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Energia eólica no Brasil e avaliação preliminar do recurso eólico em Tangará da Serra – MT

Wind energy in Brazil and preliminary assessment of wind resources in Tangara da Serra, Mato Grosso State

Jhonatan de Brito Ferreira[1], Tarsila Marilia de Oliveira[2,*]

[1] Aluno de Graduação em Engenheira Civil, Universidade do Estado de Mato Grosso – UNEMAT, campus Tangará da Serra, MT, Brasil
[2] Professora de graduação, Universidade Estadual de Mato Grosso do Sul – UEMS, campus Naviraí, MS, Brasil
*Autor para correspondência, E-mail: tarsila.oliveira@uems.br

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Resumo: A crescente expansão econômica mundial eleva gradativamente o consumo de energia elétrica. Diante da preocupação com a sustentabilidade e a possível escassez de combustíveis fósseis, diversos países têm investido em fontes renováveis de energia, entre as quais se destaca a energia eólica. No Brasil, essa fonte vem ganhando participação crescente na matriz elétrica, com capacidade instalada de 33,3 GW em 2025 e potencial estimado entre 300 e 500 GW. O presente artigo apresenta uma revisão bibliográfica sobre a produção de energia eólica no país e avalia, de forma preliminar, a viabilidade técnica da implantação de aerogeradores no município de Tangará da Serra – MT, com base em dados anemométricos do INMET e da literatura. Os resultados indicam que a velocidade média dos ventos na região (~6 m/s a 50 m de altura) está abaixo do limiar convencionalmente considerado viável (7–8 m/s), embora turbinas projetadas para regimes de baixa velocidade possam ampliar essa perspectiva.
Palavras-chave: Energia eólica; Potencial eólico; Aerogeradores; Viabilidade técnica; Tangará da Serra.

Abstract: *The growing global demand for energy, driven by economic expansion, has intensified the search for sustainable alternatives to fossil fuels. Among renewable energy sources, wind power has gained increasing relevance worldwide. In Brazil, installed wind energy capacity reached 33.3 GW in February 2025, distributed across 1,109 wind farms and accounting for 15.9% of the national electricity matrix, with an estimated potential ranging from 300 to 500 GW. This paper presents a literature review of wind energy production in Brazil and provides a preliminary assessment of the technical feasibility of installing wind turbines in the municipality of Tangará da Serra, Mato Grosso State. The analysis draws on anemometric data from the Brazilian National Institute of Meteorology (INMET) and published studies. Results indicate that the mean annual wind speed in the region (~6 m/s at 50 m height) falls below the conventional threshold for economically viable wind generation (7–8 m/s), although low-wind-speed turbine technologies may improve this outlook.*
Keywords: Wind energy; Wind potential; Wind turbines; Technical feasibility; Tangará da Serra.

1 Introduction

Electricity generation is a crucial factor for the social and economic development of humanity (Carvalho, 2014). In recent years, there has been growing awareness regarding the rational use of natural resources (Goldemberg and Lucon, 2007). Energy resources are classified as renewable -- such as biomass, hydraulic, wind, and solar -- and non-renewable -- such as petroleum, natural gas, coal, and uranium. Among renewable sources, solar energy (Fraidenraich and Lyra, 1998) and wind energy (Kaspary and Jung, 2015) stand out.

Renewable energy sources have been gaining ground worldwide due to the potential depletion of non-renewable resources. In Brazil, the share of renewable sources in the domestic electricity supply accounted for 42.9% in 2017, according to National Energy Balance (BEN, 2018).
In many cases, wind turbines are not used as the sole source of electricity. This is due to two main factors: (1) the cubic relationship between wind speed and generated power, which requires oversizing to meet peak demand; and (2) wind intermittency, which causes variations in power output over time. These factors favor the use of hybrid systems with complementary sources to ensure continuous energy supply (Ribeiro, 2002). In Brazil, wind energy is predominantly exploited in coastal regions, where winds are more constant and intense (Galdino et al., 2000). By February 2025, Brazil's installed wind capacity reached 33.3 GW, distributed across 1,109 projects (Santos et al., 2025). Wind power accounts for 15.9% of the national electricity matrix (Andrade, 2024), establishing itself as the country's second-largest source of clean energy generation.

