A Statistical Estimation of Wind Data Generation in the Municipality of Bragança, Portugal.

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***Abstract*—The existing wind energy potential in Portugal makes way for developing electrical energy in the northern region. In this work, wind speed data were statistically investigated using Weibull distribution to identify the characteristics of converting wind energy in Serra da Nogueira mountain in the Municipality of Braganca. An hourly wind speed time series data set from January 2002 to December 2021 have been exported from OPEN-METEO online platform after reliability data was proved through a correlation study with real data. The Weibull parameters including form K and scale C factors, frequency distribution function $f(v)$, has been used to describe the best wind distribution. Moreover, statistical estimation of wind energy potential at different altitudes (10m, 50m, 100m, 150m, and 200m) throughout vertical extrapolation and wind direction study is performed to identify the suitable high wind turbine hub. Finally, the evaluation of the predicted electrical energy produced is done while considering the judicious choice of the wind turbines and the charge factor. The Weibull parameters, frequency distribution, wind speed stability, and potentially provided by this study were motivating results for implementing wind farm in the mountain of Serra da Nogueira.**

***Index Terms*—Wind speed; Wind direction, Weibull distribution; Wind turbine; Electrical production.**

I. Introduction

The use of fossil fuels is exhaustible and, as they emit CO_2, they contribute to global warming. Faced with this fact, most countries in the world have undertaken an energy transition [1]. In the last UN Climate Change Conference of 2022, which took place in the framework of COP27 in Egypt, the member states reached important decisions in the framework of reinforcing the energy transition strategy that becomes an important political issue for many reasons including environmental, climate concerns, public health concerns, energy prices, and economical growth [2]. Three main avenues can be used to accomplish this transition, the first is the improvement of energy efficiency including building renovations, the second one concern the decarbonization of energy production and consumption by replacing fossil fuels with Renewable Energy Resources (RES) or bio-based energy and the last one is related with emissions reduction by using less emissive technologies through the replacement of coal-fired power plants with gas-fired plants, ensuring grid balance while reducing air pollution and Green House Gas (GHG) emissions [3]. "The energy transition is not happening" is the conclusion of the State of the World's Renewable Energy 2022 Report established by renewable energy actors from science, academia, governments, and industries [4]. According to this report, the share of renewable energy in final energy consumption worldwide is stagnating since it has gone from 8.7% in 2009 to only 11.7% in 2021. However, the growth of renewable energies has not been sufficient to cope with the increase in energy consumption and a further rise in the use of fossil fuels is remarked [5]. RES is now the fourth source of primary energy after nuclear, oil, and natural gas. The production level of the bio-energy sector share in RES has decreased significantly. Renewable electricity production is still dominated by hydro-power, Even though, the share of wind and solar photovoltaic power is growing strongly [6].

In May 2022, according to the Portuguese Association for Renewable Energy (APREN) [7], Portugal had a spectacular month of green production. The country produced 3.337 GWh of electricity, with solar generation accounting for 8.2% of the total production as presented in Fig.1, the highest level ever recorded in the country. However, solar energy did not reach its full potential in Portugal, as it was only the fourth most efficient renewable energy source. Wind energy was the most important, representing 25% of total production, followed by hydropower (13%) and biomass (9.8%), Renewable energy production saved Portugal about 274 million euros in natural gas imports in May, equivalent to 215.20 €/MWh.

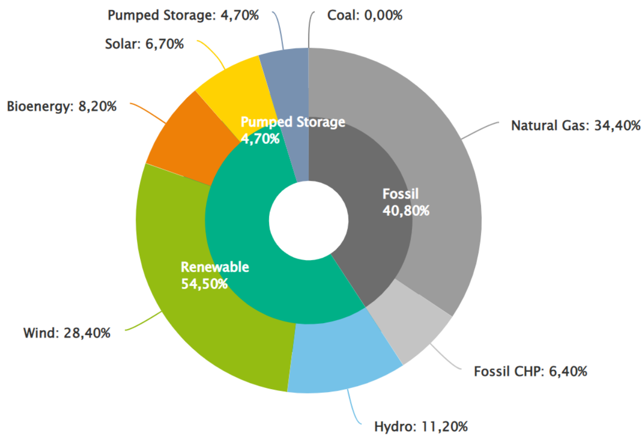

Fig. 1. Electricity Generation by Energy Sources in Mainland Portugal in 2022 [7].

