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# Modeling the Potential of Wind Power Plants in Kupang Regency Based on Weighted Overlay and Remote Sensing

**Muhammad Fauzan Fadilah*, Ai Sulastri, Rahman Firmansyah, Fikri Algifahri**
*Program Studi Sains Informasi Geografi, Universitas Pendidikan Indonesia, Bandung, Indonesia*
*Correspondance: mfauzanfadilah12@upi.edu*

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***Abstract***

*Kupang Regency has significant wind energy potential, offering opportunities for wind farm development to address electricity shortages and support the transition to green energy. This study aims to analyze the wind energy potential in Kupang Regency for wind farm development. The weighted overlay method used integrates various criteria to determine the feasibility of recommended locations. Parameters such as wind speed, elevation, and land use were processed using Geographic Information Systems (GIS) technology. The results indicate that the southern and northern regions of Kupang Regency are optimal for wind farm development, considering high wind speeds (6 m/s), suitable land use (shrublands or sandy areas), and favorable elevation (highlands). The integrated analysis identified moderately potential, potential, and very potential zones covering 108,734.20 ha, 53,391.24 ha, and 7,198.73 ha, respectively. These findings are expected to serve as a reference for effective renewable energy planning and help address the energy crisis in the region.*

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***Abstrak***

*Kabupaten Kupang memiliki potensi energi angin yang signifikan, sehingga menawarkan peluang untuk membangun pembangkit listrik tenaga angin guna mengatasi kekurangan listrik dan mendukung transisi energi hijau. Penelitian ini bertujuan untuk menganalisis potensi energi angin di Kabupaten Kupang untuk pengembangan ladang angin. Metode yang digunakan adalah weighted overlay, yang mengintegrasikan berbagai kriteria untuk menentukan kelayakan lokasi yang direkomendasikan. Parameter seperti kecepatan angin, ketinggian, dan penggunaan lahan diproses menggunakan teknologi Sistem Informasi Geografis (SIG). Hasil penelitian menunjukkan bahwa wilayah selatan dan utara Kabupaten Kupang merupakan area yang optimal untuk pengembangan ladang angin, dengan mempertimbangkan kecepatan angin yang tinggi (6 m/s), penggunaan lahan yang sesuai (semak belukar atau zona pasir), serta ketinggian yang mendukung (dataran tinggi). Analisis terpadu mengidentifikasi zona cukup potensial, potensial, dan sangat potensial masing-masing seluas 108.734,20 ha, 53.391,24 ha, dan 7.198,73 ha. Temuan ini diharapkan dapat menjadi acuan dalam perencanaan energi terbarukan yang efektif serta membantu mengatasi krisis energi di wilayah tersebut.*

## INTRODUCTION

Indonesia has significant potential for wind power plant (WPP) development due to its extensive coastline, stretching approximately 81,000 km, and an average annual wind speed of 3–5 m/s, with certain locations reaching 8–10 m/s. The government, through the National Energy Policy, has set a target for renewable energy to contribute 17% of the national energy mix by 2025, later strengthened to 23% in the same year. Among various renewable energy sources, wind energy holds a strategic position as an environmentally friendly, inexhaustible, and relatively low-cost option compared to other renewable technologies (Aditya et al., 2025). Nevertheless, the national contribution of wind energy remains low due to technological and infrastructural limitations, as well as fluctuations in wind direction and speed. Kupang, as part of East Nusa Tenggara (NTT) Province, is one of the regions with the highest wind energy potential in Indonesia. Several locations in NTT, including Kupang, record average wind speeds above 8 m/s at a height of 50 meters. This finding aligns with Pambudi et al. (2025), who reported that Indonesia's wind energy potential reaches 154.9 GW, with NTT identified as one of the priority regions (Gatya et al., 2024).

Kupang's geographical position on the southern coast of Timor Island exposes it directly to consistent ocean winds, making it an ideal candidate for WPP development. However, the electrification ratio in eastern Indonesia, including NTT, remains relatively low, forcing many communities to rely on costly diesel generators that cannot operate continuously. In this context, renewable energy sources such as wind and solar become crucial alternatives to improve energy access and reduce dependency on fossil fuels (Helmiyatinnisa et al., 2024).

In comparison with other renewable sources, solar energy has experienced more rapid adoption in Southeast Asia due to its abundant irradiation levels, which range from 4 to 5 kWh/m²/day (Smith et al., 2024). Vietnam, for instance, has been recognized as having solar potential of up to 300 GW, making solar the dominant renewable energy technology in the region (Riva Sanseverino et al., 2020). However, wind energy provides complementary advantages, particularly in coastal and island regions, where strong and consistent wind resources can offset solar intermittency.