The state of Mato Grosso has sought to expand investments in clean and renewable sources. Its electricity matrix is predominantly composed of 11 hydroelectric plants and 84 small hydroelectric plants (SHPs), in addition to 1 natural gas thermal plant, 7 biomass thermal plants, and 4 diesel oil thermal plants (RDNews, 2019; SEDEC, 2019).

Given this context, this study has two objectives: (1) to present a literature review on wind energy production in Brazil; and (2) to conduct a preliminary assessment of the technical feasibility of installing wind turbines in the municipality of Tangará da Serra, Mato Grosso State, based on anemometric data from INMET and published studies.

2 Methodology

This study is characterized as exploratory research, both qualitative and quantitative in nature, based on a literature review and analysis of secondary data.

The literature review covered scientific articles, technical reports, and institutional documents related to wind energy production in Brazil and worldwide, obtained from databases such as Google Scholar, CAPES journals, and publications from ABEEolica, ANEEL, BEN, and EPE.
For the technical feasibility analysis of wind conditions in Tangara da Serra, MT, the following data sources were used:

- Anemometric data from the automatic weather station of the Brazilian National Institute of Meteorology (INMET), located on the campus of Mato Grosso State University (UNEMAT), at 10 meters height, for the month of November 2018;
- Mean wind speed data published by Moreira (2012), referring to the year 2014;
- Historical wind speed series (2003--2009) published by Dallacort et al. (2010);
- Mean annual wind speed map at 50 meters height, extracted from the Brazilian Wind Atlas (CRESESB, 2001).

Technical feasibility was assessed by comparing the mean wind speed in the region with the minimum threshold of 7--8 m/s, indicated by Grubb and Meyer (1993) as necessary for a power density equal to or greater than 500 W/m2 at 50 meters height. The analysis presented herein is preliminary.

3 The growing expansion of electricity consumption

The growing desire for economic expansion and improved quality of life has considerably increased global energy consumption. According to the National Electric System Operator (ONS), Brazil recorded a 1.5% increase in electricity consumption in 2017 compared to 2016, reflecting the country's slow economic recovery.

Although this increase in consumption represents economic improvement, it also brings challenges: the potential depletion of non-renewable resources, environmental impacts, and the need for investment in new energy sources (ANEEL, 2018). According to the National Energy Balance (BEN, 2018), the share of renewable sources in Brazil's domestic electricity supply was 42.9%, while non-renewable sources accounted for 57.1%, as shown in Table 1.

Table 1. Electricity production in Brazil by source.

Renewable		**Non-renewable**	
Sugarcane biomass	17,0%	Petroleum and derivatives	36,4%
Hydraulic	12,0%	Natural gas	13,0%
Charcoal	8,0%	Coal	5,7%
Black liquor and other renewables	5,9%	Uranium	1,4%
Wind	21,3%	Other non-renewables	0,6%
Solar	0,4%		
Others	27,7%		

Source: Adapted from the National Energy Balance (BEN, 2018).

3.1 Wind energy production in Brazil

Historically, electricity production in Brazil has been concentrated in two main sources: hydroelectric and thermoelectric. However, driven by growing demand and the need for matrix diversification, wind energy has been expanding rapidly, as shown in Figure 1. Between 2015 and 2022, cumulative installed capacity grew from 9 GW to 26 GW, with investments reaching US$ 6.2 billion in 2022 (Pacheco et al., 2024). By 2023, capacity reached 30.45 GW (Andrade, 2024).

