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WIND GENERATION ECONOMIC FEASIBILITY IN NORTHEAST BRAZIL

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ABSTRACT

This study seeks to pinpoint and define variables that exert the most significant influence on the economic feasibility of operating equipment and wind farms in Northeast Brazil. It aims to identify key performance factors crucial for the economic analysis, including technologies, equipment size, and productive efficiency. Brazil boasts one of the world's cleanest energy matrices, primarily relying on hydro power. Through cash flow analysis, the study enables the calculation of break-even points for various scrutinized variables such as equipment load factor, wind turbine investment, and effective hours available for wind generation. Despite the economic viability of wind generation projects in Northeast Brazil under the examined conditions, their profitability remains relatively low over a 15-year period.

Keywords: Eolic Energy; Wind generation Viability; Energy Sustainability.

1. INTRODUCTION

The increasing utilization of water resources has led to a shift in energy production to regions distant from major industrial and urban centers. This has resulted in elevated costs associated with energy generation, transportation, and distribution. In this context, wind energy generation emerges as a significant alternative, complementing traditional sources like hydro and thermoelectricity. In recent years, there has been a substantial surge in energy generation from alternative sources such as wind and solar energy (Araujo *et al*., 2021; Assali *et al*., 2019; Ogbonnaya *et al*., 2019; Pali & Vadhera, 2018).

Presently, wind power in Brazil is sufficient to supply approximately 20 million homes. In 2015, over 100 wind farms commenced operations in Brazil, attracting investments totaling around 5.2 billion USD and generating 41 thousand jobs. Brazil is currently the fourth country globally in terms of wind energy growth (Empresa de Pesquisa Energética, 2018).

Among all energy generation modalities, wind energy exhibited the highest growth in 2017 compared to other sources. According to the Brazilian Ministry of Energy, in 2017, wind energy accounted for 8.3% of Brazil's energy matrix, ranking the country 8th globally in installed capacity. An additional 213 wind farms are expected to be in operation by 2023, positioning Brazil as one of the six largest producers of this energy type globally. To support the decision to invest in expanding wind power generation in Brazil, a comprehensive study was proposed, considering technical and economic feasibility aspects to inform this decision (Empresa de Pesquisa Energética, 2018).

Brazil boasts one of the cleanest energy matrices globally, primarily based on hydroelectric power. The country represents a highly promising market for wind energy in Latin America, with an estimated wind potential of 300 GW (some analysts even consider a potential of 500 GW). Energy demand is projected to increase by 2 GW annually until 2020. Wind conditions in Brazil are characterized as strong and stable, with a primary focus on onshore wind energy due to lower costs and land availability. Specialists do not foresee a promising future for offshore wind energy in Brazil within the next 10 to 20 years. Despite currently contributing 8.3% to the country's energy production, wind energy is still far from the 70% produced by hydroelectric plants but closely rivals the 9.3% from biomass plants, securing its position as the second-highest contributor in the national energy ranking (Associação Brasileira de Energia Eólica, 2018; Empresa de Pesquisa Energética, 2018).

This research aims to identify and define variables that strongly impact the economic viability of operating equipment and wind farms in Northeast Brazil. Key performance factors for economic analysis, including technologies, equipment size, and productive efficiency, will be identified. The study specifically focuses on wind turbines with an installed capacity above 1MW, capable of generating power at more competitive costs. The research is limited to Northeast Brazil, particularly the federal State of Ceara, due to its wind potential in the coastal region and extensive surveys and studies conducted by local governmental planning institutions and the State University of Ceara (UFC).

2. LITERATURE BACKGROUND

Wind energy stands out as the most economically competitive renewable energy source, thereby enhancing business management and bolstering the competitiveness of organizations. Onshore wind energy, in particular, proves to be more cost-effective than other renewable energy alternatives, competing favorably with conventional power generation sources like coal and gas (Barbosa *et al*., 2020; Joos & Staffell, 2018; Son & Ma, 2017).

When accounting for pollution costs and subsidies, not factored into Levelized Cost of Energy (LCOE) estimates, onshore wind emerges as the most economical generation source in Europe. Additionally, offshore wind is steadily progressing towards cost reduction, with anticipated costs of €100/MWh by 2020 and further reductions to €85 to €79/MWh by 2025, a forecast already surpassed in some European countries where wind generation costs currently stand at around €50 Euros/MWh (Global Wind Energy Council, 2018).