Despite its vast potential, the development of WPPs in Kupang faces several challenges. Accessibility, hilly topography, and dispersed settlement patterns are major constraints. A study by Yulianto et al. (2019) in East Sumba revealed that even with abundant renewable energy resources (solar, hydro, biomass, wind, and biogas), the region's energy security index was only 5.91, categorized as low, primarily due to limited energy affordability and inadequate supporting infrastructure. In the case of NTT, although the regional government and Indonesia State Electricity Corporation have initiated pilot renewable energy programs, including small-scale hybrid solar wind projects, implementation is often hindered by regulatory barriers and insufficient coordination across institutions. Moreover, social challenges remain significant. Community acceptance, electricity usage culture, and land acquisition issues frequently influence project outcomes, especially in dispersed rural settlements where energy needs are highly localized and traditional reliance on diesel generators persists (Sinaga et al., 2017). Without addressing these institutional and socio-cultural dimensions alongside infrastructure and financing, the large-scale integration of wind power in Kupang may face considerable delays.

Previous studies have provided technical insights into WPP development in NTT. Tjahjono & Setiawaty (2017) conducted a simulation and optimization of a diesel wind hybrid system on Timor Island, including Kupang, using HOMER software, and found that wind energy contributed between 7–22% under optimal scenarios, with an electricity cost ranging from USD 0.47–0.53/kWh. Suharta et al. (2011) designed a wind farm in Oelbubuk, South Central Timor, with a configuration of 10 turbines totaling 3.3 MW, producing 10.54 GWh of net annual energy and a capacity factor of 36.4%. Both studies concentrated on technical performance and cost modeling, without incorporating spatial planning considerations, environmental and social dimensions, or explicitly addressing regulatory and infrastructural limitations that influence feasibility in NTT.

Building on the limited technical focus of previous studies that did not incorporate spatial planning, environmental, and social consider-

ations, assessing the wind energy potential in Kupang becomes strategically important to address both scientific and practical challenges in the clean energy transition. This research aims to evaluate and map wind energy potential in Kupang Regency by integrating wind speed, topography, and land use parameters through a multi-criteria GIS approach. The novelty of this study lies in applying a spatially explicit, multi-criteria framework that bridges technical assessment with spatial planning dimensions, thereby extending beyond conventional techno-economic analyses. The findings are expected not only to provide a scientific basis for identifying optimal WPP locations but also to inform policymakers and investors in decision-making and contribute to the development of sustainable, renewable energy infrastructure in the region.

## METHOD

This research is located in Kupang Regency, an administrative region in East Nusa Tenggara Province, Indonesia, which plays a strategic role in the eastern part of the country. The regency is bordered by the Timor Sea to the north and the Indian Ocean to the south, offering diverse geographical features ranging from coastal areas to mountainous terrain. Covering an area of approximately 5,890 km² with a topography dominated by hills, Kupang Regency holds significant potential for the development of wind energy infrastructure. The specific location is illustrated in Figure 1.

