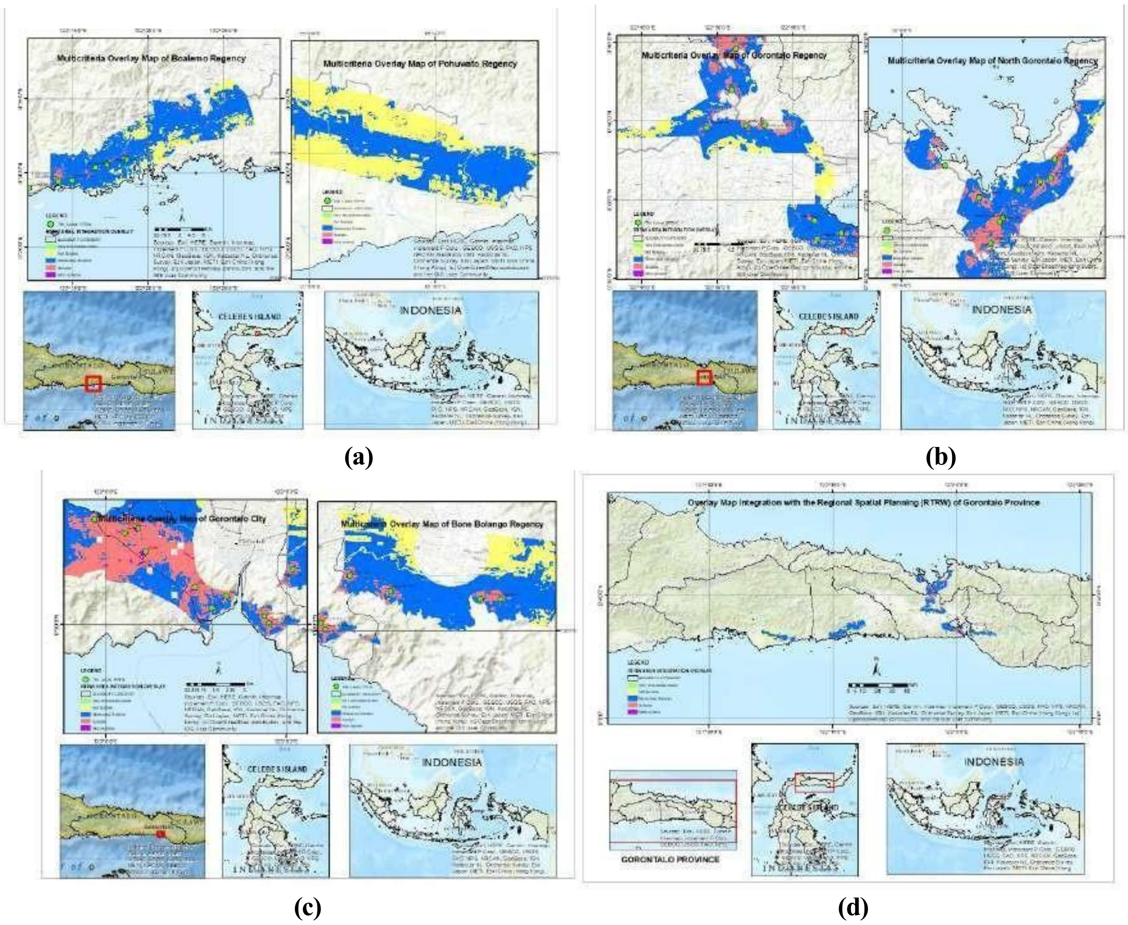


Figure 11. Map of Conformity with Regional Spatial Planning; (a) Boalemo & Pohuwato Regency; (b) Gorontalo & North Gorontalo Regency; (c) Gorontalo City & Bone Bolango Regency; (d) Gorontalo Province

Spatial validation was conducted at selected sites using GPS coordinates and photographic documentation (Figure 11). Field checks confirmed accuracy in land cover, access roads, topographic consistency, and general site conditions. Validation also indicated that modeled suitability zones correspond closely with on-the-ground environmental characteristics.

