Irvylle Raimunda Mourão Cavalcante

ASSESSMENT OF WIND FARMS IN NORTHEAST BRAZIL BY DATA ENVELOPMENT ANALYSIS (DEA)

Dissertation in the context of the Master in Energy for sustainability-oriented by Professor Álvaro Filipe Peixoto Gomes and co-oriented by Professor Carla Margarida Saraiva de Oliveira Henriques and presented to the Department of Mechanical Engineering of the University of Coimbra

October 2021

“There is a driving force more powerful than steam, electricity and atomic energy: the will.”

Albert Einstein

Acknowledgements

I would first like to thank God for illuminating the paths I have walked on and being light in the face of what I still cannot see. I am very grateful for all the pains, joys, challenges and daily experiences that have made me a better person and strengthened my faith.

I would also like to thank my supervisors Álvaro Gomes and Carla Henriques, for all the scientific support, insights, meetings, and sharing knowledge so this work could contribute to the literature.

To my parents, Ana Geovanda and Justineto, my total gratitude would be impossible to express in a single lifetime, much less in words. I am a version of everything I learned from you and that not even death could separate genuine love. I also thank my sisters Thamyres and Kamylle, who have always supported me throughout my personal and professional journey. It is a privilege to have them as sisters and a source of inspiration to me.

I thank the relatives who contributed with countless wishes for my success, representing all my grandparents and grandfather, Raimunda, Maria José and Manoel Diogo.

To my boyfriend Joel, I thank you for all the years you have dedicated to my side and for being my safe port. You are light.

To my friends that Coimbra gave me, I thank you for making my days lighter and happier. I could not highlight Jônatas, Luiz, Marthinha, Marcos, João, Gabriela, Jade, Gabriel, Tiago and Joelson. Also, my dear friends from Brazil always supported me.

Abstract

The increase in energy consumption and the consequent environmental impacts challenge meeting its growing demand and sustainability. Therefore, the search for alternative solutions for renewable energy sources has intensified. In this context, wind energy has proven to be an essential source in the clean energy scenario. In addition, there are several incentives to counteract the intermittency of renewable generation. Therefore, the present research assesses wind farms' efficiency in northeast Brazil by Data Envelopment Analysis (DEA) through the Weighted Russell Directional Distance Model (WRDDM). This non-parametric method allows the assessment of various factors influencing wind generation, sets benchmarks between Decision-Making Units (DMUs), proposes corrective projections, thus contributing to performance assessment and consequently better competitiveness of wind power systems. Overall, the DMUs presented an average capacity factor (40%) above the world average (34%) and are wind power plants of types II-C and III. The best performances are obtained in DMUs mainly located in the Rio Grande do Norte (RN), Bahia (BA) and Ceará (CE), i.e., in regions within Brazil's best wind power potential. Also, the analysis showed that efficient wind farms have a slightly higher number of turbines, age of operation and installed power capacity than inefficient DMUs.

Keywords: Wind energy, Data Envelopment Analysis, Weighted Russell Directional Distance Model

Resumo

O aumento do consumo de energia e os consequentes impactos ambientais mostram um desafio entre a necessidade de satisfação da crescente demanda aliada com as metas de desenvolvimento sustentável. Por conseguinte, a procura de soluções alternativas para suprir as necessidades energéticas das nossas sociedades através de fontes de energia renováveis intensificou-se. Neste contexto, a energia eólica provou ser uma fonte essencial no cenário da energia limpa. Além disso, existem vários incentivos e estão a ser desenvolvidos esforços para lidar mais eficazmente com a intermitência da produção de energia renovável. Assim, a presente pesquisa visa avaliar a eficiência dos parques eólicos no nordeste do Brasil através da ferramenta *Data Envelopment Analysis* (DEA) aplicando o método *Weighted Russell Directional Distance Model*. Este método permite a avaliação de vários factores que influenciam a geração eólica. Assim, estabelece *benchmarks* entre Unidades de Tomada de Decisão (DMUs), propõe projecções correctivas, contribui para avaliação de desempenho e consequentemente melhor competitividade dos sistemas eólicos. No geral, as DMUs apresentaram um factor de capacidade média (40%) acima da média mundial (34%) e são centrais eólicas dos tipos II-C e III. Os melhores desempenhos são obtidos em DMUs localizadas principalmente no Rio Grande do Norte (RN), Bahia (BA) e Ceará (CE), ou seja, em regiões dentro do melhor potencial eólico do Brasil. A análise também mostrou que os parques eólicos eficientes têm um número ligeiramente superior de turbinas, idade de operação e capacidade instalada do que as DMUs ineficientes.

Palavras-chave: *Energia Eólica, Análise Envoltória de Dados (DEA), Modelo de Distância Direcional de Russell Ponderada*

Summary

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Abbreviations and Acronyms

BCC	Banker, Cooper, Charnes
CCR	Cooper, Charnes, Rhodes
CRS	Constant Returns to scale
CO_2	Carbon Dioxide
DMU	Decision- Making Unit
DEA	Data Envelopment Analysis
EU	European Union
EPE	Energy Research Company
GHG	Greenhouse Gas Emissions
GWEC	Global Wind Energy Council
HAWT	Horizontal Axis Wind Turbines
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
ONS	Brazilian national Electrical System Operator
O&M	Operate and Maintenance
RES	Renewable Energy Sources
RTS	Return to Scale
SDGs	Sustainable Development Goals
SIN	Brazilian National Interconnected System
VRS	Variable Returns to Scale
VAWT	Vertical Axis Wind Turbines
WWEA	World Wind Energy Association

1 Introduction

The current energy supply system based mainly on fossil fuels endangers the environment, ecosystems, cities and compromises energy security. The penetration of renewable energy sources as an intermittent supply in growing demand is a more sustainable alternative. Also, some changes in the regulatory energy market have been intensified to drive the growth of renewable technology.

Thereby, wind energy has shown promise as a source, and according to [1], it will be necessary three times fast the global wind power capacity achieve a net-zero pathway. Besides, a significant investment in electrification and efficiency improvements is required. The benefits of wind energy are diverse for nations' energy security, economic, and social development. Its main contributions are highlighted in **Figure 1** [2]:

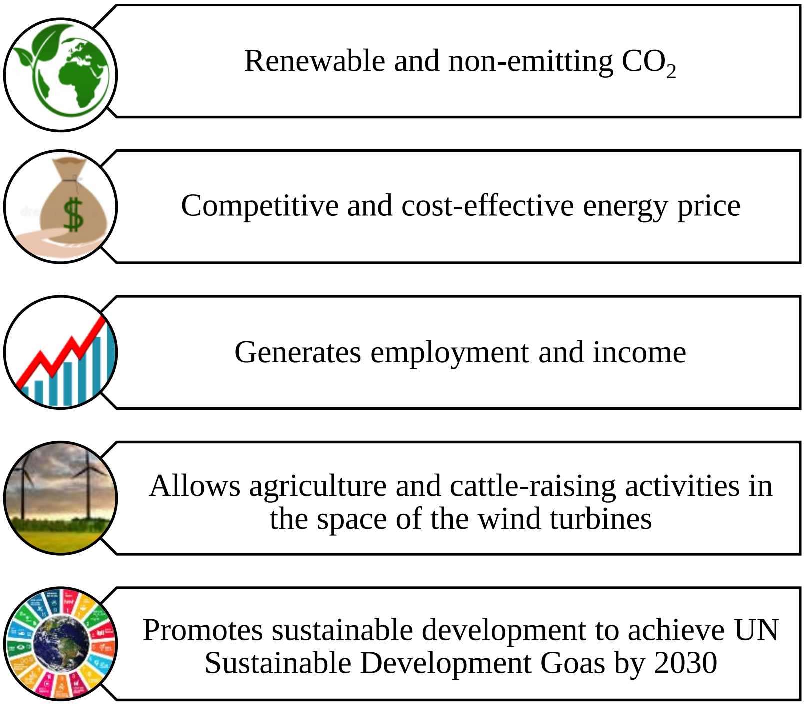
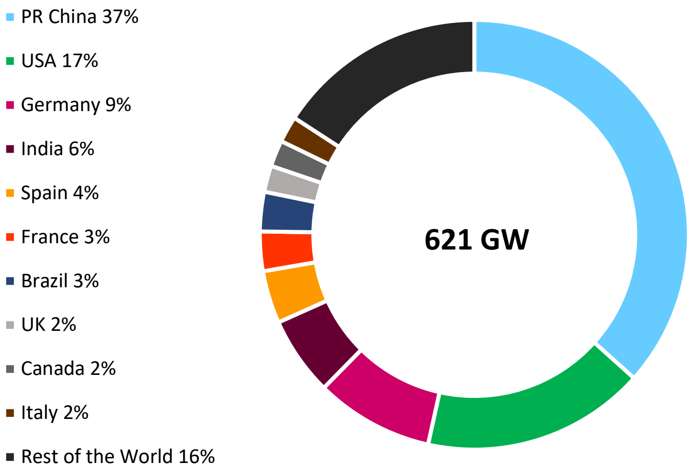
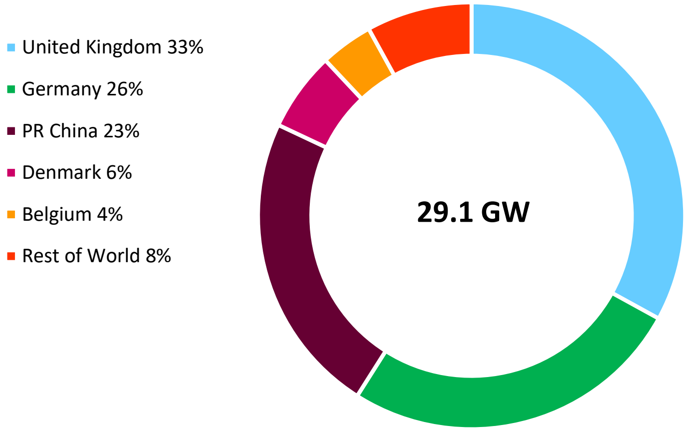


Figure 1 - Main wind energy contributions [2]

Also, according to [1], China, the United States, Germany, India, and Spain lead the wind market, which together accounts for 72% of the world's total installed capacity (**Figure 2**). Furthermore, based on an analysis of the installed capacity by region, Asia is the largest wind market, followed by Europe, North America, Latin America, Africa and the Middle East, respectively [3].



a) Onshore



b) Offshore

Figure 2 - Total share of onshore (a) and offshore(b) wind power installed capacity [1]

In addition, the deployment of 355GW of wind power capacity is being planned for the next five years [4]. Installed renewable power in 2020 reached almost 200GW, and by 2021 renewables are expected to expand by a record 10% [5]. Therefore, wind energy can achieve leadership in the energy transition soon. Nevertheless, it is still necessary to solve the challenges of intermittency and non-dispatchability e in wind power generation.

1.1 Motivation

The incentive for greater participation of Renewable Energy Sources (RES) in the global energy and electricity matrix in the face of the high competition for energy resources has intensified the study of Renewable energy generation.

Another aspect that motivated this research work is that Brazil's northeast region is a world reference in wind generation due to the predominance of the trade winds. However, and to the best of our knowledge, no study has been applied so far in this region's efficiency assessment of wind power generation. Hence, the present work aims to shed light on the efficiency of wind farms in this particular region by using the DEA method. In summary, the motivation for this research is threefold:

i) It is the first contribution in the literature about DEA application in the world's reference region for wind power generation. In addition, wind energy is one of the pillars of the energy transition. However, significant investment in electrification and efficiency improvements is required. It is necessary to evaluate its performance, which besides contributing to endogenous evaluation and promoting corrections for improvements, also consequently drives greater penetration and competitiveness compared to other technologies.

ii) DEA is a powerful tool, and the analysis of the factors assessed by this method contributes to helping operators to make better-informed decisions.

iii) This work intends to employ the DEA Weighted Russell Directional Distance Model (WRDDM), which allows handling non-controllable factors of evaluation, such as wind speed and intermittency. The present research contributes to the scientific literature as there is a lack of scholarly attention related to assessing the operational efficiency of wind farms.

1.2 Objectives

A careful analysis of wind farms after deployment is essential to ensure an acceptable efficiency level and the high initial investment cost. Using the DEA methodology, it is possible to evaluate the performance of the energy generation delivered to society, also encompassing a set of indicators affecting the energy system.

Main Objective

Evaluate the efficiency of 460 wind farms in northeastern Brazil employing the DEA methodology by considering a set of indicators obtained from Brazil's electricity sector database.

Specific Objective

- Conduct a literature review on RES, wind power generation, and the DEA method.
- Collect inputs and output data regarding wind farms in northeastern Brazil from the Brazilian electricity sector.
- Apply the WRDDM for assessing the efficiency of wind farms.
- Contribute to the scientific literature and increase access to studies on wind energy from DEA.
- Publish research results related to renewable energy.

1.3 Dissertation Content

Section **1** presents a global overview of wind energy and the forecast for future years. It also discusses the motivation for building this research and highlights the importance of RES in the sustainable energy transition process and the relevance of DEA as a tool for efficiency assessment in the electricity sector. In section **2,** an overview of wind energy in Brazil is shown, highlighting the Northeast region. Section **3** conducts a literature review on DEA. Section **4** provides further details on the methodological WRDDM used. Section **5,** the results are discussed. Finally, section **6** presents the conclusions drawn from this study and insights for future work.

2 Wind Power

The following subsection addresses some aspects of energy conversion technology. The potential wind assessment will also be covered to analyse the shape and scale parameters addressed as input data in this work. Lastly, the wind energy scenario in Brazil will be explored, especially in the Northeast region, where the wind farms in this case study are located.

2.1 Wind Energy Technology

Wind energy commercialisation developed rapidly in several countries after the oil crisis in 1970 [6] to supply the energy demand in the face of the total dependence on fossil fuels. Wind turbines can be classified into two types according to their axis of rotation: Vertical-axis Wind Turbines (VAWT) and Horizontal-axis Wind Turbines (HAWT) [7]. The VAWT is composed of curved blades and driven by lifting forces. HAWT is the most used globally and are also driven by lift and drag forces. The usual configuration for HWAT is propeller type and consists of three blades [8]. In addition, the maximum power capacity of the existing turbines on the market currently employed in a large-scale generation is up to 5MW, and the turbines have a useful life of 20 years [9]. **Figure 3** shows the evolution in size and power capacity of wind turbines (HAWT).

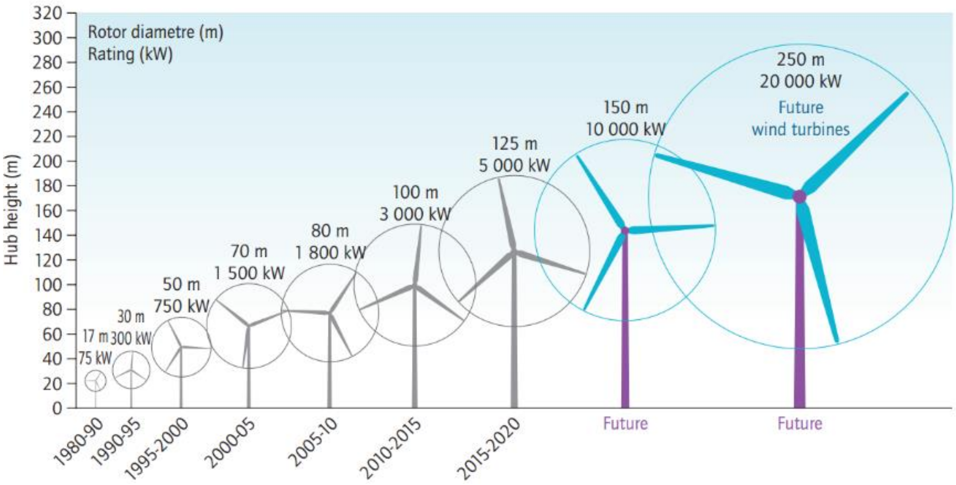


Figure 3 - Evolution in size and power capacity of wind turbines over the years [10]

Also, wind farms can be classified depending on land (*onshore*) or sea (*offshore*). However, onshore technology is most widely used globally and currently represents 95.52% of the installed capacity [1].

Offshore technology requires a high initial investment, complex logistics, operation, maintenance, and transmission logistics costs. It also requires special materials adapted for use in severe marine conditions, where the turbines are exposed to the highest wear and tear. Although more recent, offshore wind energy has grown considerably due to declining available onshore locations and the high offshore wind potential. [11].

2.1.1 Horizontal Axis Wind Turbine Components

The main components of a horizontal axis wind turbine are the tower, generator, yaw drive, rotor blades, nacelle, and control mechanism [8] (see **Figure 4**). **Table 1** shows the main functions of these components:

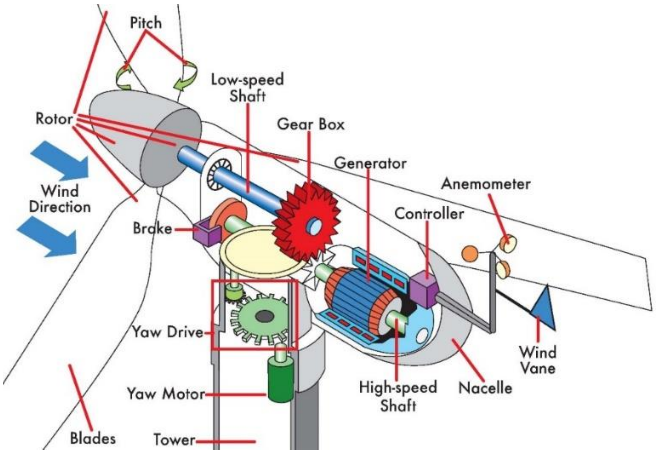


Figure 4 – Wind turbine components [12]

Table 1-Description of the wind turbine components [8]

Wind turbine Components	Function
Nacelle	Housing where the generator, gearbox, brake control system, and anemometer are located
Blades	Responsible for the interaction with the wind and converts part of the kinetic energy into mechanical work
Tower	Support the rotor and nacelle at a height suitable for blade rotation and optimal wind harnessing.
Gearbox	Increase the shaft speed between the generator and the rotor hub
Generator	Transforming the mechanical energy of rotation into electrical power through electromagnetic conversion
Controller	Align the rotor with the wind direction
Yaw Drive	Align the rotation plane to be perpendicular to the wind direction.

In addition, the wind farms can be classified according to the mode of operation that influences the National Interconnected System (SIN), and in this way, establish a connection with the National Electric System Operator (ONS) [13]. **Figure 5** below shows the classification of the modes of operation of wind power plants.

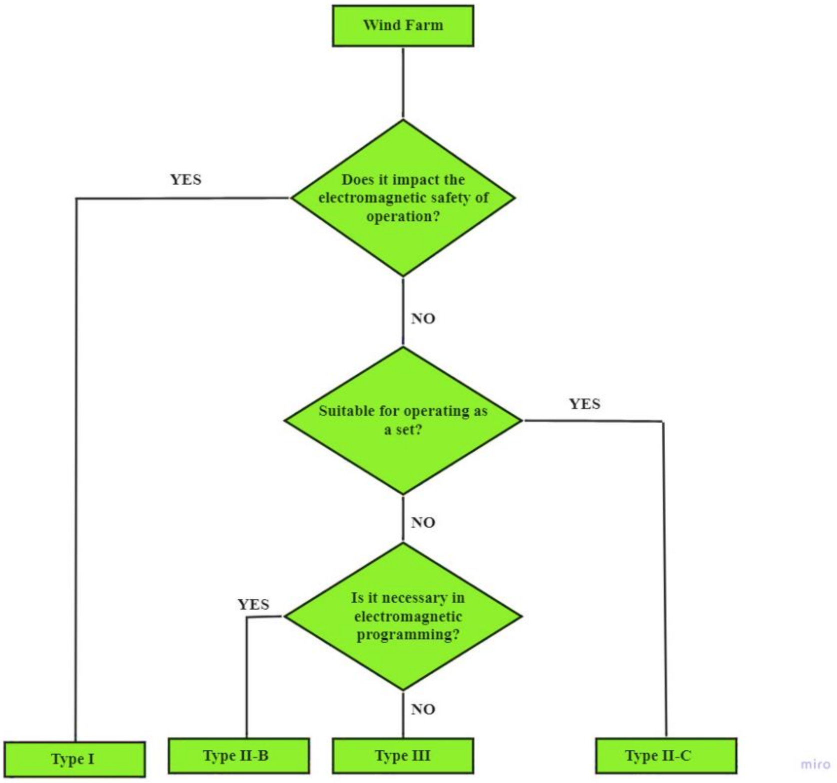


Figure 5 – Classification of the operation mode of wind power plants. Adapted from [13]

2.2 Wind Energy Conversion

Part of the wind's kinetic energy passing through the aerodynamic rotor of the wind turbine is converted into mechanical energy through torque. It is then transformed into electrical power using a generator [14], as illustrated in **Figure 6** below.

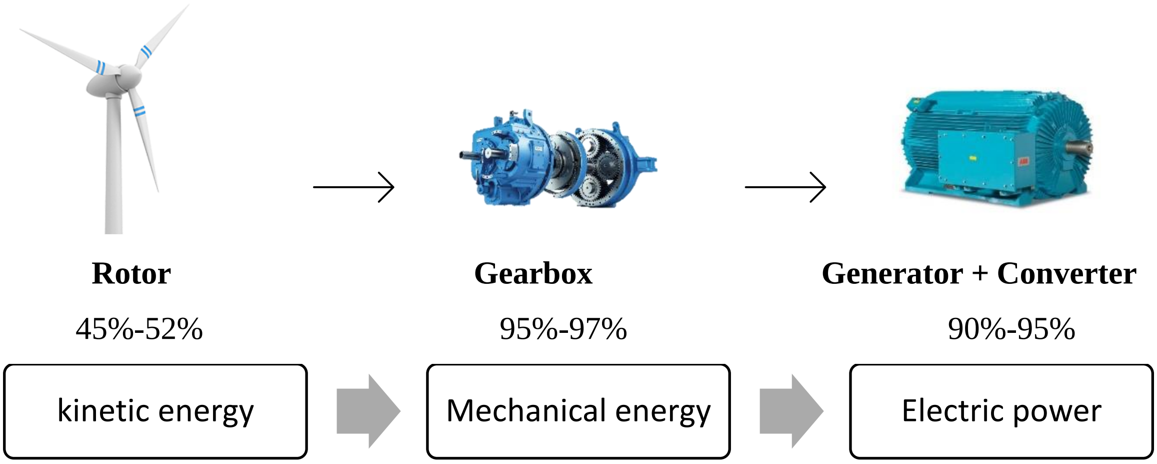


Figure 6 – Wind energy conversion [15]

Therefore, it is only possible to extract part of the kinetic energy from the air passing through the area swept by the rotating blades[16]. The air volume is cylindrical for horizontal axis turbines (HAWT), as shown in (**Figure 7)**.

