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Assessment of Wind Energy Potential in Anguía, Chota, Cajamarca: A Proposal for Rural Energy Development

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ABSTRACT

In the face of the current challenges posed by climate change, there is a growing need to propose technical solutions that allow for the diversification of the energy matrix and the reduction of vulnerability among the most disadvantaged populations. This research focused on estimating the wind energy potential in the district of Anguía, Cajamarca, one of the areas with the highest poverty rates in Peru. The study is based on recognizing wind energy as a viable and sustainable alternative to promote local development. For this purpose, a three-dimensional model of the area was developed using computer-aided design (CAD) tools and subsequently evaluated through simulations based on computational fluid dynamics (CFD). The input parameters were defined using satellite meteorological data provided by the Modern-Era Retrospective Analysis for Research and Applications, Version 2 (MERRA-2) system, which ensured realistic boundary conditions. The results made it possible to identify areas with higher concentrations of wind energy, providing quantitative support for prioritizing future interventions. In addition, it was demonstrated that CFD modeling of small surfaces facilitates improved visualization of local wind flow patterns. In conclusion, this methodology can significantly contribute to the design of decentralized energy projects that benefit vulnerable rural communities.

1. INTRODUCTION

The global energy transition has become one of the main pillars of environmental and sustainable development policies in recent decades, driven by the need to reduce emissions associated with the intensive use of fossil fuels and to limit the adverse effects of climate change [1]. In this context, renewable energy sources have assumed a strategic role by offering generation alternatives with a lower environmental footprint and greater compatibility with decarbonization objectives established in international agreements such as the Paris Agreement [2].

In view of the accelerated increase in global greenhouse gas (GHG) emissions, the adoption of measures that promote the transition toward a sustainable energy model has become urgent [3]. Within this context, the use of non-conventional energy sources, such as wind energy, represents one of the most effective strategies to reduce dependence on fossil fuels and mitigate the environmental impact associated with their consumption [4]. Diversifying the energy matrix responds to a climatic imperative. It also creates opportunities to improve access to energy in vulnerable regions.

Wind resources, being closely linked to atmospheric conditions and the interaction between airflow and the Earth's surface, exhibit high spatial and temporal variability [5]. Therefore, accurate wind assessment requires tools capable of capturing the effects of terrain, surface roughness, and atmospheric boundary conditions, all of which directly influence wind behavior and its potential for energy exploitation [6].

Despite the significant growth of wind energy over recent decades, its implementation still faces several limitations on a global scale [7]. Among the main challenges are social resistance due to landscape impacts, the natural variability of the resource, difficulties in integrating wind power into conventional electrical grids, and high initial installation costs [8]. Furthermore, the lack of detailed local studies on wind behavior in specific areas has generated uncertainty in the design and siting of new wind farms, especially in developing countries [9].

Within this framework, numerical simulation techniques, particularly computational fluid dynamics (CFD), have become key tools for analyzing wind flow over complex terrain [10]. These methodologies enable high spatial resolution evaluation of velocity distributions, turbulence, and flow patterns, overcoming the limitations of point-based measurements obtained from conventional meteorological stations [11].

Peru, despite having diverse geography and favorable climatic conditions for the development of renewable energy, has not yet managed to significantly harness its wind energy potential [12]. According to the National Energy Balance 2021 (see Figure 1), wind energy accounted for only 0.6% of the national primary energy matrix, with a contribution of just 6,558.1 Terajoule (TJ), reflecting a marginal increase of only 0.5% compared to the previous year [13]. This limited utilization contrasts with the abundance of wind resources available in different regions of the country, particularly in rural areas where access to the electrical grid is restricted. In addition, most existing wind infrastructure is concentrated in specific regions, highlighting technological centralization and weak energy decentralization [7]. In this context, it is urgent to develop and implement methodologies that allow for more accurate identification of sites with higher wind capacity, thereby facilitating the expansion of micro-scale distributed generation projects [14]. This is especially relevant in rural communities, where renewable energy could play a key role in improving quality of life, energy autonomy, and sustainable local development.

