An Assessment of Wind Energy Generation Potentials in Jos, Plateau State, Nigeria.

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Abstract
The demand for sustainable and clean energy has increased the need for renewable and eco-friendly energy such as wind energy in Nigeria. The potential to generate wind energy may vary from one region to another. The information on the potential to generate wind energy is largely unavailable in Nigeria, thereby limiting the generation of wind energy and underutilization of environmental resources that could use for wind energy generation particularly in highland regions such as Jos Plateau that are considered favorably disposed to powerful wind movement. This study assessed wind energy generation potential of Jos, Plateau State, Nigeria, with focus on the influence of terrain characteristics and land use/land cover on wind speed and site suitability. The objectives of the study are, to analyze spatial variations in wind speed and direction across different elevations, slopes, and landforms in Jos, to assess the influence of land surface characteristics such as slope aspect, surface roughness, and land use types on wind energy availability, to develop wind energy potential maps using GIS and remote sensing tools, integrating topographic and meteorological data, to identify and recommend optimal locations for wind turbine siting in Jos based on multi-criteria terrain suitability analysis. Digital Elevation Model (DEM) data, and Landsat satellite imagery were analyzed using Geographic Information Systems (GIS) software, ArcGIS, alongside remote sensing techniques. Land use/land cover classification, wind speed maps, and terrain maps (elevation, slope, and aspect) were generated and integrated using a weighted overlay multi-criteria decision analysis (MCDA) to produce a wind energy suitability map. The results showed that about 69.1% of the study area is characterized by gentle slopes (0–7°), which is suitable for turbine installation, while steeper slopes are limited. Aspect analysis revealed a dominance of east- and west-facing slopes, which favour prevailing wind flow. Elevation analysis indicated that a large portion of the plateau lies between 1,101 m and 1,300 m, with about 36.5% of the area above 1,301 m, contributing to higher wind speeds due to terrain-induced acceleration. The average wind speed across the study area ranged between 3.0 m/s and above 5.0 m/s, with moderate wind speeds (4.1–5.0 m/s) covering 35.9% of the area and high wind speed zones (>5.0 m/s) accounting for 22.2%, mainly along ridgelines in areas such as Jos East and Bassa. Lower wind speeds (<3.0 m/s) were confined to valleys and sheltered areas. Land use analysis revealed that grasslands (about 41.5%) and low-density agricultural lands provide the most suitable surfaces for wind energy development due to low surface roughness, while forests and built-up areas reduce wind speed and are less suitable. The suitability analysis indicated that approximately 22.5% of the study area is highly suitable for wind energy development, while 34.3% is suitable, with favourable locations concentrated in elevated and open areas such as Riyom, Barkin Ladi, Jos East, and parts of Bassa.

Keywords: *Wind energy potential; GIS; Land use/land cover; Wind speed distribution; Terrain analysis; Renewable energy.*

Introduction

Nigeria's energy sector is characterized by unreliable electricity supply, heavy dependence on fossil fuels, and frequent grid failures (Oyedepo et al., 2022). Despite the country's significant renewable energy potential, wind energy remains largely underutilized due to limited data availability, weak infrastructure, and inadequate site-specific studies. National wind resource assessments in Nigeria often rely on sparse meteorological data and low-resolution mapping, which do not adequately capture micro-scale terrain variations that influence wind behavior (Adebayo et al., 2023). As the global demand for clean and sustainable energy continues to rise, there is increasing pressure to reduce reliance on fossil fuels due to its contribution to greenhouse gas emissions, environmental degradation, and resource depletion. In line with the demand for clean and sustainable energy, renewable energy technologies have gained global attention as viable alternatives way of generating sustainable energy. Among these alternatives, wind energy has emerged as one of the most promising and cost-effective renewable energy sources (International Renewable Energy Agency [IRENA], 2023).

Globally, the development of wind mill power generation has experienced remarkable growth over the past decade. According to the International Renewable Energy Agency (IRENA, 2023), total installed wind energy capacity exceeded 837 gigawatts (GW) by 2022, representing an annual growth rate of approximately 9 percent. This rapid expansion is largely driven by technological advancements, declining turbine costs, improved energy conversion efficiency, and the environmental benefits of wind energy, particularly its minimal greenhouse gas emissions (Global Wind Energy Council [GWEC], 2023). However, the development and efficiency of wind energy systems are highly location-specific, as wind resources vary considerably across geographic landscapes.

The viability of wind power generation depends significantly on several physical and environmental factors, including topography, elevation, slope, land use, and surface roughness. These factors influence wind speed, direction, turbulence intensity, and ultimately the energy output of wind turbines (Zhao et al., 2022). The configuration of the land surface plays a crucial role in determining the availability and reliability of wind resources. Features such as elevation, slope, aspect, and terrain morphology interact with atmospheric processes to shape wind regimes across different environments. Elevated terrains, including ridges and escarpments, often experience stronger and more consistent wind flows due to orographic lifting and funneling effects (Mousavi et al., 2023). In contrast, low-lying landscapes or densely vegetated areas tend to exhibit reduced wind velocities and higher turbulence levels as a result of surface roughness, frictional drag, and physical obstructions that disrupt airflow (Manwell et al., 2010; Burton et al., 2021).

Understanding these terrain-related influences is therefore essential for accurate wind resource assessment and efficient wind farm planning. Without such knowledge, wind turbines may be installed in unsuitable locations, resulting in reduced energy yield, increased operational costs, and shorter turbine lifespan (Güney et al., 2022). In many developing regions, particularly in Sub- Saharan Africa, wind energy development remains limited due to insufficient site-specific assessments and weak integration of geospatial analysis into energy planning.

One of the under-explored region in terms the capacity to support generation of wind energy is Jos, the capital of Plateau State in Nigeria's North-Central region. Climatic data have indicated the occurrence of moderate to strong winds in the region, particularly during the dry season and harmattan period (Ajayi et al., 2011). However, despite these favorable environmental conditions, comprehensive empirical evaluations of wind energy potential within the Jos Plateau remain limited. The varying surface conditions exert different influences on wind speed, turbulence, and overall wind energy potential. Terrain-induced turbulence may affect turbine performance, mechanical fatigue, and operational efficiency, making it necessary to integrate both landform and surface characteristics into wind farm site selection and planning processes (Sharma et al., 2022).