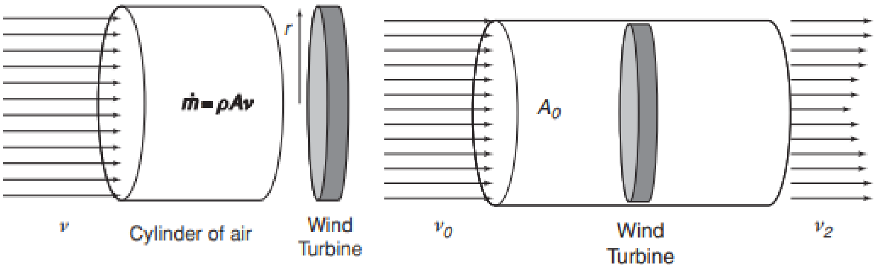


Figure 7 – Air mass flow around wind turbine [8]

Therefore, According to the theory of the efficiency of rotor-based turbines [16] the Betz limit C_p is the maximum power that a wind turbine with a disc-like rotor can extract from the wind. It is up to 59.3% of the energy of the air mass passing through the wind turbine [17]. Thus, also considering the efficiency of the electrical system of the generator and transmission set, it is possible to summarise the electrical power of a wind turbine in **Equation 1** [8]:

$$P = \frac{1}{2}\rho A_r v^3 C_p \eta \qquad (1)$$

ρ - Air density kg/m^3
A_r - Wind turbine rotor area (m^2)
v^3 - Wind Speed (m/s)
C_p - Power coefficient
η - Efficiency of the generator/transmission set

Also, another pertinent analysis is the fact that when kinetic energy is absorbed upstream of the wind turbine, the wind speed gradually decreases downstream. In this way, a spiral wake of vortices is formed from the aerodynamic support forces on the rotor blades dissipated by mixing with the air masses [18]. Therefore, this effect is called the wake effect and is associated with performance losses caused by interference from one wind turbine close to another. Therefore, to minimise this effect, a design distance is considered adequate so that the flow recovers the original velocity conditions when mixing with the air mass. Thus, as shown in **Equation 2**, the angular speed of rotation is inversely proportional to the rotor diameter (D) [19]:

$$RPM = \frac{1150}{D} \tag{2}$$

This adequate distance between turbines varies with site wind speed, terrain roughness, turbine operating conditions, and thermal stability. In general, a suitable distance is about ten times the rotor diameter (10D) if installed downstream and five times the rotor diameter (5D) if installed next to it [20], as illustrated in **Figure 8** [14]:

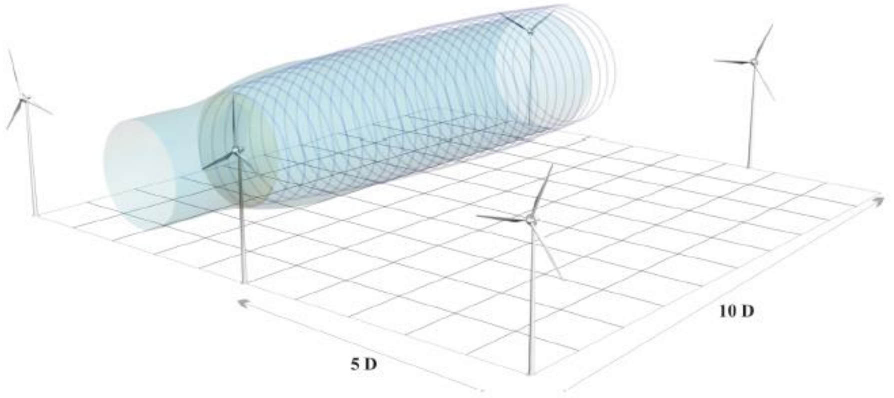


Figure 8 – Wake effect of a wind turbine [19]

2.3 Wind Energy Potential Assessment

The performance of the wind system depends essentially on wind speed and a well-designed design study to ensure adequate efficiency. Optimal performance in power generation from wind turbines requires profile stable, constant, and unidirectional speeds [21]. Therefore, the wind is considered a continuous random variable that varies over minutes, hours, days, months, and years. For a consistent analysis of wind speeds, the function best describes the wind energy study from the statistics is the Weibull probability function or Weibull distribution function that is defined by **Equation 3** [22]:

$$f(V) = \left(\frac{k}{c}\right)\left(\frac{V}{c}\right)^{k-1} exp\left[-\left(\frac{V}{c}\right)^{k}\right] \tag{3}$$

The function has three parameters: wind speed (***V***), shape parameter (***K***), which are adimensional and represent the shape of the Weibull distribution curve according to the variance of speeds. In general, the literature reports that the annual wind speed distribution of the shape parameter varies between the range of (1.5 – 3) [23] but can reach values above six in some months in northeastern Brazil [24]. So the higher the (***K***) value, the more regular and constant the wind speeds also narrower the curve. Thus, the shape factor is calculated from the average wind speed ($\boldsymbol{\bar{V}}$) and the standard deviation ($\boldsymbol{\sigma}$) as expressed in **Equation 4** [25]:

$$k = \left(\frac{\sigma}{\bar{V}}\right)^{-1.086} \tag{4}$$

The scale parameter ($\boldsymbol{c}$) is related to the average wind speed at the analysed location and, therefore, has the same unit (m/s) and is calculated from the average wind speed and the gamma function ($\boldsymbol{\Gamma}$) in **Equation 5** [23].

$$c = \frac{\bar{V}}{\Gamma(1 + \frac{1}{k})} \tag{5}$$

The cumulative Weibull function (see **Equation 6**) can also be represented and is related to the probability of wind speeds higher than wind speeds (***V***) [26].

$$F(V) = 1 - exp\left[-\left(\frac{V}{c}\right)^{k}\right] \tag{6}$$

To better illustrate, it is possible to observe in **Figure 9** the variation of the scale parameter and shape parameter for different values, consequently the curve variation.

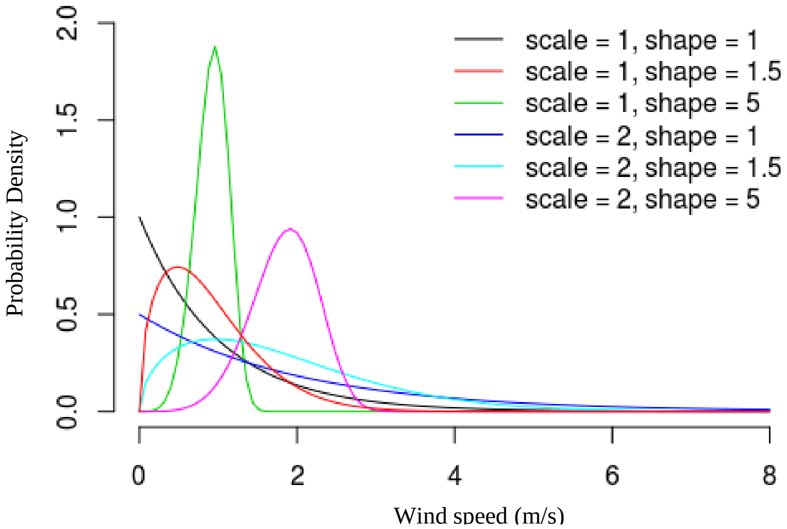


Figure 9 – Weibull Distribution [27]

In addition, the power density flow can be calculated from the Weibull distribution parameters in **Equation 7**. Where the parameters (**k**) and (**c**) is known by the Weibull probability function and (***ρ***) is the air density [28].

$$\frac{\boldsymbol{P}}{\boldsymbol{A}} = \int_0^{\infty} \frac{1}{2} \rho V^3 f(V) dV = \frac{1}{2} \rho c^3 \Gamma \left(1 + \frac{3}{k}\right) \tag{7}$$

Besides, it is fundamental to analyse the wind direction from the distribution of speeds along with the wind rose. This study of wind directions is very effective in adjusting the position of the turbines to obtain a more efficient use of energy [23].

2.4 Wind Energy in Brazil

Brazil has a privileged wind regime due to its location in the tropical zone, which is under the influence of trade winds that are favourable for wind energy harnessing. Furthermore, the participation of renewable energies in the Brazilian electric matrix is quite considerable, totalling 83.1%, and wind energy have a share of 9.8% [29] (see **Figure 10**).

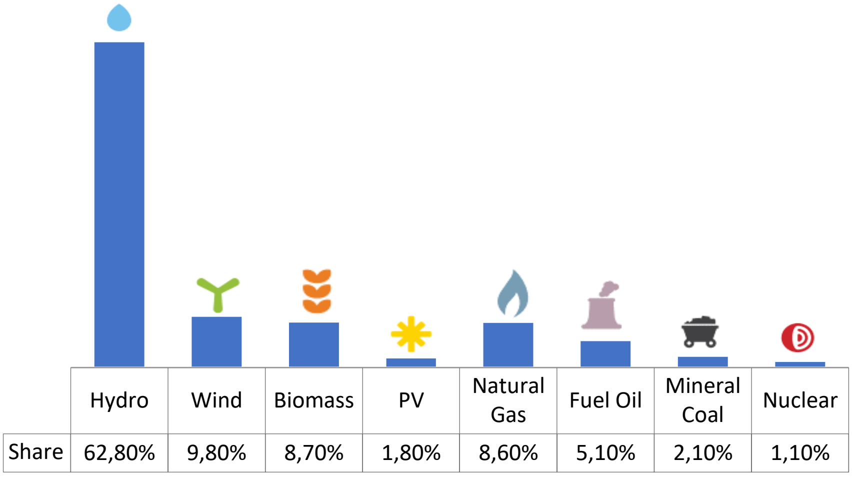


Figure 10 – Brazilian electric matrix [29]

Currently, Brazil occupies the 7th position in the world ranking of installed wind capacity. In Brazil, electric energy transmission comprises the National Interconnected System (SIN), which is composed of the South, Southeast/Mid-west, Northeast (except for the State of Maranhão) and North subsystems [30]. The interconnection through an extensive power grid is an energy security strategy for any subsystem lacking energy supply. Also, according to [29], 14.7% of the energy consumed in the SIN (National Interconnected System) comes from wind energy. In addition, any source of energy connected to the SIN contributes to meeting the entire energy system.

The average capacity factor in Brazil is 42.7%, which is higher than the world average of 34%. Furthermore, a considerable evolution in the increase of installed capacity is expected until 2030 according to the ten-year expansion plan of energy released by the Energy Research Company (EPE) in Brazil [31]. Therefore, a 3.9% growth in the share of renewables is expected, consequently reducing the percentage of non-renewable sources in the Brazilian electricity matrix.

In addition, Brazil has 19GW of installed wind capacity and a total of 733 wind farms and over 8000 wind turbines in operation distributed across fourteen Brazilian states [32] (see **Table 2**). According to [33], the forecast is that by 2024 Brazil will have 26.9GW of installed wind capacity.

Table 2- Wind energy in the Brazilian states [34]

State	Installed Capacity (MW)	Wind Farms
RN	5461.8	188
BA	5101.8	200
CE	2394.6	94
PI	2354.6	81
RS	1835.9	81
PE	800.4	35
MA	426	16
SC	250.6	18
PB	157.2	15
SE	34.5	1
RJ	28.1	1
PR	2.5	1
MG	0.156	1
SP	0.002	1
TOTAL	**18848.2**	**733**

Among the Brazilian regions that stand out in the production of energy from wind, it is possible to highlight in the first place the northeast region, in which about 94.4% of the energy consumed by the population comes from wind power. In second place is the southeast subsystem with 16.9%, and in third place, the northern subsystem with 7.44% [29].

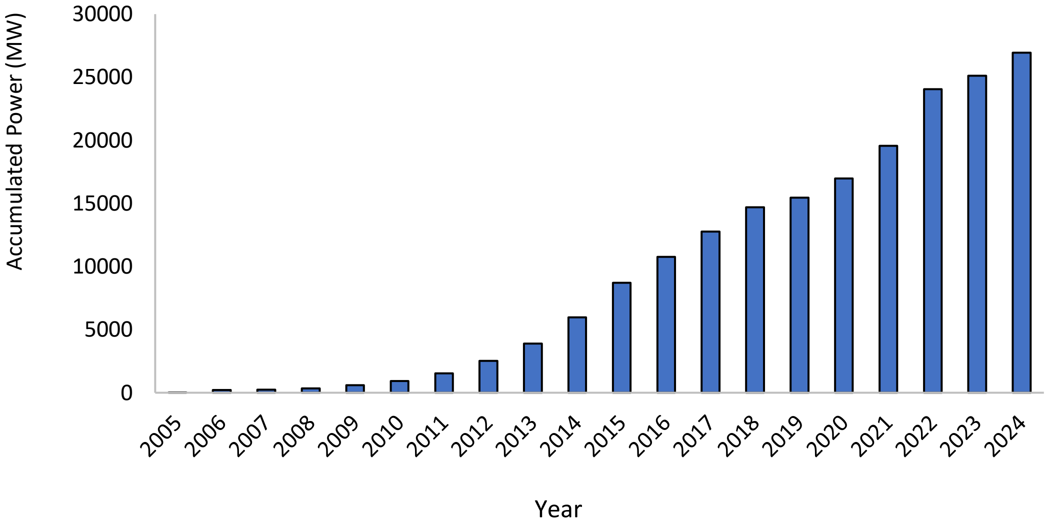


Figure 11 – Evolution of installed wind capacity in Brazil [35]

Regarding the historical evolution of the installed capacity, it is possible to observe a growing increase (see **Figure 11** and **Figure 12)**. The future forecast until 2024 is to reach 26.9 GW of installed capacity based on data from auctions already held in the free market [35].

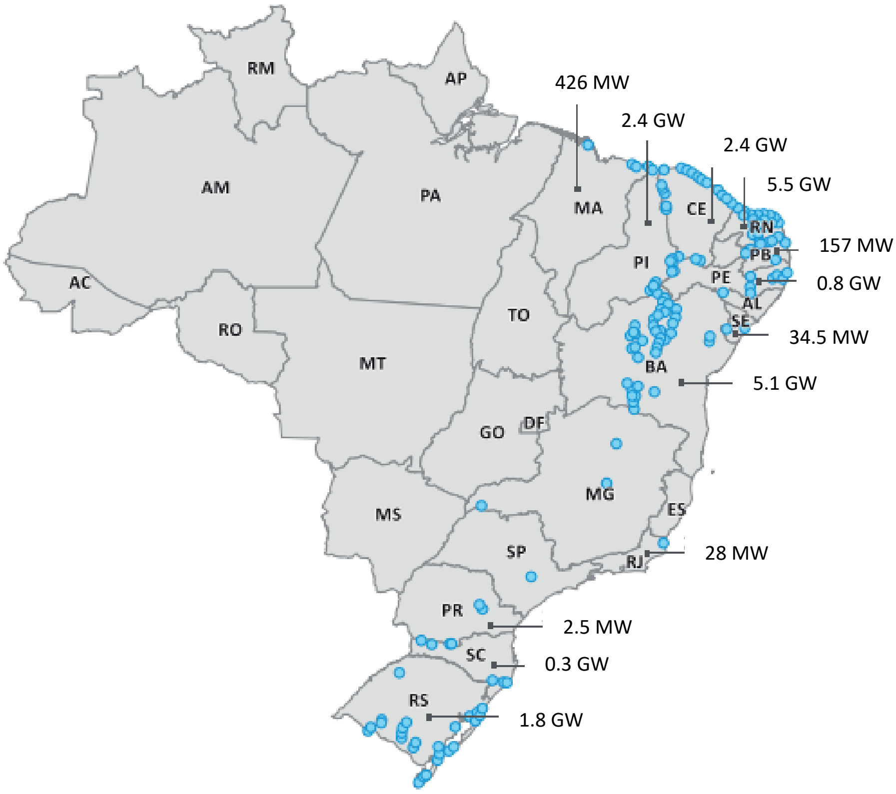


Figure 12 – Installed wind capacity in Brazil by states. Adapted from [36]

Wind power and hydropower are complementary in Brazil. During the dry season, the water volume in the reservoirs decreases and consequently, the hydroelectric generation declines. Still, during this same period, the wind speed grows and hence the wind power generation is more significant (see **Figure 13**) [37].

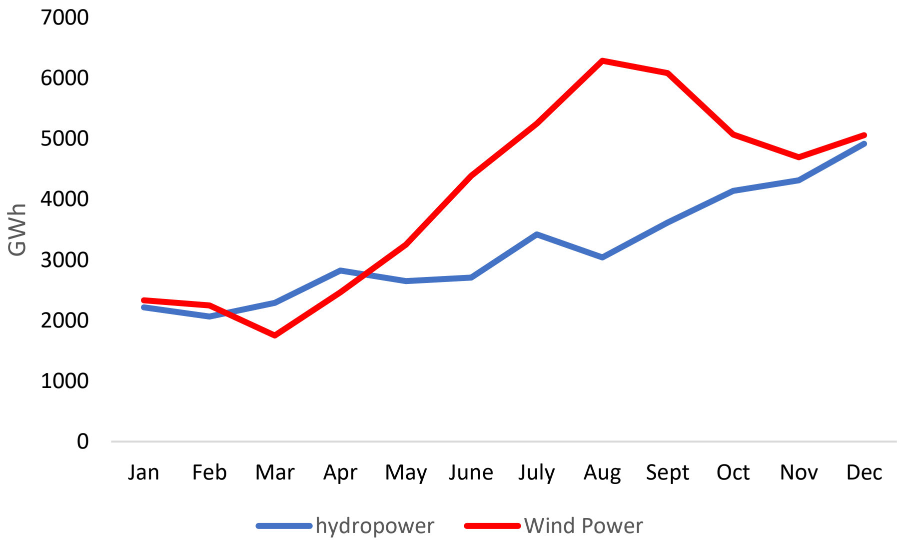


Figure 13 – Seasonal complementarity between hydro and wind power [38]

Therefore, Brazil has an installed capacity of 164 GW, and renewable sources have the largest share in the Brazilian electric matrix (83%), while RES in the global wind matrix is only 25% [29].

2.5 Wind energy in Northeast Brazil

The Brazilian northeast is geographically favoured by the intensity and constancy of the trade winds [39]. In addition, the northeast region is located in an area with the prevalence of a semi-arid climate, in which the availability of water resources is scarce. Therefore, it suffers from constant droughts when there is a predominance of the El Niño phenomenon in which the wind speed reaches above average values [40]. Thus, the wind source has represented an essential role in this region's energy security, and about 94% of the energy consumed in the northeast subsystem comes from wind energy generation [29].

The Northeast subsystem connected to the SIN (National Interconnected System) comprises seven Brazilian states with 614 wind farms. Furthermore, it presents an average capacity factor of 71.14% and an installed wind power capacity of 16.43 GW (see **Figure 14**). Rio Grande do Norte is the state which generates most wind energy, secondly Bahia and thirdly Ceará [36].

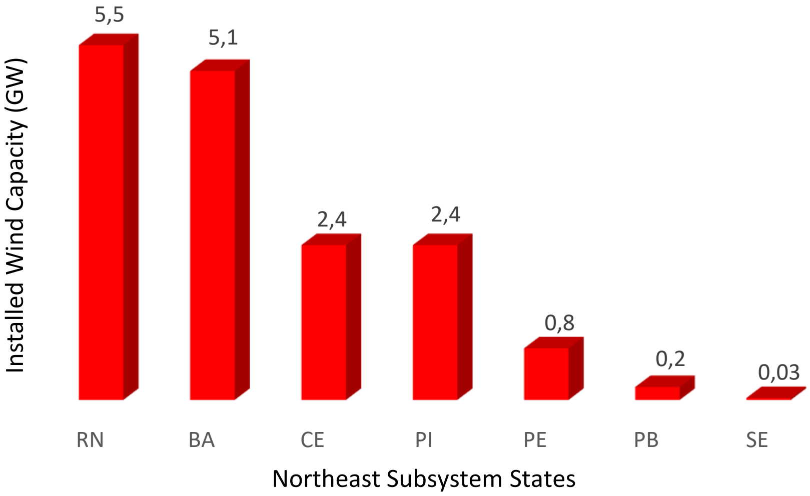


Figure 14 – Installed wind capacity in Northeast Brazil [34]

The period from July to October is known as wind harvest (see **Figure 15**) due to the greater constancy in the speed, direction, intensity of the trade winds and consequently more effective use of wind energy generation. These characteristics make the northeast region a world reference in wind power, and 80% of the Brazilian wind farms are located there. Moreover, The Northeast represents 85.4% of wind generation in Brazil [41].

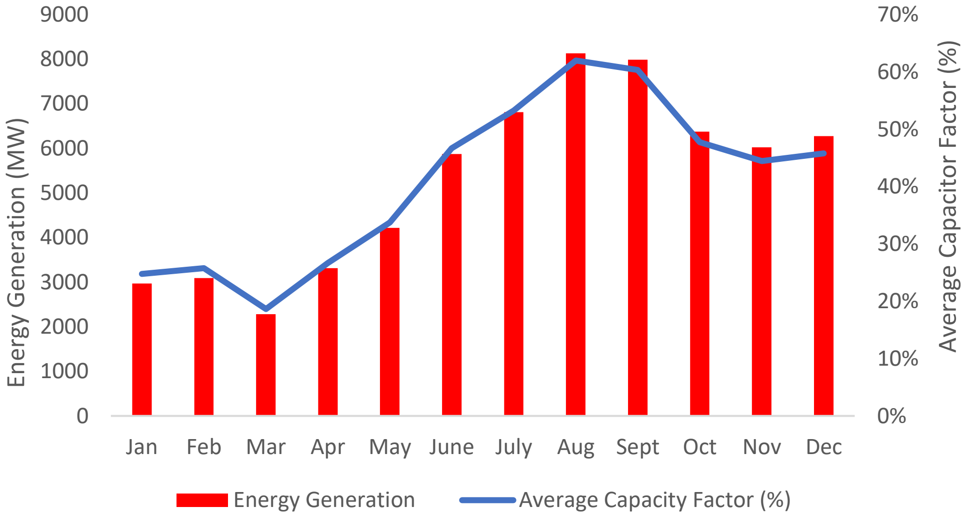


Figure 15 – Annual wind energy generation and average capacity factor in Northeast Brazil [38]

3 Literature Review

Renewable source technologies have gained remarkable growth due to decarbonization policies and as a complementary source of generation capacity capable of meeting high demands but limited by intermittent weather conditions. Consequently, there has been increasing research on renewable energy sources to overcome intermittency challenges and improve efficiency.