FUENTE	2020		2021		VARIACIÓN
	Cantidad	Part.	Cantidad	Part.	
De yacimientos de fuentes fósiles y minerales					
Gas Natural + LGN	659 166,0	64,0%	628 265,0	62,1%	-4,7%
Petróleo Crudo	84 091,0	8,2%	81 142,4	8,0%	-3,5%
Carbón Mineral	3 295,2	0,3%	3 923,9	0,4%	19,1%
Subtotal	**746 552,2**	**72,5%**	**713 331,4**	**70,5%**	**-4,4%**
Otras fuentes de energía primaria					
Hidroenergía	137 229,3	13,3%	143 595,3	14,2%	4,6%
Leña	109 721,6	10,7%	120 796,3	11,9%	10,1%
Bagazo	20 528,0	2,0%	18 509,4	1,8%	-9,8%
Bosta & Yareta	4 654,3	0,5%	4 405,4	0,4%	-5,3%
Energía Solar	4 592,9	0,4%	4 776,9	0,5%	4,0%
Energía Eólica	6 527,6	0,6%	6 558,1	0,6%	0,5%
Subtotal	**283 253,7**	**27,5%**	**298 641,4**	**29,5%**	**5,4%**
TOTAL	**1 029 805,8**	**100,0%**	**1 011 972,8**	**100,0%**	**-1,7%**

Figure 1. Domestic primary energy production

The diverse geography of Peru generates a wide range of wind regimes influenced by variations in elevation, terrain morphology, and atmospheric circulation patterns. In mountainous regions, particularly within the Andean corridor, local wind behavior can be strongly affected by topographic features such as valleys, slopes, and ridges [15]. These terrain-induced effects often produce spatial variability in wind speed and turbulence, creating localized areas where wind energy potential may be higher than surrounding zones.

Despite these favorable geographic characteristics, many rural areas in the Peruvian Andes remain insufficiently studied in terms of their wind energy resources. In regions such as Cajamarca, the combination of complex terrain and limited meteorological monitoring infrastructure has restricted the availability of detailed wind assessments [16]. As a result, the identification of zones with suitable wind conditions for renewable energy development remains a challenge, particularly at local and micro-regional scales.

Within this context, the district of Anguía, located in the province of Chota in northern Peru, represents an area of interest for evaluating local wind resources [17]. The region is characterized by mountainous terrain and rural settlements where access to reliable electricity infrastructure can be limited. Assessing the spatial distribution of wind behavior in such areas may provide valuable information for exploring decentralized renewable energy solutions aimed at improving energy accessibility and supporting sustainable rural development.

Within this framework, the present study gains relevance by proposing a technical approach to evaluate wind energy potential in Anguía through numerical simulations based on CFD [18]. This approach enables a detailed characterization of airflow interactions with complex terrain and provides high-resolution information on wind velocity patterns across the study area. Such analyses contribute to identifying zones where wind conditions may be comparatively more favorable for energy exploitation.

Finally, the integration of wind resource assessment with high-resolution numerical modeling strengthens the understanding of local atmospheric dynamics and supports the identification of areas with relatively higher wind energy potential [19]. The results of this study aim to provide a scientific basis that can contribute to future renewable energy planning initiatives, particularly those focused on decentralized energy solutions for rural communities in the Andean region.

2. METHOD

This research is framed within a quantitative approach, as it seeks to numerically measure and analyze the wind energy potential in a specific geographical area using objective and verifiable data. The research design adopted was non-experimental, descriptive, and cross-sectional, since no variables were manipulated. Instead, wind behavior was observed and analyzed at a specific moment through numerical simulation.

To represent the topography of the district of Anguía, a three-dimensional solid model was developed using computer-aided design (CAD) tools. This model was imported into a CFD simulation environment using ANSYS CFX 2025 R1 Student software. The simulation considered boundary conditions based on satellite meteorological parameters obtained from the Modern-Era Retrospective Analysis for Research and Applications, Version 2 (MERRA-2) system, which were processed to define the reference wind speed and the vertical wind profile according to the logarithmic law.