Policy validation confirms strong alignment with RUED 2019 goals, which aim to develop 5 MW of Wind Power Plant by 2025. Identified suitable zones also comply with the Regional Spatial Planning Articles 40–45 and 51. However, the Medium-Term Development Plan has not yet explicitly incorporated the Wind Power Plant, indicating a gap in current development planning.

Triangulation integrating spatial outputs, regulatory documents, and stakeholder interviews reveals strong technical feasibility but uneven policy integration. Although Regional Spatial Planning and RUED are compatible with Wind Power Plant development, broader institutional readiness, particularly in infrastructure investment and alignment with the Medium-Term Development Plan, requires strengthening. Nevertheless, the triangulation confirms that the identified zones are technically feasible, environmentally compliant, and policy-permissible.

Overall, the results demonstrate that Gorontalo Province has considerable wind-energy potential concentrated within specific corridors. Multi-criteria spatial analysis, combined with policy integration, reveals several zones suitable for immediate feasibility studies and investment consideration. The spatial outcomes provide a scientifically grounded, legally consistent basis for strategic planning of wind-power development in Gorontalo Province.

DISCUSSION

The findings of this study reveal that Gorontalo Province possesses a clear, spatially clustered potential for wind-power development, shaped by the interaction of biophysical resources, infrastructure readiness, and planning and policy constraints. The dominance of wind speed, transmission-line proximity, and terrain slope as primary determinants aligns with well-established theoretical and empirical frameworks in wind-energy siting, which consistently identify minimum wind thresholds of 4–5 m/s, adequate grid access, and slopes below 15% as prerequisites for viable turbine operation. In Gorontalo, 15.72% of the province meets the ≥5 m/s requirement, and high-wind corridors along the northern and southern coasts mirror coastal wind-channeling patterns observed globally. These characteristics indicate that the province holds technically robust pockets of wind potential suitable for medium-scale deployment.

However, the spatial feasibility of these areas is substantially constrained by infrastructural and institutional factors. Only 6.65% of the province lies within 1 km of the 70–150 kV transmission network, and removing this constraint increases potential development areas by 329.4%. This confirms that grid access, not wind availability, is the most significant bottleneck, consistent with international findings that transmission infrastructure often dictates economic viability more than resource quality. Field validation further confirmed that the modeled suitability zones accurately represent ground conditions, adding confidence to the spatial outputs as reliable early-screening tools.

Policy integration likewise plays a decisive role. After overlaying suitability results with the Regional Spatial Planning 2024, feasible areas shrink from 12,743.36 ha to approximately 7,300 ha, and very suitable areas from 113.8 ha to 63.97 ha. This reduction highlights the influence of regulatory zoning—particularly conservation and restricted-use designations- in determining where development can legally proceed. The finding that all priority sites fall within cultivation areas and compatible strategic areas suggests strong spatial policy alignment. Yet institutional readiness remains uneven: while RUED 2019 targets 5 MW of Wind Power Plant development, the Medium-Term Development Plan does not explicitly incorporate wind energy, indicating fragmented policy commitment.

Taken together, the results underscore both opportunity and challenge. Gorontalo's wind potential is technically feasible, spatially coherent, and largely compatible with current zoning regulations. Yet large-scale deployment will require targeted investment in transmission infrastructure and improved cross-agency coordination.

These findings contribute to renewable-energy siting scholarship by demonstrating the value of integrating multi-criteria GIS analysis with legal, institutional, and stakeholder-based validation. The study offers a replicable methodological framework for provinces facing similar data limitations and governance complexities, reinforcing the need for policy-coherent spatial planning to accelerate Indonesia's transition toward low-carbon energy systems.