In the electrical sector, several parameters must be analysed to evaluate the energy system's performance. Among these, it is crucial to assess the supply-side to contribute to energy security. Some methods can be used to assess the performance of energy systems and consequently identify generation potentials. Reference [42] considers the performance of a small group of wind farms using three multi-criteria analysis methodologies, which are the Analytic Hierarchy Process (AHP), the Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE), and Data Envelopment Analysis (DEA). In addition, the criteria evaluated in [42] were the following indicators: Economic (Revenue and average O&M costs), Energetic (Installed active power, average capacity factor and Availability) and Technical (Lifetime of equipment, mean failure and repair time). The authors conclude that the DEA method is preferable in this study because it shows the required improvements to make an inefficient unit efficient.

Furthermore, [43] also uses AHP and DEA to analyze the performance of energy systems. The indicators analyzed were: Economic (Investment, O&M cost, generating capacity), Technical (Hours of equipment utilization, power capacity and efficiency), Social (Land use, sulfur dioxide emission and Carbon dioxide emissions), Environmental (The degree of social acceptance, land use and the number of jobs provided).

Reference [44] highlights the main research on DEA, specifically addressing two-stage analysis, cross-efficiency and ranking. Reference [45] addresses a literature survey and presents a general framework of the DEA methodology, models approach and the main features on 100 publications related to DEA in energy and environment. Reference [46] reviews DEA models related to energy efficiency and presents 144 papers on DEA for efficiency analysis in the energy sector. It also [46] categorizes the articles into nine areas: renewable energy, environmental efficiency, economic and eco-efficiency, energy efficiency issues, energy performance, energy-saving, integrated energy efficiency, and other application areas. Reference [47] covers 693 articles on DEA applied to energy and environment over the past four decades, highlighting 400 articles applied to energy, particularly energy efficiency, electricity generation, renewables and transmission & distribution networks.

The advancement in the wind farm industry has driven efficiency evaluation to make improvements and make them more efficient. The literature on DEA applied to wind energy includes comparative efficiency analysis between other technologies and efficiency evaluation for a set of wind farms as decision-making units (DMUs).

Among the approaches to assessing the performance of a wind farm, **Table 3** provides a summary of the primary studies applied to DEA for evaluating the performance of utility-scale wind farms' efficiency. We can highlight that these studies conclude that it is essential to measure efficiency to ensure profitability and better performance of the energy system. Also, all the studies reviewed use oriented and radial DEA methodologies, limiting the assessment, especially when it is required to consider simultaneous and distinct adjustments of the inputs and output factors involved in the analyses. Therefore, the WRDDM, which is a non-radial non-oriented model, has been used in this study.

Table 3- Summary of literature on the application of DEA in wind farms

Reference	DMUs	Methods	Inputs	Outputs
[48]	13 wind farms in Greece	BCC	Installed capacity Project cost Number of turbines Wind speed Wind power density O&M costs	Power generation
[49]	39 state's wind power in United States	CCR BCC	Installed capacity Project cost Number of turbines Lease payment	Net generation Energy production Employment CO2 emissions avoided
[50]	57 wind farms in Spain	CCR BCC	Installed capacity Wind Speed Fuel Interposed surface	Active energy

Reference	DMUs	Methods	Inputs	Outputs
[51]	95 wind farms in Texas	BCC CCR	Installed capacity Number of turbines Wind power density	Generated electricity Capacity factor
[52]	236 wind farms in the USA	BCC CCR	Installed capacity Number of turbines Wind power density	Generated electricity Value of production Homes powered
[53]	42 wind farms in China	BCC CCR	Installed capacity Auxiliary electricity Wind power density	Electricity generated Availability
[54]	7 offshore wind farms	CCR BCC	Installed capacity Distance to operating Annual wind speed Annual energy production Availability	Energy performance
[55]	146 wind farms in Turkey	CCR BCC	Installed capacity Number of turbines Wind power density	Electricity Generated Availability

3.1 Data Envelopment Analysis Method

DEA was developed by Charnes in 1978 [46] and is a non-parametric linear programming approach to evaluate the relative performance of Decision Making Units (DMUs).
Furthermore, DEA is an optimization technique and not a regression model. While regression analysis estimates the average behaviour of a series of DMUs, the DEA method analyses each DMU in terms of efficiency against its peers, allowing to obtain the benchmarks, i.e. the DMUs which perform best in the frontier line [56].
According to [57], the DEA approach is considered more flexible since it encompasses multiple evaluation factors, i.e. multiple inputs and outputs.
With the DEA method, it is possible to identify the DMUs that should be considered benchmarks (i.e., that should be viewed as a reference of best practices), thus enabling

understanding the required adjustments to make an inefficient DMU efficient. In this way, it is possible to take corrective actions to improve efficiency performance to achieve efficiency in electricity production [58].

The DEA models more often used are CCR (Charnes, Cooper, Rhodes) and BCC (Banker, Charnes, Cooper) [59]. The CCR model evaluates the overall efficiency considering Constant Returns to Scale (CRS), whereas the BCC model uses Variable Returns to Scale (VRS). The maximum score that each DMU receives in both models varies between zero and one [60].

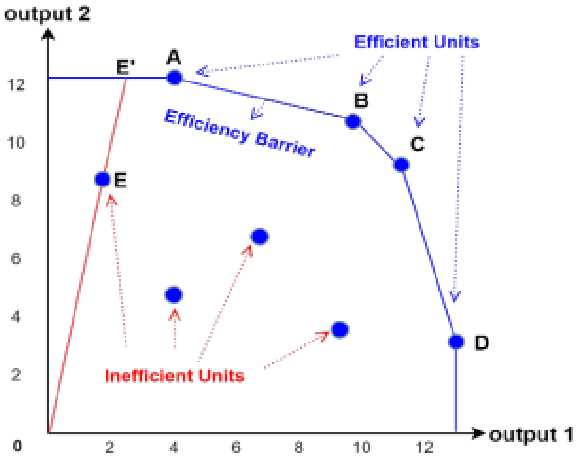


Figure 16 – DEA efficiency frontier [42]

Thus, as illustrated in **Figure 16**, a production unit that operates on the frontier (A, B, C, D) is considered efficient. Still, if it operates just below the frontier line, it is inefficient, and the farther from the frontier, the greater the degree of inefficiency [50]. Furthermore, the distance between E and E' measures the projected amount of adjustment to make the unit efficient.

The models addressed by DEA can be grouped into four classes: radial, non-radial, oriented and non-oriented. The radial model considers proportional increase or decrease of inputs and outputs to achieve efficiency, while the oriented model keeps the inputs or outputs fixed. The BCC and CCR models can be output or input-orientated models [61]. The inputs in DEA for wind farms can be controllable, as the project cost, for example, or non-controllable, as wind speed.

In this study, we employ the WRDDM to analyze the non-controllable variables related to wind energy production.

4 Methodology

The directional distance function seeking to augment the outputs and reduce the inputs directionally can be stated as:

$$sup\{\rho: (\boldsymbol{x} - b\boldsymbol{g}_x, \boldsymbol{y} + b\boldsymbol{g}_y) \in T\} \tag{8}$$

where vector $\boldsymbol{g} = (-\boldsymbol{g}_x, \boldsymbol{g}_y)$ defines the "directions" in which inputs and outputs are scaled and the technology reference set $T = \{(\boldsymbol{x}, \boldsymbol{y}): \boldsymbol{x}\text{ can produce }\boldsymbol{y}\}$ satisfies the assumptions of CRS, with strong disposability of inputs and outputs, i.e. it considers that the inputs/outputs are freely disposable [62].

For two input and output vectors, $\boldsymbol{x} = (x_1, \ldots, x_m)^T$ and $\boldsymbol{y} = (y_1, \ldots, y_r)^T$, respectively, and n DMUs, the DEA piecewise reference technology can be obtained as follows:

$$\begin{aligned} T = \{(\boldsymbol{x}, \boldsymbol{y}): & \textstyle\sum_{j=1}^{n} \lambda_j y_{rj} \geq y_r, r = 1, \ldots, s, \\ & \textstyle\sum_{j=1}^{n} \lambda_j x_{ij} \leq x_i, i = 1, \ldots, m, \\ & \lambda_j \geq 0, j = 1, \ldots, n\} \end{aligned} \tag{9}$$

Therefore, for each DMU under assessment, DMU$_o$, the directional distance function can be obtained by solving the following LP problem [63]:

$$\begin{aligned} & \max\ \beta_o \\ & \text{s.t. } \textstyle\sum_{j=1}^{n} \lambda_j y_{rj} \geq y_{ro} + \beta_o g_{yr}, r = 1, \ldots, s, \\ & \textstyle\sum_{j=1}^{n} \lambda_j x_{ij} \leq x_{io} - \beta_o g_{xi}, i = 1, \ldots, m, \\ & l_j \geq 0, j = 1, \ldots, n, \end{aligned} \tag{10}$$

where β_o measures simultaneously the maximum enlargement of outputs and reduction of inputs that remain technically feasible and can serve as a measure of technical inefficiency. If $\beta_o = 0$, then DMU$_o$ operates on the frontier of T with technical efficiency. If $\beta^o > 0$, then DMU$_o$ operates inside the frontier of T and it is inefficient. Finally, the parameter $\beta_o g_{xi}$ indicates the level by which DMU$_o$ must reduce its i-th input to become efficient. Analogously, the parameter $\beta_o g_{yr}$ provides information on the level by which DMU$_o$ must enlarge its r-th output in order to become efficient.

Besides being a generalisation of the Shephard's distance functions, the directional distance function can be specified to embed different assumptions. If $\boldsymbol{g} = (-\boldsymbol{g}_x, \boldsymbol{g}_y)$= $(-\boldsymbol{x}^o, \boldsymbol{y}^o)$, i.e., the direction is set to account for the observed data, β^o corresponds to the potential proportional variation in outputs and inputs. If alternatively, $\boldsymbol{g} = (-\boldsymbol{g}_x, \boldsymbol{g}_y)$= $(-1, 1)$, then the solution value can be viewed as the net improvement in performance in terms of feasible enlargement in outputs and feasible reduction in inputs [64]. Conversely, with $\boldsymbol{g} = (0, \boldsymbol{g}_y)$, the directional output distance function is thus obtained.

Since one of the limitations of this approach is that it does not account for the inefficiencies associated with non-zero slacks and it eventually has the problem of miss specifying some evaluated DMUs as efficient units, we consider the WRDDM formulation suggested in [62], which can easily be adjusted to account for inputs that cannot be varied at the discretion of management (in our case the index of economic, social and cultural status), by considering the one-stage models approach proposed in [65], given as follows:

$$
\begin{aligned}
&\max \beta_o^R = max\ (w_y(\textstyle\sum_r \varpi_y^r \alpha_o^r) + \\
&w_x(\textstyle\sum_i \varpi_x^i \zeta_o^i)) \\
&\text{s.t. } \textstyle\sum_{j=1}^{n} \lambda_j y_{rj} \geq y_{ro} + \alpha_o^r g_{yr},\ r = 1, \ldots, s, \\
&\textstyle\sum_{j=1}^{n} \lambda_j x_{ij} \leq x_{io} - \zeta_o^i g_{xi},\ i = 1, \ldots, m, \\
&\textstyle\sum_{j=1}^{n} \lambda_j z_{uj} \leq z_{uo},\ u = 1, \ldots, q, \\
&\textstyle\sum_{j=1}^{n} \lambda_j = 1,\ l_j \geq 0,\ j = 1, \ldots, n,
\end{aligned}
\tag{11}
$$

where the vectors of inputs and outputs of DMU$_o$ are $\boldsymbol{x}_o$ and $\boldsymbol{y}_o$, respectively, and the vector of non-discretionary factors of DMU*o* is given by $\boldsymbol{z}_o$. The parameters α_o^r and ζ_o^i are the individual inefficiency measures for each output and input, respectively, and all variables are nonnegative except for β_o. The parameter $\zeta_o^i g_{xi}$ indicates the level by which DMU$_o$ must reduce its *i*-th input to become efficient. Analogously, the parameter $\alpha_o^r g_{yr}$ provides information on the level by which DMU$_o$ must enlarge its *r*-th output in order to become efficient. The coefficients w_y and w_x may be regarded as the given priorities associated with the outputs and inputs, and their sum should be one. Furthermore, the inefficiencies of each related output and input can also have different priorities and $\sum_{r \in O} \varpi_y^r = 1$, $\sum_{i \in I} \varpi_x^i = 1$. In this case, it is necessary that the directional vectors are measured according to the same measurement units as the original vectors of inputs and outputs in order to add α_o^r and ζ_o^i. Finally, we assume the VRS technology, which implies the imposition of the additional constraint $\sum_{j=1}^{n}\lambda_j = 1$, $l_j \geq 0$ $(\forall_j)$.

If the WRDDM inefficiency measure is zero ($\beta_o^R = 0$), then the DMU is fully efficient. The reference set of the inefficient DMU$_o$ based on (11) can be obtained through problem (12), assuming that α_o^{r*} and ζ_o^{i*} are the optimal solutions to problem (11):

$$\begin{aligned}
&\max \textstyle\sum_r s_r^+ + \sum_i s_i^- + \sum_u s_u^-, \\
&\text{s.t. } \textstyle\sum_{j=1}^{n}\lambda_j y_{rj} - s_r^+ = y_{ro} + \alpha_o^{r*} g_{yr},\ r = 1, \ldots, s, \\
&\textstyle\sum_{j=1}^{n}\lambda_j x_{ij} + s_i^- = x_{io} - \zeta_o^{i*} g_{xi},\ i = 1, \ldots, m, \\
&\textstyle\sum_{j=1}^{n}\lambda_j z_{uj} + s_u^- = z_{uo},\ u = 1, \ldots, q, \\
&\textstyle\sum_{j=1}^{n}\lambda_j = 1,\ l_j \geq 0,\ j = 1, \ldots, n, \\
&s_r^+ \geq 0\ (\forall_r),\ s_i^- \geq 0\ (\forall_i),\ s_u^- \geq 0\ (\forall_u)
\end{aligned} \tag{12}$$

The point of the efficient frontier which can be viewed as a target DMU for the WRDDM - inefficient DMU$_o$ is given by:

$$(\hat{\boldsymbol{x}}_o, \hat{\boldsymbol{y}}_o) = \left(\textstyle\sum_{j\epsilon E_o}\lambda_j^*\boldsymbol{x}_j\ , \sum_{j\epsilon E_o}\lambda_j^*\boldsymbol{y}_j\ , \sum_{j\epsilon E_o}\lambda_j^*\boldsymbol{z}_j\ \right) \tag{13}$$

where (α_o^{r*}, ζ_o^{i*}, s_r^{+*}, s_i^{-*}, s_u^{-*}, λ_j^*) is the optimal solution to (12) and the reference set of the WRDDM-inefficient DMU$_o$ is:

$$\mathrm{E}_o = \{\ \mathrm{j}: \lambda_j^* > 0,\ j = 1,\ \ldots,\ n\} \tag{14}$$

Additionally, the WRDDM inefficiency measure can be transformed into a slacks-based measure through the following transformation:

$$\begin{aligned}
&\max \left(w_y\left(\textstyle\sum_r \varpi_y^r \frac{s_r^{+\prime}}{g_{yr}}\right) + w_x\left(\sum_i \varpi_x^i \frac{s_i^{-\prime}}{g_{xi}}\right)\right) \\
&\text{s.t. } \textstyle\sum_{j=1}^{n}\lambda_j y_{rj} = y_{ro} + s_r^{+\prime},\ r = 1, \ldots, s, \\
&\textstyle\sum_{j=1}^{n}\lambda_j x_{ij} = x_{io} - s_i^{-\prime},\ i = 1, \ldots, m, \\
&\textstyle\sum_{j=1}^{n}\lambda_j z_{uj} = z_{uo} - s_u^{-\prime},\ u = 1, \ldots, q,
\end{aligned} \tag{15}$$

$$\sum_{j=1}^{n} \lambda_j = 1,\ l_j \geq 0,\ j=1, \ldots, n, \tag{16}$$
$$s_r^{+\prime} \geq 0\ (\forall_r),\ s_i^{-\prime} \geq 0\ (\forall_i),\ s_u^{-\prime} \geq 0\ (\forall_u)$$

Since the slacks can be distinct, the objective in (15) reproduces all inefficiencies by computing the maximum increase and reduction of all outputs and inputs, respectively. Let $(s_r^{+*\prime}, s_i^{-*\prime}, s_u^{-*\prime}, \lambda_j^*)$ be the optimal solution to (15), then the overall WRDDM inefficiency measure is given by:

$$\left(w_y\left(\sum_r \alpha_o^{r*\prime}\right) + w_x\left(\sum_i \zeta_o^{i*\prime}\right)\right), \text{ where } \alpha_o^{r*\prime} = \varpi_y^r \frac{s_r^{+\prime}}{g_{yr}} \text{ and } \zeta_o^{i*\prime} = \varpi_x^i \frac{s_i^{-\prime}}{g_{xi}} \tag{17}$$

4.1 Data and Variables

In this work, the performance of wind farms located in the northeast of Brazil has been evaluated. Data from 460 wind farms was collected from the following institutions: National Electric System Operator (ONS) [38], National Electric Energy Agency (ANEEL) [34], Chamber of Electric Energy Commercialization (CCEE) [66], Reference Centre for Solar and Wind Energy Sérgio S.Brito (CRECESB) [67] and Wind Energy Market Intelligence [67].

In addition, the software opensolver 2.9.0 was utilized, available from https://opensolver.org/ and created an Excel-Visual Basic based application that uses OpenSolver as a backend to model and solve our DEA problems.

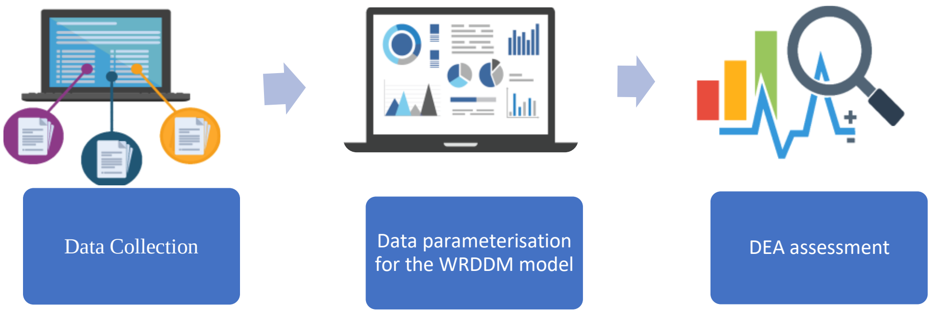


Figure 17 – Methodology overview

The novelty of this research is twofold: 1) the WRDDM, which is a non-oriented non-radial method, was employed to assess the efficiency of wind farms in northeastern Brazil. 2) as a proxy of wind speed quality using the shape and the scale parameters has been used.

From the literature review conducted, three inputs and one output were chosen. The first input is power installed capacity, a controllable factor that provides maximum rated power [52]. The second input is the shape parameter that quantifies the regularity and constancy of wind speeds [67]. The third input is the scale parameter related to the average wind speed at the wind farm site. The output selected is the amount of generated electricity directly dependent on the installed capacity and operation time [53]. **Table 4** shows the statistical analysis of DMUs for each selected input and output variable from 2016 to 2020.

Table 4- Descriptive statistics of inputs and output (2016-2020)

Variable	Description	Unit	Mean	Minimum	Median	Maximum	S.D
X_1	Installed Capacity	MW	26.01	2.4	28	105	9.57
X_2	Shape Parameter	_	2.36	1.63	2.38	2.83	0.29
X_3	Scale Parameter	m/s	7.44	4.69	7.49	9.81	0.81
Y_1	Energy Generation	GWh	92.29	6.2	94	242.2	32.45

Source: Authors' own calculations

5 Results and discussion

The efficiency scores are given in **Table 1A** (see the **Appendix**). In the period under analysis, there were 18 efficient DMUs. General information on these DMUs is provided in **Table 2A** (see the **Appendix**). The efficient wind farms, which are also viewed as benchmarks, are DMUs 273, 200, 46, 191, 195, 202, 238, 246, 332, 334, 397 and 416. Specific information on these DMUs is also shown in **Table 5**. Efficient DMUs present values for each input and output above the overall average shown in **Table 4**. These results are directly associated with the wind potential of each northeastern state. Thus, wind farms located in different areas also possess different wind potentials. DMUs situated in the Rio Grande do Norte (RN), Ceará (CE) and Bahia (BA) have a higher average wind speed of 6.96 m/s, 6.33 m/s and 6.13 m/s, resulting in a higher average power density of 331 W/m², 271 W/m² and 260W/m², respectively. In particular, the present capacity factors of 49.1%, 39.5% and 37% for RN, BA and CE represent amounts well above the world average (34%) [29]. According to the literature, these values are ideal for efficient wind power generation [8].

