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Analysis of economic and financial viability and risk evaluation of a wind project with Monte Carlo simulation

Análise de viabilidade econômico-financeira de um projeto eólico com simulação Monte Carlo e avaliação de risco

Carlos Alberto Anjoletto Macedo[1]
Andrei Aparecido de Albuquerque[1]
Herick Fernando Moralles[1]

Abstract: The world is experiencing a deep climate change caused by the predatory activity of man, due to the long time economic activities practiced without concerns on the environmental impacts. However, nowadays there is the necessity to expand the current economy without compromising the necessary resources for the survival of the future generations. The intensive use of alternative energy configures a contribution to this new development path. In another perspective, the main technical analysis of economic and financial feasibility is widely known; however, the application of techniques that consider the risk is not so usual. Thus, this current work addresses whether it is possible to identify the economic feasibility of a potential wind power generation plant in different Brazilian locations considering the risk of applying Monte Carlo simulation and Beta distribution techniques. In order to answer this question tests were performed in four different locations in Brazil, utilizing the Internal Rate of Return (IRR) method with the mentioned techniques to consider the risk in investment analysis. The results showed the sensitivity of the wind project to the financing costs, regardless the region studied.

Keywords: Wind power; Economic and financial viability; Internal Rate of Return.

Resumo: *O mundo está vivenciando uma profunda mudança climática, causada pela atividade predatória do homem, tendo em vista que as atividades econômicas foram exercidas sem preocupação com os impactos causados ao meio ambiente. Entretanto, na atualidade, percebe-se a necessidade de se expandir a economia atual sem comprometer os recursos necessários para a sobrevivência das futuras gerações. O uso intensivo de fontes alternativas de energia se configura uma contribuição a essa nova perspectiva de desenvolvimento. Em outra vertente, as principais técnicas de análise de viabilidade econômico-financeira são amplamente conhecidas, entretanto, a aplicação de técnicas que considerem o risco não é tão trivial. Assim, o presente trabalho aborda a seguinte questão: é possível analisar a viabilidade econômico-financeira de um potencial parque de geração de energia eólica em diferentes localidades do Brasil considerando o risco por meio das técnicas auxiliares simulação de Monte Carlo e a distribuição Beta? Para responder tal questionamento, foram realizados testes considerando quatro diferentes localidades no Brasil, aplicando o método da Taxa Interna de Retorno (TIR) aliado às mencionadas técnicas auxiliares a fim de considerar o risco na análise de investimentos. Os resultados demonstraram a sensibilidade do projeto eólico à necessidade de financiamento para todas as regiões estudadas.*

Palavras-chave: *Energia eólica; Viabilidade econômico-financeira; Taxa Interna de Retorno.*

1 Introduction

Climate change has entered the political and economic debate of the 21st century. Year after year, natural disasters are recorded around the planet and are usually attributed to human activity on Earth. According to the Intergovernmental Panel on Climate Change (IPCC), most scientists suggest that there is a correlation between such climatic events and global warming, whose main cause is the increased concentration of greenhouse gases in the atmosphere, especially CO2 from the burning of fossil fuels (Dincer, 2000; IPCC, 2001).

In this context, the focus on sustainability has come to be considered. The world needs to develop in order to meet its current needs without

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[1] Universidade Federal de São Carlos – UFSCar, Rodovia Washington Luís, SP-310, Km 235, CEP 13565-905, São Carlos, SP, Brazil, e-mail: anjoletto.carlos@gmail.com; andrei@dep.ufscar.br; herickmoralles@dep.ufscar.br

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compromising the resources needed for the survival of future generations. For this purpose, the greater use of alternative energy sources would be a good solution, generating great business opportunities on a global scale (Dincer, 2000; Sims, 2004).

According to the Renewable Energy Policy Network for the 21st Century (REN21) the most commonly used renewable sources are: biomass, geothermal, ocean tides, hydro, solar and wind sources. Together, they accounted for 21.7% of all the produced energy in the world in 2012. In absolute terms, renewables had 1,470 GW of installed capacity, of which 990 GW came from hydroelectric plants. In that same year, wind energy showed the highest growth among renewables, around 39% of additional capacity, followed by hydroelectric and solar plants, which expanded 26% each (REN21, 2013).

Brazil, is one of the global leaders in renewable energy generation, according to the Energetic Research Company (EPE), whose reports indicate the share of renewables in the Brazilian Energy Matrix is among the highest in the world, reaching a mark of 42.4% in 2012. When we observe only the Brazilian Electrical Matrix of 2012, this percentage reaches an incredible 84.5%, of which 76.9% came from hydraulic sources, 6.8% from biomass and 0.9% wind (EPE, 2013a). These figures reflect the old strategy of investing only in the country's water potential.

Dutra & Szklo (2008) argue, on the other hand, that in 2002, Brazil launched the Alternative Energy Sources Incentive Program (PROINFA) in order to reduce this dependence on hydroelectric dams. In fact, the program consolidated several incentive measures adopted in the 1990s to explore the potential of the country's biomass, small hydroelectric and wind power resources. Therefore, the authors explain that two stages were defined: the first one aimed at adding 3,300 MW of installed capacity, 1,100 MW for each modality, requiring the approved projects to start operating in December 2006. In the second stage, a wider goal: by 2026, 10% of all energy consumption in Brazil should come from alternative sources of energy.

In addition to different goals, the second step changed the way of contracting energy projects (Dutra & Szklo, 2008). The federal government opted for auctions that would stimulate competition among the three project types rather than offering a fixed amount per kWh for each. According to Dutra & Szklo (2008), this model is interesting because it allows greater control over the marginal cost of electricity in the long term, but penalizes wind energy, which has a cost per kWh higher than the others. So the solution would be to promote separate auctions for biomass projects (which has the lowest cost per KWh), something that has happened sporadically.