According to the National Wind Atlas (CRESESB, 2001), Brazil is the country in Latin America and the Caribbean with the greatest potential for wind energy generation. In 2019, the 601 Brazilian wind farms accounted for approximately 8.5% of total installed capacity (ABEEolica, 2019). Table 2 presents the installed capacity by state.

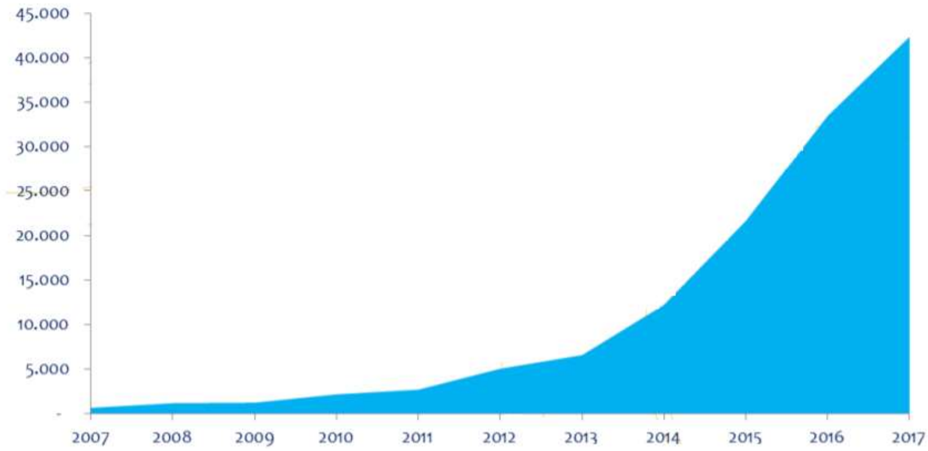

Figure 1. Evolution of installed wind energy capacity in Brazil per year. Source: Energy Research Company (EPE).

Table 2. Installed wind capacity by state and number of plants.

State	Capacity (MW)	Number of plants
RN	3.949,3	146
BA	3.525,0	133
CE	2.049,9	80
RS	1.831,9	80
PI	1.521,1	55
PE	781,3	34
SC	238,5	14
MA	220,8	8
PB	156,9	15
SE	34,5	1
RJ	28,1	1
PR	2,5	1
Total	14.339,6	568

Source: ABEEolica (2019).

Brazil's wind potential is significantly greater than current installed capacity. The 2001 Wind Atlas, based on measurements at 50 meters height, estimated a potential of 143 GW. Figure 2 presents the spatial distribution of mean wind speeds. This map illustrates the spatial distribution of wind potential across Brazil. The color scale represents the annual average wind speed at a height of 100 m above ground level (m/s), where warmer colors (yellow to red) indicate areas with higher wind speeds and greater potential for wind energy generation. The highest wind potential is mainly concentrated along the northeastern coast and in parts of southern Brazil, while the central and western regions generally present lower average wind speeds. The labels in the original map are in Portuguese: *"Brasil – Potencial Eólico"* means *Brazil – Wind Potential*, and *"Velocidade Média Anual do Vento a 100 m de Altura (m/s)"* refers to the *Annual Average Wind Speed at 100 m Height (m/s).* However, this potential was estimated using the technologies of that era, which employed 45-meter towers. With modern turbines, whose towers can exceed 100 meters in height, the actual potential is considerably greater. Consulting firms such as DEWI estimate values of up to 500 GW.