Table 5- Specific characteristics of efficient wind farms

Wind Farm	DMU	Energy Generation (GWh)	Installed Capacity (MW)	Shape Parameter -	Scale Parameter (m/s)	Efficiency score
Alegria 2	2	242.2	100.65	2.76	8.46	1.036
Icaraizinho	321	174.8	54.6	1.99	6.36	1.025
Ventos de São Abraao	273	160.7	28	2.58	7.69	1.009
Praia Formosa	341	210.4	105	2.33	7.53	1.007
Eol Andorinhas	200	149.4	30	2.5	4.98	1.000
Eol Cabeço Vermelho	46	128	26	2.04	6.86	1.000
Campo Largo XV	171	84.3	29.7	2.17	4.69	1.000
Delfina 4	191	31	8	2,5	4.98	1.000
Diamante II	195	86.7	17.5	2.12	8.66	1.000
Eol Baraunas II	202	79.4	25.85	1.63	6.92	1.000
Pedra Branca	238	116.2	30	1.63	6.92	1.000
Porto Seguro	246	28.6	6,4	2.17	8.15	1.000
Eol de Taíba	308	12,2	5	2.07	6.65	1.000
Lagoa do Mato	332	11,4	3.23	2.64	7.26	1.000
Mucuripe	334	6,2	2.4	2.24	5.78	1.000
Ventos de Santo Onofre I	397	134,8	30	1.98	7.65	1.000
Coelhos II	416	13,4	4.8	2.08	7.54	1.000
Vitória	425	10,2	4.5	2.08	7.54	1.000

Source: Authors' own calculations.

The overall efficiency scores range from -0,995 to 1.035, the mean efficiency score is 0.764, and the median score is 0.800. **Table 6** provides the statistical description of the data referring to efficient wind farms. Moreover, there are 80 DMUs with an efficiency score of 0.9 and 132 with 0.8. Overall, around 57% of wind farms operate between the optimal and acceptable levels of efficiency (i.e., between 0.8-1).

Table 6- Descriptive statistics regarding efficient DMUs

	Energy Generation (GWh)	Installed Capacity (MW)	Shape Parameter -	Scale Parameter (m/s)	Wind Power Density (W/m^2)	Wind speed (m/s)	Capacity Factor	Efficiency
Mean	93.33	28.42	2.19	6.92	306.17	6.83	0.36	1.00
Standard deviation	17.33	7.18	0.07	0.27	72.69	0.54	0.07	0.002
Median	85.50	25.92	2.14	7.09	285	6.64	0.38	1.00
Minimum	6.20	2.40	1.63	4.69	227	6.08	0.19	1.00
Maximum	242.20	105.00	2.76	8.66	457	7.85	0.45	1.035
1st Quartile	149.4	29.70	2.33	6.86	386	7.53	0.38	1.00
2nd Quartile	85.50	25.93	2.15	7.09	285	6.64	0.38	1.00
3rd Quartile	13.40	5.00	2.08	7.26	285	6.64	0.39	1.00

Source: Authors' own calculations.

The results obtained suggest that factors such as wind speed and consequently wind density, the physical guarantee of operation (assured energy delivered by the system), number of turbines and age of the wind farm are also important for an overall assessment (see **Table 7**). Therefore, for inefficient DMUs, it is possible to suggest a re-evaluation regarding altitude wind speed, predominant wind direction from the wind rose study, and the influence of turbulence caused by the wake effect.

Table 7- Descriptive statistics regarding inefficient DMUs

	Energy Generation (GWh)	Installed Capacity (MW)	Shape Parameter -	Scale Parameter (m/s)	Wind Power Density (W/m^2)	Wind speed (m/s)	Capacity Factor	Efficiency
Mean	92.25	25.92	2.37	7.47	305.95	6.60	0.40	0.75
Standard deviation	29.62	7.70	0.28	0.78	92.42	0.72	0.09	0.18
Median	94.15	28.00	2.38	7.49	300.00	6.64	0.41	0.79
Minimum	8.60	4.80	1.63	4.98	84	4.42	0.12	-0.99
Maximum	177.40	68.47	2.83	9.81	596	8.73	0.65	0.99
1st Quartile	108.00	28.20	2.34	7.49	297	6.64	0.43	0.87
2nd Quartile	94.15	28.00	2.38	7.49	300	6.64	0.41	0.79
3rd Quartile	83.80	27.30	2.49	7.49	304	6.64	0.39	0.70

Source: Authors' own calculations.

Based also on the analysis from the data available in **Tables 3A** (see the **Appendix**), it is possible to observe that the most efficient DMUs present an average of 16 wind turbines, 8.71 years of operation and a physical guarantee of 11.44 MW (see **Table 8** and **Table 9).**

Table 8- Characteristics of efficient DMUs.

Wind Farm	DMU	State	Number of times considered as reference	Number of turbines	Wind farm's age	Physical guarantee of operation (MW)	Wind power plants type
Alegria 2	2	RN	2	61	9.5	29.13	I
Icaraizinho	321	CE	2	26	11.75	20.76	I
Ventos de São Abraao	273	BA	333	15	3.1	17.7	II-C
Praia Formosa	341	BA	1	50	11.9	28.83	I
Eol Andorinhas	200	BA	125	15	5.6	15.9	II-C
Eol Cabeço Vermelho	46	RN	243	13	3.2	15	II-C
Campo Largo XV	171	BA	2	11	1.1	14.1	II-C
Delfina 4	191	BA	29	15	3.75	3.8	II-C
Diamante II	195	BA	43	15	3.25	7.7	II-C
Eol Baraunas II	202	BA	10	11	5.3	10.7	II-C
Pedra Branca	238	BA	75	10	8.3	12.2	II-C
Porto Seguro	246	BA	62	5	7	2.7	II-C
Eol de Taíba	308	CE	4	10	22	2.3	III
Lagoa do Mato	332	CE	62	2	12.5	1.15	III
Mucuripe	334	CE	110	4	19	1.1	III
Ventos de Santo Onofre I	397	PI	34	15	6.5	16.2	II-C
Coelhos II	416	PB	22	6	12.5	1.32	III
Vitória	425	PB	1	3	10.6	1.35	III

Source: Authors' own calculations.

Also, the present analysis showed that efficient wind farms present a slightly higher number of turbines, age of operation and installed power than inefficient DMUs.(see **Table 6**, **Table 9** and **Table 10**). In addition, as mentioned earlier, the better performance of wind farms located in states with higher wind speeds and, therefore, more significant wind potential has a relevant contribution to efficiency.

Table 9- Descriptive statistics regarding data on efficient DMUS

	Number of turbines	Wind farm's age	Physical guarantee of operation (MW)
Mean	15.94	8.71	11.44
Standard deviation	15.61	5.79	9.03
Median	12.00	7.00	12.2
Minimum	2.00	1.10	1.10
Maximum	61.00	22.00	29.13

Source: Authors' own calculations.

Table 10- Descriptive statistics regarding data on inefficient DMUS

	Number of turbines	Wind farm's age	Physical guarantee of operation (MW)
Mean	13.50	6.20	12.37
Standard deviation	6.68	2.52	3.96
Median	14.00	5.60	13.20
Minimum	3.00	2.50	1.20
Maximum	62.00	15.00	22.80

Another factor evaluated is the inefficiency contributions of each factor, thus highlighting the inability of inefficient DMUs in terms of wind power generation for the considered installed capacity (see **Figure 18**). Also, the DEA model shows the projections of installed capacity and energy generation to attain efficiency (see **Figure 19** and **Figure 20**). It is possible to notice that some DMUs can be more efficient producing with a lower installed capacity due to the intermittency of the environmental conditions analysed by the shape parameter and the scale parameter variables [25].

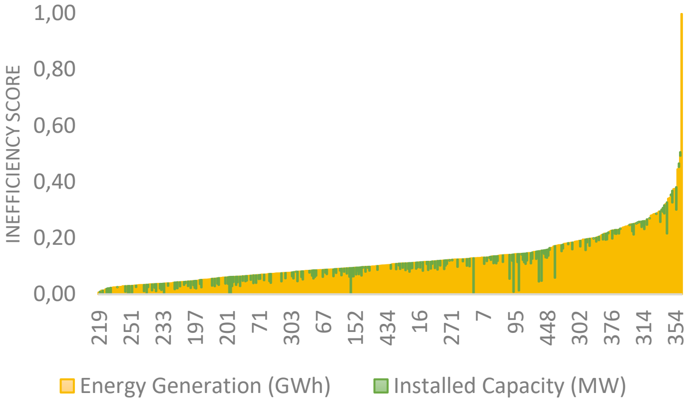


Figure 18 – Contribution to inefficiency. Source: Authors' own calculations.

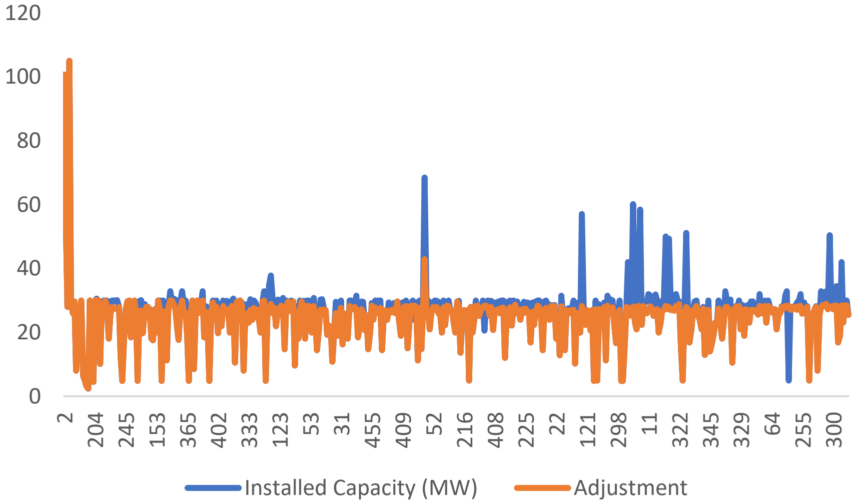


Figure 19 – Real installed capacity vs projection corrections. Source: Authors' own calculations.

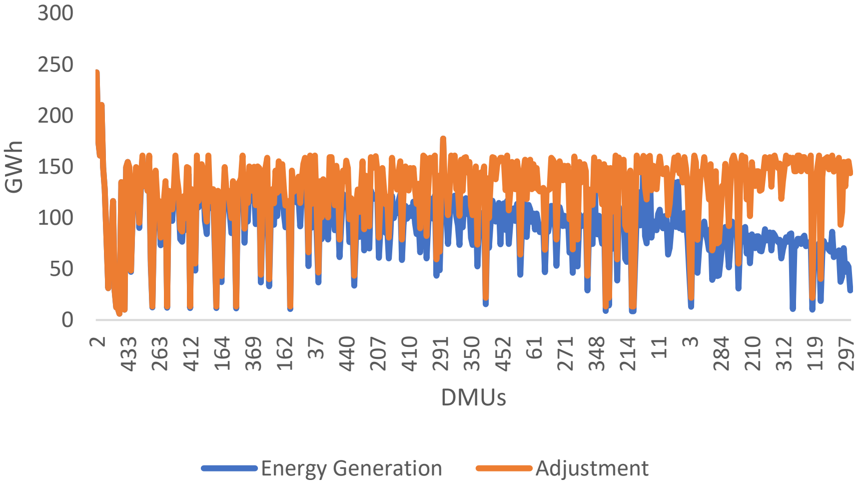


Figure 20 – Energy Generation vs projection corrections. Source: Authors' own calculations.

Finally, it is also possible to observe the correlation of inputs and outputs with efficiency (see **Figure 21**). Thus, as shown below, the most efficient DMUs present shape parameters between 2.1 and 2.7, scale parameters between 4 and 8.5 m/s, and installed capacity in the range between 2.4-30 MW. According to the literature, the values for the shape parameter are between 1.5 and 3, so the higher the (***K***) value, the more regular and constant the wind speeds, the narrower the curve, and the scale parameter is related to wind speed.

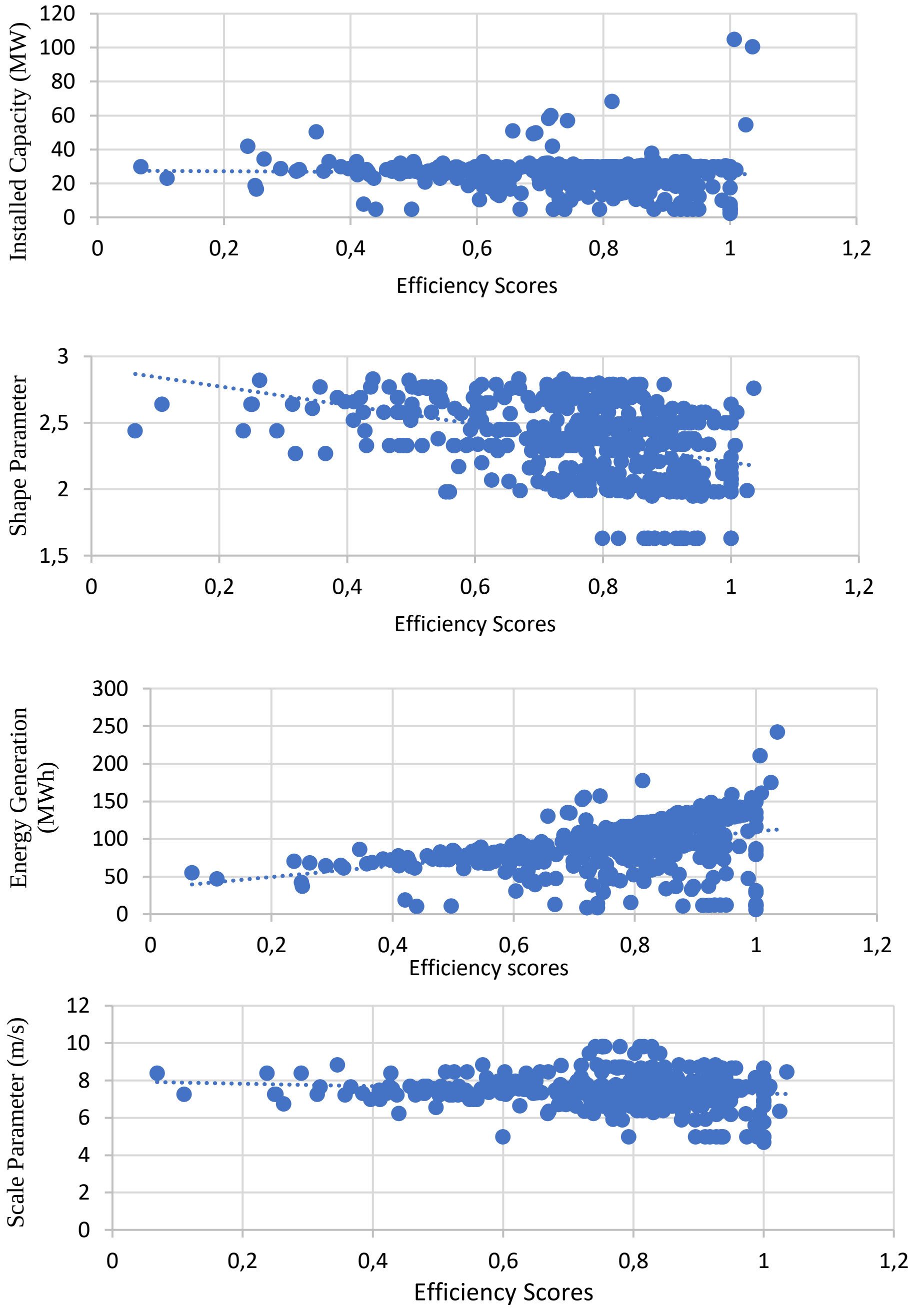


Figure 21 – Inputs and output vs efficiency scores. Source: Authors' own calculations

6 Conclusion

The growing competitive search for resources to meet the demand for energy consumption combined with the solution of environmental problems arising from excessive fossil fuels use has stimulated studies on conversion technologies from renewable sources. In addition, the energy transition continues to move forward at a rapid pace due to falling prices, technological improvements, and an increasingly favourable political environment. Renewable sources are the pillars of the solution for countries seeking to support economic growth, limit carbon emissions, expand energy access, and improve energy security.

Brazil has a vast potential for wind power generation. Therefore, promoting a faster energy transition towards a cleaner and more sustainable energy future is advantageous.

The Northeast's potential in wind energy consolidates this region as a world benchmark in wind power generation.

The present study uses the Brazilian electric sector data to provide a different understanding of the main variables that influence wind farms' efficiency. So, to the best of our knowledge, this is the first work that proposes using the non-radial WRDDM in the efficiency analysis of wind farms in Brazil.

In this study, 460 wind farms in northeastern Brazil have been assessed considering three inputs (installed power capacity, shape parameter and scale parameter) and one output (generated electricity). The DEA models used to evaluate the performance of the wind farms were the oriented and non-oriented versions of the non-radial WRDDM model. In general, the results showed that the DMUs presented an average capacity factor (40%) above the world average (34%) due to the privileged wind potential of the Brazilian northeast due to the unidirectional, constant and intense trade winds. Besides, the efficient DMUs presented an average of 16 turbines per wind farm, 8.71 years of operation and a physical guarantee of 21.22 MW. Also, most of the DMUS analysed are type III and II-c. These DMUs that presented the best performance are located mainly in RN, BA, and CE, which have higher wind speed and wind power potential in the country. It is also possible to highlight that the efficient DMUs have a higher number of turbines in the wind farm set, a higher age, and slightly greater installed power.

Furthermore, 57% of the DMUs operate between the optimal or acceptable level (0.8-1), and inefficient DMUs require a re-evaluation regarding wind turbine altitude, predominant wind direction, and turbulence caused by the wake effect.

For future work, it is possible to expand this research to all the other states of the Brazilian coast with the technology and compare it with other countries such as China, USA, Germany and India that lead the wind energy market.

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🟨 DMU efficient

Appendix

*** each colour represents a group of efficiency scores

Table 1A- Efficiency scores and rankings of DMUs.

Non- oriented model				Input-oriented model				Output-oriented model			
DMU	Efficiency	Rank	Nº of times as Benchmark	DMU	Efficiency	Rank	Nº of times as Benchmark	DMU	Efficiency	Rank	Nº of times as Benchmark
2	1.036	1	2	2	1.107	1	2	2	1.036	1	67
321	1.025	2	2	321	1.053	2	2	321	1.025	2	119
273	1.009	3	333	273	1.012	3	328	273	1.020	3	367
341	1.007	4	1	200	1.002	4	39	341	1.007	4	1
200	1.000	5	125	46	1.000	5	188	200	1.000	5	148
46	1.000	6	243	171	1.000	5	2	46	1.000	6	143
171	1.000	6	2	191	1.000	5	28	171	1.000	6	2
191	1.000	6	29	195	1.000	5	35	191	1.000	6	29
195	1.000	6	43	202	1.000	5	17	195	1.000	6	43
202	1.000	6	10	238	1.000	5	87	202	1.000	6	10
238	1.000	6	75	246	1.000	5	117	238	1.000	6	135
246	1.000	6	62	308	1.000	5	14	246	1.000	6	62
308	1.000	6	4	332	1.000	5	182	308	1.000	6	4
332	1.000	6	62	334	1.000	5	286	332	1.000	6	62
334	1.000	6	110	341	1.000	5	1	334	1.000	6	110
397	1.000	6	34	397	1.000	5	6	397	1.000	6	110
416	1.000	6	22	416	1.000	5	67	416	1.000	6	22
425	1.000	6	1	425	1.000	5	10	425	1.000	6	1
204	0.999	19	0	204	0.999	19	0	204	0.999	19	0
433	0.993	20	0	433	0.987	20	0	433	0.995	20	0
218	0.990	21	0	218	0.983	21	0	218	0.981	21	0

Non- oriented model				Input-oriented model				Output-oriented model			
DMU	Efficiency	Rank	Nº of times as Benchmark	DMU	Efficiency	Rank	Nº of times as Benchmark	DMU	Efficiency	Rank	Nº of times as Benchmark
219	0.987	22	0	206	0.980	22	0	399	0.979	22	0
206	0.987	23	0	219	0.978	23	0	219	0.975	23	0
399	0.981	24	0	413	0.977	24	0	156	0.974	24	0
208	0.974	25	0	415	0.973	25	0	206	0.974	25	0
398	0.973	26	0	412	0.969	26	0	398	0.969	26	0
70	0.973	27	0	414	0.965	27	0	151	0.956	27	0
237	0.965	28	0	399	0.963	28	0	384	0.952	28	0
156	0.960	29	0	411	0.961	29	0	236	0.949	29	0
384	0.957	30	0	166	0.960	30	0	208	0.948	30	0
151	0.957	31	0	263	0.959	31	0	155	0.946	31	0
236	0.954	32	0	250	0.955	32	0	70	0.945	32	0
272	0.953	33	0	208	0.954	33	0	233	0.940	33	0
150	0.951	34	0	70	0.949	34	0	237	0.931	34	0
413	0.951	35	0	418	0.949	35	0	251	0.927	35	0
438	0.950	36	0	398	0.947	36	0	404	0.926	36	0
245	0.949	37	0	169	0.941	37	0	389	0.924	37	0
166	0.949	38	0	230	0.941	38	0	391	0.921	38	0
263	0.948	39	0	417	0.938	39	0	235	0.921	39	0
370	0.947	40	0	422	0.938	39	0	59	0.920	40	0
23	0.943	41	0	424	0.938	39	0	234	0.916	41	0
250	0.942	42	0	237	0.935	42	0	158	0.913	42	0
235	0.942	43	0	165	0.926	43	0	383	0.907	43	0
415	0.942	44	0	150	0.924	44	0	272	0.907	44	0
404	0.941	45	0	370	0.924	45	0	36	0.903	45	0
251	0.941	46	0	156	0.922	46	0	150	0.902	46	0
19	0.941	47	0	272	0.919	47	0	413	0.902	47	0