Currently, in Brazil there is an investment prospect in the generation of wind energy. According to the Brazilian Wind Energy Association (ABEEólica), in August 2014, wind power had around 4.5 GW of installed capacity in the country, distributed in 181 power plants. Only in 2013, there were four energy auctions, of which three contemplated the wind power source, resulting in 4.7 GW of contracted energy, most of it in the Northeast. A record to the sector (ABEEólica, 2014).

In this scenario, the following research question was defined: **Is it possible to analyze the economic and financial viability of a potential wind power generation facility in different Brazilian locations considering the risk through Monte Carlo simulation techniques and Beta distribution?** In order to answer this question, the following research objective has been established: **To develop an economic feasibility study of a potential wind power generation park in different Brazilian locations considering the risk using Monte Carlo simulation techniques and Beta distribution**.

So, this paper intends to contribute to the literature by defining the most relevant cost categories to be studied and, finally, to provide a broader view on the study of the economic feasibility of wind projects in Brazil by inserting allied risk analysis techniques.

The present study will address a wind project (one case) considering its implementation in four alternative locations. According to Dutra & Tolmasquim (2000), wind generation projects should be treated as case studies and, coincidentally, most of the works found are characterized as these ones. Some examples in Latin America are Watts & Jara (2011), Melo (2012) and Salles (2004). The accuracy of the information used in this type of analysis is greater, but these are more limited.

This paper is divided into four other sections, in addition to this introduction. Firstly, a bibliographical review about the main topics related to the research topic is presented. Next, the research method used in this work is discussed. Finally, the obtained results are presented and discussed through all the considerations made throughout the text, and finally, the last section presents the main conclusions and limitations of the research, besides suggesting possible topics for future studies.

2 Bibliographic review

Over the last few decades, evidence of environmental degradation has become more apparent, which, according to Dincer (2000), are the result of a combination of factors, such as the industrial revolution, fast population growth and the economy exclusively focused on consumption, among others. In the 1970s, the aim was to understand the relationship between conventional pollutants such as SO_2, NOx and CO and their respective environmental impacts (Dincer, 2000). As time went by, attention has focused on pollutants with global impact, especially those related to global warming, which is defined as an increase in atmospheric temperature due to the increase in the gases concentration emitted by human activities, of which highlights CO_2 (Dincer, 2000; Sahin, 2004).

According to Herbert et al. (2007), energy is the basic ingredient for the socioeconomic development of any country. Since it is essential to the development of nations and uses fossil fuels, electricity generation accounts for more than 33% of all CO_2 emissions related to the energy sector in the world (Ang et al., 2011). As a result, these authors state that this is one of the sectors with the greatest potential for reducing the emission of carbon dioxide in the world, provided that appropriate measures are taken, such as the use of renewable sources and the increase of the efficiency in the processes of energy generation.

Sims (2004) believes the most plausible solution is, in fact, the replacement of fossil fuels with carbon-free energy sources. According to this author, many technologies have already been developed in this direction and have a high degree of maturity, such as large hydropower, projects that exploit geothermal energy and nuclear energy. However, all of them are still subject to socio-environmental concerns. Hydroelectric dams, for example, result in large flooded areas and the consequent removal of riverine families. Geothermal projects raise doubts about its long-term sustainability, since, in order to be feasible, it requires the rate of heat extraction from the earth to be greater than its replacement. Nuclear technology is a matter of concern to society because it does not have an adequate treatment of its waste, because it helps to proliferate atomic weapons and because they are potential targets for terrorist attacks (Sims, 2004).

Still, Herbert et al. (2007) believe that renewable energy sources would be the best solution to reduce the global economy's dependence on fossil fuels as well as to eradicate carbon dioxide emissions. Among the available options, wind energy is considered one of the best alternatives because it is environmentally correct and has a huge potential still unexplored.

Banco Nacional de Desenvolvimento Econômico e Social (BNDES) classifies wind turbines as being devices that convert the kinetic energy present in the air masses into electric energy (BNDES, 2009). Technically, wind turbines come in two categories, depending on the direction of their rotating axis: **vertical**, which is assembled perpendicular to the ground, or **horizontal**, which is assembled parallel to the ground (BNDES, 2009). Horizontal-axis turbines are more suitable for electric power generation, as their propellers are suspended many meters above the ground, exploiting higher velocity winds. In addition, the equipment takes up little space in the soil, which can be used for other purposes, such as agriculture, for example. The counterpoint of this model is that it requires a mechanism that performs a constant repositioning of the rotating axis in relation to the direction of the wind, something that makes it more costly (BNDES, 2009). Although they do not pollute the atmosphere or generate radioactive waste, Leung & Yang (2012) argue that wind turbines are not totally harmless to the environment. According to them, in order to guarantee a truly sustainable society, we need to understand their environmental impacts, such as bird noise and death.

2.1 The costs of modern wind turbines

According to Blanco (2009), the main factors governing the costs of wind power generation are:

a) **Acquisition costs –** include turbines, ground foundation, construction of accesses and connection to the electrical network. This category can account for up to 80% of the cost of a project over its useful life;

b) **Energy generation costs** – include operating and maintenance costs (most significant portion), land rent, insurance and administration fees. These costs are relatively low, accounting for around 20% of all investment;

c) **Energy produced** – depends on local winds, turbine specifications and ground characteristics. The indicator that best defines the capacity of electricity generation of a wind farm is its *capacity factor*, which expresses, in percentage, the time that the wind farm effectively produces energy during the year;

d) **Opportunity cost** and **lifetime of the venture** – both reflecting the risk of the project, the domestic market of each country and the profitability of alternative investments.

Blanco (2009) points out that the fundamental difference between renewable energy generation (wind, solar, hydroelectric, etc.) and other conventional sources of energy (thermal, nuclear, etc.) is in the fact that renewables have a zero cost of fuel. For example, in a natural gas plant, about 40 to 60% of the costs refer to the purchase of fuel, operating and maintenance expenses (Blanco, 2009).

