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ECONOMIC FEASIBILITY OF WIND GENERATION IN NORTHEAST BRAZIL

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Abstract: *Brazil has one of the cleanest energy matrices in the world, mainly a matrix based on hydropower. The research aims to identify and define variables that most strongly influence the economic viability of operating equipment and wind farms in Northeast Brazil, identifying the key performance factors for the economic analysis performed, such as technologies, equipment size and productive efficiency. The cash flow analysis allowed the calculation of the break-even for the different variables analyzed, equipment load factor, wind turbine investment and effective hours available for wind generation, among others. Although for the situation analyzed, wind generation projects in the Northeast of Brazil are economically viable, the profitability of these projects for the assumptions of the calculation assumed is still low, considering they generate a 15 year pay-back and a return rate of 9.22% p.a. as opposed to an assumed financing cost of 7.35% p.a.*

Keywords: *wind energy, sustainability, energetic viability*

1. Introduction

The progressive use of water resourceshas shifted energy production to regions farthest from major industrial and urban centres, increasing the costs of energy generation, transportation, distributionand reducing the accumulation of solid residues, contributing to the mitigation of environmental impacts(Assali et al., 2019; Espuny et al., 2022; Ogbonnaya et al., 2019).Thus, in this sense, the generation of wind energy emerges as an important complementary alternative when compared with traditional sources such as hydro and thermoelectricity. For this reason, in recent years, there has been a strong increase in energy generation with alternative sources such as wind and solar energy(Araujo et al., 2021; Assali et al., 2019; Ogbonnaya et al., 2019; Pali & Vadhera, 2018).Currently, the wind power generated in Brazil is enough to supply about 20 million homes. In 2015 alone, more than 100 wind farms started operating in Brazil, with about 5.2 billion USD in investments generating 41 thousand jobs. This expansion is attracting large international companies that are betting on the growth of this type of energy in Brazil, being currently the fourth country in the world in what concerns the growth of wind energy (Empresa de Pesquisa Energética, 2018).

In comparison to other sources of electricity generation,among all modalities, it was the

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one that grew the most in 2017. According to the Brazilian Ministry of Energy, in 2017, wind energy represented 8.3% of the Brazilian energy matrix of which, in relation to installed capacity, Brazil is currently ranked 8th in the world ranking. Another 213 wind farms are expected to be additionally in operation in2023, which is expected to make Brazil, one of the six largest producers in the world, in this type of energy.

Thus, to support the decision to invest in the expansion of wind power generation in Brazil, it was proposed to carry out a comprehensive study considering aspects of the technical and economic feasibility of wind power generation to subsidize this decision(Empresa de Pesquisa Energética, 2018).

Brazil has one of the cleanest energy matrices in the world, mainly a matrix based on hydro power. The country can be considered the most promising market for wind energy in Latin America, with an estimated wind potential of 300 GW (some analysts consider even a potential of 500 GW) and the energy demand increased by 2 GW per year until 2020. Moreover, wind conditions in Brazil are characterized as strong and stable. The focus on the Brazilian wind energy sector is mainly onshore, due to lower cost,land availability and sector specialists do not foresee a promising future for offshore wind energy in Brazil within the next 10 to 20 years. This segment which is already responsible for 8.3% of the energy produced in the country, a percentage still far from the 70% produced by hydroelectric plants. plants, but already close to the 9.3% of biomass plants production, occupy the second place in the national energy ranking(Associação Brasileira de Energia Eólica, 2018; Empresa de Pesquisa Energética, 2018).

The proposed research aimed to identify and define variables that most strongly impact the economic viability of operating equipment and wind farms in Northeast Brazil, identifying the key performance factors for the economic analysis performed, such as technologies, equipment size and productive efficiency. The study focused on wind turbines with installed capacity above 1MW, capable of generating power at more competitive costs. The research was limited to Northeast Brazil, and more specifically to the Brazilian federal State of Ceara, by its wind potential in the coastal region of this State and by extensive surveys and studies carried out by local governmental planning institutions and the local State University of Ceara (UFC).

2. Literature Background

Wind energy is the most cost competitive renewable energy source, thus, helping to improve business management, making organizations more competitive. Onshore wind energy is cheaper than any other renewable energy and it is competitive with conventional power generation sources such as coal and gas(Barbosa et al., 2020; Joos & Staffell, 2018; Son & Ma, 2017). When taking into consideration pollution costs and subsidies, which are not included in LCOE (Levelized Cost of Energy) estimations, onshore wind is the cheapest generation source in Europe; offshore wind is on a steady cost reduction pathway with expected costs of €100/MWh by 2020 and €85 to €79/MWh by 2025.The above forecast, contained in the document 'The Economics of Wind Energy', published by EWEA. has already been surpassed, with wind generation costs in some European countries are currently standing at the level of €50 Euros/MWh(Global Wind Energy Council, 2018).