Subsequently, the analysis domain was defined and boundary conditions were applied (inlet, outlet, walls, and top opening), materials (air) were selected, and the numerical parameters of the solver were controlled until stable results were obtained. Finally, the simulation results allowed for the quantitative identification of areas with higher wind intensity, enabling an assessment of their feasibility for future small-scale wind energy projects.

Subsequently, the methodological process followed in this study is presented schematically, from the collection and analysis of meteorological information to the generation of results through computational fluid dynamics simulation. This process is summarized in a flow diagram (Figure 2) that clearly and sequentially illustrates each stage of the methodology, facilitating the understanding of the procedure used to identify areas with higher wind energy potential within the study area.

2.1 Wind direction and speed

To ensure the reproducibility and transparency of CFD analysis, the main numerical parameters and solver configurations used in this study are summarized in Table 1. The simulation was performed considering the governing equations for atmospheric airflow and an appropriate turbulence closure model to represent wind behavior over complex terrain. Boundary conditions, solver controls, and convergence criteria were defined to guarantee numerical stability and reliable results during the iterative solution process. These settings allowed the model to capture the spatial variability of wind flow and estimate the wind power density distribution within the study area.

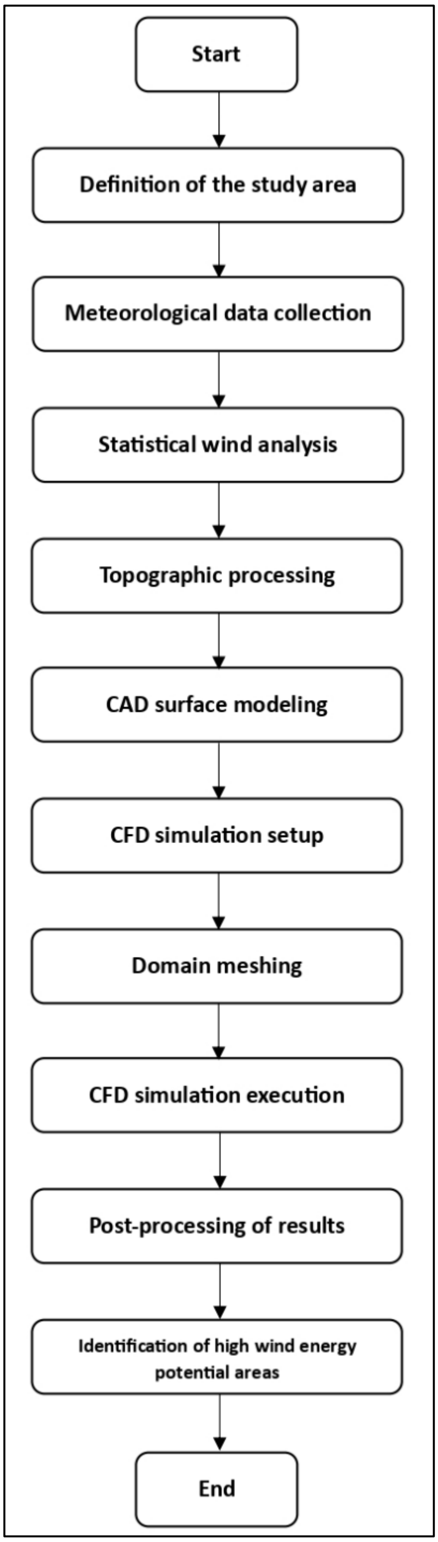

Figure 2. Methodological workflow of the wind resource assessment

Table 1. Computational fluid dynamics (CFD) numerical setup parameters

Parameter	Configuration
Governing equations	RANS
Turbulence model	k-ε
Air density	0.91 kg/m^3
Inlet boundary	Logarithmic wind profile
Outlet boundary	0 Pa
Ground	No-slip wall
Top boundary	Symmetry
Residual convergence	10^{-3}
Iterations	1000

Note: RANS = Reynolds-Averaged Navier-Stokes

3. RESULTS

The results obtained from the development of the model and the simulation of wind behavior in a selected area of the district of Anguía are presented below. For this purpose, a representative study area was delineated using a geographic polygon covering a total perimeter of 8.81 km and a surface area of 4.86 km^2 (Figure 3). This delimitation strategically included zones with higher relative elevation compared to their surroundings, since elevated areas are typically exposed to higher wind speeds and therefore exhibit greater potential for wind energy generation. The selection of this area allowed the analysis to focus on geographically favorable regions, facilitating a more precise and localized assessment of the available wind resource in the district.