On the other hand, Blanco (2009) states that wind projects require high starting capital. In general, according to the author, the entrepreneur must have a good part of the amount to be invested (approximately 80%) before starting. Therefore, credit access and good financing conditions are prerequisites to the sector development. However, after the installation process and considering that wind resources have been correctly estimated, the cost of generating power becomes predictable, something that reduces the overall risk of a company or the portfolio of a country (Blanco, 2009).

2.2 The wind energy market

According to the Renewable Energy Policy Network for the 21st Century (REN21), the global demand for renewable energy will maintain its growth trend in a short term. The Figure 1 illustrates the growth of global wind energy capacity from 1996 to 2013.

According to the *Global World Energy Council* (GWEC), the world achieved a significant 318 GW of installed capacity in 2013, an increase of 35 GW (12.5%) compared to 2012, which represented a strong growth in the face of the current economic scenario growth, but below the average growth observed in the last 10 years (21%). This decline can be explained in part by the abrupt slowdown in the US market, which recorded a record expansion in 2012 but did not maintain it during 2013. On the other hand, China had another good year, maintaining its leadership in the sector and sustaining much of the global growth (GWEC, 2014).

GWEC also comments that by the end of 2013, only 24 countries had more than 1 GW of installed capacity - Brazil is among them - while only six had more than 10 GW installed. At some point in 2014, China would exceed 100 GW of installed capacity, making Asia the continent with the largest wind energy production capacity in the world by the end of 2014, beating Europe (GWEC, 2014).

In the surge of world growth, the Brazilian energy market, in general, has been showing a strong expansion in recent years, according to the Energy Research Company (EPE). Data from the National Energy Balance of 2013 indicate that, in 2012, total energy demand in the country increased by 11.3 million metric tons of oil equivalent (Mtoe), recording a growth rate of 4.1% in relation to 2011. Among all energy-demanding sectors, the transportation segment, both cargo and people, was the fastest growing (7.2%).

Within the electricity sector, wind energy appears as a highlight, practically doubling its installed capacity between 2011 and 2012 (EPE, 2013b). More recent data from the Brazilian Wind Energy Association (ABEEólica) indicate that the month of December 2013 ended with an increase of 10 MW in installed capacity compared to the previous month, causing installed wind power to reach 3.46 GW, distributed by 142 parks (ABEEólica, 2014). According to ABEEólica, in August 2014, these numbers jumped to around 4.5 GW of installed capacity, distributed in 181 parks. The Figure 2 illustrates the expected growth of the Brazilian wind sector up to 2018.

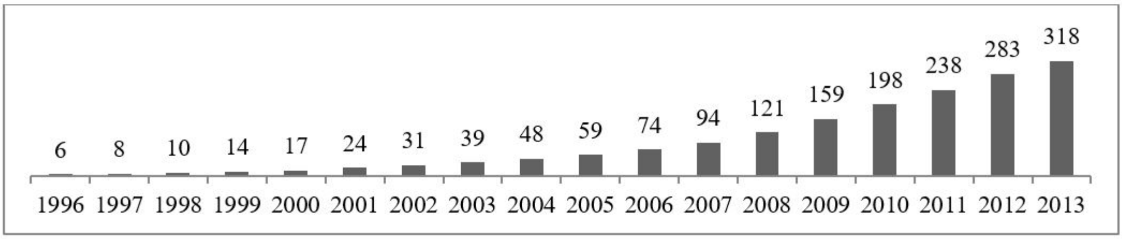


Figure 1. The growth of global capacity of wind energy generation (GW). Source: Adapted from GWEC (2014, p. 21).

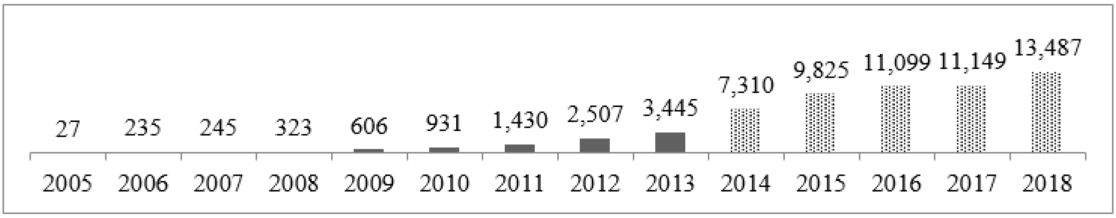


Figure 2. The development of wind energy in Brazil (MW). Source: ABEEólica (2014, p. 4).

2.3 Specificities of wind generation and economic viability

The use of hydroelectric plants in Brazil depends on the hydrological regime, which is subject to significant seasonal fluctuations, making in some periods such a matrix is complemented by conventional sources such as the use of thermoelectric power plants. However, wind power can help in generation complementary to hydroelectric power.

Studies such as Silva et al. (2016) show that the offshore winds of the north and northeast regions of Brazil were highly complementary with the hydrological regimes of the basins of São Francisco, East Atlantic, Southeast Atlantic, Paraná, Paraguay, Uruguay and South Atlantic; although not correlated with the Southeast basins.

The same seasonal complementarity between the Brazilian wind and hydroelectric potential is found in de Jong et al. (2016), demonstrating that wind power can replace all fossil fuel generation by 2020.

In fact, studies have shown that countries in South America have relevant wind power potential. In fact, Garcia-Heller et al. (2016) observe in their study that large capacity is found in Argentina, followed by Brazil, Mexico and Chile. Specifically, the study estimates the wind power supply curve in such nations and creates a scenario for the year 2025, where the Brazilian potential is 26 GWh / year, considering the installation of three-bladed turbines.

Despite its great potential in terms of generation and sustainability, wind energy presents specificities in terms of the effects that key attributes such as location, area, and form of disposal of such systems, so that total output can vary widely according to such characteristics (Ribeiro et al., 2016).

Such specificities strongly justify the use of economical engineering techniques to verify the viability of the installation of such systems, since the potential of generation in a specific locality may not present a return greater than the costs of investment, operation, and capital.