In September 2022 renewable incorporation on electricity generation was 54.50%. On the other hand, fossil electro-production centers represent 40.8 % as shown in Fig.2.

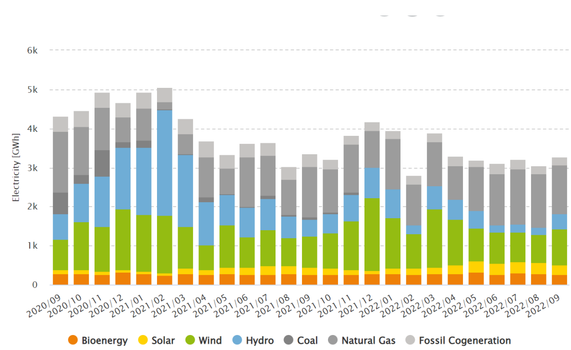

Fig. 2. Distribution of the electricity generation by source (September 2020 to September 2022) [7].

Increased renewable energy production has allowed for the reduction of certain emissions in the domestic power generation sector [8]. This, combined with the closure of the Sines and Pego coal-fired power plants, emissions have dropped to 134 $kg\ CO_2/MWh$ by 2021, a reduction of 74 $kg\ CO_2/MWh$ compared to early-century values [9]. In the coming years, renewable electricity is expected to have a further impact on the decarbonization of the Portuguese energy society, motivated by forecasts of increased renewable energy [10].

As presented earlier in this article, statistics have shown that wind energy is strongly used in Portugal, and is seeing remarkable growth with almost 28.4% of total electricity production in the country [11]. The largest part of Portugal's wind energy capacity is situated in the north-northeast region. Today, the province of Viseu is ranked as the district with the largest installed capacity of over than 934.5 MW, followed by Coimbra, Vila Real, and Castelo Branco. There is also 2 MW of floating WindFloat offshore capacity located near the Aguçadoura wave park in Póvoa de Varzim in Portugal. It was successfully tested and moved to Viana do Castelo in 2016 with a planned expansion and renamed Windfloat Atlantic, and the Póvoa de Varzim was disposed of with a new offshore plant. The city of bragança is currently situated in the 13th position in the national rank of electricity production via wind power. An expansion of this production remains a favorable option, on the other hand, incorporation of this production in micro-grids remains a solution to achieve a higher green production, which explains the purpose of this article which will investigate the wind in this region using a statistical approach [12].

Wind energy is a sustainable source of income for the owners, which can be private or state-owned of the farms on which it is located. The critical variables to be identified in any wind assessment activity are wind speed and its characteristics at a given location [13]. The systematic study needed to start by recording several parameters of wind mainly including velocity, direction, furthermore, atmospheric pressure, and temperatures for a considerable period. These measurements are analyzed to identify the potential of the wind. The measured wind speed data are mainly employed to provide the Weibull frequency distribution which is used to determine the wind potential. The Weibull distribution is described by a scale parameter C in (m/s) and a dimensionless parameter K. The Weibull distribution can be represented by the probability density functions (PDF) given by $f(v)$ and the cumulative distribution functions (CDF) given by $F(v)$. Comprehensive definitions are given in the next section [14].

In the literature, Weibull is the most frequently used distribution function. In [15], the authors used the Weibull distribution for analyzing the wind in 11 regions in Iran using data set of one year. The result of the study shows the Empirical, Moderate Maximum Likelihood approach to estimate the wind speed with the least error. Moreover, both moment and modified maximum likelihood are the best options for assessing the energy output of wind turbines. Saed et al in [16] analyzed the potential of wind power in Pakistan using data from two years at four heights (80, 60, 40, and 20 m from sea level) employing six numerical methods for the estimation of Weibull parameters (form "K" and scale "C"). From these methods, the Modified Maximum Likelihood Method (MMLM) proved to be the most effective in analyzing wind data. In [17], the authors applied a goodness fit approach to determine the Weibull parameters for wind energy analysis.