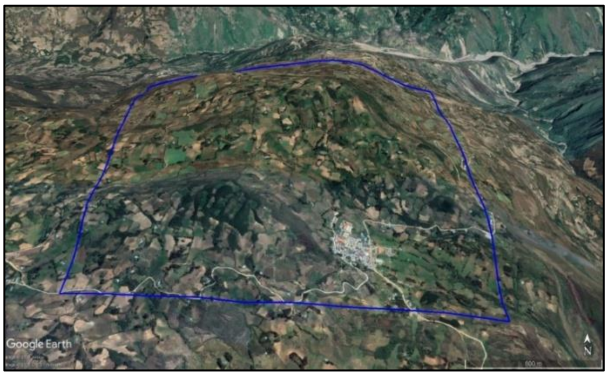

Figure 3. Geographic polygon

3.1 Wind direction and speed

In the first stage of the study, historical wind direction data corresponding to the last ten years were collected using the MERRA-2 platform as the data source. For this purpose, the geographic point with the highest elevation within the delimited area was selected, located at coordinates 6°19'55.55" south latitude and 78°36'26.51" west longitude. Analysis of this information indicated that the prevailing wind blows predominantly from a direction of 40° (Figure 4), oriented toward the northeast.

Once the prevailing wind direction was determined, three points located at the same elevation of 2,379 m above sea level, near the northeastern boundary of the geographic polygon, were selected to adequately represent wind inflow into the study area. At these three points, daily average wind speed data for the last decade were downloaded, also from the MERRA-2 platform.

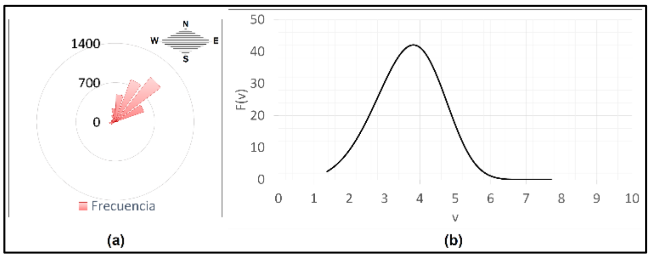

Figure 4. Wind characteristics analysis (a) Wind rose and (b) Weibull distribution

The collected values were consolidated and statistically analyzed using the Weibull distribution, yielding a shape parameter (k) of 4.5 and a scale parameter (c) of 4.03. Based on these parameters, a mean wind speed of 3.68 m/s at a height of 50 m above ground level was estimated. Finally, to project the wind speed to a height of 100 m, the logarithmic vertical wind profile equation was applied, resulting in an adjusted mean wind speed of 3.98 m/s. These values served as the basis for developing the wind behavior simulation within the defined area.

3.2 Computer-aided design modeling of the study area

In order to define an analysis zone representing the areas of highest elevation within the established geographic polygon, a contour level was validated that included only the highest elevations without exceeding the polygon boundaries. The selected contour corresponded to an elevation of 2,710 m above sea level. From this reference, all geographic points above this elevation were extracted using Global Mapper software. These points were subsequently exported to the Civil 3D environment, where a representative topographic surface was generated. Based on this surface, a solid model replicating the three-dimensional relief of the high-altitude area of the district of Anguía was constructed.

This solid was then exported to ANSYS (student version), where an upper control volume representing the space through which the wind flow would circulate was defined. Finally, this volume was meshed considering the technical limitations of the student version, resulting in a mesh composed of 383,960 nodes and 268,514 elements (Figure 5).