CONCLUSION

This study demonstrates that Gorontalo Province possesses measurable and spatially coherent wind-energy potential, with suitability concentrated in coastal and mid-altitude corridors where wind speeds exceed 5 m/s, slopes remain below 15%, and infrastructure access is achievable. The multi-criteria GIS analysis combined eight spatial determinants: wind speed, slope, elevation, land cover, forest status, hazard levels, proximity to both roads and transmission lines, revealing that 12,743.36 ha were initially classified as suitable and 113.8 ha as very suitable. When integrated with the Regional Spatial Planning 2024 zoning framework, these values narrowed to approximately 7,300 ha and 63.97 ha, respectively, underscoring the decisive influence of policy constraints alongside technical feasibility. Wind speed, proximity to transmission lines, and slope emerged as the strongest suitability drivers.

The findings highlight that Gorontalo's wind-energy prospects are technically feasible and legally supported within several spatial clusters, particularly in Kwandang–Anggrek–Monano, West Gorontalo City, and Tibawa–Batudaa. However, grid limitations and incomplete institutional alignment—especially the absence of Wind Power Plant commitments in the Medium-Term Development Plan- remain barriers to large-scale deployment. By integrating technical, environmental, and policy layers, this study contributes to the growing body of literature emphasizing the necessity of policy-integrated spatial planning in renewable energy siting. Future research should explore micro-siting, grid expansion scenarios, and economic feasibility modeling to support full-scale development pathways.

Declaration by Authors

Acknowledgement: None

Source of Funding: None

Conflict of Interest: No conflicts of interest declared.

REFERENCES

1. Armstrong, H. E. (1931). The Paris Agreement. *Nature*, *127*(3207), 600–601. https://doi.org/10.1038/127600a0
2. BAPPEDA Provinsi Gorontalo. 2023. Rencana Tata Ruang Wilayah Provinsi Gorontalo 2024-2045. Gorontalo
3. Badan Meteorologi, Klimatologi dan Geofisika, BMKG. 2025. Global Wind Atlas.
4. Badan Nasional Penanggulangan Bencana, BNPB. (2022). *Dokumen kajian risiko bencana nasional provinsi gorontalo 2022 – 2026*.
5. Denholm Paul, Hand Maureen, Jackson Maddalena, & Ong Sean. (2009). Land-Use Requirements of Modern Wind Power Plants in the United States. *National Renewable Energy Laboratory*, *August*. http://www.osti.gov/bridge%0Ahttp://www.osti.gov/bridge%0Ahttps://www.nrel.gov/docs/fy09osti/45834.pdf
6. Díaz-Cuevas, P. (2018). GIS-based methodology for evaluating the wind-energy potential of territories: A case study from Andalusia (Spain). *Energies*, *11*(10). https://doi.org/10.3390/en11102789
7. Dimitriou, I. C., Sarmas, E., Trachanas, G. P., Marinakis, V., & Doukas, H. (2025). Multi-Criteria GIS-based offshore wind farm site selection: Case study in Greece. *Renewable and Sustainable Energy Reviews*, *207*(March 2024), 114962. https://doi.org/10.1016/j.rser.2024.11496 2
8. Eftekhari, H., Mahdi Al-Obaidi, A. S., & Eftekhari, S. (2022). Aerodynamic Performance of Vertical and Horizontal Axis Wind Turbines: A Comparison Review. *Indonesian Journal of Science and Technology*, *7*(1), 65–88. https://doi.org/10.17509/ijost.v7i1.43161
9. Gavériaux, L., Laverrière, G., Wang, T., Maslov, N., & Claramunt, C. (2019). GIS-based multi-criteria analysis for offshore wind turbine deployment in Hong Kong. *Annals of GIS*, *25*(3), 207– 218. https://doi.org/10.1080/19475683.2019.1 618393
10. Ge, M., Friedrich, J., & Vigna, L. (2024). *Where Do Emissions Come From? 4 Charts Explain Greenhouse Gas Emissions by Sector*. https://www.wri.org/insights/4-charts- explain-greenhouse-gas-emissions-countries-and-sectors
11. Ifkirne, M., El Bouhi, H., Acharki, S., Pham, Q. B., Farah, A., & Linh, N. T. T. (2022). Multi-Criteria GIS-Based Analysis for Mapping Suitable Sites for Onshore Wind Farms in Southeast France. *Land*, *11*(10).