Despite Nigeria's vast renewable energy potential, the development and utilization of wind energy have remained limited due to technical, policy, and data-related constraints. One of the most significant challenges is the inadequate understanding of how local terrain and land characteristics influence wind flow patterns, especially in regions with complex topography such as the Jos Plateau (Oyedepo et al., 2022). Most existing wind resource studies in Nigeria rely on large-scale meteorological data or satellite reanalysis datasets with low spatial resolution. Such datasets often fail to capture localized variations in wind patterns caused by differences in elevation, slope, and land cover (Aliyu et al., 2021; Adaramola & Agelin Chaab, 2021). Consequently, wind energy planning and development in many parts of the country remain largely speculative.

This lack of localized and empirical wind resource data limits both academic understanding and policy development in Nigeria's renewable energy sector. It also discourages private sector investment due to uncertainties surrounding wind resource availability and site suitability. Without a structured and data-driven approach to analyzing how terrain and land characteristics influence wind energy potential, Nigeria risks missing significant opportunities for low-cost and environmentally sustainable energy generation needed to support national development goals and the Energy Transition Plan (Federal Government of Nigeria, 2022).

In response to these challenges, this study provides a terrain-informed assessment of wind energy potential in Jos using advanced geospatial and computational techniques. Specifically, the research integrates high-resolution digital elevation model (DEM) analysis, computational fluid dynamics (CFD) modeling, and GIS-based multi-criteria evaluation (MCE) to examine the spatial variability of wind resources and identify suitable locations for wind turbine deployment. By combining terrain analysis with meteorological datasets, the study generates wind energy potential maps and provides scientific evidence to guide sustainable wind energy development.

The Study Area

Jos is located between latitudes 9°30'N and 10°10'N and longitudes 8°30'E and 9°00'E. The city lies on the Jos Plateau at an average elevation of about 1,200 meters above sea level, rising to over 1,400 meters in some areas (Adebayo & Tukur, 1999; Plateau State Government, 2022; Olaniran & Sumner, 2018). The terrain is rugged and dissected, consisting of hills, escarpments, valleys, rocky outcrops, and open grasslands (Odeyemi et al., 2021; Akinyemi & Awotoye, 2022). These elevated landforms enhance wind movement through orographic lifting and channeling effects, making the area suitable for wind resource assessment (Güney et al., 2022).

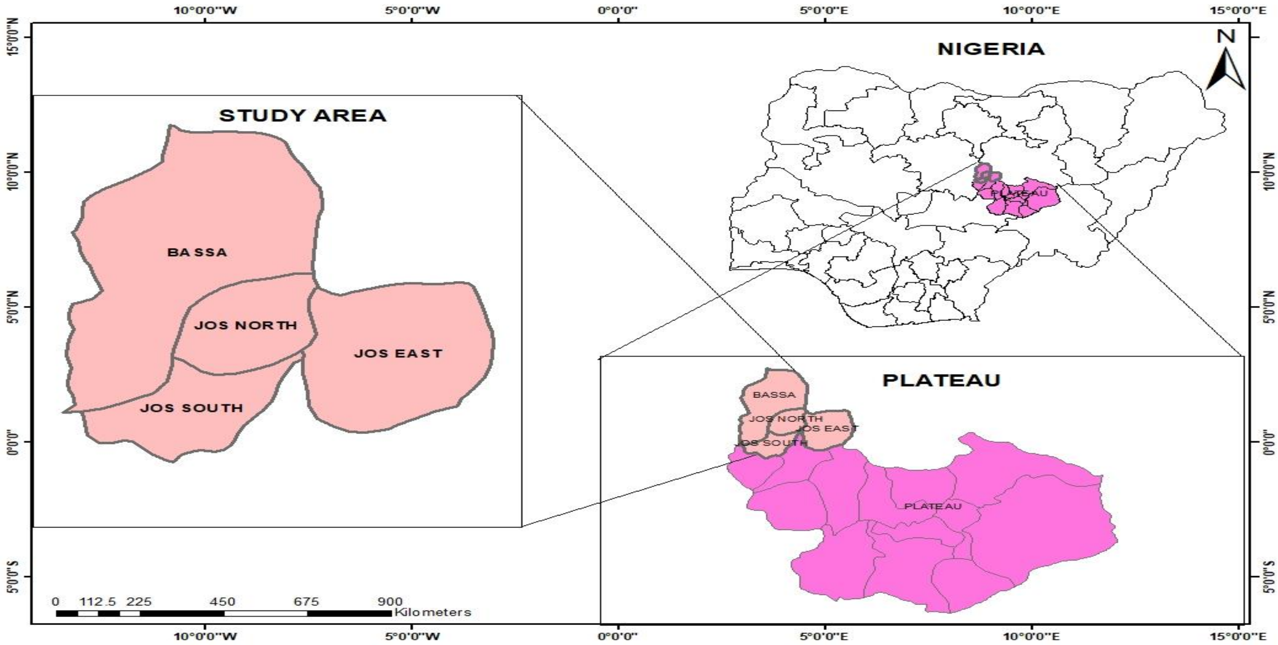
Jos experiences a tropical highland climate with moderate temperatures ranging from about 18°C to 25°C throughout the year (Adebayo & Tukur, 1999; NiMet, 2022; Olaniran & Sumner, 2018). The climate is characterized by two main seasons: a dry season (November–March) dominated by northeast trade winds known as harmattan, which bring dry air and relatively stronger winds, and a wet season (April–October) influenced by the northward movement of the Inter Tropical Discontinuity (ITD), bringing moist air and increased rainfall. Annual rainfall on the plateau generally exceeds 1,300 mm, with peak precipitation between July and

August (Olaniran & Sumner, 2018). These seasonal changes contribute to variations in wind direction and speed across the plateau.

The vegetation is dominated by montane vegetation interspersed with shrubs, cultivated farmlands, and patches of gallery forest along river valleys. Common species include *Hyparrhenia rufa*, *Andropogon gayanus*, *Combretum* spp., *Khaya senegalensis*, *Ficus* spp., and *Vitex doniana* (NEST, 2022). This heterogeneous vegetation cover creates varying surface roughness conditions that influence wind flow patterns and turbulence characteristics (Zhao et al., 2022).

Geologically, the Jos Plateau is underlain mainly by Precambrian basement complex rocks such as granites, migmatites, and gneisses associated with the Younger Granite Complex (Obaje, 2022). These formations have produced the plateau's distinctive rugged relief of hills and inselbergs, while the drainage system consists of rivers such as the Delimi, Shere, and Gada, which form dendritic drainage patterns across the plateau (NEST, 2022; Mousavi et al., 2023).