The objective of the proposed work in this paper carried out in the province of Braganca in the northern region of Portugal, is to define the density function of velocity distribution to estimate from acquired meteorological data measurements, thanks to the climatic database OPEN-METEO, the available and recoverable wind power stably during a day on the one hand and along a year on the other hand as a function of the altitude and to propose a study of a wind farm to be installed.

The paper is divided as follows: Section II presents the study zone. The data used are analyzed in Section III. The material and methods employed to carry out this study are presented in Section IV. The procedure used for the design of the wind farm is explained in Section V. Section VI presents the results and discussion. finally, Section VII concludes the study and proposes guidelines for future works.

II. Presentation of the study zone

Bragança is a city and a municipality located in the north-east of Portugal, at an altitude of 693 m above sea level. Table I shows the geographical coordinates of the site.

TABLE I
Geographical data of Bragança municipality.

Geographical data	
Latitude	41°48 N
Longitude	6°45 W
Altitude	693 m
Height of Mount	131.9 m

Looking for a mountain for better speeds at altitude in the region, the Serra da Nogueira has been chosen as a zone for implementing a wind farm, this area requires a study of its wind potential. This mountain is located in a strategic position in terms of noise in the municipality of Bragança. In addition, the mountain benefits from a high of 132 m, a flat and high surface with a ground made of sandstone for the implantation of wind turbines, Fig. 3 gives an overview of the study zone.

Fig. 3. Mountain of Serra da Nogueira

III. Wind Data analysis

OPEN-METEO is used as a reference database for wind speed historical data. In order to assess the reliability of this source, a correlation study was performed using real wind speed data from the meteorological station of the Polytechnic Institute of Bragança in Portugal, a Pearson correlation coefficient matrix was calculated for the period of 01 January 2019 to 31 December 2019 between these real data and the data from the web platform as presented in Table II.

According to the results obtained from the data correlation, the reliability of the website can be proved, and therefore the historical data for making the study are provided from the OPEN-METEO platform.

To carry out this study, a data set for a period of 20 years (1st of January 2022 to 1st of September 2022) has

TABLE II
Data correlation between real and website data.

	Pearson Correlation Coeficiant
JAN	0.82
FEB	0.81
MAR	0.68
APR	0.71
MAY	0.76
JUN	0.80
JUL	0.63
AUG	0.67
SEP	0.47
OCT	0.69
NOV	0.78
DEC	0.48

been considered including the wind speed and wind direction presented as a box and whiskers plot in Fig. 4 and Fig. 5 respectively. The wind speed and direction measurements are made at a height of 10 m and performed within 1-hour time intervals. From the data analysis, the average wind speed is evaluated at 2.43 m/s with the maximal value attended being 12.55 m/s and a minimum value of 1.21 m/s. The average blowing wind direction evaluated is 220º in the direction North-North-East.

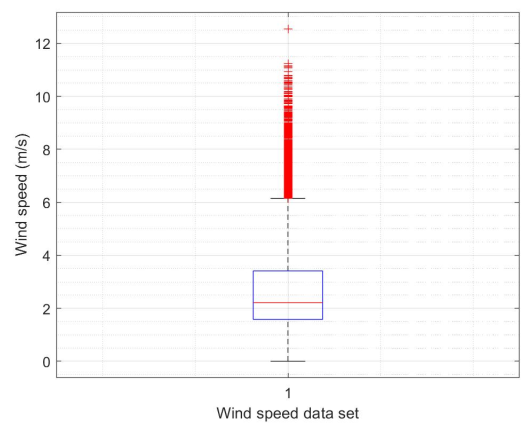

Fig. 4. Box and whiskers plot of the wind speed data set.

IV. Material and methods

A. Materials used

The site localization and the determination of the geographical parameter are done through the Google Mapp site. The OPEN-METEO collects the hourly data of the site. Measurement results are validated after a comparison and correlation study with real-situation data. To extract the wind rose and frequency distribution, the WindPro software was used.