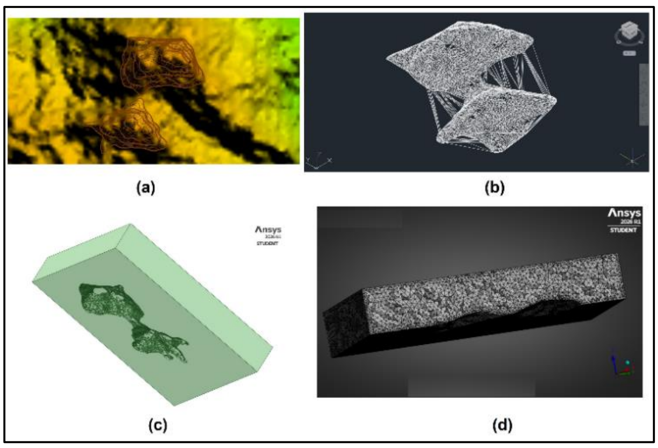

Figure 5. CAD modeling and computational domain generation for CFD simulation (a) contour levels obtained from Global Mapper, (b) solid generation in Civil 3D, (c) control volume in ANSYS, and (d) section of the control volume mesh

3.3 Computational fluid dynamics simulation

3.3.1 Quantitative analysis of wind power density

In addition to the spatial visualization of wind flow patterns obtained through CFD, a quantitative analysis of wind power density was conducted to better characterize the energetic potential of the study area. This analysis allows a clearer interpretation of the spatial distribution of wind resources and supports a more objective assessment of the zones with higher potential for wind energy exploitation.

To facilitate interpretation, the study area was classified into different wind power density intervals commonly used in preliminary wind resource assessments. Table 2 presents the estimated area and relative proportion of terrain associated with each power density range.

Table 2. Distribution of wind power density ranges within the study area

Power Density (W/m²)	Area (km²)	Percentage (%)
0–30	0.9951	31.00
30–50	1.1449	35.67
50–100	0.8132	25.33
> 100	0.2568	8.00
Total	**3.21**	**100**

To complement the spatial classification, statistical indicators were calculated for a representative point within the simulation domain, located at coordinates 6°19'55.55" south latitude and 78°36'26.51" west longitude. These indicators help describe the central tendency and variability of wind conditions relevant for wind energy evaluation at the study location. Table 3 summarizes the main descriptive statistics of wind speed and wind power density derived from the Weibull-based wind characterization and the corresponding power density calculations for this point.

Table 3. Statistical indicators of wind speed and power density

Statistic	Wind Speed (m/s)	Power Density (W/m²)
Mean	3.68	22.68
P50	3.71	23.24
P90	4.85	51.90

Overall, the quantitative analysis provides a clearer understanding of the distribution and magnitude of wind energy resources in the Anguía study area. The combination of spatial visualization and statistical indicators strengthens the reliability of the assessment and contributes to identifying zones with relatively higher wind energy potential that could be considered for preliminary rural energy planning.

3.3.2 Identification of optimal zones

Through CFD simulation, a zone with high wind energy potential was clearly identified, where wind power density exceeds 50 W/m² at a height of 50 m above ground level. This finding is highly relevant, as it demonstrates the existence of a sustained and sufficiently energetic wind flow suitable for potential utilization by small-scale wind turbines or decentralized rural energy applications.

To ensure the reliability of the analysis, ANSYS Student 2025 and RWIND 2.02 software were employed, maintaining the required simulation parameters such as air density, ambient temperature, and the wind profile generated from the mean wind speed obtained through statistical analysis. In addition, the CAD solid was rotated according to the previously determined prevailing wind direction. This type of analysis enables more accurate and efficient planning of renewable energy projects by optimizing equipment placement based on the spatial distribution of the wind resource, as validated in Figure 6.

In Figure 6(a), the ANSYS Fluent working environment is shown, where the CFD simulation was performed over a specific topography. The color scale represents the distribution of wind power density, highlighting the most energetic zones in warm colors such as yellow and red, while areas with lower power density are represented in cool tones such as blue. The influence of terrain on flow acceleration and the formation of favorable zones for wind energy capture is clearly observed.

Figure 6(b) presents an overlay of the simulation results on a satellite image of the terrain using Google Earth. The areas highlighted in greenish tones correspond to zones with the highest wind energy potential identified in the simulation. This geospatial visualization enables precise identification of regions of interest for future wind projects, facilitating their analysis in relation to existing infrastructure, accessibility, and environmental characteristics.