Non- oriented model				Input-oriented model				Output-oriented model			
DMU	Efficiency	Rank	Nº of times as Benchmark	DMU	Efficiency	Rank	Nº of times as Benchmark	DMU	Efficiency	Rank	Nº of times as Benchmark
391	0.940	48	0	172	0.917	48	0	438	0.899	48	0
266	0.939	49	0	384	0.914	49	0	245	0.899	49	0
190	0.938	50	0	151	0.914	50	0	166	0.898	50	0
362	0.938	51	0	173	0.912	51	0	263	0.895	51	0
154	0.936	52	0	438	0.911	52	0	370	0.894	52	0
196	0.935	53	0	170	0.911	53	0	432	0.887	53	0
319	0.934	54	0	167	0.908	54	0	23	0.886	54	0
153	0.934	55	0	236	0.907	55	0	250	0.885	55	0
217	0.934	56	0	245	0.906	56	0	362	0.885	56	0
59	0.933	57	0	362	0.900	57	0	415	0.883	57	0
412	0.932	58	0	190	0.898	58	0	19	0.881	58	0
389	0.932	59	0	154	0.897	59	0	363	0.881	59	0
395	0.932	60	0	196	0.897	60	0	266	0.879	60	0
223	0.930	61	0	266	0.897	61	0	395	0.878	61	0
276	0.929	62	0	319	0.897	62	0	190	0.876	62	0
155	0.929	63	0	23	0.896	63	0	154	0.872	63	0
194	0.928	64	0	365	0.895	64	0	364	0.870	64	0
432	0.928	65	0	19	0.893	65	0	196	0.870	65	0
158	0.927	66	0	217	0.892	66	0	319	0.869	66	0
242	0.926	67	0	155	0.891	67	0	126	0.868	67	0
24	0.926	68	0	153	0.889	68	0	153	0.868	68	0
36	0.926	69	0	233	0.889	69	0	217	0.868	69	0
233	0.926	70	0	235	0.889	70	0	412	0.864	70	0
363	0.925	71	0	395	0.889	71	0	320	0.863	71	0
383	0.924	72	0	223	0.888	72	0	360	0.862	72	0
365	0.923	73	0	174	0.888	73	0	223	0.860	73	0

Non- oriented model				Input-oriented model				Output-oriented model			
DMU	Efficiency	Rank	Nº of times as Benchmark	DMU	Efficiency	Rank	Nº of times as Benchmark	DMU	Efficiency	Rank	Nº of times as Benchmark
414	0.922	74	0	164	0.886	74	0	229	0.858	74	0
400	0.922	75	0	391	0.885	75	0	400	0.858	75	0
230	0.922	76	0	251	0.885	76	0	276	0.858	76	0
164	0.922	77	0	404	0.883	77	0	80	0.856	77	0
169	0.921	78	0	194	0.883	78	0	194	0.855	78	0
193	0.918	79	0	276	0.882	79	0	199	0.853	79	0
364	0.916	80	0	234	0.881	80	0	390	0.853	80	0
360	0.916	81	0	242	0.877	81	0	242	0.853	81	0
234	0.914	82	0	168	0.876	82	0	24	0.852	82	0
261	0.914	83	0	400	0.875	83	0	201	0.850	83	0
199	0.914	84	0	402	0.874	84	0	387	0.849	84	0
157	0.913	85	0	24	0.873	85	0	369	0.848	85	0
411	0.912	86	0	59	0.871	86	0	197	0.847	86	0
185	0.912	87	0	292	0.870	87	0	365	0.847	87	0
226	0.911	88	0	193	0.869	88	0	414	0.845	88	0
188	0.910	89	0	363	0.868	89	0	230	0.844	89	0
126	0.909	90	0	36	0.866	90	0	164	0.843	90	0
402	0.908	91	0	432	0.865	91	0	185	0.842	91	0
390	0.908	92	0	389	0.864	92	0	169	0.841	92	0
371	0.907	93	0	201	0.860	93	0	79	0.841	93	0
197	0.906	94	0	188	0.860	94	0	248	0.836	94	0
387	0.905	95	0	158	0.859	95	0	193	0.836	95	0
369	0.904	96	0	360	0.856	96	0	226	0.833	96	0
145	0.904	97	0	226	0.856	97	0	187	0.831	97	0
49	0.901	98	0	146	0.855	98	0	261	0.828	98	0
187	0.898	99	0	261	0.854	99	0	157	0.826	99	0

Non- oriented model				Input-oriented model				Output-oriented model			
DMU	Efficiency	Rank	Nº of times as Benchmark	DMU	Efficiency	Rank	Nº of times as Benchmark	DMU	Efficiency	Rank	Nº of times as Benchmark
80	0.897	100	0	157	0.852	100	0	411	0.825	100	0
292	0.897	101	0	383	0.852	101	0	188	0.820	101	0
165	0.896	102	0	364	0.850	102	0	124	0.818	102	0
138	0.896	103	0	371	0.849	103	0	367	0.817	103	0
277	0.896	104	0	185	0.848	104	0	402	0.816	104	0
453	0.895	105	0	304	0.847	105	0	371	0.813	105	0
146	0.894	106	0	199	0.847	106	0	359	0.811	106	0
304	0.892	107	0	49	0.846	107	0	145	0.808	107	0
367	0.889	108	0	126	0.841	108	0	401	0.807	108	0
333	0.889	109	0	277	0.840	109	0	160	0.807	109	0
248	0.889	110	0	390	0.839	110	0	252	0.805	110	0
244	0.888	111	0	333	0.838	111	0	381	0.804	111	0
124	0.886	112	0	138	0.837	112	0	49	0.801	112	0
401	0.884	113	0	352	0.836	113	0	123	0.795	113	0
445	0.884	114	0	393	0.834	114	0	275	0.794	114	0
162	0.884	115	0	387	0.834	115	0	281	0.794	115	0
122	0.881	116	0	369	0.832	116	0	292	0.794	116	0
172	0.881	117	0	453	0.831	117	0	165	0.792	117	0
201	0.881	118	0	197	0.829	118	0	182	0.792	118	0
418	0.880	119	0	145	0.826	119	0	138	0.792	119	0
160	0.878	120	0	244	0.823	120	0	277	0.791	120	0
229	0.877	121	0	122	0.819	121	0	453	0.790	121	0
320	0.876	122	0	187	0.817	122	0	37	0.789	122	0
381	0.876	123	0	367	0.814	123	0	146	0.788	123	0
182	0.875	124	0	175	0.813	124	0	304	0.784	124	0
372	0.875	125	0	162	0.812	125	0	358	0.778	125	0

Non- oriented model				Input-oriented model				Output-oriented model			
DMU	Efficiency	Rank	Nº of times as Benchmark	DMU	Efficiency	Rank	Nº of times as Benchmark	DMU	Efficiency	Rank	Nº of times as Benchmark
252	0.874	126	0	80	0.812	126	0	333	0.778	126	0
123	0.874	127	0	401	0.811	127	0	244	0.776	127	0
454	0.874	128	0	372	0.808	128	0	221	0.771	128	0
359	0.874	129	0	396	0.807	129	0	96	0.769	129	0
352	0.873	130	0	445	0.806	130	0	445	0.768	130	0
275	0.871	131	0	47	0.805	131	0	97	0.768	131	0
173	0.871	132	0	454	0.805	132	0	162	0.767	132	0
221	0.870	133	0	71	0.801	133	0	268	0.765	133	0
37	0.870	134	0	135	0.800	134	0	222	0.764	134	0
170	0.869	135	0	248	0.800	135	0	403	0.763	135	0
175	0.868	136	0	90	0.796	136	0	122	0.763	136	0
224	0.867	137	0	124	0.796	137	0	232	0.763	137	0
47	0.866	138	0	426	0.793	138	0	172	0.762	138	0
358	0.865	139	0	275	0.791	139	0	418	0.759	139	0
167	0.864	140	0	140	0.791	140	0	224	0.758	140	0
403	0.864	141	0	37	0.789	141	0	372	0.751	141	0
71	0.863	142	0	182	0.789	142	0	207	0.748	142	0
96	0.863	143	0	381	0.788	143	0	454	0.748	143	0
97	0.862	144	0	303	0.788	144	0	95	0.746	144	0
53	0.860	145	0	434	0.787	145	0	352	0.746	145	0
90	0.860	146	0	160	0.787	146	0	173	0.743	146	0
268	0.860	147	0	440	0.786	147	0	31	0.740	147	0
426	0.859	148	0	306	0.786	148	0	170	0.738	148	0
135	0.859	149	0	262	0.785	149	0	385	0.737	149	0
140	0.856	150	0	139	0.784	150	0	175	0.736	150	0
232	0.855	151	0	221	0.784	151	0	94	0.733	151	0

Non- oriented model				Input-oriented model				Output-oriented model			
DMU	Efficiency	Rank	Nº of times as Benchmark	DMU	Efficiency	Rank	Nº of times as Benchmark	DMU	Efficiency	Rank	Nº of times as Benchmark
222	0.855	152	0	403	0.784	152	0	47	0.733	152	0
440	0.855	153	0	224	0.783	153	0	60	0.732	153	0
25	0.854	154	0	186	0.782	154	0	98	0.731	154	0
262	0.853	155	0	142	0.780	155	0	167	0.729	155	0
163	0.852	156	0	252	0.780	156	0	71	0.727	156	0
186	0.852	157	0	123	0.780	157	0	53	0.720	157	0
393	0.851	158	0	291	0.779	158	0	90	0.720	158	0
89	0.851	159	0	285	0.778	159	0	426	0.718	159	0
385	0.850	160	0	359	0.775	160	0	135	0.718	160	0
139	0.849	161	0	53	0.775	161	0	113	0.715	161	0
274	0.848	162	0	143	0.773	162	0	140	0.712	162	0
31	0.848	163	0	163	0.772	163	0	440	0.710	163	0
142	0.847	164	0	18	0.772	164	0	25	0.709	164	0
81	0.847	165	0	429	0.770	165	0	388	0.709	165	0
303	0.847	166	0	115	0.770	166	0	262	0.707	166	0
240	0.846	167	0	89	0.769	167	0	163	0.704	167	0
98	0.844	168	0	96	0.769	168	0	317	0.704	168	0
60	0.842	169	0	358	0.769	169	0	186	0.703	169	0
115	0.840	170	0	274	0.768	170	0	393	0.703	170	0
88	0.840	171	0	134	0.768	171	0	89	0.702	171	0
207	0.839	172	0	97	0.767	172	0	116	0.701	172	0
396	0.838	173	0	88	0.767	173	0	181	0.699	173	0
429	0.838	174	0	91	0.767	174	0	139	0.698	174	0
113	0.837	175	0	240	0.765	175	0	274	0.697	175	0
388	0.836	176	0	81	0.764	176	0	142	0.694	176	0
39	0.836	177	0	136	0.762	177	0	81	0.694	177	0

Non- oriented model				Input-oriented model				Output-oriented model			
DMU	Efficiency	Rank	Nº of times as Benchmark	DMU	Efficiency	Rank	Nº of times as Benchmark	DMU	Efficiency	Rank	Nº of times as Benchmark
306	0.834	178	0	385	0.762	178	0	382	0.694	178	0
143	0.833	179	0	318	0.760	179	0	303	0.694	179	0
91	0.833	180	0	25	0.759	180	0	240	0.691	180	0
455	0.833	181	0	268	0.759	181	0	410	0.686	181	0
66	0.832	182	0	325	0.758	182	0	455	0.686	182	0
181	0.831	183	0	229	0.758	183	0	144	0.683	183	0
382	0.829	184	0	293	0.758	184	0	82	0.681	184	0
317	0.829	185	0	320	0.756	185	0	115	0.681	185	0
116	0.829	186	0	232	0.755	186	0	88	0.681	186	0
134	0.828	187	0	228	0.754	187	0	159	0.680	187	0
228	0.828	188	0	222	0.753	188	0	409	0.677	188	0
323	0.827	189	0	39	0.752	189	0	396	0.676	189	0
67	0.827	190	0	430	0.751	190	0	429	0.676	190	0
410	0.827	191	0	305	0.750	191	0	39	0.671	191	0
54	0.825	192	0	428	0.750	192	0	306	0.668	192	0
176	0.825	193	0	410	0.748	193	0	141	0.668	193	0
82	0.825	194	0	388	0.747	194	0	239	0.668	194	0
18	0.824	195	0	31	0.746	195	0	143	0.667	195	0
174	0.824	196	0	98	0.746	196	0	91	0.666	196	0
55	0.823	197	0	350	0.745	197	0	375	0.666	197	0
285	0.823	198	0	66	0.745	198	0	176	0.665	198	0
409	0.823	199	0	409	0.743	199	0	247	0.664	199	0
443	0.820	200	0	423	0.743	200	0	152	0.664	200	0
144	0.820	201	0	439	0.741	201	0	265	0.664	201	0
325	0.819	202	0	443	0.741	202	0	443	0.664	202	0
428	0.818	203	0	67	0.741	203	0	366	0.663	203	0

Non- oriented model				Input-oriented model				Output-oriented model			
DMU	Efficiency	Rank	Nº of times as Benchmark	DMU	Efficiency	Rank	Nº of times as Benchmark	DMU	Efficiency	Rank	Nº of times as Benchmark
451	0.818	204	0	60	0.740	204	0	66	0.663	204	0
159	0.817	205	0	176	0.740	205	0	451	0.657	205	0
457	0.817	206	0	457	0.740	206	0	134	0.657	206	0
141	0.817	207	0	382	0.740	207	0	228	0.657	207	0
136	0.815	208	0	323	0.738	208	0	323	0.655	208	0
239	0.815	209	0	455	0.737	209	0	67	0.655	209	0
291	0.814	210	0	55	0.736	210	0	52	0.654	210	0
375	0.813	211	0	427	0.736	211	0	405	0.651	211	0
79	0.813	212	0	113	0.736	212	0	54	0.650	212	0
366	0.813	213	0	181	0.733	213	0	386	0.650	213	0
152	0.812	214	0	141	0.733	214	0	100	0.650	214	0
293	0.810	215	0	405	0.731	215	0	15	0.648	215	0
405	0.810	216	0	118	0.730	216	0	18	0.648	216	0
52	0.810	217	0	189	0.730	217	0	174	0.648	217	0
265	0.810	218	0	378	0.730	218	0	280	0.647	218	0
247	0.809	219	0	184	0.729	219	0	55	0.647	219	0
386	0.807	220	0	207	0.727	220	0	285	0.647	220	0
305	0.806	221	0	52	0.726	221	0	325	0.638	221	0
241	0.806	222	0	54	0.726	222	0	428	0.637	222	0
15	0.805	223	0	269	0.725	223	0	457	0.634	223	0
427	0.804	224	0	82	0.725	224	0	106	0.633	224	0
444	0.804	225	0	116	0.725	225	0	136	0.630	225	0
100	0.804	226	0	317	0.724	226	0	291	0.628	226	0
215	0.804	227	0	451	0.722	227	0	180	0.626	227	0
118	0.802	228	0	366	0.722	228	0	287	0.624	228	0
350	0.802	229	0	375	0.721	229	0	444	0.622	229	0

Non- oriented model				Input-oriented model				Output-oriented model			
DMU	Efficiency	Rank	Nº of times as Benchmark	DMU	Efficiency	Rank	Nº of times as Benchmark	DMU	Efficiency	Rank	Nº of times as Benchmark
378	0.801	230	0	247	0.721	230	0	99	0.622	230	0
168	0.799	231	0	144	0.721	231	0	293	0.621	231	0
180	0.799	232	0	241	0.721	232	0	305	0.617	232	0
439	0.798	233	0	386	0.716	233	0	241	0.611	233	0
34	0.797	234	0	239	0.714	234	0	427	0.609	234	0
216	0.795	235	0	159	0.712	235	0	26	0.608	235	0
21	0.795	236	0	431	0.711	236	0	215	0.607	236	0
324	0.795	237	0	444	0.710	237	0	249	0.607	237	0
434	0.794	238	0	458	0.710	238	0	118	0.604	238	0
189	0.793	239	0	225	0.709	239	0	350	0.603	239	0
184	0.792	240	0	38	0.709	240	0	29	0.603	240	0
56	0.792	241	0	220	0.709	241	0	378	0.603	241	0
99	0.790	242	0	34	0.709	242	0	168	0.598	242	0
456	0.786	243	0	21	0.707	243	0	439	0.597	243	0
33	0.785	244	0	447	0.706	244	0	28	0.596	244	0
442	0.785	245	0	56	0.706	245	0	125	0.595	245	0
26	0.784	246	0	152	0.706	246	0	34	0.593	246	0
458	0.783	247	0	137	0.706	247	0	216	0.591	247	0
452	0.782	248	0	215	0.706	248	0	380	0.590	248	0
29	0.781	249	0	456	0.705	249	0	21	0.590	249	0
447	0.780	250	0	324	0.705	250	0	324	0.589	250	0
249	0.780	251	0	100	0.704	251	0	183	0.589	251	0
220	0.780	252	0	408	0.704	252	0	101	0.588	252	0
408	0.779	253	0	133	0.703	253	0	434	0.587	253	0
38	0.779	254	0	265	0.703	254	0	408	0.586	254	0
125	0.779	255	0	227	0.702	255	0	189	0.585	255	0

Non- oriented model				Input-oriented model				Output-oriented model			
DMU	Efficiency	Rank	Nº of times as Benchmark	DMU	Efficiency	Rank	Nº of times as Benchmark	DMU	Efficiency	Rank	Nº of times as Benchmark
380	0.778	256	0	15	0.702	256	0	184	0.584	256	0
28	0.778	257	0	357	0.700	257	0	16	0.584	257	0
183	0.777	258	0	442	0.700	258	0	56	0.583	258	0
269	0.776	259	0	307	0.700	259	0	27	0.583	259	0
227	0.776	260	0	344	0.699	260	0	452	0.583	260	0
101	0.774	261	0	78	0.699	261	0	419	0.580	261	0
16	0.773	262	0	130	0.698	262	0	392	0.575	262	0
203	0.773	263	0	279	0.698	263	0	456	0.572	263	0
27	0.772	264	0	216	0.697	264	0	33	0.570	264	0
441	0.772	265	0	33	0.697	265	0	442	0.570	265	0
392	0.771	266	0	407	0.694	266	0	1	0.566	266	0
61	0.770	267	0	249	0.693	267	0	458	0.566	267	0
349	0.769	268	0	203	0.692	268	0	368	0.564	268	0
14	0.769	269	0	406	0.691	269	0	43	0.564	269	0
368	0.769	270	0	131	0.691	270	0	407	0.563	270	0
225	0.769	271	0	99	0.691	271	0	447	0.561	271	0
407	0.769	272	0	180	0.691	272	0	220	0.559	272	0
307	0.766	273	0	132	0.690	273	0	17	0.559	273	0
318	0.765	274	0	61	0.690	274	0	38	0.559	274	0
406	0.765	275	0	380	0.688	275	0	374	0.557	275	0
130	0.764	276	0	452	0.687	276	0	406	0.555	276	0
374	0.763	277	0	51	0.686	277	0	30	0.555	277	0
43	0.763	278	0	349	0.686	278	0	269	0.552	278	0
17	0.761	279	0	63	0.684	279	0	227	0.551	279	0
8	0.761	280	0	93	0.684	280	0	14	0.550	280	0
137	0.760	281	0	77	0.684	281	0	394	0.550	281	0

Non- oriented model				Input-oriented model				Output-oriented model			
DMU	Efficiency	Rank	Nº of times as Benchmark	DMU	Efficiency	Rank	Nº of times as Benchmark	DMU	Efficiency	Rank	Nº of times as Benchmark
394	0.759	282	0	22	0.684	282	0	441	0.549	282	0
30	0.758	283	0	368	0.683	283	0	203	0.546	283	0
83	0.758	284	0	8	0.683	284	0	307	0.541	284	0
132	0.756	285	0	392	0.682	285	0	61	0.539	285	0
271	0.756	286	0	441	0.681	286	0	349	0.538	286	0
353	0.756	287	0	129	0.680	287	0	225	0.537	287	0
267	0.754	288	0	26	0.679	288	0	83	0.537	288	0
22	0.753	289	0	183	0.676	289	0	315	0.536	289	0
51	0.752	290	0	29	0.676	290	0	318	0.530	290	0
133	0.752	291	0	121	0.676	291	0	420	0.529	291	0
419	0.752	292	0	117	0.676	292	0	130	0.527	292	0
117	0.752	293	0	374	0.674	293	0	8	0.522	293	0
78	0.752	294	0	14	0.674	294	0	137	0.520	294	0
93	0.751	295	0	446	0.673	295	0	271	0.517	295	0
450	0.751	296	0	28	0.673	296	0	32	0.517	296	0
20	0.750	297	0	353	0.673	297	0	361	0.516	297	0
6	0.749	298	0	6	0.673	298	0	450	0.515	298	0
315	0.749	299	0	125	0.672	299	0	267	0.513	299	0
423	0.748	300	0	16	0.672	300	0	132	0.512	300	0
361	0.747	301	0	394	0.671	301	0	353	0.511	301	0
63	0.744	302	0	101	0.670	302	0	22	0.507	302	0
77	0.744	303	0	450	0.669	303	0	10	0.506	303	0
281	0.743	304	0	361	0.668	304	0	51	0.505	304	0
348	0.743	305	0	27	0.668	305	0	133	0.505	305	0
129	0.743	306	0	68	0.668	306	0	117	0.503	306	0
121	0.742	307	0	290	0.667	307	0	78	0.503	307	0

Non- oriented model				Input-oriented model				Output-oriented model			
DMU	Efficiency	Rank	Nº of times as Benchmark	DMU	Efficiency	Rank	Nº of times as Benchmark	DMU	Efficiency	Rank	Nº of times as Benchmark
446	0.742	308	0	69	0.665	308	0	93	0.503	308	0
69	0.741	309	0	7	0.664	309	0	20	0.500	309	0
7	0.739	310	0	20	0.664	310	0	231	0.500	310	0
422	0.739	311	0	43	0.663	311	0	6	0.499	311	0
32	0.739	312	0	348	0.661	312	0	114	0.497	312	0
430	0.739	313	0	17	0.661	313	0	84	0.497	313	0
84	0.738	314	0	437	0.659	314	0	423	0.496	314	0
279	0.738	315	0	83	0.659	315	0	45	0.491	315	0
357	0.734	316	0	5	0.658	316	0	63	0.489	316	0
114	0.732	317	0	327	0.657	317	0	77	0.488	317	0
131	0.730	318	0	128	0.657	318	0	421	0.487	318	0
420	0.729	319	0	214	0.657	319	0	205	0.487	319	0
205	0.729	320	0	271	0.656	320	0	348	0.486	320	0
231	0.729	321	0	294	0.656	321	0	129	0.485	321	0
45	0.728	322	0	30	0.655	322	0	11	0.484	322	0
344	0.725	323	0	114	0.655	323	0	121	0.484	323	0
214	0.724	324	0	267	0.654	324	0	446	0.484	324	0
298	0.723	325	0	299	0.650	325	0	161	0.483	325	0
161	0.722	326	0	298	0.649	326	0	69	0.483	326	0
417	0.721	327	0	419	0.648	327	0	7	0.478	327	0
424	0.721	327	0	351	0.645	328	0	422	0.477	328	0
68	0.720	329	0	35	0.644	329	0	430	0.477	329	0
5	0.720	330	0	379	0.644	330	0	279	0.475	330	0
287	0.719	331	0	315	0.642	331	0	149	0.472	331	0
437	0.719	332	0	84	0.641	332	0	357	0.472	332	0
104	0.718	333	0	3	0.639	333	0	104	0.470	333	0