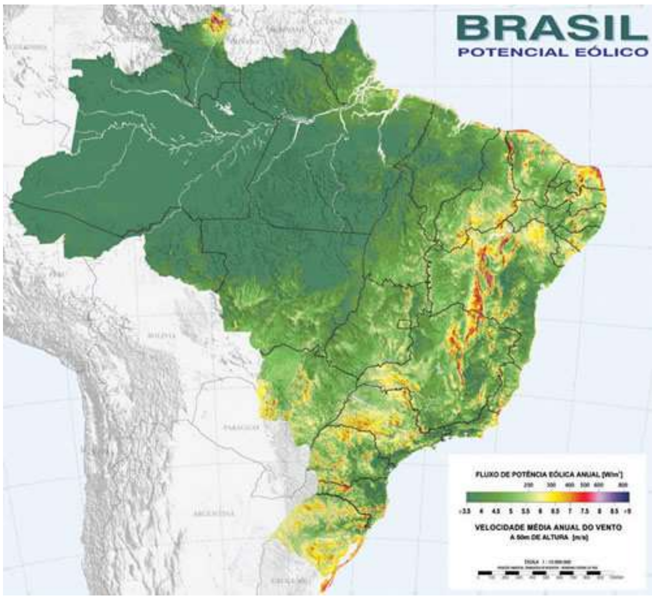

Figure 2. Mean annual wind speed at 50 meters height. Note: axis labels are in Portuguese. Source: Brazilian Wind Atlas (CRESESB, 2001).

3.2 Basic principles of wind energy production

Electricity generation through wind turbines is based on the conversion of the kinetic energy of winds into mechanical energy, which is subsequently converted into electrical energy by a generator coupled to the turbine.

When wind strikes the rotor blades, it transfers part of its kinetic energy, causing the shaft to rotate. This rotational movement is transmitted to a speed multiplier (gearbox), which increases the rotation to levels suitable for driving the electric generator.

The power available in the wind is given by Eq. 1:

$$Pd = \frac{1}{2}\rho A v^3 \quad (1)$$

where, ρ is the air density (kg/m³); A is the area swept by the blades (m^2) and V is the wind speed (m/s). Note the cubic dependence of power on wind speed: small variations in speed result in large variations in available power.

However, not all kinetic energy of the wind can be converted into mechanical energy. According to Betz's Law, the maximum fraction of energy extractable from a free airflow is approximately 59.3% (maximum power coefficient Cp = 16/27 = 0.593). This occurs because the air passing through the turbine at velocity V1 (upstream) is decelerated to velocity V3 (downstream), with the velocity at the rotor plane V2 being the arithmetic mean of V1 and V3, as expressed in Eq. 2:

$$V2 = \frac{V1+V3}{2} \quad (2)$$

Figure 3 illustrates the behavior of the velocity vectors in the airflow passing through the wind turbine rotor. The incident wind velocity (V1) decreases as it interacts with the rotor, reaching velocity V2 at the rotor plane and V3 in the downstream wake region.

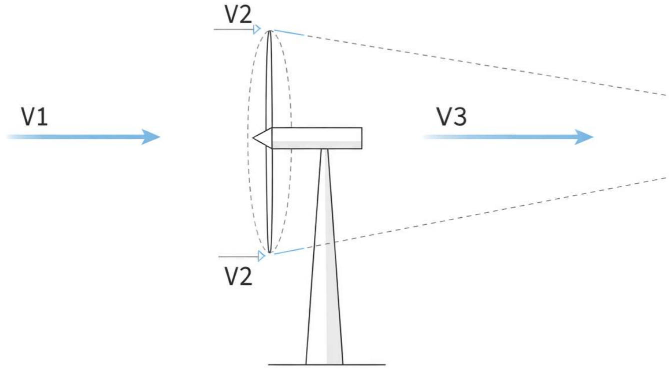

Figure 3. Schematic representation of velocity vectors at the rotor.

4 Electricity production in Mato Grosso

The state of Mato Grosso has an area of 903,357 km2 and an estimated population of 3.442 million inhabitants (IBGE, 2018). The state is self-sufficient in electricity production. According to the Electric Energy Trading Chamber (CCEE), 14.7 million MWh were consumed in the state in 2017, with a 2.9% increase in the first nine months of 2018. Residential consumption in the state was 2,735 GWh in 2017 (BEN, 2018).

According to BEN (2018), the state of Mato Grosso produced 19,952 GWh of electricity in 2017, of which 18,110 GWh were generated by SHPs and hydroelectric plants. Table 3 presents the distribution of production by source.