B. Methodes

1) Wind potential of the site: The hourly wind speed data used was provided by OPEN-METEO online platform from 2002 to 2022. The wind distribution is based on the Weibull

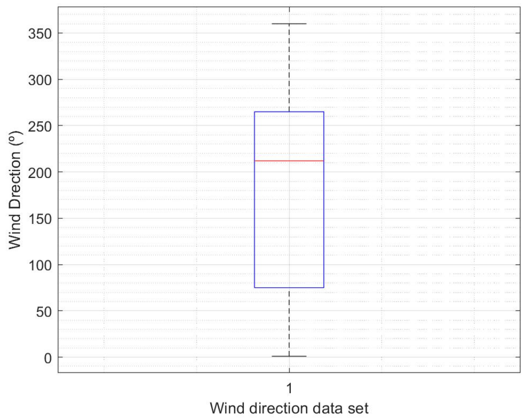

Fig. 5. Box and whiskers plot of the wind direction data set.

model used by climatologists. It is used as a model for a series of wind measurements (at least 10 years). Its parameters K and C are calculated according to the measurements [18]. The Weibull distribution of velocities is expressed by the relation:

$$f(v) = \left(\frac{K}{C}\right)\left(\frac{v}{C}\right)^{k-1} e^{-\left(\frac{v}{C}\right)^{k}} \quad (1)$$

where $f(v)$ is the occurrence frequency of the wind speed, K and C are the Weibull parameters. The parameter K called the shape factor is dimensionless and characterizes the shape of the frequency distribution, while C is the scale factor that determines the wind quality. These are determined by the Energy Factor Method (EPF). This method is one of the most accurate and efficient ways of identifying C and K [19].

K is the form factor determined by the Equation (2):

$$K = 1 + \frac{3.69}{{E_{PF}}^{2}} \quad (2)$$

With E_{PF} the factor energy obtained as a function of the instantaneous velocity V_i by the relation (3):

$$E_{PF} = \frac{\frac{1}{n}\sum_{i=1}^{n} {v_i}^{3}}{\left(\sum_{i=1}^{n} v_i\right)^{3}} \quad (3)$$

C is the scale factor that determines the wind quality and is given in m/s by relation (4):

$$C = \frac{V_m K^{2.6674}}{0.184 + 0.8116K^{2.73855}} \quad (4)$$

with V_m is the average wind speed.

2) Extrapolation of wind speed as a function of altitude: In order to have adequate speeds for wind turbine operation, extrapolations are made to increase the actual wind speed [20].

$$V(Z_2) = V(Z_1)\left(\frac{Z_2}{Z_1}\right)^{a} \quad (5)$$

$$a = \frac{1}{\ln\left(\frac{\bar{Z}}{Z_0}\right)} - \frac{0.0881}{1 - 0.00881\ln\left(\frac{Z_1}{Z_0}\right)\ln\left(\frac{V(Z_1)}{6}\right)} \quad (6)$$

$$\bar{Z} = \sqrt{Z_1 Z_2} \quad (7)$$

$v(z)$, is the reference velocity measured at 10 meters; Z_1 and Z_2 denote the heights at 10 m and at variable values above 10 m respectively; Z_0 is the ground roughness.

3) Extrapolation of Weibull parameters as a function of altitude: From the parameters K and C calculated at 10 meters from the ground (C_{10} and K_{10}), an extrapolation is made to the height where the wind turbines are to be installed. The following formulas are used formulas [21]:

$$n = 0.37 - 0.088\ln(C_{10}) \quad (8)$$

$$K_z = \frac{K_{10}}{1 - 0.00881\ln\left(\frac{Z}{10}\right)} \quad (9)$$

$$C_Z = C_{10}\left(\frac{Z}{Z_{10}}\right)n \quad (10)$$

Z, represents the altitude at which the wind turbines would be installed, whereas, C_Z and K_z represent the corresponding parameters of scale and form factors respectively.