Socio-economic activities in the region include agriculture, mining, commerce, and public services. Major crops include maize, potatoes, tomatoes, and cabbage, while historic tin and columbite mining have shaped parts of the landscape (Adeoye & Musa, 2022; Umar et al., 2023). Urban centres such as Jos North and Jos South also host major institutions including the University of Jos and Jos University Teaching Hospital (Plateau State Government, 2022). These land use patterns influence surface roughness and local wind flow dynamics.



Source: NARSDAR Price Abubakar Audu University
Figure 1: Map of Jos Showing Study Area

Methods

This study used a descriptive research design aimed at assessing wind energy potential on the Jos Plateau and examining how terrain, land use, and environmental factors influence wind suitability. Descriptive research focuses on the systematic collection and analysis of data to identify patterns and relationships within a phenomenon (Njokwu, 2018). The design allowed the integration of geospatial datasets with qualitative insights from relevant stakeholders involved in environmental management and renewable energy development.

The population of the study consisted of institutions, agencies, and community representatives involved in environmental management and renewable energy generation within Jos and its environs. These included the Plateau State Ministry of Environment, the Plateau State Ministry of Energy and Mineral Resources, the Plateau State Urban Development Board, and the Plateau State Emergency Management Agency (SEMA). Academic experts from the University of Jos, renewable energy practitioners in the North-Central region, and community representatives from wind-prone settlements were also included. A purposive sampling technique was further used to select participants based on their expertise and relevance to the study. A total of 33 participants were selected, comprising eleven government officials, six academic experts, six renewable energy practitioners, and ten community representatives. This sample size was considered adequate for obtaining meaningful insights from knowledgeable stakeholders (Guest, Namey, & Chen, 2020).

Both primary and secondary data sources were used. Primary data were collected through Key Informant Interviews (KIIs) using a semi-structured interview guide and through field observations of terrain and land-use characteristics. Secondary data included geospatial datasets such as the Copernicus GLO-30 Digital Elevation Model (DEM) for terrain analysis, ESA World Cover (2021) land-use and land-cover data, administrative boundary data from the Office of the Surveyor-General of the Federation (OSGOF), and wind data from the ERA5 wind speed reanalysis dataset. All spatial datasets were projected to the WGS84 / UTM Zone 32N coordinate system for spatial consistency.

Data analysis involved both qualitative and geospatial techniques. Interview responses were analyzed using thematic analysis to identify key patterns and perspectives related to wind energy development and environmental conditions. Geospatial analysis was conducted using GIS and remote sensing tools to derive terrain parameters such as elevation and slope from the DEM. A Multi-Criteria Evaluation (MCE) approach was applied to integrate terrain, land use, settlement buffers, and vegetation factors using weighted overlay analysis to identify suitable areas for wind energy development. The results were presented through thematic maps showing elevation, slope, land-use patterns, and potential wind suitability zones.

Results and Discussions

Analysis of data collected were carried out, the data analyzed comprised of integrated primary data obtained from key informants and secondary geospatial data derived from GIS and remote sensing.

Table 1: Respondent's Perception of Terrain as a factors affecting wind Flow

Categories of Respondents	Frequency	Percentage (%)
Government Agencies	11	33.3
Academic Experts	6	18.2
Renewable Energy Practitioners	6	18.2
Community Representatives	10	30.3
Total	**33**	**100**

Source: Field Survey, 2025

The study involved 33 respondents drawn from government agencies, academic institutions, renewable energy practitioners, and community representatives in order to capture institutional, technical, and local perspectives on wind energy development in the Jos Plateau. Government agencies constituted the largest group (33.3%), reflecting their role in environmental regulation and energy policy, while community representatives accounted for 30.3%, providing local knowledge on land use and environmental conditions. Academic experts and renewable energy practitioners each represented 18.2% of the respondents and contributed scientific and operational insights on terrain suitability and wind energy implementation.

Respondents overwhelmingly agreed that terrain characteristics significantly influence wind flow patterns. All participants indicated that elevation affects wind speed, highlighting the importance of high ridges and plateau surfaces for wind energy generation. Similarly, all respondents acknowledged that slope influences wind direction, while vegetation density and built-up areas were also identified as factors that modify wind flow by creating friction and turbulence. These responses emphasize that open landscapes with minimal vegetation and limited urban obstruction provide more favourable conditions for wind energy development.

Table 2: Elevation Distribution of the Study Area

Elevation Range (m)	Area (km^2)	Percentage (%)
900 – 1,100	412.6	28.4
1,101 – 1,300	508.3	35.0
1,301 – 1,500	376.4	25.9
1,501 – 1,700	154.2	10.6

Source: GIS Analysis, 2025

The elevation distribution of the Jos Plateau was derived from a Digital Elevation Model (DEM) obtained from the Copernicus GLO-30 dataset with 30-m spatial resolution. The DEM was processed in ArcGIS Pro using the re-classification tool to categorize terrain into four elevation classes representing lowlands, midlands, highlands, and ridge zones. The Zonal Geometry function was then used to calculate the spatial extent of each elevation class.

Results show that the largest portion of the study area (35.0%) falls within the 1,101–1,300 m elevation range, followed by 28.4% between 900–1,100 m and 25.9% between 1,301–1,500 m. Only 10.6% of the area lies above 1,500 m, representing the highest ridges of the plateau. These higher elevation zones are particularly significant for wind energy development because wind speeds generally increase with altitude and reduced surface friction. Consequently, ridge areas and elevated terrains within the plateau present favorable conditions for wind turbine installation.