Brazil occupied the eighth position in the world ranking of accumulated capacity of wind generation (14.7 MW) in 2017, surpassing Canada (12.3 MW) with projections to reach an installed capacity of 19.4 MW in 2023, which refer in this situation to contracts made possible in auctions already carried out and to be negotiated, in the spot market in the future.Brazil has been very proactive in renewable sources, both wind and solar, and has an ambitious program to increase this share of wind energy in the country's energy matrix. Among the top ten wind energy producers in the country, the three largest are in Northeast Brazil, respectively in the Brazilian federal states of Rio Grande do Norte, Bahia and Ceara(Associação Brasileira de Energia Eólica, 2018; Empresa de Pesquisa Energética, 2018).

Feasibility studies that have been published analyze details such as siting, permits, grid interconnection and energy output in connection to meteorological conditions. There are a variety of models available for calculating the feasibility of utility scale projects, however, small wind projects lack feasibility analysis of a general model(Chen et al., 2017; Qolipour et al., 2017; Wang et al., 2018).The cost of energy production per kWh was calculated for the first year of operation. The economics of wind energy and thereby the feasibility of the power project were examined by estimating per unit cost of energy.For this it was necessary to evaluate the feasibility of this project using the traditional methods such as Net Present Value (NPV), Benefit-cost ratio (B-C), Internal Rate of Return (IRR), and Pay-back period (Khambalkar et al., 2007; Son & Ma, 2017; Wang et al., 2018).

In this wind energy conversion project, three costs: the installed capital cost, specific capital cost, and life cycle cost of energy, were examined for the evaluation of the production cost of the energy generated. Considering the discount rate on the investment for the project as 7.5 percent, the B-C ratio came to 3.51 and the IRR to 21.82%(Khambalkar et al., 2007; Shoaib et al., 2019; Yang et al., 2018). Economic cost evaluation on the economic feasibility of producing energy with offshore wind turbine, in OffshoreWind Turbine (OWT) farm. A developed model was used in this research to evaluate the economic cost of an OWTs at different phases of the project. Additionally, the effect of the cost drivers at the changed phases of the OWTs was studied correspondingly. Results obtained showed that over 50% of the OWT project cost emanated from capital expenditure while a value less than 50% came from operating expenditures(Abdullahi et al., 2022; Ren et al., 2021; Wu et al., 2019).

Wind conditions in Southeast Asia are generally much less favorable as compared to other parts of the world, although several economies in this region consider offshore wind energy as a long-term solution to decarbonize the electricity sector and to diversify the source of electricity(Araujo Jr, 2022; Horvat et al., 2011; Matayoshi et al., 2018; Nian et al., 2019).It is necessary to evaluate the true benefits of offshore wind energy under the region's suboptimal climatic conditions." This study employed the Life-cycle analysis to conduct a Cost-benefit analysis of offshore wind energy in the Southeast Asia context. Findings from the study suggested that the offshore wind energy cost remained high at that moment of the research for this Asian region(Bonou et al., 2016; Crawford, 2009; Nian et al., 2019).

3. Research Method

From the point of view of its nature, this research is an Applied Research that is the one that aims to generate knowledge for practical application, directed to the solution of specific problems. It can be considered Qualitative Research, the type of research that requires the interpretation of phenomena and where the attribution of meanings does not necessarily require the use of statistical methods and techniques(Cardoso et al., 2022; Kothari & Garg, 2019; Reis et al., 2021). It is also research, in which the researcher tends to analyze its 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 was preceded by extensive bibliographic research on the following topics: wind energy economics, wind energy costs, operation and maintenance costs of wind turbines, economic feasibility studies on the wind generation, Brazilian wind energy market and Brazilian renewable energy market.

The elaboration of the Discounted Cash Flow (DCF) and the adoption of indicators such as Net Present Value, Internal Rate of Return and Pay-back, 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 the calculation of the break-even for the different variables analyzed, equipment load factor, wind turbine investment and effective hours available for wind generation, among others.The economic viability analysis of wind power equipment in this study considered the income tax legislation and accounting legal depreciation as practiced in Brazil.

