RCMOS – Revista Científica Multidisciplinar O
Saber. ISSN: 2675-9128. São Paulo - SP.
Ano VII, v.1 2026 | submissão: 15/08/2026 | aceito: 18/08/2026 | publicação: 21/08/2026

Wind resource assessment: methodologies and implications for the feasibility of generation projects

Avaliação do recurso eólico: metodologias e implicações na viabilidade de projetos de geração

Evaluación del recurso eólico: metodologías e implicaciones para la viabilidad de proyectos de generación

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Abstract:
The operational and financial success of a wind farm is intrinsically dependent on the availability and characteristics of the wind at the installation site. This article presents a qualitative literature review aimed at analyzing wind resource assessment methodologies and their importance in mitigating risks in energy-generation projects. The methodology is based on an integrative literature review covering classic wind-engineering manuals and recent studies on remote sensing. The results indicate that resource assessment requires rigorous on-site measurement campaigns combined with statistical modeling, with the Weibull distribution serving as the gold standard for representing wind-frequency patterns. It is concluded that accuracy in estimating annual energy production (AEP) is the determining factor in project bankability and that new measurement technologies are improving the mapping of areas with highly complex topography.

Keywords:
Wind resource. Anemometry. Weibull distribution. Financial feasibility. Wind energy.

Resumo:
O sucesso operacional e financeiro de uma usina eólica é intrinsecamente dependente da disponibilidade e das características do vento no local de instalação. O presente artigo apresenta uma revisão bibliográfica qualitativa com o objetivo de analisar as metodologias de avaliação do recurso eólico e sua importância na mitigação de riscos em projetos de geração de energia. A metodologia fundamenta-se em uma revisão integrativa da literatura, abordando manuais clássicos de engenharia eólica e estudos recentes sobre sensoriamento remoto. Os resultados indicam que a avaliação do recurso exige campanhas de medição rigorosas in loco, aliadas à modelagem estatística, sendo a Distribuição de Weibull o padrão ouro para representar a frequência dos ventos. Conclui-se que a precisão na estimativa da produção anual de energia (AEP) é o fator determinante para a bancabilidade dos projetos, e que novas tecnologias de medição estão otimizando o mapeamento de áreas de alta complexidade topográfica.

Palavras-chave:
Recurso eólico. Anemometria. Distribuição de Weibull. Viabilidade financeira. Energia eólica.

Resumen:
El éxito operativo y financiero de un parque eólico depende intrínsecamente de la disponibilidad y de las características del viento en el lugar de instalación. Este artículo presenta una revisión bibliográfica cualitativa cuyo objetivo es analizar las metodologías de evaluación del recurso eólico y su importancia para mitigar riesgos en proyectos de generación de energía. La metodología se fundamenta en una revisión integradora de la literatura que abarca manuales clásicos de ingeniería eólica y estudios recientes sobre teledetección. Los resultados indican que la evaluación del recurso exige campañas rigurosas de medición in situ combinadas con modelación estadística, siendo la distribución de Weibull el estándar de referencia para

representar la frecuencia de los vientos. Se concluye que la precisión de la estimación de la producción anual de energía (AEP) determina la bancabilidad de los proyectos y que nuevas tecnologías de medición están optimizando el mapeo de áreas de alta complejidad topográfica.

Palabras clave:
Recurso eólico. Anemometría. Distribución de Weibull. Viabilidad financiera. Energía eólica.

1. Introduction

The feasibility of any wind-generation venture is grounded in the quality of its "fuel": the wind. Unlike thermal power sources, whose inputs can be controlled and stored, wind energy is stochastic and sensitive to climatic, spatial, and temporal variations (BURTON et al., 2011). An overestimate in wind-speed forecasting can make a wind farm's financial return unviable because extracted power is proportional to the cube of wind speed. In this context, prospecting and measurement cease to be simple preliminary steps and become the strategic foundation for plant planning (AMARANTE et al., 2001). This study aims to analyze methodological processes for wind resource assessment, from physical anemometric campaigns to the statistical treatment of observational data, in order to understand how these techniques ensure the technical and economic feasibility of the wind-energy production chain.

2. Theoretical framework

2.1. Anemometric campaigns and data collection

The primary assessment of a wind site requires the installation of meteorological masts equipped with calibrated sensors (anemometers, wind vanes, thermometers, and barometers) positioned at different heights. According to Manwell, McGowan, and Rogers (2010), these campaigns must last at least one complete annual cycle to capture local climate seasonality, although periods of two to three years are preferable for reducing interannual uncertainty. In addition to physical measurements, terrain roughness and orography strongly affect the vertical wind-shear profile. To capture these nuances at heights beyond the reach of conventional tubular towers, recent literature points to the increasing adoption of acoustic- and optical-based remote sensors, such as SoDAR (Sonic Detection and Ranging) and LiDAR (Light Detection and Ranging) (BROWER, 2012).

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2.2. Statistical treatment and the Weibull distribution

Raw data collected in the field form extensive time series that must be summarized to forecast annual energy production (AEP). The most widely accepted model for describing the frequency of the wind regime at a given site is the Weibull probability-density function, a continuous mathematical distribution (PINTO, 2013). The Weibull distribution uses two fundamental parameters: the shape factor (k), which indicates speed variability (the higher it is, the more constant the winds), and the scale factor (c), which is directly proportional to the site's average wind speed (BURTON et al., 2011). Combining the site's Weibull curve with the wind turbine's certified power curve makes it possible to calculate expected energy generation.

3. Materials and method

The research is characterized as a qualitative study based on an integrative literature review that seeks to synthesize the state of the art in wind resource assessment. The material collected included fundamental books on atmospheric engineering, wind atlases, and scientific articles indexed in databases from 2010 to 2024. Priority was given to studies linking observational meteorology and energy engineering. Data analysis followed a thematic-categorization technique, dividing the findings into field-collection methods and statistical-extrapolation methods.

4. Results and discussion

The review results highlight that rigor in wind resource assessment is the main mitigator of financial risk. Brower (2012) emphasizes that financing institutions require independent wind certifications with uncertainty margins calculated through probability-of-exceedance values, such as the P90 scenario, in which there is a 90% probability that generated energy will exceed the estimated value. Contemporary technical discussion centers on the difficulty of modeling terrain with highly complex topography and forest cover. Extrapolating tower measurements to the rest of a wind farm with classic linear-flow models such as WAsP (Petersen et al.) often has limitations in rugged terrain. Consequently, conventional methodologies are shifting toward computational fluid dynamics (CFD) simulations, which can map wind flow over nonuniform terrain and wake effects between turbines more accurately (PINTO, 2013).

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5. Final considerations

This article concludes that wind resource assessment is the pillar supporting the feasibility of investments in wind energy. The methodological transition from conventional towers to three-dimensional simulations (CFD) and laser measurements (LiDAR) demonstrates the sector's evolution in pursuit of increasingly accurate energy estimates. This study contributes by synthesizing the methodological flow that transforms wind, a chaotic phenomenon, into a predictable financial asset through Weibull statistics. Future investigations should analyze the effects that climate change and long-term global warming may have on interannual wind patterns and, consequently, on the financial service life of operating wind farms.

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