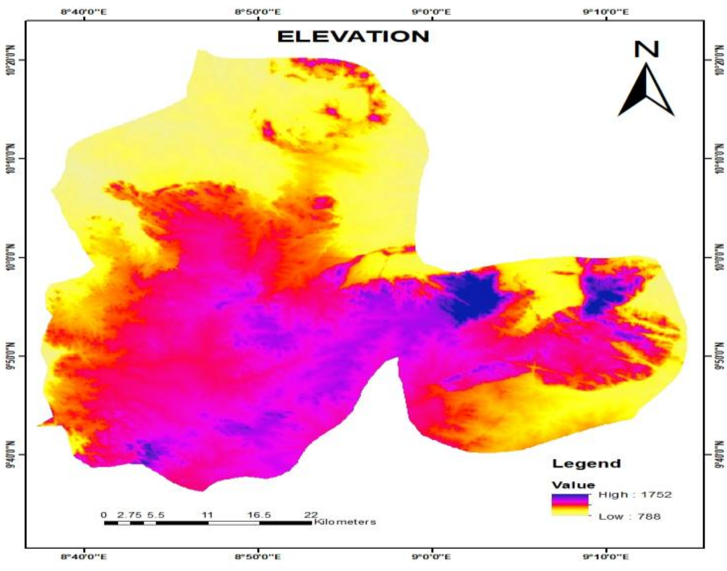


Figure 1: Elevation Classification of Jos Plateau

The terrain of the Jos Plateau varies moderately across the study area, influencing wind exposure and potential wind energy development. In Jos South, elevation generally ranges between 1,200 m and 1,400 m above sea level. Areas like Vom and Kuru lie on broad plateau surfaces with gentle undulating terrain and scattered rock outcrops. Bukuru and Du are moderately elevated but not extreme peaks. Wind exposure is moderately enhanced in open highland areas but may be affected by vegetation and settlement density.

In Jos North, the terrain averages 1,200–1,350 m and forms part of the area with limited relief variation. Urban neighbourhoods such as Terminus, Angwan Rogo, Rayfield, and Tudun Wada are on a gentle elevated terrain. Wind flow in this area is influenced more by urban structures such as building density than by altitude differences. Elevation patterns in Bassa are more varied than other urban neighborhoods. The southern parts maintain typical plateau elevations, while northern areas become more dissected with valleys and drainage depressions that fall below 1,200 m. Wind potential is therefore stronger on the exposed ridges and open highlands but weaker in the valley floors.

In Jos East, the terrain is more rugged and dissected with the height ranging from about 1,150 m in valleys to over 1,350 m on ridges. Pronounced relief variation and exposed ridgelines may provide an enhance wind acceleration in some locations.

Table 3: Slope Category Distribution

Slope (°)	**Area (km²)**	**Percentage (%)**
0–3	529.1	36.5
4–7	472.8	32.6
8–14	302.3	20.9
15+	147.3	10.0

Source: GIS Analysis, 2025

Table 3 shows that gentle slopes dominate the study area. The 0–3° category (36.5%) represents flat or nearly flat plateau surfaces suitable for development and potential wind energy installations. The 4–7° class (32.6%) reflects gently undulating terrain typical of the Jos Plateau and allows relatively stable wind movement. Moderately steep slopes of 8–14° (20.9%) occur mainly in upland transitional zones, especially toward the direction of Bassa on one hand and towards Jos East direction on the other hand. The steepest slopes above 15° (10.0%) are concentrated in the Shere Hills, characterized by rugged ridges and escarpments. Overall, the dominance of slopes between 0–7° (69.1%) indicates that the area is largely composed of stable plateau surfaces, though localized topographic variation may influence wind flow patterns.

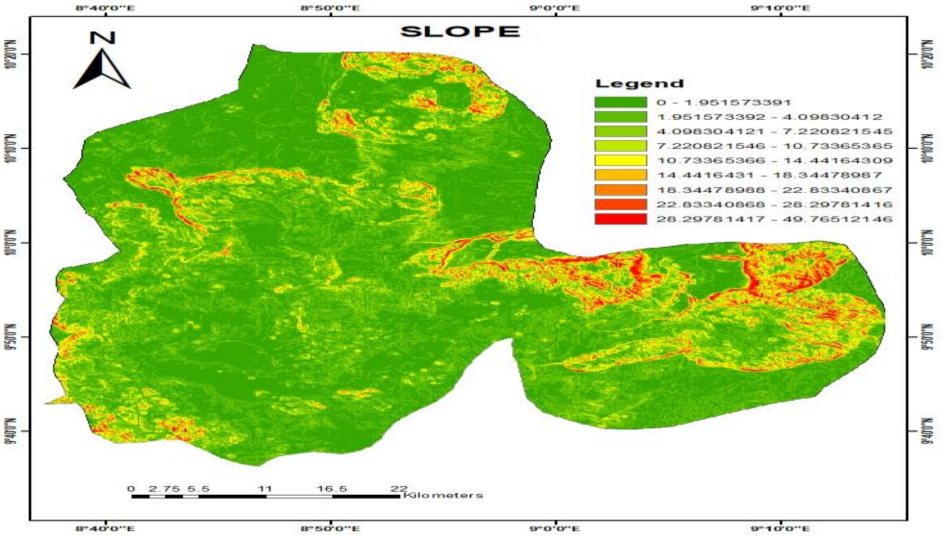


Figure 2: Slope Category Distribution

The slope map illustrates the spatial distribution of terrain steepness across the study area using a GIS-derived Digital Elevation Model (DEM). The visualization shows a clear dominance of gentle slopes (green tones) across Jos North, Jos South, and parts of Bassa, indicating broad stable Plateau surface with minimal inclination. These areas are suitable for urban development, agriculture, and potential wind energy infrastructure due to lower terrain constraints.

Moderate slopes represented with yellow color, appear mainly along drainage corridors and transition zones, especially in parts of Bassa and central Jos South. These areas reflect gradual erosional processes shaping the plateau surface to its current state. In contrast, steep and very steep slopes represented with orange to red colors are concentrated in localized zones, particularly in deeper parts of Jos East, where rugged terrain dominates around the Shere Hills. These areas exhibit sharp ridges and escarpments that influence runoff, erosion, and localized wind acceleration. In the overall assessment, the slope pattern confirms that about two-thirds of the study area is characterized with gentle slope, this is consistent with earlier geomorphological descriptions of the Jos Plateau as a largely undulating highland with dissected margins (Oyedepo et al., 2022). This distribution may have important implications for land use, settlement expansion, and wind energy suitability, as gentle slopes enhance accessibility while steeper zones may offer higher wind potential along exposed ridges.

Table 4: Characteristics of Slope Aspect Orientation

Aspect	Area (km²)	Percentage (%)
North-facing	228.6	15.7
South-facing	301.4	20.8
East-facing	356.2	24.5
West-facing	321.7	22.2
Flat	243.6	16.8

Source: GIS Analysis, 2025

The aspect map was derived from a Digital Elevation Model (DEM) using GIS-based terrain analysis. The DEM was processed using the Aspect tool to determine the direction of slopes orientation, which was then reclassified into north, south, east, west-facing direction, and the flat surfaces. The area of each class was computed based on raster cell counts and converted into square kilometers and percentages.