Moreover, most of the recent studies found in the literature only address the generation potential of the northern and northeastern regions of Brazil, so this work also contributes to compare the viability of the installation of such generators in the southeast region, as well as rarely perform some kind of investment analysis after calculating the generation potential. In fact, using some search operators with keywords relevant to the area, few studies not found in the *Scopus* database.

Among the studies that address the economical-financial viability of wind projects, it is possible to find Li et al. (2013) that they carry out an investment risk analysis of wind projects in China through a process that estimated the NPV with Monte Carlo method and then analyzed the payback period of the investment. The results of the simulation demonstrated a high investment risk, and the authors present suggestions for the mitigation or reduction of such possible adversities.

Albadi & El-Saadany (2007) conduct a viability study considering six wind speed scenarios for different types of wind turbines. However, the study only presents estimates of IRR, NPV, and *payback*.

According to Vithayasrichareon & MacGill (2014) and Segura et al. (2007), good financial planning, together with a correct data analysis, maximizes the chance of a successful enterprise. A good example of a financial study done together with an evaluation of wind data is the work of Kim et al. (2013), which uses the analyzes made by Oh et al. (2012) to define the best location for the installation of offshore wind turbines in South Korea.

In Brazil, Dutra & Tolmasquim (2000) made a survey of the characteristics pertinent to this type of project, making use of information about several models of wind turbines available in the market at that time, thus estimating the costs of installation, operation and maintenance of the wind parks.

Besides this, other researches were elaborated by Brazilian scholars with the purpose of determining the viability of Brazilian wind farms. Melo (2012) conducted a study in a Northeastern wind farm, applying several economic and financial analysis tools - such as Net Present Value (NPV) and Internal Rate of Return (IRR). Salles (2004), on the other hand, used some stochastic methods to generate scenarios, such as the Monte Carlo simulation, and then analyze a hypothetical wind farm economically, which has been configured in the most faithful way possible. The situation of cash flow in companies in the sector.

Finally, in spite of the relevance that the viability analyzes have, relatively few studies on wind energy have been published in Brazil. The present work aims, therefore, to contribute to the reduction of this gap.

3 Calculation model

This section presents the tools and fundamentals that were used to prepare an economic-financial analysis of the Brazilian wind projects, constituting as the method Internal Rate of Return, *Taxa Interna de Retorno*, in risk conditions.

3.1 Internal return rate

According to Ross et al. (2003), the Internal Rate of Return (IRR) of a cash flow is the necessary interest rate for the net present value to be null, being considered an intrinsic rate to the project, since it depends only on the estimated cash inflows and outflows. Its calculation is done as follows:

$$\sum_{t=1}^{n}\left[\frac{CF_t}{(1+IRR)^t}\right]-I_0=0 \tag{1}$$

where: CFt = expected inflows of cash in each period; IRR = internal rate of return or periodic equivalent rate of return; I_0 = amount of the investment at the time.

As illustrated in this Equation 1, calculating IRR is not a very simple process, requiring a series of successive approximations (Ross et al., 2003). Therefore, this work used spreadsheets to calculate IRR of the studied sites.

According to Melo (2012), once IRR is obtained, it must be compared to the discount rate (or minimum acceptable rate of return - MARR) at the moment the decision on the investment is made. To accept it, IRR must be greater than MARR, indicating that the project's rate of return is greater than its opportunity cost (Melo, 2012).

3.2 Analysis of investments in risk conditions

According to Melo (2012), the Net Present Value (NPV) and IRR method are classic methods for evaluating any investment; however, they have a deterministic nature, considering the fixed and known cash flows over the useful life of the project under review.

Thus, considering the complexity of the economic environment and its inherent uncertainty, the present work makes use of two auxiliary techniques in order to consider risk in the analysis of investments. These are Monte Carlo Simulation (MCS) and Beta distribution.

For MCS, the Normal distribution and the distribution of Extreme Values on the left (Gumbel type I) were considered. The latter, considering its shape, is intended to reflect a pessimistic situation, considering the higher probability of occurrence of cash flows below of the expected average value.

Therefore, random numbers were generated using deterministic flows as the first moment of the distribution, and the magnitude of 30% of the same value, as the second moment. The probability density functions (PDF) of the used distributions are shown in the Figure 3.

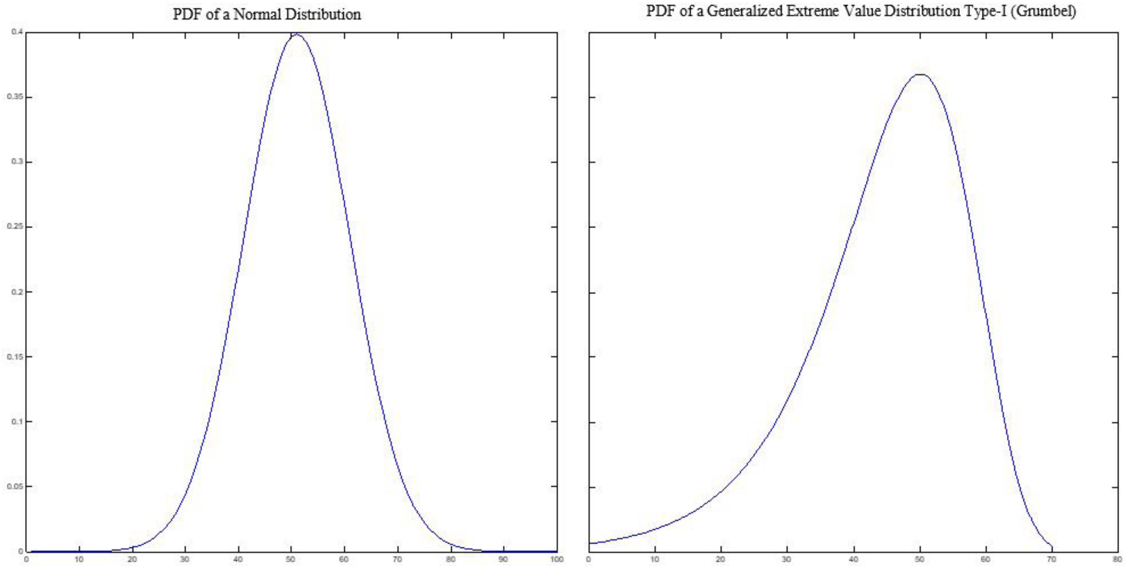
In addition to MCS with the above-mentioned two distributions, we also consider the risk analysis through the beta distribution, whose moments are described in Equations 2 and 3, according to Casarotto & Kopittke (1998).