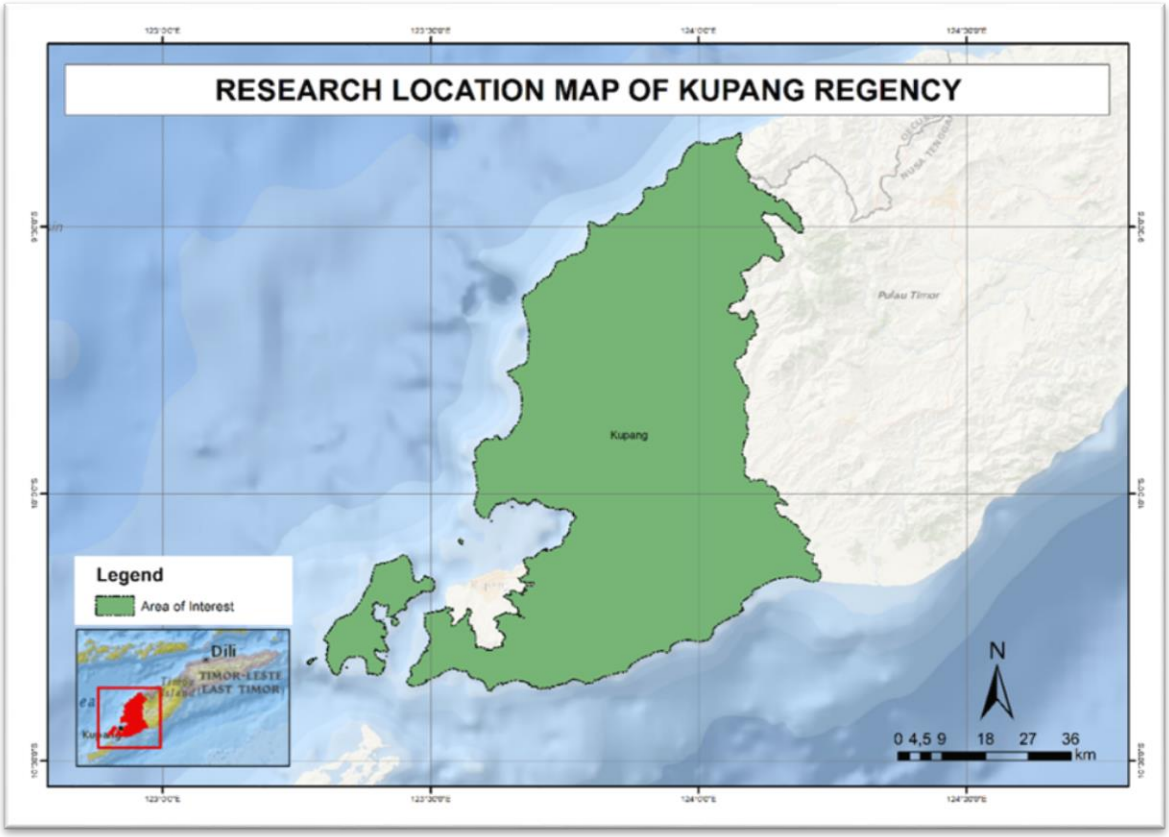


**Figure 1.** Location Map of Kupang Regency

### Data

This study utilized several reference parameters to assess site suitability for WPP development, including elevation, land use, and wind speed maps (Rendra & Yasri, 2016). Elevation data were derived from the DEMNAS dataset obtained from the Geospatial Information Agency, with a spatial resolution of 5-8 meters, to evaluate topographic conditions affecting wind flow and turbine placement. Land use data, also sourced from the Geospatial Information Agency, were used to identify areas compatible with wind farm construction. Wind speed data were obtained from the Global Wind Atlas to determine potential energy availability and identify high-wind zones suitable for development. A summary of the datasets and their respective sources is presented in Table 1.

**Table 1.** Data Research

| Data | Type | Resolution/Scale | Year | Source |
|---|---|---|---|---|
| Regency Administrative Boundary | Vektor | 1:25.000 | 2024 | BIG, 2024 |
| Landuse | Vektor | 1:25.000 | 2024 | BIG, 2024 |
| DEMNAS Data | Raster | 30 m | 2023 | BIG, 2024 |
| Wind Speed Data | Raster | 250 m x 250 m | 2024 | Global Wind Atlas, 2024 |

### Analysis Data

The site suitability analysis for WPP development was carried out using the Weighted Overlay approach within a Geographic Information System (GIS) framework. This method combines two main stages: scoring and weighting. Scoring is an assessment technique that assigns values to each parameter class based on predetermined criteria, reflecting the degree of suitability for the analysis objectives (Sholikhan et al., 2019). In this study, scoring was applied to wind speed, elevation, and land use. Weighting was used to assign different levels of importance to each parameter according to its influence on site feasibility, with the highest weight given to wind speed, followed by elevation and land use (Muhamad, 2015; Arca & Keskin Citiroglu, 2022). The data processing stages in this study are presented in Figure 2 below.