The results show a relatively balanced distribution of slope orientations, with east-facing slopes (24.5%) being the highest, followed by west-facing (22.2%) and south-facing (20.8%) areas. North-facing slopes account for 15.7%, while flat surfaces represent 16.8% of the study area. This relatively even distribution suggests diverse microclimatic conditions across the Jos Plateau, which can influence solar exposure, moisture retention, vegetation patterns, and wind flow behavior, with all relevant for wind energy assessment and land-use planning.

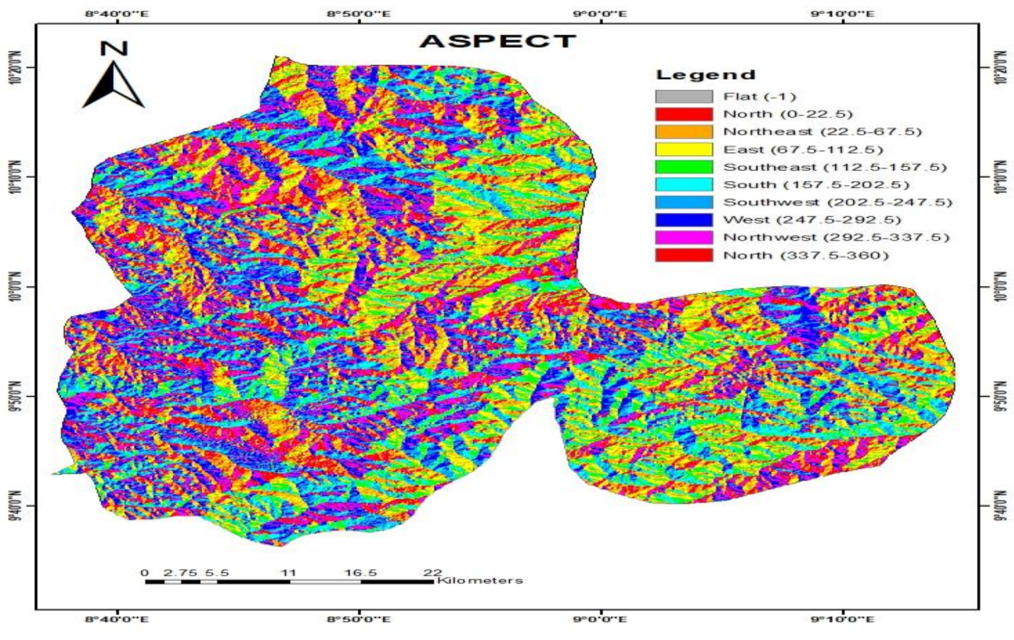


Figure 3 : Aspect Orientation Characteristics

The above map reveals a heterogeneous pattern slope aspect across the Jos Plateau, reflecting its rugged and undulating terrain. In Jos North, slopes are mainly east-, southeast-, and southwest-facing, particularly around elevated rocky areas, indicating zones with greater exposure to prevailing seasonal winds. Jos South shows a mix of south-, southwest-, and west-facing slopes, with valley floors and ridge crests creating variable microclimatic conditions and localized wind variations. In Bassa, north-, northeast-, and northwest-facing slopes dominate, aligning with exposure to the dry-season harmattan winds. In Jos East, slopes are mainly east-, northeast-, and southeast-facing, reflecting more open upland terrain with relatively consistent wind exposure. In the overall assessment, east-facing slopes are the most common (24.5%), followed by west-facing (22.2%) and south-facing (20.8%), while north-facing slopes are the least (15.7%). Flat areas accounted for 16.8%. These variations influence wind flow, sunlight exposure, drainage, and vegetation distribution across the plateau.

Table 5: Land Use and Land Cover Distribution in Jos Plateau

Land Use Type	Area (km²)	Percentage (%)
Grassland	602.4	41.5
Agricultural Land	431.7	29.7
Forest	213.5	14.7
Built-up / Urban	124.9	8.6
Rocky Outcrops	79.0	5.4

Source: GIS Analysis, 2025

The Land Use and Land Cover (LULC) data were derived using GIS-based supervised classification of satellite imagery and topographic datasets. Each land cover type was digitized, refined, and its spatial extent computed within the GIS environment. Results shows that grassland dominates the study area (41.5%), followed by agricultural land (29.7%), while forest accounted for (14.7%), built-up areas (8.6%), while rocky outcrops accounted for smaller proportions of (5.4%). This distribution highlights the dominance of open vegetation cover, which generally supports more favourable wind flow conditions compared to densely built-up or forested areas.