$$\mu_t=\frac{a+4m+b}{6} \tag{2}$$

$$\sigma_t^2=\frac{b-a}{6} \tag{3}$$

where: μ_t is the average of the beta distribution; σ_t^2 is the variance of the beta distribution; a = pessimistic value; b = optimistic; m = most likely value.

Bearing in mind that beta distribution is truncated, the average and variance moments are based on optimistic, pessimistic, and more likely estimates for each cash flow over time, so there is no need to posit a priori, a distribution of probability or variance for cash flows. It should be noted that in


PDF of a Normal Distribution

PDF of a Generalized Extreme Value Distribution Type-I (Grumbel)

Figure 3. Probability density function (PDF) of the Normal and Extreme Values distribution. Source: Self elaboration.

this analysis, the deterministic value was considered the most probable (*m*), while the pessimistic value (*a*) represents 60% of "*m*", and the optimist 30% above "*m*".

3.3 Weighted average cost of capital

According to Assaf (2002), the resources of a company can come from its owners or its creditors, who demand a certain level of return in order to make capital available for the business. The remuneration formally committed to the creditor, expressed in the form of interest and other financial expenses, defines the cost of a loan or financing operation, i.e. the cost of third-party capital allocated to the project (Assaf, 2002). Similarly, the shareholders or owners of a corporation expect a certain return on the investment made in order to offset the risks of the transaction. Thus, the cost of equity represents that rate of return required by the owners of the business (Assaf, 2002).

According to Melo (2012), the Weighted Average Cost of Capital (WACC) would be precisely the balance between these two types of cost and the ideal would be to use it as the discount rate used in NPV calculations. As a result, WACC was obtained according to Equation 4 (Miller, 2009):

$$WACC = w_i * k_i * (1 - T) + w_e * k_e \quad (4)$$

where: w_i is the proportion of third-party capital within the company's financing structure; w_e is the proportion of equity within the company's financing structure; k_i is the cost of third-party capital; k_e is the cost of equity; T is the Income Tax rate.

It is important to emphasize that capital costs are calculated, in most cases, according to a method developed in the 1960s, the Capital Asset Pricing Model (CAPM), which relates which types of risk influence the expected return for a given portfolio of investment (Perold, 2004). As Perold (2004) describes in his work, the expected minimum return of a given investment can be expressed in the Equation 5.

$$k_e = r_f + \beta * (r_M - r_f) \quad (5)$$

where: k_e is the minimum rate of return required by shareholders, which can be understood as the cost of equity; r_f is the rate of return of risk-free assets; r_M is the average rate of return offered by the market in its entirety; β is a systematic risk measure of the asset.

The present study looked at these parameters at Damodaran (2014) and Reuters (2014), which compile data from various industries and companies in several countries around the world. Unfortunately, there are no data from public sources regarding Brazil and, therefore, data from the US and Europe will be used, whose markets are better developed and stable.

The logic of CAPM model was also used to formulate the Minimum Acceptable Rate of Return (MARR) to compute a required minimum return adjusted for risk.

Thus, this indicator was calculated as presented in Equation 6. That, in performing the calculations, obtained a MARR of 13.12%.

$$TMA = r_f + \beta(r_M - r_f) \quad (6)$$

where:r_f is the profitability of *Tesouro Direto* on 09/23/2015 (risk free rate); r_M is the total cost of the BNDES card (market return); β Is the leveraged beta of the Brazilian electric sector, equal to 0.72, as found in Pinto & Parente (2010).

3.4 The calculation of energy potential

According to Masters (2004), the calculation of the energy potential of a given region is given by the Equation 7:

$$E = P_R * 8760 * CF \quad (7)$$

where: P_R is the nominal power of the wind farm (kW); E is the annual energy generated (kWh/year); 8760 is the number of hours in a year (h/year); CF is the capacity factor (percentage of the time that the park actually produces energy during the year).

Finally, when analyzed wind data were characterized as a statistical distribution of Rayleigh (Weibull with factor $k = 2$), the capacity factor (CF) could be obtained from the following Formula 8 (Masters, 2004).

$$CF = 0{,}087 * \bar{V} - \frac{P_R}{D^2} \quad (8)$$

where: $\bar{V}$ is the average velocity of the winds (m/s); P_R is the nominal power of the wind farm (kW); D is the rotor diameter of wind turbines (m).

3.5 The definition of the data sample

The database that guided the present study was made available on the Internet by the Environmental Data Organization System, *Sistema de Organização de Dados Ambientais* (SONDA), which is a project of the National Institute of Space Research, *Instituto Nacional de Pesquisas Espaciais* (INPE) aimed at implementing physical infrastructure and human resources in some Brazilian cities with the objective of improving the database on solar and wind energy resources in Brazil. The municipalities that have wind data available online are: Brasília (DF), Ourinhos (SP), São Martinho da Serra (RS), Petrolina (PE), Triunfo (PE), Belo Jardim (PE), São

João do Cariri (PB) and Ouro Preto d'Oeste (RO). In order to compare the different regions of Brazil, we analyzed the winds of four different federative units: Brasília (DF), Ourinhos (SP), São Martinho da Serra (RS) and Triunfo (PE).