Concerning the Brazilian legislation, the depreciation of wind generators, its depreciation rate and depreciation period are still under study, and for this reason it was adopted in this study a depreciation period of 10 years equivalent to that of hydraulic turbines (code 8410 of the Brazilian Federal Revenue Service). Although wind equipment at the end of a considered useful life of 20 years, still has residual value and incur expenses for disposal (wind turbines made of composite material, fiberglass, and wood laminate) must be dismantled and destroyed with special environmental care). These revenues and expenses due to calculation difficulties and because they not strongly impact the cash flow, were not considered in the Cash Flow simulation(Empresa de Pesquisa Energética, 2018).

The data for the elaboration of Cash Flows under the conditions of economic analysis in Northeast Brazil, such as investment in the acquisition of wind generators, civil engineering costs in infrastructures (foundations, access roads, electrical connections, etc.), wind generators load factors , wind conditions, Brazilian IRS taxes, tariffs, among others, were obtained from different sources. The most important were, among others, equipment working hours and power of wind turbines, load factor, average tariffs practiced in energy auctions in Brazil were obtained from the document "Installed generation capacity in the Brazilian electricity system", published by the Ministry of Mines and Energy of Brazil, in June 2018

(Empresa de Pesquisa Energética, 2018).Information related to the wind conditions of the State of Ceara, Brazil, its speeds and distributions were obtained inState Secretariat Of Infrastructure Of The State Of Ceará (2019).

For the calculation of project returns, its viability, regulatory and legal framework must be analyzed in accordance with the specific conditions of the region and the country. Country-specific conditions for the development of wind energy projects are based upon the policy framework conditions prepared by national or regional governments.The financial feasibility of any wind energy project proposed to sell electricity to the grid depends on the available framework conditions for support. Inadequate or non-existent framework conditions often form crucial barriers impeding the exploitation of available wind energy potential.

4. Result and Discussions

The economic analysis was performed using conventional Cash Flows, which considered parameters as used in traditional economic viability deterministic models, such as Net Present Value (NPV), Internal Rate of Return (IRR) and Pay-back followed by a sensitivity analysis of the variables; additionally, we have adopted the US Dollar as our monetary reference. In the case of amounts originated in Brazilian currency Real, these were converted into the American currency at the parity on the date they were generated.

To analyse the economic viability of wind power projects, in Northeast Brazil, in the context of this research, three cash flows were elaborated, considering technical and tax aspects. We can consider cash Flow 1 according to Brazilian technical and tax parameters, 20-year life span and 20-year straight-line depreciation period; cash flow 2 according to Brazilian technical and tax parameters, 20-year life span and a10-year straight-line depreciation period; and cash flow 3 according to Brazilian technical and tax parameters and a 5-year straight-line depreciation period.The above three cash flows show the main differences among the cash flows considered in the economic feasibility analysis of wind generating projects in Northeast Brazil consisting of the main differences between these flows, in the project lifecycle and in the equipment depreciation. Although there is a difference in relation to the cost of wind turbines and civil works in projects being implemented in Brazil, in the absence of detailed data and more precise budgets, we have adopted international values for the implementation of wind power projects in Northeast Brazil.

4.1. Projects and Financing Conditions

Projects financed by the Brazilian BNDES (‘National Bank for Economic and Social Development’) consider in its financial cost a basic rate for long-term projects called TJLP (Long-term Interest Rate), the quarterly interest rate, which is currently equivalent to 6.5% yearly. For direct operations, the final interest rate is made up of the financial cost and the BNDES rate (including the bank remuneration and the credit risk rate): Interest Rate = Cost Factor x BNDES Rate Factor – 1.Let's consider the example: Financial cost = 6% p.a.; BNDES rate = 1.3% p.a. Financial Cost Factor = 1.06; BNDES Rate Factor = 1.013. Interest rate = 1.06 x 1.013 - 1 = 7.3% p.a. For indirect operations, the final interest rate is composed of the Financial Cost, the BNDES Rate (including the remuneration of the National Brazilian BNDES and the financial intermediation rate) and the Financial Agent Rate, being made up of the following equation: Interest Rate = (Cost Factor x 'BNDES' Rate Factor x Agent Rate Factor) – 1.

Let us consider the following example: Financial cost = 6% p.a.; BNDES Rate = 1.3% p.a.; Agent Rate = 3% p.a. Financial Cost Factor = 1.06; BNDES Rate Factor = 1.015; Agent Rate Factor = 1.03. In this case, the BNDES interest rate is calculated as: Interest rate = 1.06 x 1.013 x 1.03 - 1 = 10.6% p.a. According to the Sectorial Chamber of renewable energies of the Federation of Industries of the State of Ceara (FIEC), the financing rates follow the same financing rules as those of the BNDES and vary according to the company's project rating and payment capacity, location, and default factor (the latter factors concerning Northeast Brazil). Additionally, a risk rate is included, which considers the transaction conditions and the and the economic and equity situation of the loan borrower. At the interest rate adopted for this study, a BNDES interest rate of 6% p.a. and a BNDES rate factor of 1.3% p.a. were considered, and without an intermediary economic agent in the operation, it would result in a wind project financing rate of 7.3% p.a., adopted in this research.