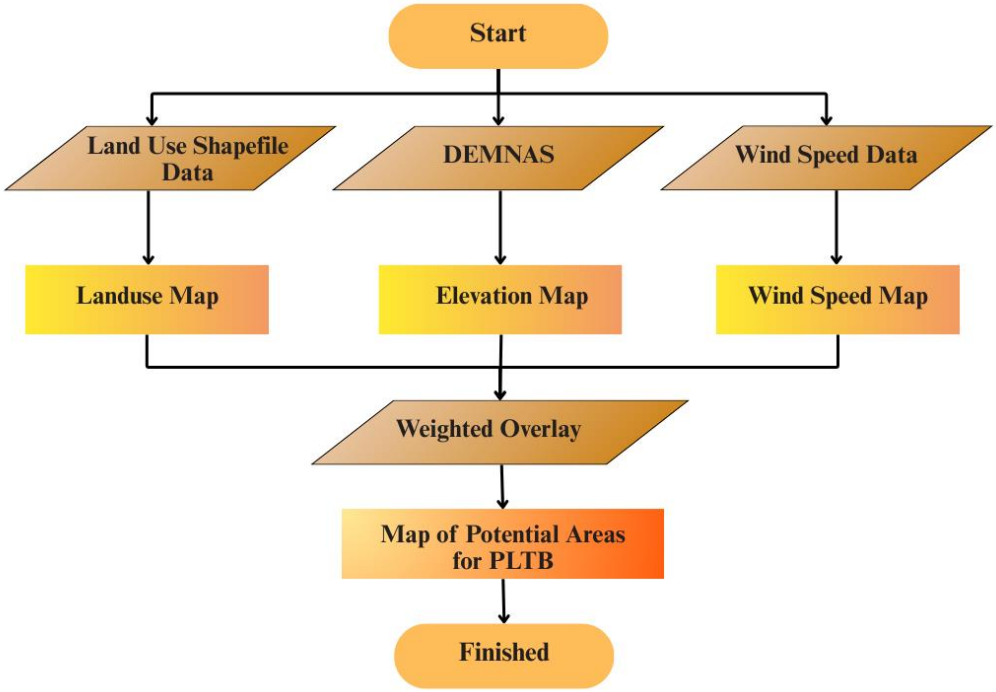


**Figure 2.** Research Flow Chart

## RESULT AND DISCUSSION

### Elevation of Kupang Regency

The elevation distribution of Kupang Regency ranges from coastal lowlands at 0 -200 masl to highland areas exceeding 1,400 meters, with the northern part exhibiting significant variability where high-altitude zones dominate between 801-1,200 meters and small pockets surpass 1,400 meters. As shown in Figure 3, these elevated regions, particularly in the central-northern area, are strategically important for WPP development because higher altitudes are often associated with stronger and more consistent wind speeds due to reduced surface friction and orographic effects (Nabil et al., 2024). In contrast, the southern and western coastal zones, characterized by lower elevations, may experience relatively weaker wind speeds but can remain viable for development when combined with favorable land use conditions and proximity to transmission infrastructure. This spatial variation in elevation provides critical input for incorporating topographic parameters into the multi-criteria assessment for identifying suitable WPP sites. The results of the Kupang Regency elevation map are shown in Figure 3.