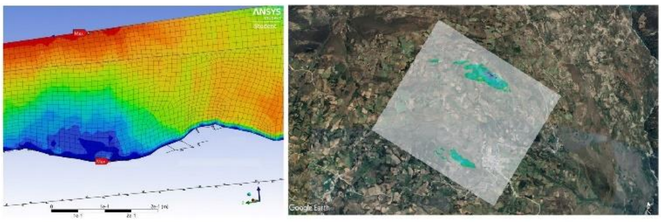
(a) (b)

Figure 6. Simulation results in (a) ANSYS Student 2025 and (b) RWIND 2.02

4. DISCUSSION

The present research builds upon relevant previous studies that have contributed to the analysis of wind resources in the department of Cajamarca. In particular, the study conducted by Carrasco [20] is noteworthy, as it focused on identifying areas with high wind energy potential within the area of influence of the Yanacocha mining operation, located in the province and department of Cajamarca. Although that study did not include validation of results through fluid dynamics simulation tools such as ANSYS Student, it provided a valuable precedent by demonstrating that this region exhibits favorable conditions for harnessing wind as a renewable energy source.

The current research takes this previous work as a starting point and advances the analysis through a more detailed methodology and the use of more sophisticated tools. Specifically, the study focuses on the district of Anguía, in the province of Chota, also within Cajamarca, an area that had not previously been the subject of a dedicated analysis. Unlike the study by Carrasco [20], this research incorporates computational simulations using ANSYS Student 2025, complemented by RWIND 2.02, which has enabled a more precise visualization of wind behavior over the modeled geographical surface and the identification of zones with higher energy concentration in terms of wind power density.

The wind speed values obtained in the present study show general consistency with the ranges reported in previous wind resource assessments carried out in the Cajamarca region. Carrasco [20], for example, reported mean wind speeds in the order of 3.5–5.5 m/s depending on elevation and terrain exposure. In the case of Anguía, the mean wind speed estimated through Weibull distribution analysis was approximately 3.68 m/s at the representative point analyzed. Although this value is located in the lower range of the previously reported interval, it remains within the expected variability for mountainous environments where terrain shielding and local topography can significantly influence wind flow behavior.

Differences between studies may be attributed to several factors. First, the data source used in this research (MERRA-2 reanalysis data) provides spatially interpolated atmospheric information that may differ from ground-based measurements used in other assessments. Second, the spatial scale of the analysis differs from previous studies, as the present work focuses on a specific district-scale polygon rather than a broader regional area. Finally, the incorporation of CFD modeling allows the representation of terrain effects such as slopes and elevation gradients, which can locally modify wind speed patterns.

This comparison highlights that moderate wind regimes are commonly observed in highland environments, where complex terrain conditions produce localized zones of relatively higher wind potential.

In addition, the research conducted by Fábregas and Márquez [21] focused on the design of a low-power wind turbine using ANSYS software, primarily addressing the aerodynamic behavior of the rotor under laboratory conditions. Although their study was carried out in a controlled and smaller-scale environment, the results laid the groundwork for validating key aspects of fluid dynamics analysis applied to wind energy. In the present research, these principles have been transferred to a broader context, in which wind behavior is simulated over a representative geographical surface at scale, specifically in the area of Anguía, province of Chota, Cajamarca region. This approach significantly increases computational cost due to geometric complexity and mesh size; however, it allows for a more accurate assessment of wind energy potential in real areas of interest.

Therefore, the use of CFD tools such as ANSYS Student 2025 and RWIND 2.02 contributes to improving the spatial understanding of wind flow in complex terrain environments. While the present results represent a preliminary assessment, the methodology demonstrates the usefulness of numerical simulation for identifying areas that may deserve further detailed investigation through field measurements and long-term monitoring.

5. CONCLUSIONS

The collection and analysis of historical wind data provided a solid foundation for modeling wind behavior in the study area. The identification of the prevailing wind direction and the application of the Weibull distribution enabled the estimation of mean wind speed at different heights, which is essential for assessing energy potential. This statistical process highlights the usefulness of platforms such as MERRA-2 for preliminary renewable resource assessments in rural areas with limited in situ measurements.