In general, SONDA measuring stations collect data at 25 m and 50 m in height, but this work only made use of the information referring to 50 m for a period of 12 consecutive months. An interesting point is that these data, available at SONDA (2014), underwent a validation process by the project's own collaborators in order to guarantee their reliability. Care was taken, therefore, to select only the bases whose data had been classified as "approved".

3.6 Calculation racional

In order to determine if a wind farm was viable in a city, the anemometric database of that municipality was first analyzed in order to estimate the average annual velocity of the wind from that location. Then, Formulas 7 and 8 were used to determine the expected annual energy generation for that locality. This amount multiplied by the average sales price of GWh of wind energy by the federal government results in the expected revenue for the entrepreneur.

The second part of the study focused on estimating wind energy costs in the country. For this, the annual reports for 2012 and 2013 of CPFL Renováveis, Renova Energia and EDP Renováveis were analyzed, as well as the documents issued by the Energy Research Company, *Empresa de Pesquisa Energética* (EPE) at the end of each wind energy auction of 2013.

Finally, it was assumed that, in case of financing need, the funds for the implementation of the project would come from BNDES through the BNDES Finem credit line, which is focused on wind farms. With these data the IRR method was used to evaluate the economic feasibility of the same wind project case located in each of the four cities analyzed. The results are presented in the following sections.

4 Introduction to the brazilian case

This section presents aspects of wind energy generation and the elements used in calculating the economic-financial viability of a wind farm in Brazil. It should be noted that the investment analysis was carried out in order to consider the wind project in two different ways. The first considers the project as small as possible, that is, without considering the need for financing, and therefore, debt services. On the other hand, it incorporates debt financing and services into the project, which results in lower magnitude cash flows.

4.1 The energy potential

In order to estimate the energy potential of a given locality, the mean wind speed of the site in question was calculated over a period of 12 months, as discussed above. The summary of the analyzes can be found in the following Table 1.

In order to estimate the energy potential of each municipality. the average velocity of the winds should follow a Weibull probability distribution with form factor k equal to 2. As shown in the Figure 4 below, this condition is satisfied for all locations except Triunfo (3). Because of this. it was not possible to use Formulas 7 and 8 for that particular location. To work around this situation. the work of Lima & Bezerra (2010) was used. which argues that the northeast city has a capacity factor of 0.62. which means that a wind farm in the municipality would

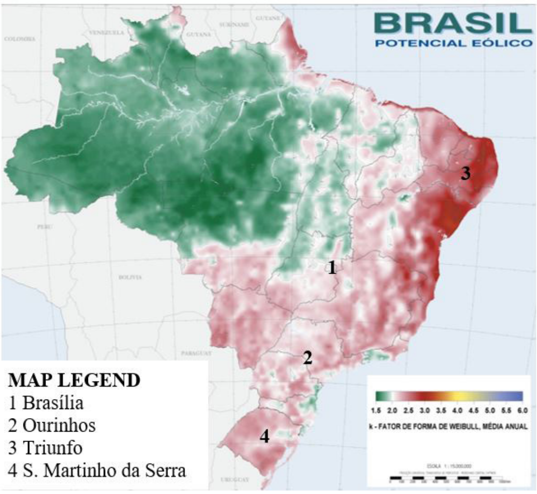


Figure 4. Annual average of the form factor (*k*) of Weibull. Source: Adapted from Ministry of Mines and Energy /MME (Brasil, 2001, p. 30).

Table 1. The characteristic of the winds to 50 m of height.

Feature	Brasília	Ourinhos	Triunfo	São Martinho da Serra
Maximum speed (m/s)	22.95	14.73	28.70	83.90
Minimum Speed (m/s)	1.44	0.03	2.32	0.00
Average speed (m/s)	6.95	3.61	13.65	3.42
Standard deviation (m/s)	2.91	1.66	4.51	2.84

Source: Prepared from data available in SONDA (2014).

generate energy for approximately 5,462 hours in the year.

The summary of the energy potential of each city is expressed in the following Table 2. For the calculations. the technical specifications of Renova Energia wind farm in the interior of Bahia were considered. which is composed of 184 General Electric (GE) wind turbines. model 1.6 XLE. whose nominal power is 1.6 MW. supported by towers of 80 meters of height and equipped with rotors with 82.5 meters of diameter.

4.2 The estimation of the price of sale

Once the energy potential of the studied locations is estimated. it is necessary to know how much the entrepreneur will receive for each MWh of energy sold. In Brazil. producers of renewable energy are remunerated based on contracts signed with the federal government during the auctions of energy contracting promoted by state entities. The Ministry of Mines and Energy. *Ministério de Minas e Energia* (MME) classifies the auctions that contemplated wind projects in 2013 as follows:

a) **Auction A-5** – aims to contract electricity from new generation projects and is carried out five years in advance of the beginning of the supply;

b) **Auction A-3** – aims to contract electricity from new generation projects and is carried out 3 years in advance of the beginning of the supply;

c) **Reserve Energy Auction (LER)** – aim to raise the level of security in the supply of electricity to the National Interconnected System. *Sistema Interligado Nacional* (SIN).

Thus. based on the average prices of the auctions held in 2013. the average price per MWh was defined as the weighted average of the amounts agreed at each auction. In this case. the weights were represented by the amount of energy (MW) contracted in each of them. Thus. it was established that the estimated sale price to be used in the economic viability calculations is **R$ 117.59/MWh**. as presented in the Table 3 below.

4.3 The costs of acquisition

Based on the documents issued by the Energy Research Company. *Empresa de Pesquisa Energética* (EPE) at the end of each auction. the average acquisition cost of wind projects in Brazil in 2013 was defined as shown in Table 4. The second auction A-5 of 2013 was disregarded because it contemplated other sources of energy other than wind power and. consequently. the cost of acquisition estimated in this auction represented the sum of all categories of energy generation traded in that trading session and is therefore incompatible with the objectives of this work. which focuses only on wind energy. Confirming the evidence presented in Blanco (2009) on the high acquisition and installation costs of wind

Table 2. The energy potential of each locality.