Non- oriented model				Input-oriented model				Output-oriented model			
DMU	Efficiency	Rank	Nº of times as Benchmark	DMU	Efficiency	Rank	Nº of times as Benchmark	DMU	Efficiency	Rank	Nº of times as Benchmark
95	0.717	334	0	459	0.636	334	0	131	0.460	334	0
299	0.714	335	0	322	0.635	335	0	344	0.450	335	0
327	0.714	336	0	373	0.633	336	0	264	0.449	336	0
10	0.713	337	0	45	0.633	337	0	214	0.447	337	0
94	0.713	338	0	32	0.632	338	0	373	0.446	338	0
128	0.713	339	0	205	0.628	339	0	298	0.446	339	0
270	0.712	340	0	79	0.626	340	0	9	0.444	340	0
264	0.711	341	0	420	0.624	341	0	417	0.442	341	0
373	0.710	342	0	231	0.623	342	0	424	0.442	341	0
11	0.710	343	0	161	0.620	343	0	86	0.442	343	0
421	0.707	344	0	270	0.619	344	0	68	0.441	344	0
211	0.707	345	0	104	0.619	345	0	5	0.440	345	0
35	0.706	346	0	211	0.618	346	0	437	0.439	346	0
149	0.706	347	0	40	0.617	347	0	449	0.433	347	0
86	0.702	348	0	435	0.617	348	0	270	0.429	348	0
379	0.699	349	0	148	0.614	349	0	299	0.428	349	0
290	0.698	350	0	282	0.614	350	0	327	0.428	350	0
449	0.696	351	0	330	0.613	351	0	128	0.425	351	0
103	0.694	352	0	264	0.613	352	0	103	0.422	352	0
280	0.693	353	0	421	0.611	353	0	211	0.414	353	0
209	0.692	354	0	179	0.611	354	0	35	0.413	354	0
106	0.689	355	0	345	0.609	355	0	448	0.410	355	0
179	0.688	356	0	10	0.608	356	0	379	0.398	356	0
85	0.686	357	0	209	0.607	357	0	290	0.396	357	0
448	0.685	358	0	449	0.605	358	0	58	0.396	358	0
9	0.683	359	0	326	0.605	359	0	85	0.391	359	0

Non- oriented model				Input-oriented model				Output-oriented model			
DMU	Efficiency	Rank	Nº of times as Benchmark	DMU	Efficiency	Rank	Nº of times as Benchmark	DMU	Efficiency	Rank	Nº of times as Benchmark
58	0.680	360	0	212	0.604	360	0	209	0.384	360	0
322	0.670	361	0	436	0.604	361	0	179	0.383	361	0
3	0.670	362	0	86	0.601	362	0	322	0.350	362	0
431	0.668	363	0	339	0.601	363	0	3	0.339	363	0
339	0.659	364	0	103	0.600	364	0	431	0.336	364	0
1	0.657	365	0	85	0.598	365	0	107	0.330	365	0
212	0.655	366	0	356	0.597	366	0	309	0.326	366	0
294	0.653	367	0	448	0.597	367	0	339	0.318	367	0
330	0.650	368	0	328	0.596	368	0	212	0.310	368	0
102	0.650	369	0	302	0.595	369	0	294	0.305	369	0
309	0.650	370	0	376	0.594	370	0	330	0.301	370	0
107	0.646	371	0	296	0.593	371	0	102	0.300	371	0
436	0.640	372	0	11	0.593	372	0	127	0.296	372	0
328	0.640	373	0	347	0.592	373	0	335	0.292	373	0
326	0.638	374	0	149	0.591	374	0	436	0.281	374	0
283	0.636	375	0	192	0.591	375	0	328	0.279	375	0
148	0.635	376	0	102	0.590	376	0	326	0.276	376	0
40	0.633	377	0	377	0.588	377	0	283	0.275	377	0
335	0.632	378	0	41	0.587	378	0	148	0.270	378	0
345	0.631	379	0	9	0.585	379	0	331	0.268	379	0
351	0.626	380	0	58	0.584	380	0	40	0.266	380	0
284	0.624	381	0	284	0.584	381	0	345	0.262	381	0
302	0.623	382	0	75	0.580	382	0	351	0.252	382	0
296	0.620	383	0	329	0.578	383	0	284	0.248	383	0
331	0.619	384	0	107	0.578	384	0	302	0.246	384	0
347	0.617	385	0	283	0.576	385	0	346	0.246	385	0

Non- oriented model				Input-oriented model				Output-oriented model			
DMU	Efficiency	Rank	Nº of times as Benchmark	DMU	Efficiency	Rank	Nº of times as Benchmark	DMU	Efficiency	Rank	Nº of times as Benchmark
377	0.611	386	0	253	0.575	386	0	243	0.240	386	0
41	0.610	387	0	213	0.574	387	0	296	0.239	387	0
127	0.610	388	0	346	0.568	388	0	347	0.235	388	0
346	0.608	389	0	309	0.566	389	0	109	0.231	389	0
213	0.606	390	0	76	0.564	390	0	377	0.221	390	0
243	0.604	391	0	295	0.562	391	0	41	0.220	391	0
282	0.604	392	0	210	0.558	392	0	213	0.212	392	0
75	0.602	393	0	62	0.553	393	0	282	0.208	393	0
253	0.601	394	0	335	0.551	394	0	253	0.206	394	0
192	0.600	395	0	331	0.548	395	0	75	0.205	395	0
109	0.597	396	0	109	0.548	396	0	192	0.200	396	0
329	0.593	397	0	73	0.548	397	0	147	0.190	397	0
147	0.590	398	0	120	0.547	398	0	329	0.186	398	0
295	0.586	399	0	42	0.540	399	0	295	0.172	399	0
210	0.578	400	0	72	0.538	400	0	13	0.163	400	0
198	0.574	401	0	259	0.538	401	0	105	0.160	401	0
76	0.568	402	0	147	0.537	402	0	210	0.156	402	0
105	0.568	403	0	278	0.536	403	0	198	0.154	403	0
338	0.566	404	0	198	0.535	404	0	338	0.152	404	0
356	0.560	405	0	287	0.534	405	0	76	0.137	405	0
376	0.554	406	0	243	0.532	406	0	111	0.120	406	0
278	0.548	407	0	74	0.531	407	0	356	0.120	407	0
13	0.546	408	0	64	0.529	408	0	108	0.115	408	0
73	0.545	409	0	127	0.527	409	0	376	0.108	409	0
87	0.542	410	0	57	0.525	410	0	87	0.097	410	0
111	0.542	411	0	257	0.524	411	0	278	0.096	411	0

Non- oriented model				Input-oriented model				Output-oriented model			
DMU	Efficiency	Rank	Nº of times as Benchmark	DMU	Efficiency	Rank	Nº of times as Benchmark	DMU	Efficiency	Rank	Nº of times as Benchmark
120	0.541	412	0	111	0.518	412	0	73	0.089	412	0
108	0.540	413	0	108	0.517	413	0	120	0.083	413	0
259	0.532	414	0	255	0.516	414	0	259	0.068	414	0
64	0.531	415	0	105	0.516	415	0	65	0.065	415	0
72	0.525	416	0	50	0.515	416	0	289	0.063	416	0
57	0.522	417	0	256	0.514	417	0	64	0.062	417	0
42	0.518	418	0	260	0.514	417	0	72	0.049	418	0
312	0.517	419	0	338	0.513	419	0	57	0.045	419	0
74	0.512	420	0	312	0.513	420	0	42	0.035	420	0
257	0.504	421	0	87	0.509	421	0	312	0.034	421	0
50	0.502	422	0	13	0.502	422	0	12	0.026	422	0
289	0.501	423	0	258	0.502	423	0	74	0.023	423	0
65	0.499	424	0	92	0.499	424	0	257	0.013	424	0
459	0.497	425	0	119	0.498	425	0	50	0.004	425	0
288	0.493	426	0	288	0.496	426	0	459	-0.006	426	0
311	0.488	427	0	311	0.493	427	0	110	-0.007	427	0
256	0.483	428	0	281	0.491	428	0	288	-0.013	428	0
260	0.483	428	0	254	0.489	429	0	311	-0.024	429	0
314	0.482	430	0	110	0.488	430	0	314	-0.025	430	0
110	0.479	431	0	289	0.484	431	0	256	-0.029	431	0
12	0.479	432	0	106	0.481	432	0	260	-0.029	431	0
255	0.478	433	0	286	0.479	433	0	255	-0.043	433	0
310	0.466	434	0	280	0.476	434	0	310	-0.058	434	0
92	0.465	435	0	316	0.476	435	0	92	-0.069	435	0
258	0.457	436	0	313	0.475	436	0	258	-0.082	436	0
435	0.440	437	0	314	0.472	437	0	435	-0.120	437	0

Non- oriented model				Input-oriented model				Output-oriented model			
DMU	Efficiency	Rank	Nº of times as Benchmark	DMU	Efficiency	Rank	Nº of times as Benchmark	DMU	Efficiency	Rank	Nº of times as Benchmark
119	0.437	438	0	12	0.470	438	0	44	-0.123	438	0
313	0.430	439	0	65	0.469	439	0	119	-0.127	439	0
286	0.428	440	0	310	0.464	440	0	313	-0.140	440	0
254	0.425	441	0	342	0.460	441	0	286	-0.145	441	0
62	0.421	442	0	48	0.456	442	0	254	-0.145	442	0
316	0.411	443	0	94	0.455	443	0	4	-0.149	443	0
44	0.410	444	0	95	0.451	444	0	62	-0.158	444	0
342	0.397	445	0	112	0.450	445	0	316	-0.178	445	0
112	0.384	446	0	1	0.448	446	0	112	-0.199	446	0
177	0.366	447	0	354	0.448	447	0	342	-0.201	447	0
48	0.357	448	0	300	0.442	448	0	177	-0.241	448	0
4	0.346	449	0	301	0.442	449	0	48	-0.285	449	0
178	0.319	450	0	44	0.431	450	0	178	-0.362	450	0
300	0.314	451	0	178	0.422	451	0	300	-0.371	451	0
340	0.290	452	0	340	0.417	452	0	460	-0.397	452	0
460	0.263	453	0	177	0.401	453	0	340	-0.417	453	0
354	0.251	454	0	297	0.396	454	0	355	-0.453	454	0
301	0.249	455	0	460	0.366	455	0	354	-0.498	455	0
355	0.237	456	0	336	0.349	456	0	301	-0.502	456	0
297	0.110	457	0	337	0.334	457	0	297	-0.780	457	0
336	0.068	458	0	4	0.310	458	0	336	-0.857	458	0
337	-0.012	459	0	355	0.310	459	0	337	-1019,000	459	0
343	-0.996	460	0	343	0.240	460	0	343	-2991,000	460	0

Table 2A- *Inputs and output variables*

		Output	Input	input non-controllable	input non-controllable
		Energy Generation (GWh)	**Installed Capacity (MW)**	**Shape Parameter (k)** -	**Scale parameter (C)** **m/s**
DMU	**Wind Farm**	Y2	X1	X2	X3
1	Alegria 1	130.2	51.15	2.76	8.46
2	Alegria 2	242.2	100.65	2.76	8.46
3	Aratuá 1	47.4	14.4	2.76	8.46
4	Areia Branca	86.2	50.4	2.61	8.84
5	Arizona 1	103	28	2.63	8.81
6	Asa Branca 1	101.4	27	2.69	7.31
7	Asa Branca 2	100	27	2.69	7.31
8	Asa Branca 3	103	27	2.69	7.31
9	Asa Branca 4	104.8	32	2.69	7.31
10	Asa Branca 5	109.2	32	2.69	7.31
11	Asa Branca 6	103.8	32	2.38	7.49
12	Asa Branca 7	82.6	32	2.69	7.31
13	Asa Branca 8	88.8	32	2.69	7.31
14	Aventura I	104	28.2	2.38	7.49
15	Baixa do feijão 1	118.8	30	2.52	7.48
16	Baixa do feijão 2	113.4	30	2.52	7.48
17	Baixa do feijão 3	111.4	30	2.52	7.48
18	Boa Esperança 1	94.7	26	2.04	6.86

		Output	Input	input non-controllable	input non-controllable
		Energy Generation (GWh)	**Installed Capacity (MW)**	**Shape Parameter (k)** -	**Scale parameter (C)** **m/s**
DMU	**Wind Farm**	Y2	X1	X2	X3
19	Cabeço preto	96.8	19.8	2.38	7.49
20	Cabeço preto 3	94.6	26	2.38	7.49
21	Cabeço preto 5	100.6	26	2.38	7.49
22	Cabeço preto 6	66	18	2.38	7.49
23	Cabeço preto IV	97.2	19.8	2.38	7.49
24	Cabeço Vermelho 2	84	17.6	2.38	7.49
25	Caiçara 1	115	27	2.49	7.07
26	Calango 1	114.6	30	2.49	8.71
27	Calango 2	112.6	30	2.49	8.71
28	Calango 3	113.6	30	2.49	8.71
29	Calango 4	114.2	30	2.49	8.71
30	Calango 5	110.4	30	2.49	8.71
31	Calango 6	126.6	30	2.49	8.71
32	Campo dos ventos 2	103.8	30	2.38	7.49
33	Campo dos ventos I	96.2	25.2	2.38	7.49
34	Campo dos ventos III	97.8	25.2	2.38	7.49
35	Campo dos ventos V	89.8	25.2	2.69	7.31
36	Carcara 1	148.6	30	2.61	8.84
37	Carcara 2	134.6	30	2.61	8.84
38	Carnaúbas	107.3	27	2.79	9.81
39	Costa branca	85.2	20.7	2.38	7.49
40	Dreen Boa vista	44	14	2.79	7.51

		Output	Input	input non-controllable	input non-controllable
		Energy Generation (GWh)	**Installed Capacity (MW)**	**Shape Parameter (k)** -	**Scale parameter (C) m/s**
DMU	**Wind Farm**	Y2	X1	X2	X3
41	Dreen Cutia	73.7	23.1	2.79	7.51
42	Dreen Guajiru	60.3	21	2.77	7.22
43	Dreen Olho d'água	111.8	30	2.77	7.22
44	Eol Aroeira	77.3	32.9	2.52	7.48
45	Eol Baixa do Feijão IV	106.4	30	2.52	7.48
46	Eol cabeço Vermelho	128	26	2.04	6.86
47	Eol Caicara II	79.2	18	2.49	7.07
48	Eol Maria Helena	67	27.3	2.77	7.22
49	Eol Parque eólico Pelado	93.8	20	2.49	8.71
50	Eol Potiguar	76.7	27.3	2.77	7.22
51	Eol São Domingos	96.2	25.2	2.79	9.81
52	Eol Ventos de São Benedito	120.6	29.4	2.79	9.81
53	Eol Vila Amazonas V	104	24	2.49	7.07
54	Eol Vila Para I	110	27	2.49	7.07
55	Eol Vila Para II	98.4	24	2.49	7.07
56	Eol Vila Para III	94	24	2.49	7.07
57	Esperança Nordeste	78.3	27.3	2.77	7.22
58	EURUS 1	96	30	2.38	7.49
59	EURUS 2	142.6	30	2.38	7.49
60	EURUS 3	121.4	30	2.38	7.49
61	ERUS IV	104.2	27	2.69	7.31
62	ERUS VI	18.6	8	2.69	7.31

		Output	Input	input non-controllable	input non-controllable
		Energy Generation (GWh)	**Installed Capacity (MW)**	**Shape Parameter (k)** -	**Scale parameter (C)** **m/s**
DMU	**Wind Farm**	Y2	X1	X2	X3
63	FAROL	74.4	20	2.77	7.22
64	GE JANGADA	79	27.3	2.77	7.22
65	Jerico	84.8	32.9	2.52	7.48
66	Junco 1	99.6	24	2.49	7.07
67	Junco 2	99	24	2.49	7.07
68	Juremas	56.6	16.1	2.38	7.49
69	Macacos	74.6	20.7	2.38	7.49
70	Macambira 1	90	18	2.55	6.22
71	Macambira 2	78.8	18	2.45	7.78
72	Mangue seco 1	76.2	26	2.76	8.46
73	Mangue seco 2	77.8	26	2.76	8.46
74	Mangue seco 3	75.2	26	2.76	8.46
75	Mangue seco 5	82.8	26	2.76	8.46
76	Mar e terra	70.4	23.1	2.61	8.84
77	Mel 2	74.4	20	2.61	8.84
78	Miassaba 2	52.6	14.4	2.76	8.46
79	Miassaba 3	177.4	68.47	2.66	8.26
80	Modelo I	135.4	30.55	2.38	7.49
81	Modelo II	108	25.85	2.38	7.49
82	Morro dos ventos 2	115.6	29.16	2.38	7.49
83	Morro dos ventos I	103.8	28.8	2.38	7.49
84	Morro dos Ventos III	101	28.8	2.38	7.49

		Output	Input	input non-controllable	input non-controllable
		Energy Generation (GWh)	**Installed Capacity (MW)**	**Shape Parameter (k)** -	**Scale parameter (C)** **m/s**
DMU	**Wind Farm**	Y2	X1	X2	X3
85	Morro dos ventos IV	94.4	28.8	2.38	7.49
86	Morro dos ventos IX	98.8	30	2.38	7.49
87	Morro dos Ventos VI	79.8	28.8	2.38	7.49
88	Parque eólico lanchinha	121.4	28	2.57	7.97
89	Pedra preta 2LFA	87.2	20.7	2.38	7.49
90	Pedra Rajada	87.8	20	2.48	7.77
91	Pedra Rajada II	84.3	20	2.48	7.77
92	PV do nordeste	74	27.3	2.77	7.22
93	Reduto	103.3	27	2.79	9.81
94	Rei dos ventos 1	152.4	58.45	2.76	7.65
95	Rei dos ventos 3	155.4	60.12	2.76	7.65
96	Renascença 5	130.8	30	2.69	7.31
97	Renascença I	130.6	30	2.69	7.31
98	Renascença II	126.8	30	2.69	7.31
99	Renascença III	116.8	30	2.69	7.31
100	Renascença IV	119.2	30	2.69	7.31
101	Riachão I	106.8	29.7	2.33	7.43
102	Riachão II	85.4	27	2.33	7.43
103	Riachão IV	95.6	29.7	2.33	7.43
104	Riachão VI	98.6	29.7	2.33	7.43
105	Riachão VII	82	29.7	2.33	7.43
106	Rio do fogo	135	49.3	2.63	8.81

		Output	Input	input non-controllable	input non-controllable
		Energy Generation **(GWh)**	**Installed Capacity** **(MW)**	**Shape Parameter (k)** -	**Scale parameter (C)** **m/s**
DMU	**Wind Farm**	Y2	X1	X2	X3
107	Santa Clara I	96.4	30	2.69	7.31
108	Santa Clara II	85.4	30	2.69	7.31
109	Santa Clara III	91	30	2.69	7.31
110	Santa Clara IV	80.2	30	2.69	7.31
111	Santa Clara V	85.6	30	2.69	7.31
112	Santa Clara VI	73.2	30	2.69	7.31
113	Santa Helena	119.4	29.7	2.38	7.49
114	Santa Mônica	108	29.4	2.7	9.46
115	Santa Úrsula	118.6	27.3	2.7	9.46
116	Santana I	122.8	30	2.49	8.71
117	Santana II	89.6	24	2.45	7.78
118	Santo Cristo	110.8	27	2.7	9.46
119	São Bento do Norte I	61.3	23.1	2.77	7.22
120	São Bento do norte II	68	23.1	2.77	7.22
121	São João	102	27	2.79	9.81
122	Serra de Santana 1	90.6	20	2.45	7.78
123	Serra de Santana 2	130.8	30	2.45	7.78
124	Serra de Santana 3	135	30	2.49	8.71
125	SM (Santa Maria)	109.2	29.7	2.38	7.49
126	Terral	144	30	2.61	8.84
127	Umbuzeiros	96.3	32.9	2.52	7.48
128	União dos Ventos 1	80.6	22.4	2.79	7.51

		Output	Input	input non-controllable	input non-controllable
		Energy Generation **(GWh)**	**Installed Capacity** **(MW)**	**Shape Parameter (k)** -	**Scale parameter (C)** **m/s**
DMU	**Wind Farm**	Y2	X1	X2	X3
129	União dos Ventos 2	83.8	22.4	2.79	7.51
130	União dos Ventos 3	86.2	22.4	2.79	7.51
131	União dos Ventos 4	38.6	11.2	2.79	7.51
132	União dos Ventos 5	91.8	24	2.79	9.81
133	União dos Ventos 6	46.2	12.8	2.79	9.81
134	União dos Ventos 7	58.6	14.4	2.79	9.81
135	União dos Ventos 8	61.4	14.4	2.79	7.51
136	União dos Ventos 9	43.4	11.2	2.79	7.51
137	União dos Ventos 10	53.2	14.4	2.79	7.51
138	União dos Ventos 12	119	25.2	2.79	7.51
139	União dos Ventos 13	81.3	18.9	2.79	7.51
140	União dos Ventos 14	92	21	2.79	7.51
141	Ventos de Santo Dimas	121.8	29.4	2.79	9.81
142	Ventos de Santo Uriel	68	16.2	2.38	7.49
143	Ventos de São Martinho	60.4	14.7	2.7	9.46
144	Vento de São Miguel	122.2	30	2.69	7.31
145	Vila Acre I	125.8	27.3	2.49	7.07
146	Alvorada	33	8	2.34	7.49
147	Ametista	82.6	28.56	2.34	7.49
148	Angical	39.4	12.95	2.29	7.77
149	Aracas	101.6	31.86	2.34	7.49
150	Assurua 3	53.7	12.5	2.12	8.66