The validation of a representative contour level and the subsequent generation of a three-dimensional surface model allowed for a realistic simulation of wind flow behavior in the highest-altitude area of the polygon. The combined use of Global Mapper, Civil 3D, and ANSYS Student enabled the transformation of topographic data into a digital environment suitable for simulation. The quality of the generated mesh, within the technical limitations of the student version of the software, ensured a reliable scenario for CFD analysis, reaffirming the importance of accurate modeling in renewable energy studies.

CFD simulation made it possible to identify zones where wind power density exceeds 50 W/m² in localized areas of the study domain. These results indicate the presence of moderate wind energy potential within specific portions of the analyzed terrain. However, such findings should be interpreted as a preliminary technical indication rather than definitive evidence for large-scale wind farm deployment.

Additional factors not addressed in the present study (including economic feasibility, electrical grid accessibility, seasonal wind variability, and uncertainty associated with atmospheric datasets) should be considered in future analyses before making infrastructure development decisions.

This research demonstrates the feasibility of applying simulation tools such as ANSYS Student 2025 and RWIND 2.02 to analyze wind behavior over scaled geographical surfaces. The methodology provides a useful framework for identifying zones with relatively favorable wind conditions and can support future studies aimed at more detailed wind resource characterization. Furthermore, it confirms the importance of considering complex terrain geometries in simulations, as they allow the identification of localized wind acceleration effects that may influence the potential performance of small-scale wind energy systems in rural environments.

Consequently, the results of this study should be understood as a first step toward a more comprehensive wind resource assessment in Anguía, which could be complemented in future work through on-site measurements, seasonal analysis, and higher-resolution atmospheric datasets.

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REFERENCES

[1] Fudjumdjum, H., Leal Filho, W. (2025). Assessing perceptions of various stakeholders on climate change mitigation and adaptation in rural areas in Cameroon: The use of ICTs. Climate Risk Management, 51: 100780. https://doi.org/10.1016/j.crm.2025.100780

[2] Schira, S., Sears, A.W., Fyke, J. (2026). A climate indicator dashboard for communicating climate change in the Okanagan Valley of BC. Climate Services, 41: 100631. https://doi.org/10.1016/j.cliser.2025.100631

[3] Al-Rubaye, A., Kadhim, H.T., Rasheed, R.H., Rona, A. (2025). Analysis of wind energy characteristics and wind turbine selection for residential use: A case study. International Journal of Thermofluids, 28: 101305. https://doi.org/10.1016/j.ijft.2025.101305

[4] Casalicchio, V., Barchi, G., Calabria, F., Manzolini, G., Prina, M.G., Moser, D. (2025). Advancing renewable energy community planning through integrated sector-coupling and economies of scale. Applied Energy, 395: 125942. https://doi.org/10.1016/j.apenergy.2025.125942

[5] Rtimi, B., Benhmidene, A., Dhaoui, M., Chaouachi, B. (2022). The overall efficiency of a solar panel under various conditions. Desalination and Water Treatment, 273: 34-42. https://doi.org/10.5004/dwt.2022.28887

[6] Alham, M.H., Gad, M.F., Ibrahim, D.K. (2023). Potential of wind energy and economic assessment in Egypt considering optimal hub height by equilibrium optimizer. Ain Shams Engineering Journal, 14(1): 101816. https://doi.org/10.1016/j.asej.2022.101816

[7] Mendoza, P.S.P. (2025). Technical-economic evaluation of a 94.5 MW wind power plant at different elevation heights. A case study in Peru's countryside. Journal of Engineering Research, 13(2): 1089-1103. https://doi.org/10.1016/j.jer.2024.03.020

[8] Wang, B., Wang, Q., Geoffroy, S. (2025). Estimation of rooftop canopy wind energy with eave deflector panel. Results in Engineering, 27: 106042. https://doi.org/10.1016/j.rineng.2025.106042

[9] Nassar, A.K., Al-Dulaimi, O., Fakhruldeen, H.F., Sapaev, I.B., Jabbar, F.I., Dawood, I.I., Khalaf, D.H., Algburi, S. (2025). Multi-criteria GIS-based approach for optimal site selection of solar and wind energy. Unconventional Resources, 7: 100192. https://doi.org/10.1016/j.uncres.2025.100192