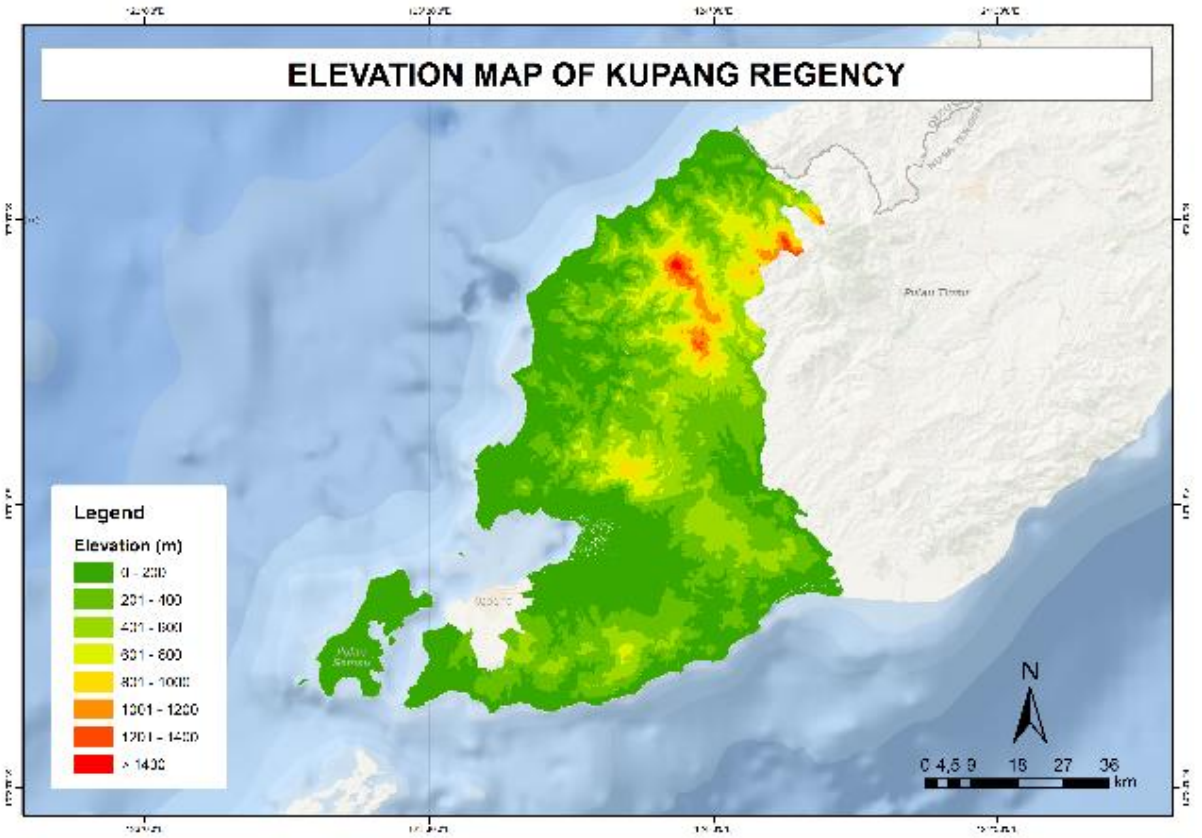


**Figure 3.** Elevation Map of Kupang Regency

## Land Use of Kupang Regency

The land use distribution in Kupang Regency is characterized by a mosaic of forests, shrublands, agricultural areas, and settlements, with significant coverage of grassland and mixed crops in both coastal and inland zones. As depicted in Figure 4, extensive shrubland and grassland areas, particularly in the northern and eastern parts of the regency, provide favorable conditions for WPP development due to minimal obstruction to wind flow and lower land conversion costs compared to densely forested or urbanized areas. Plantation zones and vacant lands scattered across the region also offer potential for infrastructure placement, while rice fields and mangrove forests may require exclusion due to ecological sensitivity and land-use restrictions. Settlement clusters are concentrated near the western and southern coasts, which could influence site selection through proximity to electricity demand centers and existing transmission lines. Integrating this spatial land use data with wind speed and elevation parameters supports a more comprehensive multi-criteria assessment for identifying optimal WPP locations.

## Wind Speed of Kupang Regency

The wind speed distribution in Kupang Regency shows a clear spatial gradient that strongly influences the feasibility of WPP development. As illustrated in Figure 5, the highest wind speeds, exceeding 6 m/s and reaching up to 8–10 m/s in some localized areas, are predominantly found along the southern coastal zone, the adjacent small islands, and certain elevated ridgelines in the central and southeastern parts of the regency. These areas offer high wind energy potential due to consistent exposure to oceanic winds and minimal topographic obstruction. In contrast, the northern and inland regions generally exhibit lower wind speeds of around 2-4 m/s, which are less favorable for large-scale wind energy generation (Sinaga et al., 2017). The concentration of high wind speed zones in open coastal and elevated landscapes makes them priority areas for WPP development when integrated with suitable land use and accessibility. The spatial pattern observed emphasizes the critical role of wind speed as the dominant parameter in determining optimal sites for wind energy infrastructure in Kupang.