Table 3. Electricity production in Mato Grosso, Brazil.

State / Region	Total Generation	Hydropower	Wind	Solar	Nuclear	Thermal	Sugarcane Bagasse	Firewood
Central-West Region	65.523	52.084	0	18	0	13.421	7.945	314
Mato Grosso State	19.952	18.110	0	5	0	1.837	589	224

Source: Adapted from the National Energy Balance (BEN, 2018).

5 Technical feasibility of wind energy production in Tangara da Serra, MT

5.1 Local electricity consumption

The municipality of Tangara da Serra is locaste in the southwestern region of the state of Mato Grosso. According to IBGE, in 2010 the population was estimated at 84,076 inhabitants, with electricity consumption of 174,704 MWh, according to data from Rede Cemat obtained by UNEMAT. The current population is estimated at 101,764 inhabitants (IBGE, 2018), and the increasing population growth implies greater energy demand.

5.2 Mean wind speed in Tangara da Serra, MT

Anemometric data were obtained from the INMET automatic weather station, located on the UNEMAT campus, at 10 meters height in an open field. During the period from November 1 to 30, 2018, the mean wind speed was 2.252 m/s, with a predominant direction of 260 degrees, corresponding to West-Southwest (WSW). Figure 4 presents the wind behavior during this period.

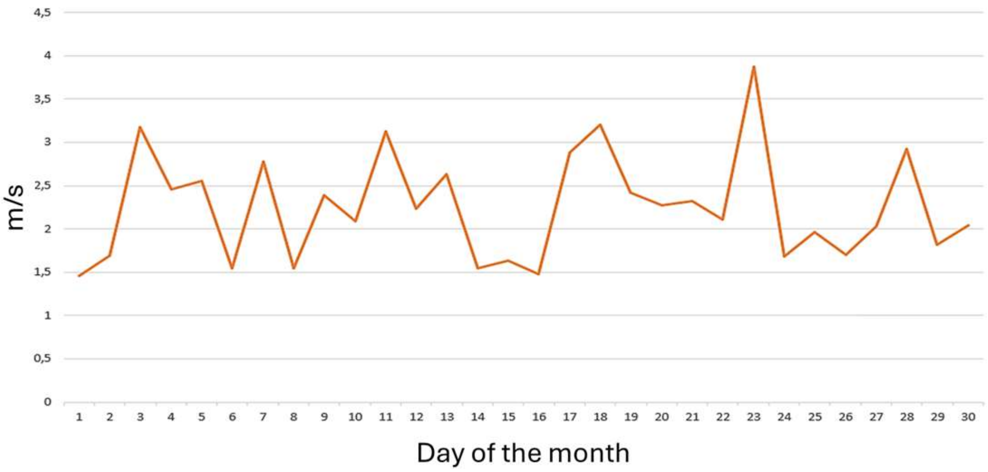

Figure 4. Wind behavior in November 2018, INMET data -- Tangara da Serra station;

Moreira (2012), in a study on meteorological variables in Tangara da Serra, recorded a mean speed of 2.75 m/s and gusts of 5.04 m/s in November 2014, with an annual mean of 2.59 m/s and gusts of 4.73 m/s.

Dallacort et al. (2010), in a study spanning six years (2003-2009), reported a mean wind speed of 3.4 m/s in the region, with daytime speed 23.2% higher than nighttime speed. The months of February and March showed the lowest mean speeds (2.6 m/s and 2.5 m/s, respectively).

5.3 Feasibility assessment

The assessment of wind potential in a region requires careful and systematic collection of wind speed and regime data. However, data from meteorological stations can provide a first estimate of gross potential (Pozo, 2006). According to Grubb and Meyer (1993), for wind generation to present proven technical feasibility, a power density equal to or greater than 500 W/m2 at 50 meters height is required, which demands minimum mean wind speeds of 7 to 8 m/s. It should be noted that the Central-West and North regions of Brazil currently have no installed wind capacity (Santos et al., 2025), reflecting less favorable wind conditions compared to the Northeast, which concentrates 93% of national capacity.