The amortization period is determined according to the capacity of payment of the enterprise, the client, or the economic group, respecting the maximum limit of 24 years. In the case of ‘Banco do Nordeste do Brasil’ (BNB), they follow the conditions of the Constitutional Financing Fund of the Northeast - FNE for Infrastructure: Interest rate IPCA + 1.2765% per year.The total funding period is up to 20 years Both development agents require real guarantees such as: mortgage, pledge, fiduciary property, receivables, etc. defined in the analysis of the operation. In the Brazilian case, an individual investor rate of 27% was adopted.

The revenues generated by the wind farms considered for the purposes of the study, a total of 8,760 annual hours and a load factor of 50%, in the case of wind farms installed in NortheastBrazil. An average tariff of 31 (USD/MWh) according to EPE (2018) was considered. A progressive increase in wind power tariffs expected for the Brazilian energy market should make wind power generation in Brazil even more attractive from an economic point of view.

The economic feasibility of stand-alone machine/equipment for wind generation was considered, due to the complexity of the analysis of wind farms. In the absence of specific information regarding the acquisition cost of wind generators, it was taken as a reference a 3 MW wind turbine with an estimated investment of US$ 1.5 million for the generation scenarios in the northeast of Brazil. For deployment and infrastructure costs, a ratio of 25% of total costs was adopted, a parameter adopted internationally.

Thus, an investment of US$ 2.2 million was adopted for the total implementation costs of a wind generator.The equipment maintenance cost considered was 1.5% of the equipment acquisition costs per year for the first 10 years of operation and 2.0% from the eleventh year to the twentieth year. The scenario that was taken as reference for the economic analyses in the Brazilian case was Cash Flow 2, which considered a depreciation of 10 years and a 20-year life span for the wind equipment.

4.2. Cash Flows for wind energy generation

We adopted several parameters to the standard Cash Flow considered for the elaboration of economic feasibility of wind energy according to Brazilian financing condition for undertakings in Northeast Brazil. As main parameters we highlight Investment interest rate (yearly) 7.3% p.a.; operation and maintenance costs: 1.5% p.a.; for the first 10 years and 2.0% p.a. for the last 10 years; annual revenue generated in the same period: 407.34 USD. Tariff: 31 [USD/MWh]; wind equipment investment: 2.28 [Million USD]; total investment civil works inclusive: 3.04 [Million USD]; depreciation of equipment: 10 years; load factor: 50%; and IRS rate: 27%.

For the above Cash Flow, of a 3 MW wind power generator whose investment was estimated at USD 2.28 million and infrastructure expenditures at 760 [USD x 1000] and total investment of 3,04 [USD x 1000], considering the parameters shown above, this investment proved to be economical feasible with following indicators: NPV equal USD 457,390 and a IRR of 9.22%. In addition to the elaboration of the investment cash flow, following variables were analyzed: interest rate, load factor, wind turbine investment and wind generation tariff, as shown in Table 1 to Table 4.

Table 1. NPV variation due to the variable 'investment rate' – Wind project in Brazil

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
IRR [%]	9,22%	9,22%	9,22%	9,22%	9,22%	9,22%	9,22%

Table 2. NPV and IRR variation due to the variable 'load factor' - Wind project in Brazil

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
IRR [%]	-1.48%	0.94%	2.96%	4.73%	6.34%	7,83%	9.22%

In Table 1, it can be verified that for interest rates above 9,22 % p.a., the NPV becomes negative and the investment unfeasible; the economic break-even point for this alternative is the internal rate of return itself, 9,22% p.a.

Table 2 shows the NPV and IRR variation due to 'load factor'.Considering the set of variables defined for the standard cash flow; the break-even for this variable is reached for a load factor of 43.18%. Under these conditions, a wind project in Brazil will be economically feasible.

Table 3. NPV and IRR variation due to the variable ‘turbine investment’ - Wind project in Brazil

Wind Turbine Investment [USD/MW]	**400,00**	**500,00**	**600,00**	**700,00**	**761,00**	**800,00**
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 the variable ‘tariff’ - Wind project in Brazil

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%

The break-even for the variables ‘turbine investment’ (Table 3) and ‘tariff’ (Table 4) was also calculated and following results were obtained: Wind Turbine Investment equal to 881.11 [USD/kW]. Regarding the sensitivity of the variables mentioned above, that is the major or minor impact on the NPV value of the evaluated flows, and as shown in Figure 1, the variable with the highest impact is the 'load factor' positively correlated with the NPV. It is followed, in order, by the variables 'turbine investment' (negatively correlated), 'tariff' (positively correlated) and 'interest rate' with negative correlation.