https://doi.org/10.3390/land11101839

12. Islam, M. R., Islam, M. R., & Imran, H. M. (2022). Assessing Wind Farm Site Suitability in Bangladesh: A GIS-AHP Approach. *Sustainability (Switzerland)*, *14*(22). https://doi.org/10.3390/su142214819
13. Kementerian ESDM. (2022). SIARAN PERS tentang NOMOR: 8. Pers/04/SJI/2022 Urgensi Transisi Energi dalam Presidensi G20 Indonesia. *Media Center Kementerian ESDM*. https://www.esdm.go.id/id/media-center/arsip-berita/urgensi-transisi-energi-dalam-presidensi-g20-indonesia
14. Kusweanto, D. S., & Jebatu, E. M. (2024). *Wind Farming Optimal Location in Semarang City Through GIS*. *September*. https://doi.org/10.51742/pelita.v5i2.1140
15. Placide, G., & Lollchund, M. R. (2024). Wind farm site selection using GIS-based mathematical modeling and fuzzy logic tools: a case study of Burundi. *Frontiers in Energy Research*, *12*(April), 1–20. https://doi.org/10.3389/fenrg.2024.13533 88
16. Prasetyo, A. (2022). *Strategi Implementasi Ruen-Rued Untuk Mewujudkan Transisi Energi Di Indonesia*. *11*(1), 1–14. https://www.energihijau.id/wp-content/uploads/2022/03/Polbrief_ruen- dan-rued-1.pdf
17. Razeghi, M., Hajinezhad, A., Naseri, A., Noorollahi, Y., & Farhan Moosavian, S. (2023). Multi-criteria decision-making for selecting a solar farm location to supply energy to reverse osmosis devices and produce freshwater using GIS in Iran. *Solar Energy*, *253*, 501–514. https://doi.org/10.1016/j.solener.2023.01.029
18. Rehman, S., Baseer, M. A., & Alhems, L. M. (2020). GIS-Based Multi-Criteria Wind Farm Site Selection Methodology. *FME Transactions*, *48*(4), 855–867. https://doi.org/10.5937/fme2004855R
19. Said, S. M., Akil, Y. S., Muzakir, M. H., Said, S. M., Akil, Y. S., & Muzakir, M. H. (2019). GIS approach for wind power plant development in South Sulawesi, Indonesia: A location suitability analysis. *AIPC*, *2097*(1), 030085. https://doi.org/10.1063/1.5098260
20. Sekretaris Daerah Provinsi Gorontalo. (2019). Peraturan Daerah Provinsi Gorontalo No 7 tahun 2019 tentang Rencana Umum Energi Daerah (RUED).
21. Suci, F. R. Z., & Muhamad, I. B. (2024). Land Suitability for Wind Farm Development in Pandeglang Regency, Banten Province, Indonesia. *Kompleksnoe Ispolzovanie Mineralnogo Syra*, *337*(2), 55–65. https://doi.org/10.31643/2026/6445.17
22. United Nations Development Programme. (2023). *Sustainable Development Goals (SDGs)*. *September*. https://doi.org/10.18356/e3cede1b-en

How to cite this article: Sudarmantao Hasan, Fitryane Lihawa, Lanto Moh. Kamil Amali. Spatial multi-criteria assessment of wind-energy feasibility in Gorontalo Province. *International Journal of Research and Review*. 2025; 12(12): 560-574. DOI: *10.52403/ijrr.20251260*

******