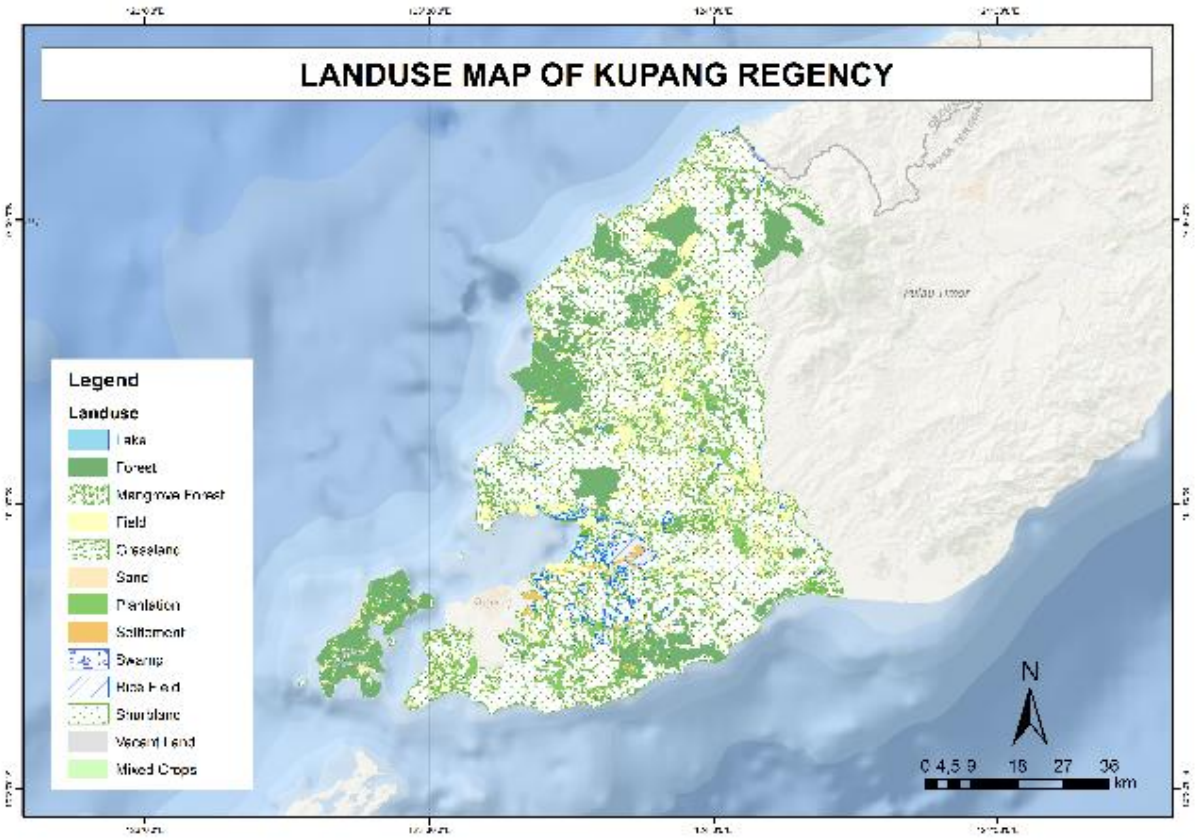


**Figure 4.** Landuse Map of Kupang Regency

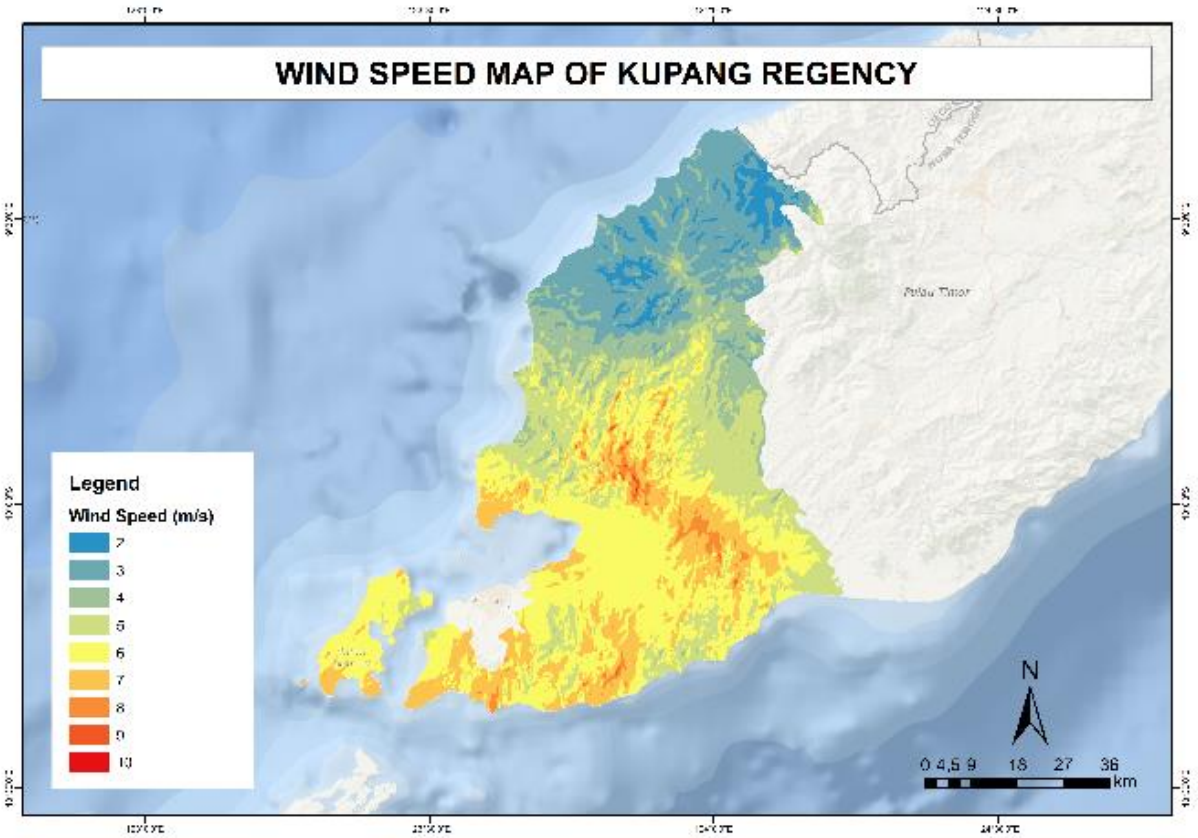


**Figure 5.** Wind Speed of Kupang Regency

The spatial variation of wind speed across Kupang Regency indicates significant differences between coastal and inland areas. Higher wind speeds, between 7 and 10 m/s, are concentrated in the coastal regions to the south and west as well as in elevated regions, as seen in Figure 5. In contrast, wind speeds in the northern regions are often lower, ranging from 2 to 5 m/s. This distribution highlights the strong potential of coastal and upland areas for wind energy development.

## Wind Energy Potential of Kupang Regency

Based on Figure 6, the moderately potential wind energy areas, shown in yellow and covering approximately 108,734.20 hectares (Table 2), are widely distributed across Kupang Regency, with a strong concentration in the southern and southwestern lowland regions. These zones, dominated by shrubland and grassland, typically experience average wind speeds of approximately 6 m/s and are typically located near coastal zones, making them relatively easy to access. As a result, they are considered suitable for the development of small to medium-scale wind power plants, although their efficiency tends to be lower than that of upland regions due to comparatively weaker wind speeds.

The potential class, represented in red and covering 53,391.24 hectares, is more concentrated in the northern foothills and several central inland areas, where elevation reaches around 400 meters above sea level, producing average wind speeds of about 7 meters per second. These areas benefit from the orographic effect, which increases wind velocity as air moves over rising terrain. Compared with previous studies (e.g., Suharta et al., 2011; Tjahjono & Setiawaty 2017), the estimated 7 m/s wind speed in this zone is consistent with their model results, confirming its reliability for energy yield analysis. For utility-scale wind farm development, such wind conditions are thought to be closer to the international standard threshold. However, because of the more complicated topography, challenging accessibility, and requirement for cutting-edge construction techniques, infra-structure development in these highland areas may require greater investment costs.