In 2017, Brazil secured the eighth position globally in the accumulated capacity of wind generation, surpassing Canada. With projections aiming for an installed capacity of 19.4 MW in 2023, Brazil demonstrates a commitment to increasing its share of wind energy in the national energy matrix. Notably, the three largest wind energy producers in Brazil are located in Northeast Brazil, specifically in the states of Rio Grande do Norte, Bahia, and Ceara (Associação Brasileira de Energia Eólica, 2018; Empresa de Pesquisa Energética, 2018).

While feasibility studies often delve into details such as siting, permits, grid interconnection, and energy output concerning meteorological conditions, there is a notable lack of feasibility analysis models for small wind projects. Cost calculations for energy production per kWh in the first year of operation play a pivotal role in assessing the economic viability of wind energy projects. Traditional evaluation methods, including Net Present Value (NPV), Benefit-cost ratio (B-C), Internal Rate of Return (IRR), and Pay-back period, are employed to gauge the feasibility of such projects (Khambalkar *et al*., 2007; Son & Ma, 2017; Wang *et al*., 2018).

This wind energy conversion project scrutinizes three key costs — installed capital cost, specific capital cost, and life cycle cost of energy — to evaluate the production cost of the generated energy. With a discount rate of 7.5 percent, the Benefit-Cost (B-C) ratio stands at 3.51, and the Internal Rate of Return (IRR) at 21.82% (Khambalkar *et al*., 2007; Shoaib *et al*., 2019; Yang *et al*., 2018).

For offshore wind turbine (OWT) farms, an economic cost evaluation focused on the economic feasibility of energy production. A developed model assesses the economic cost of OWTs at different project phases, highlighting the impact of cost drivers. Over 50% of the OWT project cost is attributed to capital expenditure, with the remaining less than 50% arising from operating expenditures (Abdullahi *et al*., 2022; Ren *et al*., 2021; Wu *et al*., 2019).

In Southeast Asia, wind conditions are generally less favorable compared to other regions. However, some economies in this area consider offshore wind energy as a long-term solution to decarbonize the electricity sector and diversify electricity sources. A life-cycle analysis, as part of a cost-benefit analysis, was employed to evaluate offshore wind energy in the Southeast Asian context. Findings suggested that, at the time of the research, offshore wind energy costs remained relatively high in this Asian region (Bonou *et al*., 2016; Crawford, 2009; Nian *et al*., 2019).

3. RESEARCH METHOD

This research is characterized as applied research, specifically aiming to generate knowledge for practical application and directed towards solving specific problems. It falls under the category of qualitative research, which entails the interpretation of phenomena, and where the attribution of meanings doesn't necessarily involve the use of statistical methods and techniques (Cardoso *et al*., 2022; Kothari & Garg, 2019; Reis *et al*., 2021). It is a type of research where the researcher analyzes data and processes, focusing on the process and its meaning (Kothari & Garg, 2019; Sales *et al*., 2022; Silva *et al*., 2021).

The field research for data collection followed an extensive bibliographic research covering topics such as wind energy economics, wind energy costs, operation and maintenance costs of wind turbines, economic feasibility studies on wind generation, the Brazilian wind energy market, and the Brazilian renewable energy market.

The development of the Discounted Cash Flow (DCF) and the use of indicators such as Net Present Value, Internal Rate of Return, and Pay-back were complemented with a sensitivity analysis of the main variables impacting the economic viability of wind investments in Brazil and Portugal. The Cash Flow analysis allowed for the calculation of the break-even for various analyzed variables, including equipment load factor, wind turbine investment, and effective hours available for wind generation. The economic viability analysis of wind power equipment in this study considered income tax legislation and accounting legal depreciation as practiced in Brazil.

Regarding Brazilian legislation, the depreciation of wind generators, its depreciation rate, and depreciation period are still under study. For this reason, a depreciation period of 10 years, equivalent to that of hydraulic turbines (code 8410 of the Brazilian Federal Revenue Service), was adopted in this study. Although wind equipment has a considered useful life of 20 years, with residual value and expenses for disposal, these aspects were not considered in the Cash Flow simulation due to calculation difficulties and their relatively minor impact on cash flow (Empresa de Pesquisa Energética, 2018).