4) Wind power densities: WPD: It is used to estimate the recoverable power at a site [22]. It is obtained by:

$$WPD = p(v) = \frac{P(v)}{S} = \frac{1}{2}\rho v^3 \lambda \quad (11)$$

λ is a function that characterizes the shape of the frequency distribution and the velocity frequency distribution, it is given by the relation.

$$\lambda(x) = \left(\sqrt{2\pi x}\right)\left(x^{x-1}\right)\left(e^{-x}\right)\left(1 + \frac{1}{12}x + \frac{1}{288}x^3 + \frac{139}{51840}x^3 + ...\right) \quad (12)$$

$$x = 1 + \frac{3}{K} \quad (13)$$

The WED (Wind Energy Density) is a very important parameter, it allows for quantifying the energy produced during a time T by the wind turbines or the wind farm [23]. It should be noted that the time T depends on the availability factor and the Charge factor. Its formula is as follows:

$$WPD = p(v)T = \frac{P(v)}{S}T = \frac{1}{2}\rho v^3 \lambda T \quad (14)$$

The choice of turbines is very complex. If the right turbines are not chosen, this difficulty is avoided by calculating the charge factor before choosing a turbine.

5) Charge factor: The charge factor (CF) takes into account five parameters. Two are site-dependent (the form factor K and the scale factor) and three are provided by the turbine manufacturer including Starting speed V_S, Nominal speed V_N, and the Stopping speed of the wind turbine V_A [24].

$$CF = \frac{e^{-\left(\frac{V_S}{C}\right)^K} - e^{-\left(\frac{V_N}{C}\right)^K}}{\left(-\frac{V_N}{C}\right)^K - \left(-\frac{V_S}{C}\right)^K} - \left(-\frac{V_A}{C}\right)^K \tag{15}$$

With a Charge factor of at least 25%, the electricity production of wind turbines is acceptable [25].

V. Sizing of the Wind Farm

To optimize the operation of wind farms, some measures must be considered. The wrong choice of certain parameters can be disadvantageous for a wind farm. In order to avoid the wake effect, the spacing of the wind turbines is taken into account. The installation of wind turbines on a site must take into account the dimensions of the ground perpendicular and parallel to the predominant wind direction [26]. The conditions to be respected are the following:

$$10H(N_1 + 1) < IN \tag{16}$$

$$3D(N_2 + 1) < L \tag{17}$$

$$N = N_1 N_2 \tag{18}$$

where I is the dimension of the ground perpendicular to the predominant wind direction; L is the dimension of the ground parallel to the predominant wind direction; D is the diameter of the rotor of the machine; H is the height of the tower; N_1 is the number of wind turbines per row; N_2 is the Number of rows of wind turbines; N is the total number of wind turbines to be placed on the site.

VI. Results and Discussions

A. Wind energy potential of the Serra da Nogueira Mountain site

From the wind speeds obtained by OPEN-METEO over the period from January 2002 to December 2021 considering hourly time series, the average monthly wind variation at the geographical coordinates 41°48 N, 6°45 W (latitude, longitude), and at a height of 10 m is presented in Fig. 6. It also shows the curves of the average monthly wind variations as a function of month and altitude on the month and the height on the mountain. The analysis of these curves shows an increase in wind velocity as a function of height. These average curves show the same pattern. The months of April, June, October, November, and December are more promising as an example average daily wind variation is reported in Fig. 7, while January, February, March, May, and September are critical as illustrated in Fig. 8. According to Table III, the heights of 10 m, 50 m, 100 m, 150 m, and 200 m show annual average velocities between 2.43 m/s and 4.10 m/s, which are favorable for electricity production considering the vertical extrapolation of Weibull parameters using Equations (5), (9), (10) as presented in Table IV.

The values of the scale factor C give an overview of the average blowing wind speeds on site. It is remarked that the C values in Table IV are consistent with the average wind speed values of Table III which indicates the potentiality of the wind power of Serra da Nogueira. The greater the value of c means more potential for wind as remarked in the vertical extrapolation of this parameter for higher altitudes. The information on average wind related to the C value is a significant parameter for choosing the wind turbine characteristics including mainly the starting wind speed of the generator. The Weibull form parameter is a highly relevant factor in identifying the characteristics of the wind wave at a particular site it provides an outline of the wind speed distribution way that can be dispersed or concentrated in given wind speed classes. The annual K values of this case study are between 1.83 and 1.84 which means that the wind wave is regular and uniform in nature.