The highly potential wind energy zones, shown in blue and occupying 7,198.73 hectares, are primarily located in the elevated highlands of central and northern Kupang Regency, including mountain peaks exceeding 1000 meters in elevation, where wind speeds surpass 8 meters per second. These high-potential regions have the highest energy yield; they present substantial development challenges, particularly in relation to steep topography, environmental preservation, and limited access to the existing State Electricity Company grid. While these areas could serve as long-term opportunities, their practical implementation requires careful cost–benefit analysis, social–environmental assessment, and alignment with the regional energy development strategy of East Nusa Tenggara, which prioritizes renewable energy integration into the provincial electricity mix.

The suitability of wind energy areas in Kupang Regency depends not only on wind speed but also on accessibility, topography, land availability, and grid connectivity. Moderately potential zones (6 m/s) in coastal and lowland areas offer easier access, flatter terrain, and proximity to settlements and the State Electricity Company's grid, making them attractive for small- to medium-scale or community-based projects. On the other hand, resources in potential and highly potential upland zones (7–8 m/s) are closer to utility-scale standards but face challenges such as steep terrain, construction difficulties, and lack of transmission lines, requiring careful cost–benefit consideration.

These findings can help the State Electricity Company and local governments prioritize upland areas for long-term strategic investment and lowland areas for short-term distributed-scale initiatives. Future research with ground-based data, longer time series, and stakeholder viewpoints is necessary, as this study is constrained by its reliance on spatial modeling without thorough field validation, seasonal wind variability, or socio-environmental aspects.

**Table 2.** Wind Energy Potential Area of Kupang Regency

| Classification | Area (ha) |
|---|---|
| Moderately Potential | 108,734.20 |
| Potential | 53,391.24 |
| Highly Potential | 7,198.73 |