Data for Cash Flow development under economic analysis conditions in Northeast Brazil, including investment in wind generators acquisition, civil engineering costs in infrastructures (foundations, access roads, electrical connections, etc.), wind generator load factors, wind conditions, Brazilian IRS taxes, tariffs, among others, were sourced from various places. Information related to wind conditions in the State of Ceara, Brazil, including speeds and distributions, were obtained from the State Secretariat of Infrastructure of The State of Ceará (2019).

For the calculation of project returns and viability, the regulatory and legal framework must be analyzed in accordance with the specific conditions of the region and the country. The development of wind energy projects depends on country-specific conditions based on the policy framework set by national or regional governments. The financial feasibility of any proposed wind energy project selling electricity to the grid hinges on the available framework conditions for support. Inadequate or non-existent framework conditions often present crucial barriers to exploiting the available wind energy potential.

4. RESULT AND DISCUSSIONS

The economic evaluation utilized traditional Cash Flows, employing parameters from established deterministic models of economic viability, including Net Present Value (NPV), Internal Rate of Return (IRR), and Pay-back, along with a sensitivity analysis of the variables. The monetary reference was the US Dollar, with amounts in Brazilian Real converted at the prevailing exchange rate on the date of generation.

To assess the economic viability of wind power projects in Northeast Brazil, three cash flows were developed, each considering technical and tax aspects:

Cash Flow 1: According to Brazilian technical and tax parameters, with a 20-year life span and a 20-year straight-line depreciation period.

Cash Flow 2: According to Brazilian technical and tax parameters, with a 20-year life span and a 10-year straight-line depreciation period.

Cash Flow 3: According to Brazilian technical and tax parameters, with a 5-year straight-line depreciation period.

These three cash flows highlight the main distinctions in project lifecycle and equipment depreciation, providing insights into the economic feasibility analysis of wind projects in Northeast Brazil. Despite variations in the cost of wind turbines and civil works in Brazilian projects, international values were adopted due to a lack of detailed data and precise budgets.

4.1 PROJECTS AND FINANCING CONDITIONS

Projects financed by the Brazilian BNDES (National Bank for Economic and Social Development) incorporate a basic rate for long-term projects called TJLP (Long-term Interest Rate), currently at 6.5% yearly. The final interest rate for direct operations comprises the financial cost and the BNDES rate. For indirect operations, it also includes the Financial Agent Rate:

Calculation example:

Financial cost = 6% p.a.

BNDES rate = 1.3% p.a.

Agent rate = 3% p.a.

Resulting interest rate = 10.6% p.a.

Financing rates, as per the Sectorial Chamber of Renewable Energies of the Federation of Industries of the State of Ceara (FIEC), follow similar rules to BNDES, varying based on project rating, payment capacity, location, and default factor. A risk rate is added, considering transaction conditions and the economic situation of the loan borrower. With a BNDES interest rate of 6% p.a. and a BNDES rate factor of 1.3% p.a., the wind project financing rate is 7.3% p.a.

The amortization period is determined based on the enterprise's capacity to pay, with a maximum limit of 24 years. For Banco do Nordeste do Brasil (BNB), they adhere to the conditions of the Constitutional Financing Fund of the Northeast (FNE) for Infrastructure, with an interest rate IPCA + 1.2765% a.a. The total funding period is up to 20 years, requiring real guarantees such as mortgage, pledge, fiduciary property, receivables, etc.

In the Brazilian case, an individual investor rate of 27% was adopted. Revenues generated by the wind farms, based on 8,760 annual hours and a 50% load factor in Northeast Brazil, were considered. An average tariff of 31 USD/MWh was used, with an anticipated increase in wind power tariffs expected to enhance the economic attractiveness of wind power generation in Brazil.

The economic feasibility focused on stand-alone machine/equipment for wind generation, considering a 3 MW wind turbine with an estimated investment of $1.5 million as a reference for the northeast of Brazil. Infrastructure costs were set at 25% of total costs, with a total investment of $2.2 million for the implementation of a wind generator.

Equipment maintenance costs were considered at 1.5% of equipment acquisition costs per year for the first 10 years and 2.0% from the eleventh to the twentieth year. The chosen scenario for economic analysis in Brazil was Cash Flow 2, which considered a 10-year depreciation and a 20-year lifespan for wind equipment.