		Output	Input	input non-controllable	input non-controllable
		Energy Generation (GWh)	**Installed Capacity (MW)**	**Shape Parameter (k)** -	**Scale parameter (C)** **m/s**
DMU	**Wind Farm**	Y2	X1	X2	X3
151	Assurua II	135.6	30	2.12	8.66
152	Assurua IV	106	30	2.12	8.66
153	Assurua V	88.2	20	2.12	8.66
154	Assurua VII	79.2	18	2.12	8.66
155	Baraunas I Energética S/A	110.2	32.9	1.63	6.92
156	Boa Vista da Lagoinha	158.7	30	2.58	7.69
157	Borgo	92.6	20.16	2.34	7.49
158	Caetite	140.2	30.24	2.34	7.49
159	Caetite 1	115.2	30	2.34	7.49
160	Caetite 2	127.4	30	2.34	7.49
161	Caetite 3	100.2	30	2.34	7.49
162	Caetite A	104.2	23.8	2.34	7.49
163	Caetite B	92	22.1	2.34	7.49
164	Caetite C	37.2	8.5	2.34	7.49
165	Campo largo 5	94	29.7	1.63	6.92
166	Campo Largo 7	103	29.7	1.63	6.92
167	Campo Largo I	89.3	29.7	1.63	6.92
168	Campo Largo III	81	29.7	1.63	6.92
169	Campo Largo IV	98	29.7	1.63	6.92
170	Campo Largo VI	90	29.7	1.63	6.92
171	Campo Largo XV	84.3	29.7	2.17	4.69
172	Campo Largo XVI	91.7	29.7	1.63	6.92

		Output	Input	input non-controllable	input non-controllable
		Energy Generation **(GWh)**	**Installed Capacity** **(MW)**	**Shape Parameter (k)** **-**	**Scale parameter (C)** **m/s**
DMU	**Wind Farm**	Y2	X1	X2	X3
173	Campo Largo XVIII	90.3	29.7	1.63	6.92
174	Campo Largo XXI	84	29.7	1.63	6.92
175	Candiba	36.8	9.6	2.21	7.49
176	Capoeiras 3	101.7	27.5	2.12	8.66
177	Casa Nova 2	68.5	32.9	2.27	7.65
178	Casa Nova III	61.5	28.2	2.27	7.65
179	Corrupião	89.8	27.75	2.29	7.77
180	Cristal	111.5	29.9	2.44	6.64
181	Cristalandia I	111	30	2.28	6.29
182	Cristalandia II	119.5	30	2.28	6.29
183	Cristalandia III	102.3	30	2.28	6.29
184	Curral de Pedras 1	70.5	20	2.12	8.66
185	Curral de Pedras 2	117.3	27.5	2.12	8.66
186	Da prata	86	21.84	2.17	8.15
187	Damascena	131.2	30	2.44	6.64
188	Delfina 1	117.5	28	2.5	4.98
189	Delfina 2	98	28	2.5	4.98
190	Delfina 3	123.3	28	2.5	4.98
191	Delfina 4	31	8	2.5	4.98
192	Delfina 5	77	28	2.5	4.98
193	Delfina 6	128.3	30	2.5	4.98
194	Delfina 7	130.5	30	2.5	4.98

		Output	Input	input non-controllable	input non-controllable
		Energy Generation **(GWh)**	**Installed Capacity** **(MW)**	**Shape Parameter (k)** -	**Scale parameter (C)** **m/s**
DMU	**Wind Farm**	Y2	X1	X2	X3
195	Diamante II	86.7	17.5	2.12	8.66
196	Diamante III	76.7	17.5	2.12	8.66
197	Dois Riachos	133	30	2.44	6.64
198	Dourados (UEEE Dourados)	76.4	28.56	2.17	8.15
199	Emiliana	122.2	28.2	2.17	8.15
200	Eol Andorinhas	149.4	30	2.5	4.98
201	Eol Bando de couro	101	32.9	1.63	6.92
202	Eol Baraunas II	79.4	25.85	1.63	6.92
203	Eol Caititu-Pindai BA	81.2	22.2	2.29	7.77
204	Campo Formoso (CF II)	149.2	30	2.5	4.98
205	Eol Coqueirinho	98.6	29.6	2.29	7.77
206	Eol Esperança	110.3	28	2.12	5.6
207	Eol Inhambu-Caetite BH	123.4	31.45	2.34	7.49
208	Eol Morrinhos	142	30	2.5	4.98
209	Eol Santa Aparecida	91	27.3	2.47	6.74
210	Eol Santa Aurora	83.7	27.3	2.57	7.37
211	Eol Santa Beatriz	92.7	27.3	2.47	6.74
212	Eol Santa Emilia	91.3	27.3	2.57	7.37
213	Eol São Gabriel	86.3	27.3	2.57	7.37
214	Eol Teiú	56.8	16.65	2.29	7.77
215	Eol Ventos da Bahia II	103.5	27	2.45	6.63
216	Eol Ventos da Bahia VIII	102.3	27	2.45	6.63

		Output	Input	input non-controllable	input non-controllable
		Energy Generation (GWh)	**Installed Capacity (MW)**	**Shape Parameter (k)** -	**Scale parameter (C)** **m/s**
DMU	**Wind Farm**	Y2	X1	X2	X3
217	Eol Ventos de Campo Formoso I	132	30	2.5	4.98
218	Eol Ventos de Guarás I	146.6	30	2.5	4.98
219	Espigão	47.2	10.08	2.17	8.15
220	Guanambi	74.4	20.8	2.21	7.49
221	Guirapá	116.8	28.8	2.21	7.49
222	Igaporã	117	30.4	2.17	8.15
223	Ilhéus (Ilhéus)	48.4	11.2	2.21	7.49
224	Joana	112.8	28.2	2.17	8.15
225	Laranjeiras 1	86	27.5	2.14	5.92
226	Laranjeiras 2	116.7	30	2.14	5.92
227	Laranjeiras 5	87	25	2.12	8.66
228	Licínio de Almeida	92.6	24	2.21	7.49
229	Macaúbas	123.8	35.07	1.95	7.34
230	Manicoba	100.5	30	1.63	6.92
231	Maron	101.6	30.24	2.34	7.49
232	Morrão	123.2	30.24	2.34	7.49
233	Morro Branco I	109.6	32.9	1.63	6.92
234	Mussambe Energética AS	107.2	32.9	1.63	6.92
235	Nossa Senhora da Conceição	131.2	28.8	2.17	8.15
236	Novo Horizonte- Eol N Horiz	126.4	30.06	1.95	7.34
237	Pajeú do Vento	129.2	25.6	2.34	7.49
238	Pedra Branca	116.2	30	1.63	6.92

		Output	Input	input non-controllable	input non-controllable
		Energy Generation (GWh)	**Installed Capacity (MW)**	**Shape Parameter (k)** -	**Scale parameter (C)** **m/s**
DMU	**Wind Farm**	Y2	X1	X2	X3
239	Pedra do Reino	109	30	2.29	6.39
240	Pedra do Reino III	70	18	2.29	6.39
241	Pedra do Reino IV	73.3	20	2.29	6.39
242	Pelourinho	97.2	21.84	2.17	8.15
243	Pilões	86.6	30.24	2.34	7.49
244	Pindaí	101.6	24	2.21	7.49
245	Planaltina	133	27.2	2.34	7.49
246	Porto Seguro	28.6	6.4	2.17	8.15
247	Primavera	121.8	29.9	2.58	7.69
248	Rio Verde	131.2	30.4	2.34	7.49
249	São Judas	116.8	29.9	2.58	7.69
250	São Pedro do Lago	104.2	30	1.63	6.92
251	Seabra	123.8	30.06	1.95	7.34
252	Seraima	122.2	30.24	2.21	7.49
253	Serra Babilonia II	89.7	28.2	2.58	7.69
254	Serra Babilonia IX	75	28.2	2.58	7.69
255	Serra Babilonia VI	72.3	25.85	2.58	7.69
256	Serra Babilonia VII	79.3	28.2	2.58	7.69
257	Serra Babilonia VIII	81	28.2	2.58	7.69
258	Serra Babilonia XI	77.3	28.2	2.58	7.69
259	Serra Babilonia XII	83.3	28.2	2.58	7.69
260	Serra da Babilonia X	79.3	28.2	2.58	7.69

		Output	Input	input non-controllable	input non-controllable
		Energy Generation (GWh)	**Installed Capacity (MW)**	**Shape Parameter (k)** -	**Scale parameter (C)** **m/s**
DMU	**Wind Farm**	Y2	X1	X2	X3
261	Serra do Espinhaço	85	18.48	2.34	7.49
262	Serra do Salto	76.2	19.2	2.21	7.49
263	Sete Gameleiras	105.2	30	1.63	6.92
264	Tamanduá Mirim	96.2	29.6	2.29	7.77
265	Tanque	113.8	30	2.34	7.49
266	Vent da ST Esperança	143.3	28	2.58	7.69
267	Ventos da Bahia I	101.7	28.6	2.45	6.63
268	Ventos da Bahia III	125.7	30.8	2.45	6.63
269	Ventos da Bahia IV	44.3	12	2.45	6.63
270	Ventos da Bahia IX	96.3	28.6	2.45	6.63
271	Ventos da Bahia XVII	102	28.6	2.45	6.63
272	Ventos da Sta Dulce	147	28	2.58	7.69
273	Ventos de São Abraao	160.7	28	2.58	7.69
274	Ventos do Nordeste	97.4	23.52	2.34	7.49
275	Ventos do São Mario	135	30	2.58	7.69
276	Ventos do São Paulo	140.7	28	2.58	7.69
277	Ventos do Sertão	123.6	30	2.5	4.98
278	Beberibe	74.6	25.6	2.66	6.98
279	Boca do Corrego	69.6	24.3	1.99	6.36
280	Bons Ventos	134.6	50	2.64	7.26
281	Canoa Quebrada (E-BV-ACEP)	157.2	57	2.64	7.26
282	Canoa Quebrada (E-RV-ACEP)	30.8	10.5	2.64	7.26

		Output	Input	input non-controllable	input non-controllable
		Energy Generation **(GWh)**	**Installed Capacity** **(MW)**	**Shape Parameter (k)** **-**	**Scale parameter (C)** **m/s**
DMU	**Wind Farm**	Y2	X1	X2	X3
283	Cataventos Acarau I	89	28	2.44	8.4
284	Central Geradora Eólica Santa Monica I	58	18.9	2.33	7.56
285	Colônia	66.2	18.9	2.07	6.65
286	Coqueiros	69.8	27	2.44	8.4
287	Dunas de Paracuru	125	42	2.45	7.34
288	Embuaca	72.6	27.3	2.33	7.56
289	Enacel	83.8	31.5	2.64	7.26
290	EOL B VEN Cacimbas 2	70.7	23.1	2.06	7.35
291	EOL B VEN Cacimbas 3	48.7	14.7	2.06	7.35
292	EOL B CACIMBAS 4	36.7	10.5	2.07	7.94
293	EOL B VEN Cacimbas 5	74.3	21	2.07	7.94
294	EOL B VEN Cacimbas 7	46.3	16.8	2.06	7.35
295	EOL Cacimbas 1	55.6	18.9	2.33	7.56
296	EOL Garrote	74.5	23.1	2.65	7.7
297	EOL Goiabeira	47	23.1	2.64	7.26
298	EOL Pedra Cheirosa I	90.5	25.2	2.45	7.97
299	EOL Pedra Cheirosa II	82.3	23.1	2.45	7.97
300	EOL Pitombeira	64.7	27.3	2.64	7.26
301	EOL Santa Catarina	42.3	18.9	2.64	7.26
302	EOL São Raimundo	74.8	23.1	2.65	7.7
303	EOL Vento Formoso	96	25.35	2.06	7.35
304	EOL Ventos de Tianguá	99	25.35	2	6.8

		Output	Input	input non-controllable	input non-controllable
		Energy Generation **(GWh)**	**Installed Capacity** **(MW)**	**Shape Parameter (k)** **-**	**Scale parameter (C)** **m/s**
DMU	**Wind Farm**	Y2	X1	X2	X3
305	EOl ventos de Tianguá Norte	92.4	27.04	2	6.8
306	EOL Ventos do Morro do Chapéu	90.4	25.35	2	6.8
307	EOL Ventos do Parazinho	90.2	27.04	2.06	7.35
308	EOL de Taíba	12.2	5	2.07	6.65
309	Estrêla	90.3	29.7	2.33	7.56
310	Faísa I	73.2	29.4	2.33	7.56
311	Faísa II	72.2	27.3	2.33	7.56
312	Faísa III	69	25.2	2.33	7.56
313	Faísa IV	63.4	25.2	2.33	7.56
314	Faísa V	74.4	29.4	2.33	7.56
315	Flexeiras I	103.6	30.004	2.33	7.56
316	Foz do Rio Choró	64.2	25.2	2.66	6.98
317	Guajirú	117	30.004	2.33	7.56
318	Icaraí	46.8	16.8	1.99	6.36
319	Icaraí I	107	27.3	1.99	6.36
320	Icaraí II	127.4	37.8	1.99	6.36
321	Icaraizinho	174.8	54.6	1.99	6.36
322	Ilha Grande	79	29.7	1.99	6.36
323	Itarema I	111.6	27	2.45	7.97
324	Itarema II	106.4	27	2.45	7.97
325	Itarema III	60.4	15	2.45	7.97
326	Itarema IV	68.4	21	2.45	7.97

		Output	Input	input non-controllable	input non-controllable
		Energy Generation (GWh)	**Installed Capacity (MW)**	**Shape Parameter (k)** -	**Scale parameter (C)** **m/s**
DMU	**Wind Farm**	Y2	X1	X2	X3
327	Itarema V	75	21	2.45	7.97
328	Itarema VI	78	24	2.45	7.97
329	Itarema VII	65	21	2.45	7.97
330	Itarema VIII	69.4	21	2.45	7.97
331	Itarema IX	91	30	2.45	7.97
332	Lagoa do Mato	11.4	3.23	2.64	7.26
333	Malhadinha 1	93.3	23.1	2.07	7.94
334	Mucuripe	6.2	2.4	2.24	5.78
335	Mundaú	88.8	30.004	2.33	7.56
336	Nova Buriti	55	30	2.44	8.4
337	Nova Cajucoco	52.2	30	2.45	7.97
338	Ouro Verde	81.8	29.7	2.33	7.56
339	Paracuru	83.2	25.2	2.45	7.34
340	Praia do Morgado	64.2	28.8	2.44	8.4
341	Praia Formosa	210.4	105	2.33	7.53
342	Praias de Parajuru	71.8	28.804	2.66	6.98
343	Quixaba	28.8	25.5	2.64	7.26
344	Ribeirão Eolos	59.8	21.6	1.99	6.36
345	Santo Antônio de Pádua	43.2	14	2.33	7.56
346	Santo Inácio III	92.5	29.4	2.65	7.7
347	Santo Inácio IV	74.3	23.1	2.65	7.7
348	São Cristovão	92.4	26	2.33	7.56

		Output	Input	input non-controllable	input non-controllable
		Energy Generation (GWh)	**Installed Capacity (MW)**	**Shape Parameter (k)** -	**Scale parameter (C)** **m/s**
DMU	**Wind Farm**	Y2	X1	X2	X3
349	São Jorge CE	88.4	24	2.33	7.56
350	Taíba Águia	80.2	23.1	2.07	6.65
351	Taíba Albatroz	43.6	16.5	2.07	6.65
352	Taíba Andorinha	52.8	14.7	2.07	6.65
353	Trairí	91.8	25.388	2.33	7.56
354	Ventos de Horizonte	37.3	16.8	2.64	7.26
355	Volta do Rio	70.2	42	2.44	8.4
356	Aura Lagoa do Barro 2	67.7	27	1.98	6.99
357	Aura Lagoa do Barro	83.3	27	1.98	6.99
358	Delta do Parnaíba	119	30	2.2	7.58
359	EOL Porto do Delta	123.4	30.8	2.2	7.58
360	Eol Santa Joana I	116	28.9	1.98	7.65
361	EOL Santa Joana III	91.4	29.3	2.03	7.65
362	EOL Santa Joana IV	114.6	27.2	1.98	7.65
363	EOL Santa Joana V	118	28.9	1.98	7.65
364	EOL Santa Joana VII	119.2	28.9	2.03	7.65
365	EOL Santo Augusto I	70	18.4	1.98	7.65
366	EOL Santo Augusto III	102.2	29.6	2.04	7.44
367	EOL Santo Augusto IV	114.2	28.9	2.04	7.44
368	EOL Santo Augusto V	95	29.6	2.03	7.65
369	EOL Santo Augusto VI	116.8	29.9	1.98	7.65
370	EOL Santo Augusto VII	73	18.4	1.98	7.65

		Output	Input	input non-controllable	input non-controllable
		Energy Generation (GWh)	**Installed Capacity (MW)**	**Shape Parameter (k) -**	**Scale parameter (C) m/s**
DMU	**Wind Farm**	Y2	X1	X2	X3
371	EOL Testa Branca I	96.4	22	2.23	7.46
372	EOL Testa Branca III	91.6	22	2.23	7.46
373	EOL Ventos de Santa Angelina	88	29.7	2.04	7.44
374	EOL Ventos de Santa Bárbara	94.8	29.7	2.04	7.44
375	EOL Ventos de Santa Fátima	102.5	29.7	2.04	7.44
376	Lagoa do Barro 7	67.3	27	1.98	6.99
377	Pedra do Sal	51.6	18	2.2	7.58
378	Porto das Barcas	73.4	20	2.2	7.58
379	Porto Salgado	64	20	2.2	7.58
380	Ventos de Santa Edwiges	97	29.7	2.04	7.44
381	Ventos de Santa Joana II	114.8	30	2.04	7.44
382	Ventos de Santa Joana IX	104.4	29.6	2.03	7.65
383	Ventos de Santa Joana VI	125.6	30	2.04	7.44
384	Ventos de santa Joana VIII	131	30	2.03	7.65
385	Ventos de Santa Joana X	108	29.6	2.03	7.65
386	Ventos de Santa Joana XI	101.2	29.6	2.04	7.44
387	Ventos de Santa Joana XII	117.4	28.9	2.04	7.44
388	Ventos de Santa Joana XIII	105.6	29.6	2.03	7.65
389	Ventos de Santa Joana XIV	127.6	30	2.04	7.44
390	Ventos de Santa Joana XV	117.4	28.9	2.03	7.65
391	Ventos de Santa Joana XVI	124.8	28.9	2.03	7.65
392	Ventos de Santa Regina	96	29.7	2.04	7.44

		Output	Input	input non-controllable	input non-controllable
		Energy Generation (GWh)	**Installed Capacity (MW)**	**Shape Parameter (k)** -	**Scale parameter (C)** **m/s**
DMU	**Wind Farm**	Y2	X1	X2	X3
393	Ventos de Santo Adriano	33.5	10.8	2.04	7.44
394	Ventos de Santo Albano	94.3	29.7	2.04	7.44
395	Ventos de Santo Augusto II	114.8	27.6	1.98	7.65
396	Ventos de Santo Augusto VIII	61	18.4	1.98	7.65
397	Ventos de santo Onofre I	134.8	30	1.98	7.65
398	Ventos de santo Onofre II	130.8	30	1.98	7.65
399	Ventos de Santo Onofre III	132	30	1.98	7.65
400	Ventos de Santo Onofre IV	112.8	27.6	1.98	7.65
401	Ventos de São vicente 14	111.8	29.4	1.99	7.21
402	Ventos de São Virgílio 3	75.5	19.8	1.99	7.21
403	Ventos de São virgílio 1	108.8	29.9	1.98	7.65
404	Ventos de São Virgílio 2	125.3	29.9	1.98	7.65
405	Ventos S Vicente 8	98.8	29.4	1.99	7.21
406	Ventos S Vicente 9	92.3	29.4	1.99	7.21
407	Ventos S Vicente 10	92.8	29.4	1.99	7.21
408	Ventos S Vicente 11	94.3	29.4	1.99	7.21
409	ventos S Vicente 12	100.8	29.4	1.99	7.21
410	Ventos S Vicente 13	101.5	29.4	1.99	7.21
411	Albatroz	11.4	4.8	2.08	7.54
412	Atlântica	11.8	4.8	2.08	7.54
413	Camurim	12.2	4.8	2.08	7.54
414	Caravela	11.6	4.8	2.08	7.54

		Output	Input	input non-controllable	input non-controllable
		Energy Generation (GWh)	**Installed Capacity (MW)**	**Shape Parameter (k)** -	**Scale parameter (C)** **m/s**
DMU	**Wind Farm**	Y2	X1	X2	X3
415	Coelhos I	12	4.8	2.08	7.54
416	Coelhos II	13.4	4.8	2.08	7.54
417	Coelhos III	8.6	4.8	2.08	7.54
418	Coelhos IV	10.8	4.8	2.08	7.54
419	EOL Canoas	115	31.5	2.68	7.47
420	Lagoa 1	110.3	31.5	2.62	7.25
421	Lagoa 2	108	31.5	2.68	7.47
422	Mataraca	8.8	4.8	2.08	7.54
423	Millennium	28.8	10.2	2.08	7.54
424	Presidente	8.6	4.8	2.08	7.54
425	Vitória	10.2	4.5	2.08	7.54
426	Eólica Serra das Vacas I S.A	106.2	23.92	2.71	8.2
427	Eólica Serra das Vacas II S.A	90.8	22.295	2.71	8.2
428	Eólica Serra das Vacas III S.A	92.4	22.235	2.71	8.2
429	Eólica Serra das Vacas IV S.A	95.4	22.295	2.71	8.2
430	Gravatá	14.2	4.95	2.83	6.24
431	Mandacaru	13	4.95	2.83	6.24
432	Pau Ferro	139.6	30.55	2.5	6.19
433	Pedra do Gerônimo	154.6	30.55	2.5	6.19
434	Pirauá	15.4	4.95	2.8	7.2
435	Santa Maria	10.2	4.95	2.83	6.24
436	Serra das vacas V	84	25.3	2.71	8.2