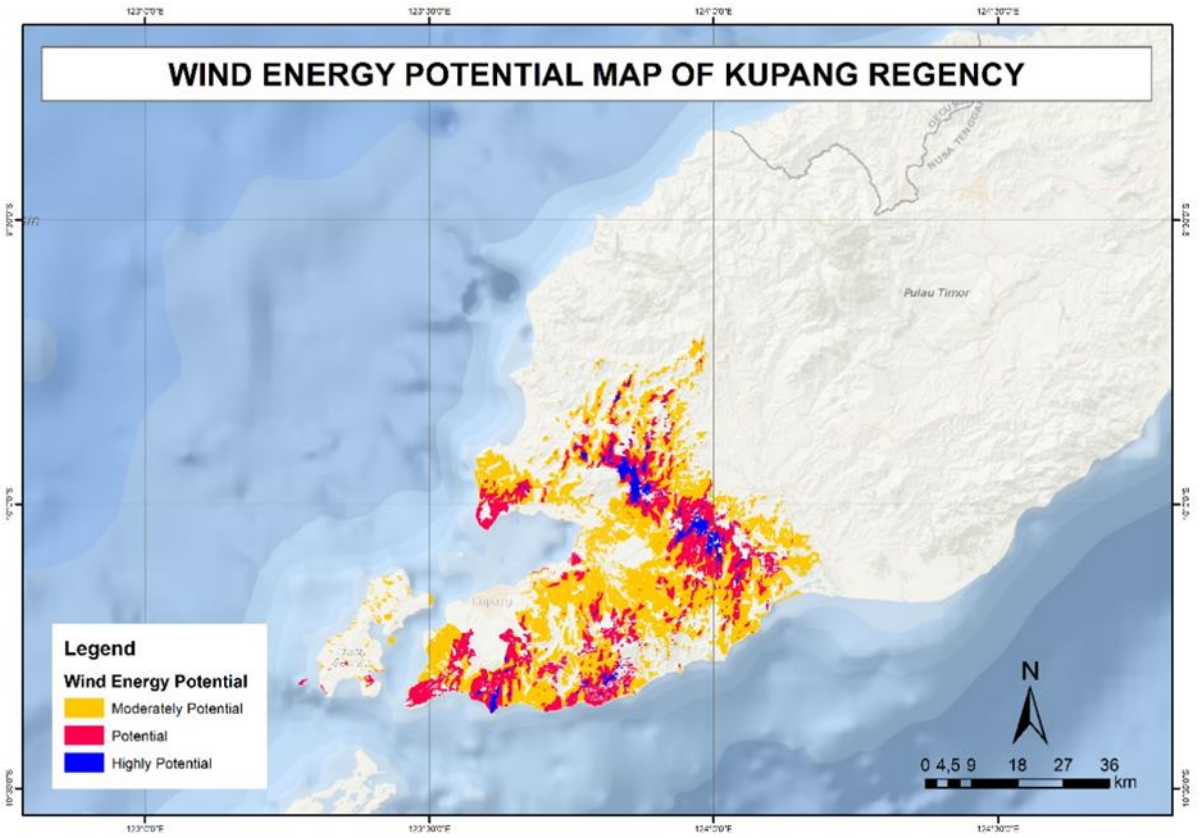


**Figure 6.** Wind Energy Potential Map of Kupang Regency

## CONCLUSION

Kupang Regency presents a diverse range of wind energy potential influenced by variations in elevation, land use, and wind speed. Elevation ranges from 0-200 meters in coastal lowlands to over 1,400 meters in highland areas, with the northern region dominated by uplands between 801-1,200 meters and small peaks above 1,400 meters, creating favorable conditions for strong and consistent winds. Land use patterns show that extensive shrubland and grassland, particularly in northern and eastern zones, minimize wind flow obstructions and lower land conversion costs, supporting wind power plant (WPP) feasibility. Wind speed distribution further emphasizes the southern coastal areas, adjacent islands, and elevated ridgelines in central and southeastern regions as priority zones, with recorded speeds exceeding 6 m/s and peaking at 8–10 m/s, compared to the northern and inland areas where speeds average only 2-4 m/s.

The integrated analysis of these parameters identifies 108,734.20 ha as moderately potential zones, 53,391.24 ha as potential zones, and 7,198.73 ha as highly potential zones for wind energy development. Moderately potential areas, mainly in the south and southwest lowlands, offer accessibility advantages but may generate lower output due to average wind speeds around 6 m/s. Potential zones, concentrated in northern foothills and central inland regions at 400 m elevation, benefit from wind speeds of about 7 m/s and orographic effects. Highly potential areas, although limited in size, are located in central and northern highlands above 1,000 m elevation and can achieve wind speeds exceeding 8 m/s, offering the highest energy yield. However, these topographically challenging sites may require higher investment and specialized infrastructure, underscoring the importance of a balanced approach that combines accessibility, wind resource quality, and land suitability for optimal WPP site selection.

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