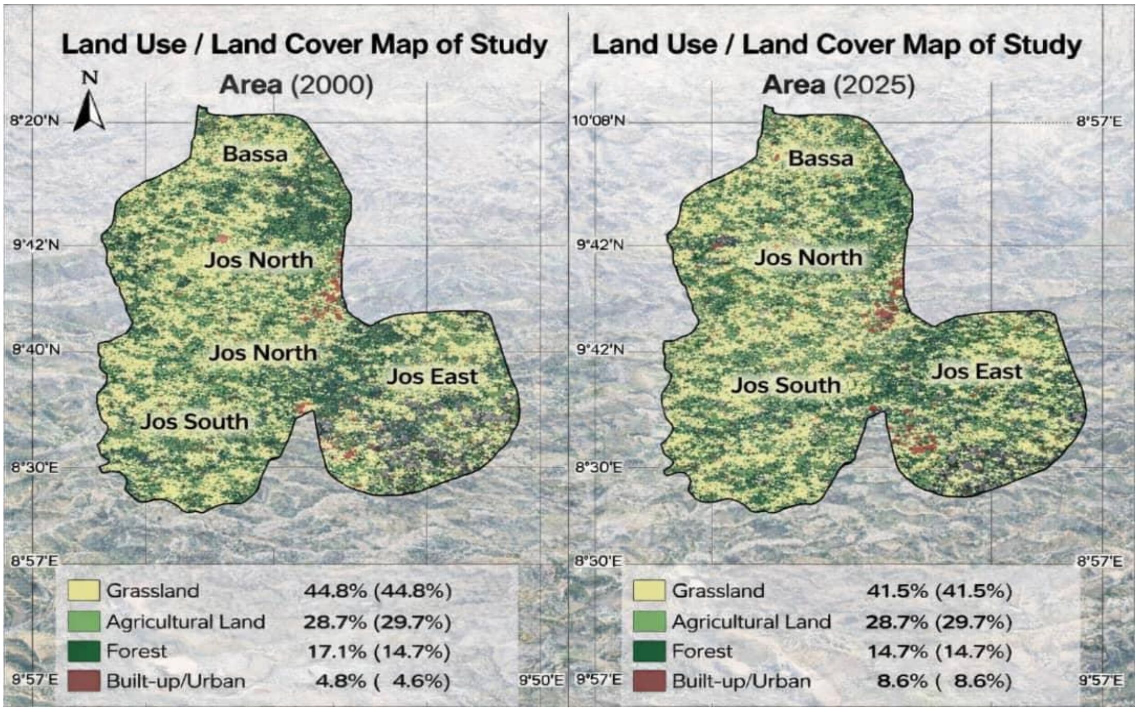


Figure 4: Land Use and Land Cover Distribution in Jos Plateau

The Land Use/Land Cover maps from 2000 to 2025 reveal notable spatial changes within the study area over the 25-year period. In 2000, grassland was the dominant land cover, accounting for about 44.8% of the area, followed by agricultural land use **(**28.7%**)** and forest cover **(**17.1%**).** Built-up areas and rocky outcrops constituted relatively smaller proportions between 4.8% and 4.6% respectively. By 2025, grassland coverage declined to 41.5%**,** while agricultural land slightly increased to 29.7%**,** indicating expansion of farming activities. Forest cover reduced further to 14.7%**,** reflecting ongoing deforestation and land conversion. Built-up/urban areas almost doubled to 8.6%**,** showing rapid urban expansion, particularly around major settlements such as Jos**,** Bukuru**,** Zawan**,** Kuru**,** and surrounding peri-urban communities. Rocky outcrops also increased marginally to 5.4%**,** possibly due to vegetation loss and increased surface exposure. Grassland (41.5%) provides the most suitable terrain for wind energy, offering minimal obstruction to wind flow. Agricultural land (29.7%) is moderately suitable, but existing crops or irrigation infrastructure may limit turbine placement. Forested areas (14.7%) reduce wind speed due to canopy roughness, while urban/built-up areas (8.6%) create significant turbulence and accessibility challenges. Rocky outcrops (5.4%) are mostly unsuitable due to construction difficulty. This land use and land cover pattern aligns with stakeholder perceptions of terrain influence and informs the suitability map for turbine installation.

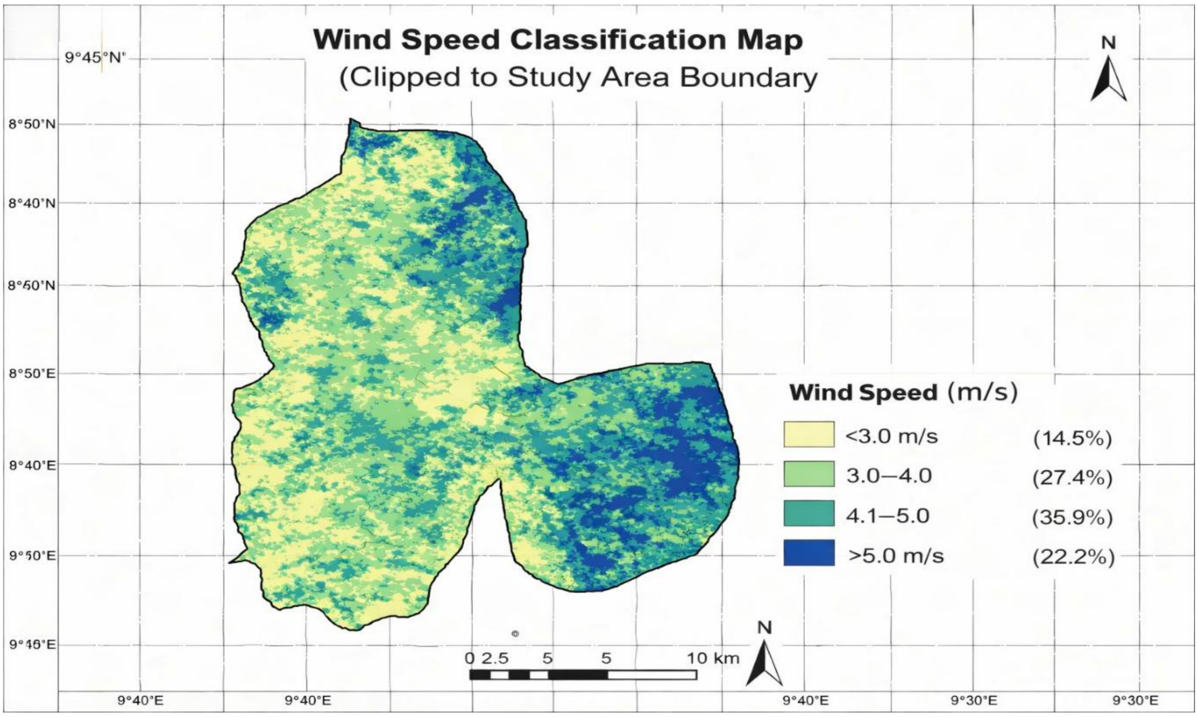


Figure 6: Shows Wind Speed Classification

The Land Use Influence on Wind Energy Suitability map illustrates how different land use/land cover categories affect the spatial suitability of wind energy development within the study area. Areas classified as highly suitable appears in dark and light green. These areas are predominantly grassland and open agricultural landscapes**,** which offer minimal surface roughness and fewer obstructions to wind flow. These zones are mainly distributed across the northern, western, and south-western parts of the study area, including locations around Bassa**,** Jos East**,** and peripheral rural communities. Moderately suitable areas appears in yellow color, these areas are largely found within areas of mixed land use, and agricultural land interspersed with patches forest. These areas experience partial wind obstruction due to vegetation cover and uneven terrain, reducing wind efficiency compared to open landscapes. Such conditions are common around transition zones between rural farmlands and expanding settlements. In contrast, unsuitable areas appears in red color, these areas are concentrated around built-up and urban centers**,** notably within and around Jos North, Jos South, Bukuru, Zawan, and Kuru. High building density, infrastructure, and surface roughness in these locations significantly disrupt wind speed and direction, making them less favorable for wind energy installations. Rocky outcrops, although limited in extent, this may also contribute locally to reduced suitability due to complex terrain effects.