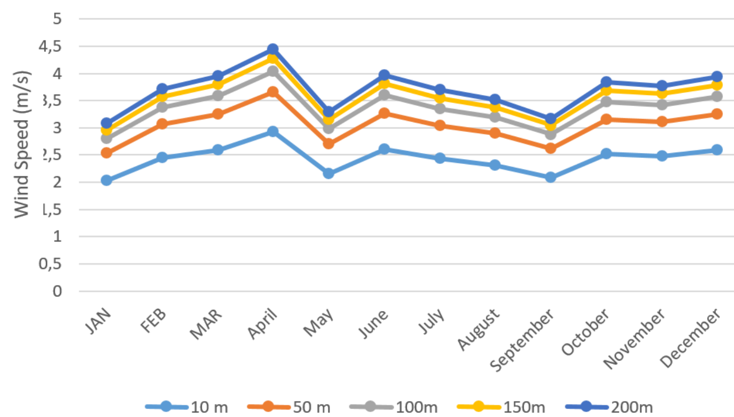

Fig. 6. Variation at different heights of the mountain's monthly average wind speeds.

TABLE III
AVERAGE ANNUAL WIND SPEED VALUES CONSIDERING THE ALTITUDE.

Altitude (m) \ Average wind speed	V (m/s)
10	2.43
50	3.04
100	3.78
150	3.93
200	4.10

B. Wind speed frequency distribution

The Weibull distribution of wind speed frequencies considering a height of 10 meters on a monthly scale for the study site considering the most profitable month (April) as well as the unfavorable month (February) is represented by

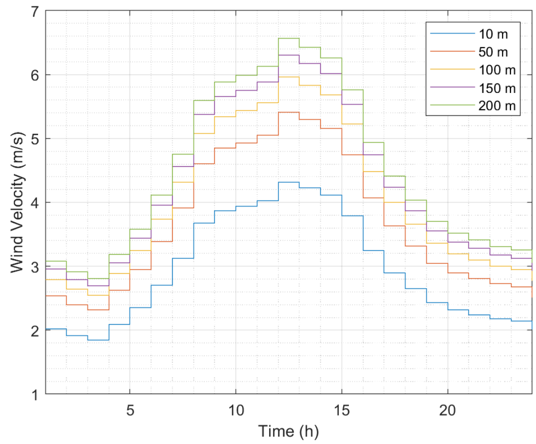

Fig. 7. Daily average wind speed variation for the month of April (Best case).

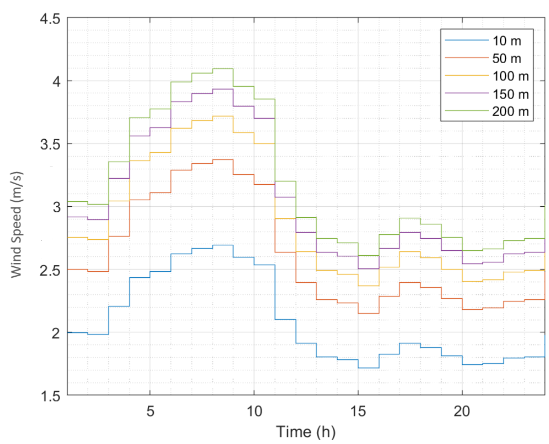

Fig. 8. Daily average wind speed variation for the month of September (worst case).

the curves in Fig. 9 and Fig. 10 respectively. The evaluation of the wind potential and information on frequency distribution are essential factors that help to assess the energy that can be produced by a wind turbine in the Serra da Nogueira locality. According to Fig. 6, the monthly average wind speed value of April is 2.83 m/s which matches with frequency distributions, the densities of wind speeds are located between the two classes 0.5 m/s and 3.6 m/s at an altitude of 10 m. According to Fig. 10, it is stated that the wind wave is dispersed between 0.5 m/s and 5.7 m/s which is not recommended for the working of a wind turbine in such a situation.