		Output	Input	input non-controllable	input non-controllable
		Energy Generation (GWh)	**Installed Capacity (MW)**	**Shape Parameter (k)** -	**Scale parameter (C)** **m/s**
DMU	**Wind Farm**	Y2	X1	X2	X3
437	Serra das Vacas VII	92.5	25.3	2.71	8.2
438	Tacaicó	89.8	18.8	2.5	6.19
439	Ventos de Santa Brígida I	52.6	13.6	2.62	6.76
440	Ventos de Santa Brígida II	120.8	27.2	2.71	8.2
441	Ventos de Santa Brígida III	108.2	28.9	2.62	6.76
442	Ventos de Santa Brígida IV	106.6	27.2	2.66	7.21
443	Ventos de Santa Brígida V	121	28.9	2.71	8.2
444	Ventos de Santa Brígida VI	115.6	28.9	2.66	7.21
445	Ventos de Santa Brígida VII	123.8	27.2	2.66	7.21
446	Ventos de Santo Estevão I	83.8	25.3	2.16	6.71
447	Ventos de Santo Estevão II	88.3	25.3	2.16	6.71
448	Ventos de Santo Estevão III	88.2	29.9	2.16	6.71
449	Ventos de Santo Estevão IV	89.5	29.9	2.16	6.71
450	Ventos de Santo Estevão V	91.6	27.6	2.16	6.71
451	Ventos de São Clemente I	118.8	29.155	2.66	7.21
452	Ventos de São Clemente II	112.6	29.155	2.66	7.21
453	Ventos de São Clemente III	125.8	29.155	2.58	5.89
454	Ventos de São Clemente IV	121.6	29.155	2.58	5.89
455	Ventos de São Clemente V	121.4	29.155	2.66	7.21
456	Ventos de São Clemente VI	101.2	25.725	2.66	7.21
457	Ventos de São Clemente VII	99	24.01	2.66	7.21
458	Ventos de São Clemente VIII	74	20.58	2.58	5.89

		Output	Input	input non-controllable	input non-controllable
		Energy Generation (GWh)	**Installed Capacity (MW)**	**Shape Parameter (k)** -	**Scale parameter (C)** **m/s**
DMU	**Wind Farm**	Y2	X1	X2	X3
459	Xavante	10.8	4.95	2.82	6.56
460	Barra dos Coqueiros	68	34.5	2.82	6.75

Table 3A- *Features of the main DMUs*

DMU	**Efficiency**	**Number of turbines**	**Wind Power Plant type**	**Physical guarantee of operation**	**Wind farm Age (years)**	**DMU**	**Efficiency**	**Number of turbines**	**Wind Power Plant type**	**Physical guarantee of operation**	**Wind farm Age (years)**
1	0.657	31	Tipo I	16.58	10.5	230	0.922	12	Tipo II-C	16.1	3.6
2	1.036	61	Tipo I	29.13	9.5	235	0.942	18	Tipo II-C	12.4	7
3	0.670	9	Tipo III	6.9	8.5	236	0.954	18	Tipo II-C	10.9	9
5	0.720	14	Tipo III	12.9	7.7	237	0.965	16	Tipo II-C	11.8	7
6	0.749	10	Tipo II-C	13.2	5.9	238	1.000	10	Tipo II-C	12.2	8.3
7	0.739	10	Tipo II-C	12.8	5.8	239	0.815	10	Tipo III	10.8	8.4
8	0.761	10	Tipo II-C	12.5	5.8	240	0.846	6	Tipo III	6.8	8.1
9	0.683	20	Tipo II-C	14	6.5	244	0.888	15	Tipo II-C	11	7

DMU	Efficiency	Number of turbines	Wind Power Plant type	Physical guarantee of operation	Wind farm Age (years)	DMU	Efficiency	Number of turbines	Wind Power Plant type	Physical guarantee of operation	Wind farm Age (years)
10	0.713	20	Tipo II-C	13.7	6.5	245	0.949	17	Tipo II-C	12.2	7
11	0.710	20	Tipo II-C	14.4	6.5	246	1.000	5	Tipo II-C	2.7	7
12	0.479	20	Tipo II-C	14.3	6.5	247	0.809	13	Tipo II-C	16.4	3.7
13	0.546	20	Tipo II-C	13.6	6.5	248	0.889	19	Tipo II-C	16.6	7
15	0.805	15	Tipo II-C	14.8	5.2	249	0.780	13	Tipo II-C	15.6	3.6
16	0.773	15	Tipo II-C	14.4	5.2	250	0.942	15	Tipo II-C	13.5	8.3
17	0.761	15	Tipo II-C	14.3	5.2	251	0.941	18	Tipo II-C	11.3	9
18	0.824	14	Tipo II-C	14.4	2.5	253	0.601	12	Tipo II-C	16.1	2.6
19	0.941	12	Tipo III	6.5	9.2	254	0.425	12	Tipo II-C	13.2	2.6
20	0.750	13	Tipo II-C	13.6	4.6	257	0.504	12	Tipo II-C	14.1	2.6
21	0.795	13	Tipo II-C	14	4.6	259	0.532	12	Tipo II-C	15.8	2.6
22	0.753	9	Tipo II-C	9.5	4.6	260	0.483	12	Tipo II-C	14.1	2.6
23	0.943	12	Tipo III	8.4	9.2	263	0.948	15	Tipo II-C	12.6	8.3
24	0.926	8	Tipo II-C	9	9.2	264	0.711	8	Tipo II-C	13.6	5.4
26	0.784	15	Tipo II-C	13.9	5.5	269	0.776	4	Tipo III	6	3.8
27	0.772	15	Tipo II-C	11.9	5.5	273	1.009	15	Tipo II-C	17.7	3.1
28	0.778	15	Tipo II-C	13.9	5.5	277	0.896	15	Tipo II-C	15.7	5.5
29	0.781	15	Tipo II-C	12.8	5.5	278	0.548	32	Tipo III	7.9	12.8
30	0.758	15	Tipo II-C	13.7	5.5	279	0.738	9	Tipo II-C	10.4	3.9
31	0.848	15	Tipo II-C	18.5	5.5	280	0.693	24	Tipo II-C	15.43	11.5
32	0.739	15	Tipo II-C	15	6.5	281	0.743	27	Tipo II-C	20.53	11.5
33	0.785	14	Tipo II-C	12.1	5	282	0.604	5	Tipo III	4.37	12.6
34	0.797	14	Tipo II-C	11.9	5.2	285	0.823	9	Tipo II-C	8.2	7.1
36	0.926	10	Tipo II-C	16.3	6.5	286	0.428	18	Tipo II-C	11.6	6.6

DMU	Efficiency	Number of turbines	Wind Power Plant type	Physical guarantee of operation	Wind farm Age (years)	DMU	Efficiency	Number of turbines	Wind Power Plant type	Physical guarantee of operation	Wind farm Age (years)
37	0.870	10	Tipo II-C	14.6	6.5	287	0.719	21	Tipo III	19.7	8.6
38	0.779	9	Tipo II-C	13.1	4.2	288	0.493	8	Tipo II-C	11.1	7.4
40	0.633	7	Tipo II-C	6.3	6.5	289	0.501	15	Tipo II-C	7.93	11.3
42	0.518	10	Tipo II-C	8.3	2.5	296	0.620	11	Tipo II-C	10.5	3.6
43	0.763	15	Tipo II-C	15.3	6.5	298	0.723	23	Tipo II-C	13.6	4
44	0.410	15	Tipo II-C	11.3	3.5	299	0.714	23	Tipo II-C	12.5	4
45	0.728	15	Tipo II-C	13.7	5.2	300	0.314	13	Tipo II-C	13.9	2.6
46	1.000	13	Tipo II-C	15	3.2	302	0.623	11	Tipo II-C	11.2	3.6
48	0.357	13	Tipo II-C	12	2.5	303	0.847	15	Tipo II-C	13.5	4.75
49	0.901	10	Tipo II-C	9	5.5	304	0.892	15	Tipo II-C	13.1	4.8
50	0.502	13	Tipo II-C	11.5	2.5	305	0.806	16	Tipo II-C	14.1	4.8
51	0.752	13	Tipo II-C	13.4	4.9	306	0.834	15	Tipo II-C	13.1	4.75
52	0.810	14	Tipo II-C	16.8	4.9	308	1.000	10	Tipo III	2.3	22
53	0.860	8	Tipo II-C	14.8	4.9	310	0.466	11	Tipo II-C	9.3	7.3
57	0.522	13	Tipo II-C	9.1	2.5	311	0.488	13	Tipo II-C	9.5	7
58	0.680	15	Tipo II-C	15.5	6.5	312	0.517	12	Tipo II-C	8.3	7.3
59	0.933	15	Tipo II-C	15.2	5.5	313	0.430	12	Tipo II-C	8.5	7.4
60	0.842	15	Tipo II-C	16.1	6.5	314	0.482	14	Tipo II-C	9	6.75
61	0.770	10	Tipo II-C	13.7	5.9	316	0.411	12	Tipo III	7.28	12.6
63	0.744	10	Tipo II-C	10.1	6.5	318	0.765	8	Tipo III	7.8	8.05
64	0.531	13	Tipo II-C	10.3	2.5	319	0.934	13	Tipo II-C	13	7.3
65	0.499	15	Tipo II-C	11.9	3.5	320	0.876	18	Tipo II-C	18	7.3
69	0.741	9	Tipo II-C	9.8	6.5	321	1.025	26	Tipo I	20.76	11.75
70	0.973	9	Tipo II-C	9.7	5	322	0.670	11	Tipo II-C	11.8	6.9

DMU	Efficiency	Number of turbines	Wind Power Plant type	Physical guarantee of operation	Wind farm Age (years)	DMU	Efficiency	Number of turbines	Wind Power Plant type	Physical guarantee of operation	Wind farm Age (years)
71	0.863	9	Tipo II-C	9	5	323	0.827	9	Tipo II-C	16.9	5.25
72	0.525	13	Tipo II-C	12.3	9.9	324	0.795	8	Tipo II-C	15.4	5.45
73	0.545	13	Tipo II-C	12	9.9	325	0.819	5	Tipo II-C	8.5	5.25
74	0.512	13	Tipo II-C	12.7	9.9	326	0.638	7	Tipo II-C	11.1	5
75	0.602	13	Tipo II-C	13.1	9.7	327	0.714	7	Tipo II-C	12.1	5.5
76	0.568	11	Tipo II-C	8.3	7.5	328	0.640	8	Tipo II-C	12.2	5
77	0.744	10	Tipo III	9.8	8.5	329	0.593	7	Tipo II-C	10.9	5
79	0.813	41	Tipo I	22.8	7.5	330	0.650	7	Tipo II-C	10.2	5
80	0.897	13	Tipo II-C	15.9	6.8	331	0.619	10	Tipo II-C	15.3	5
81	0.847	11	Tipo II-C	12.4	6.8	332	1.000	2	Tipo III	1.15	12.5
82	0.825	18	Tipo II-C	15.3	6.4	333	0.889	11	Tipo II-B	12.8	4.75
83	0.758	18	Tipo II-C	13.5	7.4	334	1.000	4	Tipo III	1.1	19
84	0.738	18	Tipo II-C	13.9	7.4	339	0.659	12	Tipo III	14.2	12.7
85	0.686	18	Tipo II-C	13.7	7.4	340	0.290	19	Tipo II-C	10.23	11.2
86	0.702	18	Tipo II-C	14.3	7.4	341	1.007	50	Tipo I	28.83	11.9
87	0.542	15	Tipo II-C	13.1	7.4	342	0.397	19	Tipo III	9.25	11.9
90	0.860	10	Tipo II-C	11	3.5	343	-0.996	17	Tipo III	9	8.75
91	0.833	10	Tipo II-C	10.1	3.5	346	0.608	14	Tipo II-C	13.6	3.7
93	0.751	9	Tipo II-C	14.4	4.1	347	0.617	11	Tipo II-C	10.7	3.7
94	0.713	35	Tipo I	21.8	7.5	348	0.743	11	Tipo II-C	14.2	6.7
95	0.717	36	Tipo I	21	7.5	350	0.802	11	Tipo II-C	10.6	7.1
96	0.863	15	Tipo II-C	15	6.5	351	0.626	8	Tipo III	6.7	12.7
97	0.862	15	Tipo II-C	14	6.5	352	0.873	7	Tipo II-C	6.5	7.1
98	0.844	15	Tipo II-C	14.2	6.5	353	0.756	11	Tipo II-C	12.7	7.7

DMU	Efficiency	Number of turbines	Wind Power Plant type	Physical guarantee of operation	Wind farm Age (years)	DMU	Efficiency	Number of turbines	Wind Power Plant type	Physical guarantee of operation	Wind farm Age (years)
99	0.790	15	Tipo II-C	14.1	6.5	355	0.237	28	Tipo II-C	19.84	10.75
100	0.804	15	Tipo II-C	14	6.5	356	0.560	9	Tipo II-C	11.3	2.7
101	0.774	11	Tipo II-C	13.6	6.1	357	0.734	9	Tipo II-C	14.2	2.75
102	0.650	10	Tipo II-C	10.5	6.1	359	0.874	14	Tipo III	12.7	4.6
103	0.694	11	Tipo II-C	12	6.1	360	0.916	17	Tipo II-C	14.7	5.6
104	0.718	11	Tipo II-C	12.3	6.1	361	0.747	16	Tipo II-C	14.3	5.3
105	0.568	11	Tipo II-C	10.5	6.1	362	0.938	16	Tipo II-C	14.2	5.6
106	0.689	62	Tipo III	20.74	15	363	0.925	17	Tipo II-C	14.1	5.6
107	0.646	15	Tipo II-C	13.7	7.4	364	0.916	17	Tipo II-C	14.8	5.6
108	0.540	15	Tipo II-C	12.7	7.4	366	0.813	16	Tipo II-C	15.6	5.6
109	0.597	15	Tipo II-C	12.5	7.4	368	0.769	16	Tipo II-C	16.2	5.6
110	0.479	15	Tipo II-C	12.3	7.4	371	0.907	11	Tipo III	14.8	4.8
111	0.542	15	Tipo II-C	12.4	7.4	372	0.875	10	Tipo III	8.8	4.9
112	0.384	15	Tipo II-C	12.2	7.4	373	0.710	11	Tipo II-C	16.8	5
113	0.837	11	Tipo II-C	16	6.2	376	0.554	9	Tipo II-C	13.8	2.6
114	0.732	14	Tipo II-C	15.6	4.5	377	0.611	20	Tipo III	7.81	12.5
118	0.802	9	Tipo II-C	15.3	4	381	0.876	15	Tipo II-C	14.8	5.5
119	0.437	15	Tipo II-C	9.7	2.5	382	0.829	16	Tipo II-C	15.8	5.9
121	0.742	9	Tipo II-C	14.3	4	383	0.924	16	Tipo II-C	15.1	5.6
123	0.874	17	Tipo II-C	13.5	5.4	384	0.957	15	Tipo II-C	15.7	5.6
124	0.886	17	Tipo II-C	12.7	5.4	385	0.850	16	Tipo II-C	16	6
125	0.779	11	Tipo II-C	15.7	11.3	386	0.807	16	Tipo II-C	16	6
126	0.909	10	Tipo II-C	16	6.4	387	0.905	15	Tipo II-C	16.9	6
127	0.610	15	Tipo II-C	12.4	3.4	388	0.836	16	Tipo II-C	16	6

DMU	Efficiency	Number of turbines	Wind Power Plant type	Physical guarantee of operation	Wind farm Age (years)	DMU	Efficiency	Number of turbines	Wind Power Plant type	Physical guarantee of operation	Wind farm Age (years)
141	0.817	15	Tipo II-C	17.2	4.8	389	0.932	17	Tipo II-C	14.9	6.6
143	0.833	7	Tipo II-C	11.5	4.6	390	0.908	15	Tipo II-C	16.2	6
144	0.820	15	Tipo II-C	12.4	6.6	391	0.940	17	Tipo II-C	17.4	6
145	0.904	13	Tipo II-C	15.2	4.1	397	1.000	15	Tipo II-C	16.2	6.5
146	0.894	5	Tipo II-C	3.9	7	398	0.973	15	Tipo II-C	16.6	6.5
148	0.635	8	Tipo II-C	6	5.4	399	0.981	15	Tipo II-C	16.7	6.5
151	0.957	15	Tipo II-C	14.6	5.25	401	0.884	14	Tipo II-C	15.6	3.9
152	0.812	12	Tipo II-C	13.1	3.5	404	0.941	13	Tipo II-C	15.4	3.9
153	0.934	10	Tipo II-C	10.1	5.25	405	0.810	14	Tipo II-C	16	3.75
154	0.936	9	Tipo II-C	8.9	5.25	410	0.827	14	Tipo II-C	13.7	3.9
155	0.929	14	Tipo II-C	12.4	5.6	411	0.912	6	Tipo III	1.43	12.5
156	0.960	15	Tipo II-C	11.2	5.4	412	0.932	6	Tipo III	1.21	12.5
160	0.878	15	Tipo II-C	11.2	6.7	413	0.951	6	Tipo III	1.29	12.5
161	0.722	15	Tipo II-C	11.2	6.7	414	0.922	6	Tipo III	1.47	12.5
162	0.884	14	Tipo II-C	12.1	5.75	415	0.942	6	Tipo III	1.38	12.5
163	0.852	13	Tipo II-C	10.9	5.75	416	1.000	6	Tipo III	1.32	12.5
164	0.922	5	Tipo II-C	4.3	5.75	417	0.721	6	Tipo III	1.31	12.5
165	0.896	11	Tipo II-C	13.8	2.7	418	0.880	6	Tipo III	1.31	12.5
166	0.949	11	Tipo II-C	14.1	3	419	0.752	15	Tipo III	17.7	3.75
169	0.921	11	Tipo II-C	13.4	2.9	420	0.729	15	Tipo III	18.7	3.75
170	0.869	11	Tipo II-C	14.1	2.6	421	0.707	15	Tipo III	17.5	3.75
171	1.000	11	Tipo II-C	14.1	1.1	422	0.739	6	Tipo III	1.27	12.5
175	0.868	6	Tipo II-C	4.2	7	423	0.748	13	Tipo III	3.95	13.6
176	0.825	12	Tipo II-C	11.6	3.25	424	0.721	6	Tipo III	1.34	12.5

DMU	Efficiency	Number of turbines	Wind Power Plant type	Physical guarantee of operation	Wind farm Age (years)	DMU	Efficiency	Number of turbines	Wind Power Plant type	Physical guarantee of operation	Wind farm Age (years)
177	0.366	14	Tipo II-C	7.1	3.6	425	1.000	3	Tipo III	1.35	10.6
178	0.319	14	Tipo II-C	5.5	3.5	426	0.859	14	Tipo II-C	12.2	5.5
179	0.688	11	Tipo II-C	13.7	5.4	427	0.804	14	Tipo II-C	10.7	5.5
180	0.799	13	Tipo II-C	15.7	3.6	428	0.818	13	Tipo II-C	11.5	5.5
181	0.831	15	Tipo II-C	14.1	3.8	429	0.838	17	Tipo II-C	11.2	5.5
182	0.875	15	Tipo II-C	14.2	3.8	430	0.739	3	Tipo III	1.34	11.25
183	0.777	15	Tipo II-C	14	3.8	431	0.668	3	Tipo III	1.32	11.25
184	0.792	8	Tipo II-C	9	3.25	434	0.794	3	Tipo III	1.28	11.2
185	0.912	11	Tipo II-C	13.5	3.25	435	0.440	3	Tipo III	1.2	11.25
187	0.898	15	Tipo II-C	16.7	5.25	436	0.640	11	Tipo II-C	11.6	3.5
191	1.000	15	Tipo II-C	3.8	3.75	437	0.719	11	Tipo II-C	11	3.5
193	0.918	15	Tipo II-C	18.1	3.75	439	0.798	8	Tipo II-C	6.6	5.5
195	1.000	15	Tipo II-C	7.7	3.25	440	0.855	16	Tipo II-C	14.7	5.5
197	0.906	15	Tipo II-C	13.9	5.6	441	0.772	17	Tipo II-C	14.4	5.5
200	1.000	15	Tipo II-C	15.9	5.6	442	0.785	16	Tipo II-C	14	5.5
201	0.881	14	Tipo II-C	12.9	5.3	443	0.820	17	Tipo II-C	15	5.5
202	1.000	11	Tipo II-C	10.7	5.3	444	0.804	17	Tipo II-C	15.1	5.5
203	0.773	11	Tipo II-C	10.5	5.4	445	0.884	16	Tipo II-C	14.9	5.5
204	0.999	15	Tipo II-C	15.5	5.5	447	0.780	11	Tipo II-C	11.9	4.2
205	0.729	18	Tipo II-C	13.5	5.4	448	0.685	13	Tipo II-C	14.2	4.5
206	0.987	13	Tipo II-C	14.7	3.6	450	0.751	12	Tipo II-C	13.6	4.5
207	0.839	17	Tipo II-C	15.5	5.4	451	0.818	17	Tipo II-C	16.6	5.2
208	0.974	15	Tipo II-C	15	5.6	452	0.782	17	Tipo II-C	15	5.2
214	0.724	8	Tipo II-C	8.2	5.4	453	0.895	17	Tipo II-C	14.9	5.2

DMU	Efficiency	Number of turbines	Wind Power Plant type	Physical guarantee of operation	Wind farm Age (years)
215	0.804	8	Tipo III	13.1	3.8
216	0.795	9	Tipo III	13.3	3.8
218	0.990	15	Tipo II-C	15.9	5.25
220	0.780	13	Tipo II-C	8.4	7
221	0.870	18	Tipo II-C	13.6	7
222	0.855	19	Tipo II-C	13.9	7
223	0.930	7	Tipo II-C	5	7
228	0.828	15	Tipo II-C	10.9	7
229	0.877	21	Tipo II-C	13.4	9
454	0.874	17	Tipo II-C	15.2	5.2
455	0.833	17	Tipo II-C	17.8	5.1
456	0.786	15	Tipo II-C	14.7	5.2
457	0.817	14	Tipo II-C	12.6	5.2
458	0.783	12	Tipo II-C	11.3	5.1
459	0.497	3	Tipo IIII	1.23	11.25