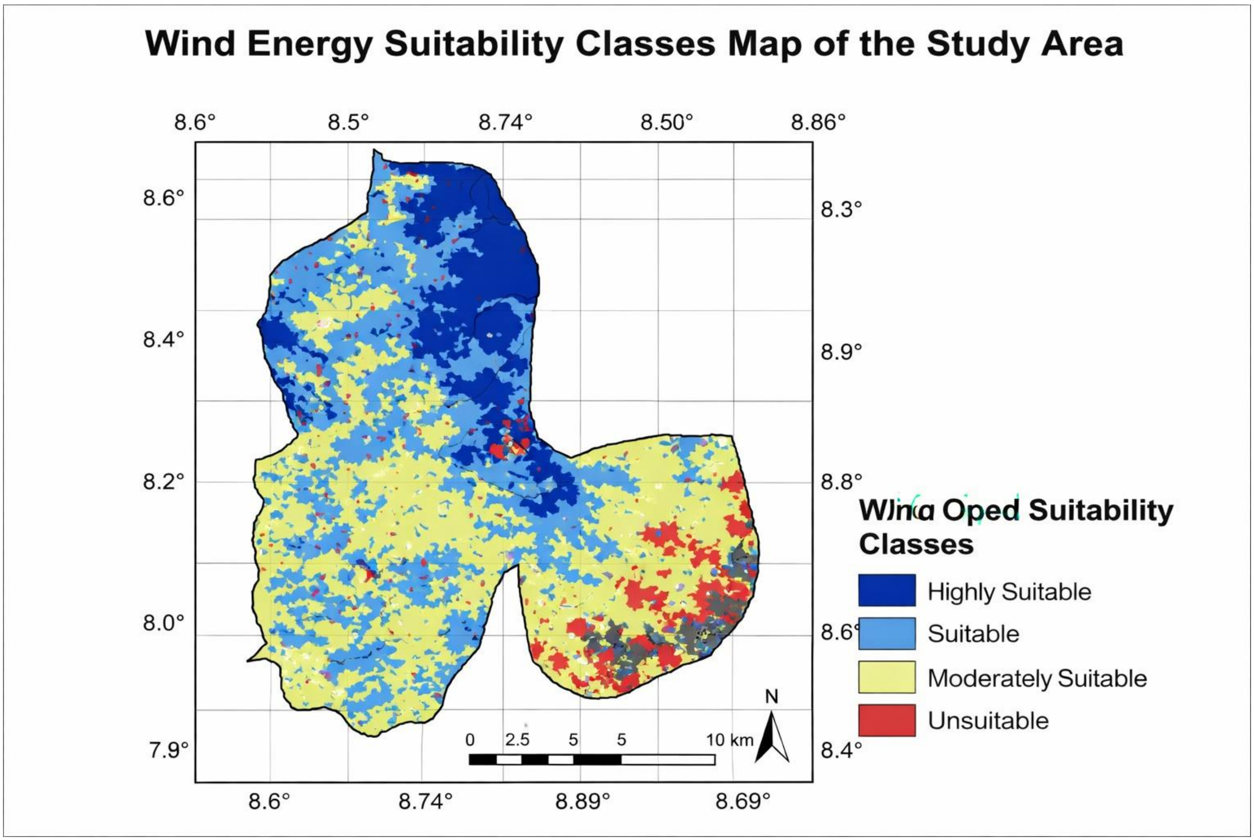


Figure 7: Wind Energy Suitability Classes

Highly suitable areas (22.5%) align with elevated ridgelines that combine high wind speeds, gentle slopes, and low vegetation density. Suitable areas (34.3%) are slightly lower elevation zones with moderate wind exposure. Moderately suitable areas (28.4%) may require site-specific adjustments or smaller turbines. Unsuitable zones (14.8%) correspond to dense forests, urban settlements, or steep slopes. These results demonstrate the integrated effect of elevation, slope, aspect, and land cover on wind energy potential, providing a spatially explicit guide for wind farm sitting.