4.2 CASH FLOW FOR WIND ENERGY GENERATION

We applied the following parameters to the standard Cash Flow analysis, considering the economic feasibility of wind energy based on Brazilian financing conditions for projects in Northeast Brazil:

Investment interest rate (annually): 7.3% p.a.

Operation and maintenance costs: 1.5% p.a. for the initial 10 years and 2.0% p.a. for the subsequent 10 years.

Annual revenue generated during the assessed period: $407.34 USD.

Tariff: $31 USD/MWh.

Wind equipment investment: $2.28 million USD.

Total investment, inclusive of civil works: $3.04 million USD.

Equipment depreciation: 10 years.

Load factor: 50%.

IRS rate: 27%.

Considering the above Cash Flow parameters for a 3 MW wind power generator, with an estimated investment of $2.28 million USD and infrastructure expenditures of $760,000 USD (total investment of $3.04 million USD), this investment demonstrated economic feasibility with the following indicators: NPV equal to $457,390 USD and an IRR of 9.22%. Additionally, in the analysis of the investment cash flow, various variables were examined, including interest rate, load factor, wind turbine investment, and wind generation tariff, as detailed in Tables 1 to 4.

Table 1 | Changes in NPV resulting from changes in the Investment Rate

Investment Rate [%]	4,0	6,0	8,0	10,0	12,0	14,0	16,0
NPV [1000 USD]	1.543,7	832,3	595, 7	-158,5	- 508,4	- 792,2	- 1.025,1

Table 1 illustrates a decline in the project's NPV as the investment rate increases. Through linear interpolation between 8% and 10% of the investment rate, the economic equilibrium point for this project is identified at 9.578%. In other words, at this investment rate, the NPV reaches zero, marking the point at which the project becomes economically unfeasible.

Table 2 | Changes in NPV as a result of variations in the Load Factor

Load Factor [%]	20	25	30	35	40	45	50
NPV [1000 USD]	-2,131.1	-1,221.0	- 885.3	-549.6	-213.9	121.7	457.4

Taking into account the same project parameters mentioned earlier, Table 2 depicts how the project's NPV and IRR fluctuate in response to changes in the Load Factor. With the established variables of the standard cash flow, the break-even point for this variable occurs at a load factor of 43.18%. In these circumstances, a wind project in Brazil becomes economically viable for 'load factors' exceeding 43.18%.

Table 3 | NPV and IRR variation due to variation in Turbine Investment'

Wind Turbine Investment [USD/MW]	400	500	600	700	761	800
NPV [1000 USD]	1.832,8	1.451,8	1.070,8	689,8	457,4	308,8
IRR [%]	19,78%	15,62%	12,65%	10,38%	9,22%	8,55%

Table 4 | NPV and IRR variation due to change in Tariff

Tariff [USD/MW]	25	30	31	40	50	60
NPV [1000 USD]	-192,30	349,10	457,40	1.431,90	2.514,80	3.597,60
IRR [%]	6,40%	8,78%	9,22%	12,91%	16,64%	20,13%

Break-even points for the variables Turbine Investment' (Table 3) and Tariff (Table 4) were also computed, yielding the following results: Wind Turbine Investment equals 881.11 [USD/kW]. In terms of sensitivity analysis for these variables, which gauges the major or minor impact on the

NPV value of the assessed cash flows, Figure 1 indicates that the variable with the most significant positive correlation with NPV is the Load Factor, followed, in descending order, by the variables Turbine Investment' (negatively correlated), Tariff (positively correlated), and Interest Rate with negative correlation.