According to the Brazilian Wind Atlas (CRESESB, 2001), the mean annual wind speed in the Tangara da Serra region at 50 meters height is approximately 6 m/s (Figure 5).

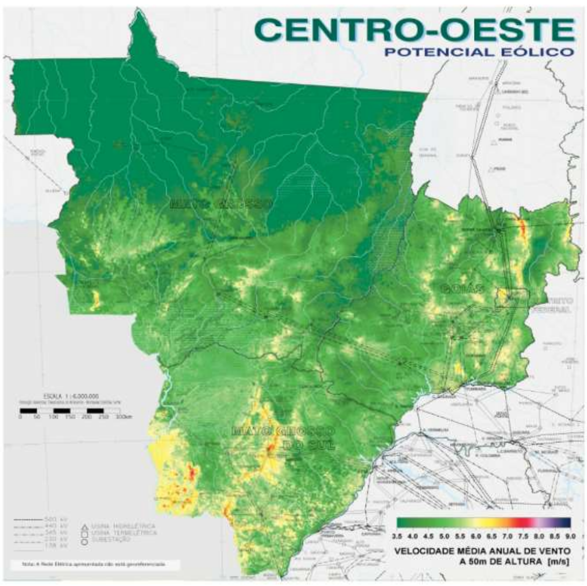

Figure 5. Mean annual wind speed at 50 meters height - Central-West region. Note: axis labels are in Portuguese. Source: Brazilian Wind Atlas (CRESESB, 2001).

The map in Figure 5 presents the spatial distribution of wind potential in the Central-West region of Brazil, including the states of Mato Grosso, Mato Grosso do Sul, Goiás, and the Federal District. Colors represent the annual average wind speed measured at a height of 100 m above ground level, expressed in meters per second (m/s). Warmer colors indicate areas with higher wind speeds and, consequently, greater potential for wind energy generation. The original labels in the map are in Portuguese: *"Centro-Oeste"* refers to the Central-West region, and *"Velocidade Média Anual de Vento a 100 m de Altura (m/s)"* means *Annual Average Wind Speed at 100 m Height (m/s)*.

This speed is below the 7 m/s threshold indicated as a reference for conventional feasibility. However, it should be noted that: (a) modern turbines operate at heights of 80--120 m, where wind speeds tend to be higher; (b) there are wind turbine models designed for low-wind-speed regimes (IEC Class III, with a reference mean speed of 7.5 m/s); and (c) in Germany, wind electricity is produced from winds of 5 to 6 m/s in inland areas (Mateus et al., 2006). Nevertheless, without data measured at representative heights and without analysis of wind frequency distribution (Weibull), it is not possible to definitively confirm feasibility.

Recent studies, such as Santos et al. (2024), applied Weibull mixture models to data from 575 Brazilian meteorological stations with series from 2000 to 2022, demonstrating the suitability of this approach for estimating wind potential in different regions of the country.

6 Conclusions

This study conducted a literature review on wind energy in Brazil and performed a preliminary assessment of the technical feasibility of installing wind turbines in Tangará da Serra, Mato Grosso State. The main findings are:

1) The mean wind speed in the region ranges from 2.5 to 3.4 m/s at 10 m height and approximately 6 m/s at 50 m, below the conventional threshold of 7–8 m/s for economically viable wind generation.
2) Under current conditions, the technical feasibility for conventional wind farms in Tangará da Serra is low.
3) Three factors may alter this outlook: (a) use of low-wind-speed turbines (IEC Class III); (b) measurements at 80–120 m height; and (c) hybrid wind-solar systems.
4) Future studies should include anemometric towers at 80–100 m for at least one year, Weibull distribution modeling, and power density calculations.

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