[10] Jiménez-Ruiz, J., Villena-Ruiz, R., Honrubia-Escribano, A., Fortmann, J., Gómez-Lázaro, E. (2026). Generic wind turbine models for power system stability assessment based on IEC 61400-27: A review. Renewable and Sustainable Energy Reviews, 231: 116740. https://doi.org/10.1016/j.rser.2026.116740

[11] Wang, P., Wang, L., Huang, S., Zhang, J., Wei, J. (2026). A novel Data-Model Hybrid-Driven strategy for voltage control and noise resistance in wind farm. International Journal of Electrical Power & Energy Systems, 176: 111666. https://doi.org/10.1016/j.ijepes.2026.111666

[12] Gestión. (2022). Windx Perú obtiene concesión para desarrollar estudios de factibilidad en el Parque Eólico Huacho Sur. Gestión. https://gestion.pe/economia/windx-peru-obtiene-concesion-para-desarrollar-estudios-de-factibilidad-en-el-parque-eolico-huacho-sur-noticia/.

[13] Ministerio de Energía y Minas. (2024). Balance Nacional de Energía 2021. Ministerio de Energía y Minas. https://www.gob.pe/institucion/minem/informes-publicaciones/5575363-balance-nacional-de-energia-2021.

[14] Campodónico, H., Carrera, C. (2022). Energy transition

and renewable energies: Challenges for Peru. Energy Policy, 171: 113261. https://doi.org/10.1016/J.ENPOL.2022.113261
[15] Hao, H., Domenech, L., Sánchez, F. (2026). Modelling rain erosion surface damage initiation in turbine blades based on inspection data at wind farms. Results in Engineering, 29: 109517. https://doi.org/10.1016/j.rineng.2026.109517
[16] Labuzzetta, C., Johnsen, A., Andress, A., Bohner, T., Grajal-Puche, A., Seymour, M., Straw, B., Thogmartin, W., Udell, B., Wiens, A., Diffendorfer, J. (2026). Hierarchical mixture models and high-resolution monitoring data can inform siting and operational strategies to mitigate bat fatalities at wind turbines. Ecological Informatics, 94: 103652. https://doi.org/10.1016/j.ecoinf.2026.103652
[17] Fang, X., Qi, B., Liu, J., Markthaler, S., Elhaus, N., Karl, J. (2025). Particle-resolved computational fluid dynamics simulation of the heat transfer in fixed-bed reactors for heterogeneous catalysis: A review. International Journal of Heat and Mass Transfer, 250: 127311. https://doi.org/10.1016/j.ijheatmasstransfer.2025.127311
[18] Martinez, A., Iglesias, G. (2024). Climate change and wind energy potential in South America. Science of the Total Environment, 957: 177675. https://doi.org/10.1016/j.scitotenv.2024.177675
[19] Bojorquez Chavez, M.A. (2018). Planteamiento de un parque eólico marino en la costa peruana: Regiones de Ica, Piura y La Libertad. Pontificia Universidad Católica del Perú.
[20] Carrasco, J. (2024). Estudio del potencial eólico para la producción de energía eléctrica en la cuenca de la Minera Yanacocha, Cajamarca. Tesis de Maestría, Universidad Nacional Mayor de San Marcos. https://cybertesis.unmsm.edu.pe/item/803d2db6-536e-4624-8f83-72fe4d7b1752.
[21] Fábregas, A., Márquez, J. (2022). Simulación de un Aerogenerador para Uso Doméstico en el Departamento del Cesar. Tesis para optar el título profesional, Universidad de Santander. https://repositorio.udes.edu.co/entities/publication/b83feb85-7a0f-48c9-a379-7423ba9b7406.

NOMENCLATURE

CAD	Computer-aided design, dimensionless
CFD	Computational fluid dynamics, dimensionless
MERRA-2	Satellite meteorological reanalysis dataset, dimensionless
ANSYS	Computational fluid dynamics solver, dimensionless
RWIND	Wind flow simulation software, dimensionless
GHG	Greenhouse gases, dimensionless