Figure 1 | Variables sensitivity analysis

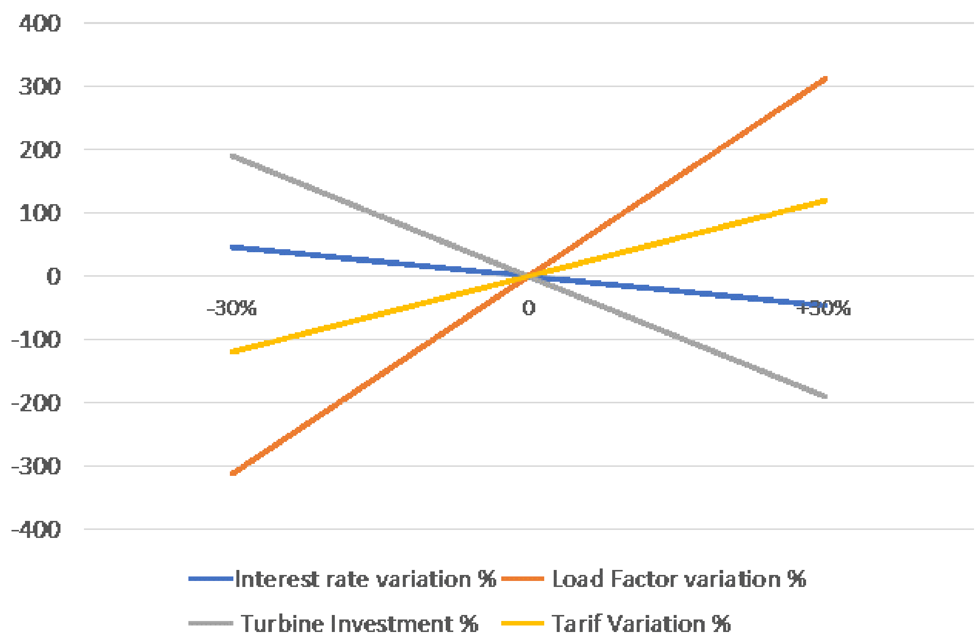

Table 5 presents the break-even points for the variables Interest rate, Load Factor, Turbine investment, and Tariff. For Interest rate and Tariff, the break-even levels for wind projects in Brazil are lower compared to similar projects in Portugal. Conversely, for the Load factor' and Turbine Investment variables, the situation is the opposite.

Table 5 | Economic break-even of the variables Interest rate, Load Factor, Turbine Investment and Tariff

Interest rate [%]	Load Factor [%]	Turbine Investment [USD/kW]	Tariff [USD/MW]
9.22	43.18	881.11	26.73

CONCLUSION

This study aimed to assess the economic viability of wind power generation in Northeast Brazil and identify the key variables influencing the feasibility of operating wind equipment and farms.

Factors such as wind conditions, technology, equipment size, and load factor were examined using data from surveys conducted by the Ceara State Secretariat of Infrastructure (SEINFRA) and other sources, including technical reports from ABEEOLICA, EPE (Brazilian Ministry of Mines and Energy), and financing information from the Federation of Industries of the State of Ceara.

The analysis employed deterministic models for investment projects, incorporating Cash Flow projections and indicators like Net Present Value (NPV), Internal Rate of Return (IRR), and Pay-back. A sensitivity analysis explored the impact of variables on the economic viability of wind investments in Northeast Brazil. The break-even points for variables such as equipment load factor, wind turbine investment, and effective hours for wind generation were calculated through cash flow analysis.

While the study found wind generation projects in Northeast Brazil to be economically viable, the profitability remains modest with a 15-year payback and a 9.22% annual return rate, considering a financing cost of 7.3% p.a. (BNDES interest rates for larger wind projects) and various risks such as tariff fluctuations, wind equipment price risks due to exchange rate variations, and uncontrollable variables like wind intensity and duration.

For the standard flow considered (Cash Flow 2) for generation in Northeast Brazil, the internal rate of return and NPV were 9.21% annually (financing BNDES rate 7.3%) and $454,136.80 USD (20-year project lifespan), respectively.

Sensitivity analysis revealed that, among the variables, the Load factor had the highest impact on NPV, positively correlated, followed by Turbine Investment' (negatively correlated), Tariff (positively correlated), and Interest rate with a negative correlation.

Simulations of the depreciation impact on wind projects in Northeast Brazil indicated that extending depreciation to a 20-year horizon resulted in an NPV of $457,395.63 and IRR of 9.22%. Alternatively, applying a 5-year accelerated average depreciation for assets increased NPV to $848,030.30 and IRR to 10.72% p.a.

The study additionally suggests that improving the profitability of wind generation projects in the northeast region of Brazil could be achieved through government initiatives, such as reducing taxes on wind equipment and IRS rates, shortening the depreciation period for related assets, and offering lower interest rates for financing wind projects.

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