Feature	Brasília	Ourinhos	Triunfo	São Martinho da Serra
Average Speed (m/s)	6.95	3.61	13.65	3.42
Capacity Factor (CF)	0.56	0.27	0.62	0.25
Energy Potential (GWh/year)	1,448	695	1,599	656

Source: Own elaboration.

Table 3. Average price of wind energy contracted in each auction of 2013.

Auction	Contracted Energy (MW)	Average price (R$/MWh)
LER 2013	1,505	110.51
A-3 2013	868	126.00
2º A-5 2013	2,338	119.03
Weighted Average	**--**	**117.59**

Source: Adapted from ABBEólica (2014, p. 2).

Table 4. Estimated acquisition cost per MW

Auction	Contracted Energy (MW)	Planned Investment
LER 2013	1,505	R$ 5.5 billion
A-3 2013	868	R$ 3.3 billion
TOTAL	2,373	R$ 8.8 billion
Average	**--**	**R$ 3.7 million/MW**

Source: Prepared from EPE (2013c, d) data.

equipment. the average initial investment per MW installed in Brazil was close to **R$ 3.7 million/MW**.

4.4 The costs of generation of wind energy

Once the wind power potential of each locality. the revenue forecast and the acquisition / installation costs of the wind infrastructure has been estimated. it is left to determine the costs of generating a wind farm. To this end. the annual reports released by three large companies in the sector (CPFL Renováveis. Renova Energia and EDP Renováveis) were analyzed. where they were searched for the following cost categories:

a) operation and maintenance;
b) taxes;
c) insurance;
d) rent and lease;
e) other administrative costs.

The following Figure 5 presents the conclusions of what was announced by the companies in the years 2012 and 2013. Then. considering the total costs of energy generation (R$/MWh) as a function of the energy actually generated (GWh) by each company in each year. it was concluded that the costs of generating wind energy revolve around **R$95.09/MWh**.

4.5 The average weighted cost of capital

As discussed in topic 3. a company's cost of capital defines the minimum rate of return on capital invested by a company.

Through the analysis of the annual reports of the three companies. information was obtained on the proportion of equity and third parties used by each company and its respective third parties. Equity costs were obtained considering a 34% income tax rate. based on a Leveraged Beta (βL) of 0.98 for EDP Renováveis. as observed on the website Reuters (2014). Then. an Unleveraged Beta (βU) was estimated for the sector of approximately 0.56. as defined by Assaf (2002). Then. βU served as input for the calculation of βL of the other two companies. With this information it was possible to determine the respective capital costs of the companies according to Equation 5. After this the weighted average cost of capital (WACC) of the three companies.

Finally. considering the WACC for the energy produced (GWh) during the year 2013 by each company. it was determined for this work that the average weighted cost of capital of a wind farm in Brazil is approximately **8.24%**.

4.6 Financing conditions

The funds to finance this project would come from the BNDES. through the credit line that serves wind farms (BNDES Finem). According to its rules. interest rates charged vary between 6% and 10.18% pa. depending on the risk profile presented by the applicant. In addition. the maximum holding of the bank may not exceed 80% of the value of the financeable items and the debt must be paid in up to 16 years. four years before the expiration of the power supply contracts to the government. whose validity is 20 years. Lastly. the bank's grace period is up to six months after the start of the commercial operation of the wind farm.

In summary, the assumptions for IRR calculations were:

a) there will be no change in energy production over the years;
b) nominal power of the park = 294 MW installed;
c) cost of acquisition = R $ 3.7 million per installed MW;
d) cost of energy generation = R $ 95.09 per MWh produced;
e) reduction of the cost of energy generation = 0.65% per year;
f) sale price = R $ 117.59 per MWh produced;

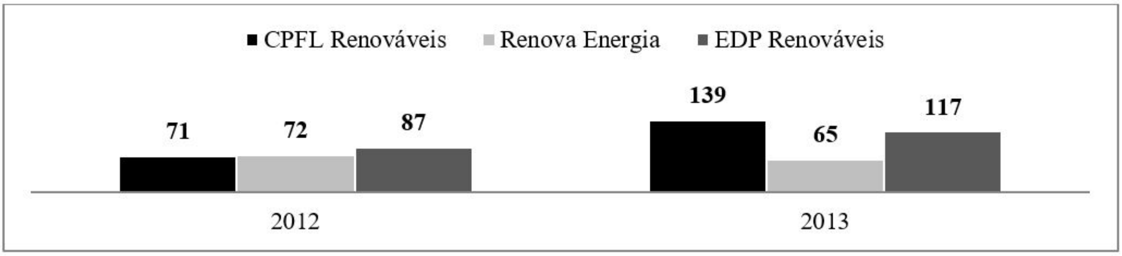


Figure 5. Total costs of power generation (R$/MWh). Source: Own elaboration.

g) increase in the sale price = 9% per year;

h) time for the park to start operating = 24 months;

i) BNDES grace period (interest only) = 24 months;

j) term of payment of the financing = 16 years;

k) financing interest rate = 10.18% per year (as conservative as possible);

l) amount financed by BNDES = 80% of the total cost of acquisition;

m) project lifetime = 20 years after completion of works;

n) the effects of Income Tax and depreciation were disregarded.

5 Results of the application of economic and financial viability analysis methods

Finally. the feasibility of this project was calculated if it was installed in each of the four cities. whose anemometric data were analyzed in Section 4.1. The assumptions for all projects were the same. with the wind potential of each locality being the only possible variable.

Therefore. Triunfo (PE) was the one that presented the best economic result. followed closely by Brasília (DF). The representatives of São Paulo and Rio Grande do Sul were economically unviable. Table 5 below shows the IRR values for each location.

According to the results presented in Table 5. if there is no need for bank financing. all projects are feasible even in pessimistic conditions as demonstrated in MCS with Distribution of Extreme Values.