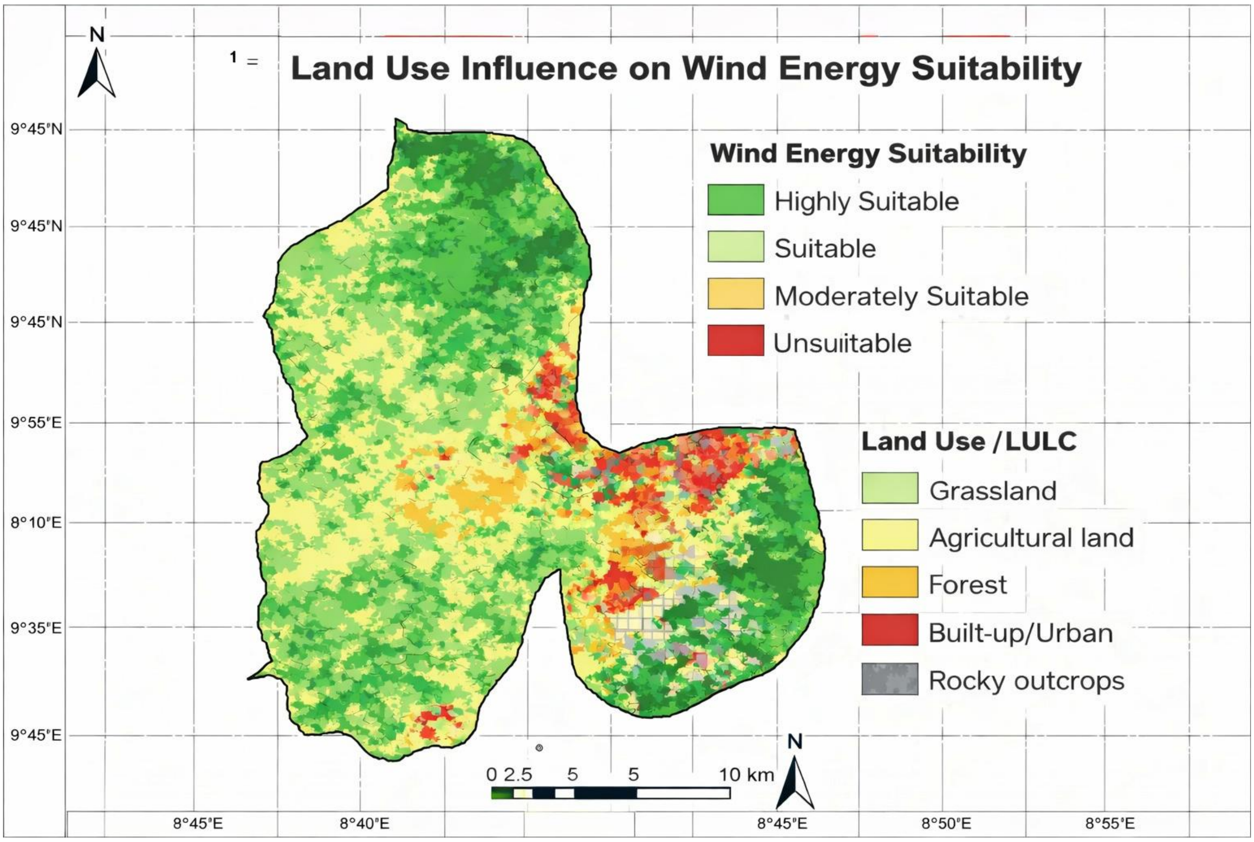


Figure 9: Shows Land Use Influence on Wind Energy Suitability

The map illustrates the spatial relationship between land use/land cover (LULC) characteristics and wind energy development potential across the study area comprising Jos North, Jos South, Jos East, and Bassa. The map integrates wind suitability classification (Highly Suitable, Suitable, Moderately Suitable, and Unsuitable) with existing land use types such as grassland, agricultural land, forest, built-up/urban areas, and rocky outcrops. This combined analysis demonstrates how surface characteristics directly influence wind flow behavior and turbine installation feasibility. From the spatial distribution, highly suitable areas (dark green) are predominantly located within open grassland and elevated rocky outcrop zones. These areas, particularly in parts of Bassa and the northern axis of Jos North, experience minimal surface obstruction, allowing for stronger and more stable wind currents. The presence of rocky outcrops also suggests higher elevations, which typically enhance wind speed due to reduced surface friction. Such locations are ideal for wind turbine installation because they maximize energy capture while minimizing interference. Areas classified as suitable and moderately suitable are largely associated with agricultural land and sparsely vegetated zones, especially within Jos South and parts of Jos East. Although these areas are relatively open spaces, farming activities, seasonal vegetation changes, and moderate human presence may slightly influence turbine placement and operational efficiency. Nevertheless, these areas still present viable opportunities for controlled wind energy development with proper land management strategies. Conversely, unsuitable zones (red) are concentrated around built-up and densely forested areas. Urban centers within Jos North show limited suitability due to structural obstructions, turbulence caused by buildings, safety concerns, and population density constraints. Similarly, dense forest areas reduce wind speed through canopy resistance and increased surface roughness, making them less favorable for wind energy projects. the map clearly demonstrates that wind energy suitability within the Jos Plateau region is strongly influenced by land use patterns. Open, elevated, and sparsely populated landscapes provide the most favorable conditions, while urban and heavily vegetated areas significantly limit wind energy development potential. This spatial pattern highlights the importance of integrating land use planning into renewable energy site selection strategies.

Test of Hypotheses

Hypothesis 1 (H_{01}): ***There is no significant relationship between landscape characteristics and wind flow on the Jos Plateau, Nigeria.***

Test: A correlation analysis (Pearson's r) between elevation, slope, aspect, LULC, and suitability class from GIS weighted overlay results.

Variable	r-value	Significance (p)
Elevation vs Suitability	0.782	0.001
Slope vs Suitability	0.654	0.005
Aspect vs Suitability	0.589	0.012
LULC vs Suitability	0.712	0.002

Decision: Since all p-values < 0.05, H_0 is rejected, indicating a significant relationship between landscape characteristics and wind energy potential in Jos Plateau.

The findings of this study indicate that the Jos Plateau has considerable wind energy potential influenced by topography, land use, and vegetation cover. Stakeholder responses showed strong agreement that elevation, slope, vegetation density, and built-up areas significantly affect wind speed and direction, with over 90% identifying elevation as a key factor and nearly 88% noting slope orientation as important. Vegetation and urban structures were also widely recognized as barriers to wind flow. This agrees with findings in similar highland environments such as Enugu State and the Drakensberg region of South Africa, where elevation and terrain structure enhance wind movement (Okoro et al., 2023; Mbatha, 2023).

GIS-based elevation analysis revealed that most of the study area lies between 1,101 and 1,300 m, while higher elevations above 1,301m occupy about 36.5% of the area, indicating favourable zones for wind energy due to exposure to stronger winds, consistent with findings from northern Pakistan (Nurudeen et al., 2022). Slope analysis showed that 69.1% of the area falls within 0–7°, indicating generally gentle terrain suitable for turbine installation, while steeper slopes are less suitable, supporting observations in Plateau State (Oyedepo, 2022). Aspect analysis indicated dominance of east- and west-facing slopes, which align with prevailing wind directions and influence local wind behaviour, consistent with Mbatha (2023). Land use and land cover results showed that grasslands dominate the landscape and provide the most suitable conditions for wind flow, while forests and built-up areas increase surface roughness and reduce wind speed. Similar patterns have been reported by Okoro et al. (2023) and Oyedepo (2022), where open land uses support higher wind potential compared to dense vegetation and urban areas. Integrated GIS-based suitability analysis identified high-potential wind zones along elevated ridges with gentle slopes and sparse vegetation, while low-suitability areas are concentrated in valleys and densely built or forested zones. This spatial pattern aligns with GIS-MCDA studies in high-altitude regions (Nurudeen et al., 2022; Adaramola & Agelin-Chaab, 2021).

Conclusion and Recommendations

The Jos Plateau has strong potential for wind energy development, especially in elevated areas with gentle slopes and open land cover. The study revealed that terrain and land-use patterns significantly influence wind speed, direction, and turbine suitability. Combining stakeholder insights with GIS analysis provides a reliable basis for identifying suitable sites and supports informed planning for sustainable wind energy development in the region. It therefore, recommends that elevated ridgelines and open grassland or low-density agricultural areas be prioritized for wind energy projects, supported by continuous wind monitoring. Turbines should be sited on gentle slopes, while steep terrains should only be used where engineering solutions allow. Dense forests and urban areas should be avoided due to low wind efficiency. GIS-based multi-criteria analysis should guide future site selection. Future studies should include socio-economic and infrastructural factors for a more comprehensive assessment, alongside long-term analysis of seasonal wind variability and environmental impacts. Research into community-based wind energy systems is also encouraged for practical implementation in similar highland regions.

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