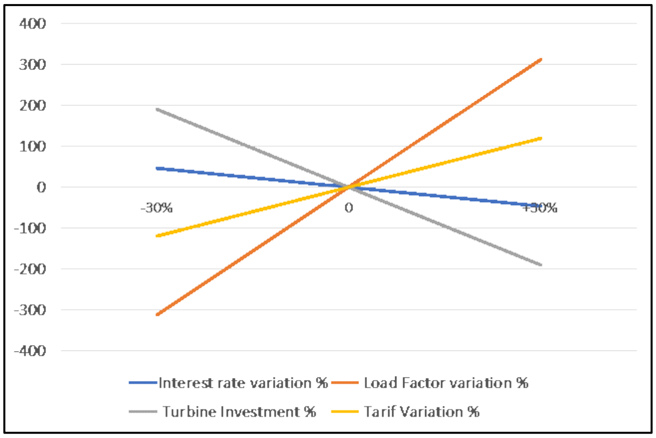

Figure 1. Sensitivity analysis of the variables

The break-even of the variables ‘interest rate’, ‘load factor’, ‘turbine investment’ and ‘tariff’ are shown in Table 5. For the variables ‘interest rate’ and ‘tariff’, the break-even for wind projects in Brazil are below the corresponding break-even in similar projects in Portugal. In the case of the load factor and turbine investment variables, the opposite is true.

Table 5. NPV and IRR variation (economic breakeven) due to the variable 'load factor' - Wind project in Brazil

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

5. Conclusion

This research aimed to analyze the economic viability of wind generation in Northeast Brazil, as well as to define the variables that currently most strongly impact the viability of operating equipment and wind farms, identifying its key economic impact..In this context, wind conditions, their intensity, direction, duration, and probability of occurrence was taken from surveys conducted by the Ceara State Secretariat of Infrastructure (SEINFRA) published in the document "Wind and Solar Atlas of Ceara State' provided for this research by the Ceara Federal University.Information for this research was also obtained from technical reports published by ABEEOLICA, EPE of the Brazilian Ministry of Mines and Energy, as well as information regarding wind project financing conditions, provided by the Federation of Industries of the State of Ceara.

Deterministic models were used in the analysis of investment projects, which included the elaboration of Cash Flows and the adoption of indicators such as Net Present Value, Internal Rate of Return and Pay-back, complemented with a sensitivity analysis of the main variables impacting the economic viability of wind investments in Northeast Brazil.The cash flow analysis allowed the calculation of the economic break-even point for the different variables analyzed, equipment load factor, wind turbine investment and effective hours available for wind generation, among others. Although under the conditions analyzed, wind generation projects in the Northeast of Brazil are economically viable, the profitability of these projects for the assumptions of the calculation assumed is still low, considering they generate a15 years Pay-back and a return rate of 9.22%. As opposed to an assumed financing cost of 7,3% p.a. (BNDES interest rates for the financing of larger wind generation projects) and also in view of therisks involved in the projects. In the Brazilian case, tariff fluctuations (due to the auctions practiced), risk in the wind equipment prices due to monetary exchange variations, and even the existence of non-controllable variables such as wind intensity and duration.

For the standard flow considered – Cash Flow 2 - for generation in Northeast Brazil the internal rate of return and the NPV are respectively of 9, 21% yearly (financing BNDES rate 7,3%) and the 454.136,80 USD (20-year project life span).

The sensitivity of the variables 'interest rate', 'load factor', 'turbine investment' and 'tariff'. Among these, in the Brazilian case, the variable with the highest impact was the 'load factor' positively correlated with the NPV followed, in order, by the variables 'turbine investment' (negatively correlated), 'tariff' (positively correlated) and 'interest rate' with negative correlation.

We simulated the impact of depreciation on wind projects for Northeast Brazil with the following result: depreciation extended to the 20-year analysis horizon for standard Cash Flow results into an NPV of USD 457,395.63 and IRR of 9.22%; by applying a 5-year accelerated average depreciation for assets, NPV increases to USD 848,030.3 and IRR to 10.72% p.a.

The research showed that in the case of wind generation in Northeast Brazil profitability ofgeneration projects can be improved, making these investments more attractive, through government action by a) reducing taxes on wind equipment and IRS rates and b) reducing the depreciation period of related equipment/assets and c) offering lower interest rates to finance wind generation projects.

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