In order to quantify the inherent risk of each project. the area of the accumulated probability density function of each case was calculated. taking into account the distributions used in the analysis. in order to calculate the probability of occurrence of a negative NPV.

In the case of the analysis performed using the Beta distribution. we calculated the probability based on a normal cumulative probability density function. considering that the sum of Beta distributions results in a normal distribution. These results are presented in Table 6.

The results presented in Table 5 are corroborated according to the inherent risk of each project. as presented in Table 6.

As for bank financing. the results obtained are in perfect agreement with the work of Lima & Bezerra (2010). which also verified the economic viability of the city of Triunfo. In addition. the Atlas of Brazilian Wind Potential 2001 (Brasil, 2001) clearly shows that the Northeast region is the one with the best average winds during the year. also showing the volume of winds in the Federal District. mainly in the second half of the year. It is also easy to observe that the regions of Ourinhos and São Martinho da Serra lack

Table 5. Results.

City	Without financing	With financing
IRR - Deterministic Results		
Brasília (DF)	28.9%*	13.3%*
Triunfo (PE)	30.3%*	14.6%*
Ourinhos (SP)	20.3%*	4.3%
São Martinho da Serra (RS)	19.0%*	3.2%
IRR - Beta Results		
Brasília (DF)	28.9%*	13.2%*
Triunfo (PE)	30.2%*	14.5%*
Ourinhos (SP)	20.3%*	4.3%
São Martinho da Serra (RS)	19.0%*	3.2%
IRR - Simulation of Monte Carlos with Normal distribution		
Brasília (DF)	29.0%*	13.4%*
Triunfo (PE)	28.9%*	13.3%*
Ourinhos (SP)	20.2%*	4.3%
São Martinho da Serra (RS)	18.9%*	3.2%
IRR - Monte Carlos simulation with extreme value distribution		
Brasília (DF)	26.4%*	10.6%
Triunfo (PE)	27.7%*	12.0%
Ourinhos (SP)	18.3%*	1.8%
São Martinho da Serra (RS)	17.3%*	3.2%

* Indicates IRR> MARR. Source: Own elaboration.

Table 6. Probability of NPV <0.

City	Without financing	With financing
IRR - BETA Results		
Brasília (DF)	0.91%	49.2%
Triunfo (PE)	0.62%	36.9%
Ourinhos (SP)	12.94%	96.4%
São Martinho da Serra (RS)	17.54%	97.5%
IRR - Simulation of Monte Carlos with Normal distribution		
Brasília (DF)	0.00%	0.00%
Triunfo (PE)	0.00%	0.00%
Ourinhos (SP)	0.00%	0.00%
São Martinho da Serra (RS)	0.00%	0.00%
IRR – Simulation of Monte Carlos with extreme value distribution		
Brasília (DF)	37.40%	97.30%
Triunfo (PE)	40.30%	77.10%
Ourinhos (SP)	99.90%	99.90%
São Martinho da Serra (RS)	99.90%	99.90%

strong winds during most of the year. a fact that makes wind power projects in their municipalities in the absence of own resources.

In view of the above. it can be stated that Brazil has interesting regions for investments in wind energy generation (Brasil, 2001). Despite this. the initial disbursement (Blanco, 2009) and the lack of reliable and updated anemometric data (Martins & Pereira. 2011) continue to be some of the obstacles to the full development of this sector in the country.

6 Conclusions

Brazil has regions with great wind potential. as illustrated in the Atlas of Brazilian Wind Potential of 2001 (Brasil, 2001). which can be economically viable. It is important to emphasize that this is the last official government study on the subject. signaling a strong outdated data sources in the sector. In addition. the figures involved in these projects are restrictive to small entrepreneurs. and can only be supported by large players in the sector. provided that they are financed at low cost. Therefore. the sustainable and long-term development of wind energy in Brazil still depends on government support to be possible. as already pointed out by Dutra & Tolmasquim (2000).

With respect to the investment analysis developed. all regions presented economic feasibility when analyzing the cash flows without the need to make payments related to the financing of the initial investment. On the other hand. in a borrowing scenario. only Brasília (DF) and Triunfo (PE) managed to prove economically viable. indicating that the use of own resources is vital for projects that aim to take advantage of the potential of the wind for the generation of energy in the south and southeast regions.

These results reinforce the northeast's vocation for wind power generation. even in pessimistic scenarios such as those demonstrated in MCS with extreme values distribution. Thus. it is expected that such results may support the decision-making of energy managers in Brazil. especially with regard to the location of projects and the policies for the provision of capital.

Another relevant point is the fact that only four cities are chosen for this study. This was due to the lack of data on the behavior of the country's winds (Martins & Pereira, 2011). In order to minimize this fact. cities were chosen from four different regions of Brazil. thus showing how different the results of an economic feasibility study can be in a country of continental dimensions. whose diversity of climates and vegetation influences the atmospheric circulation. factor Crucial for estimating the wind potential of a given site.

Another limitation of the research was the fact that Triunfo did not follow a Weibull distribution with factor $k = 2$. According to Brasil (2001), the northeastern city has a k factor close to 3.5, that is. a Normal probability distribution. This question would make it impossible to use Equations 7 and 8 to calculate the city's wind potential. In order to overcome this problem. the results of the work of Lima & Bezerra (2010) were used, which also needed to calculate the necessary parameters for the estimation of energy generation during the year.

Finally, the present study approached wind energy in a comprehensive way. touching on points not very discussed in the Brazilian scientific literature. for what was perceived in the bibliographic survey of this research. It can be said that the classification and estimation of the main cost categories in energy generation represent the main contribution sought by this study.

Based on these conclusions. future works could (i) apply statistical tests to the anemometric data of Brasília (DF), Ourinhos (SP) and São Martinho da Serra (RS) in order to verify if they actually follow a Weibull distribution with factor $k = 2$ or even test if the winds of Triumph (PE) really do not follow such a distribution; (ii) carry out similar studies for other renewable energy sources. such as solar and small hydroelectric plants.

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