Monthly evaluation of the wind speed distribution f(v) is not a conclusive decision for the risk analysis of the wind farm implementation and the decision on the reliability of the site. this study takes into account also an annual analysis for the period from 1 January 2002 to 31 December 2021. The Weibull distribution of wind speed frequencies on an annual scale for the site is represented by the curve in Fig. 11. The annual study of frequency distribution shows a regular wind blowing concentrated between 0.5 m/s and 5.7 m/s, which is a suitable situation for the trusted working of an aerogenerator in Serra da Nogueira.

TABLE IV
VERTICAL EXTRAPOLATION OF THE WEIBULL PARAMETERS.

Altitude (m) \ Parameters	C (m/s)	K
10	2.95	1.83
50	3.26	1.83
100	3.91	1.84
150	4.29	1.85
200	4.43	1.85

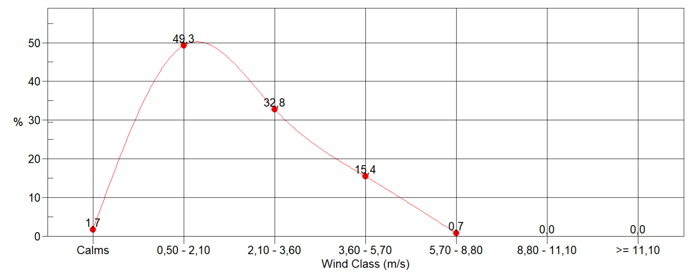

Fig. 9. Best monthly wind speed frequency distribution curves at 10 m altitude for the Serra da Nogueira Mountain (April).

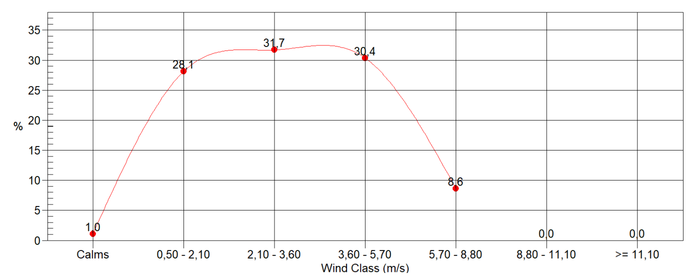

Fig. 10. Worst monthly wind speed frequency distribution curves at 10 m altitude for the Serra da Nogueira Mountain (September).

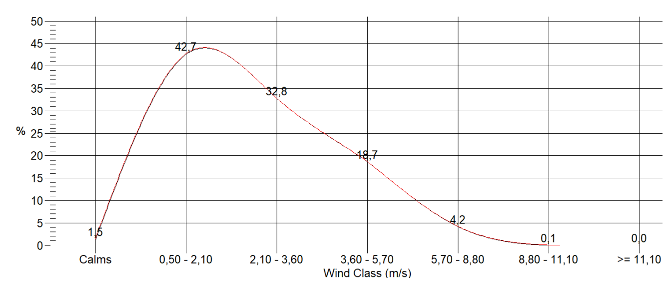

Fig. 11. Annual wind speed frequency distribution curves at 10 m altitude for the Serra da Nogueira Mountain.

C. *Wind turbine orientation*

The potential for a wind turbine to provide significant energy output is proportional to the wind characteristics. It is therefore necessary to find a constant and high wind speed, in order to avoid any disturbance. In this paper the wind direction of the Serra da Nogueira site is analyzed, Fig. 12 and Fig. 13 show the wind direction for the most favorable (April) and the most disadvantageous (September) months respectively as determined by the wind rose, while Fig. 14 shows the annual wind direction of the site. The observation and analysis of wind statistics in Fig. 12 show that the wind is predominantly in the range of North-North-East (NNE) direction. The highest wind speed is recorded in the East-North-East (ENE) direction. Moreover, this interval is the largest contributor to total energy. Despite being a speed frequency in the other directions, the average wind speed remains low. Fig. 13 Shows a disturbing wind blowing, highly concentrated in the North-North-East (NNE) and South-South-West (SSW) directions. The annual wind rose at 10 m altitude in the site shown in Fig. 14, demonstrates a dominance of the wind direction in the NE (North East) direction that will represent the final positioning of wind turbine blades in the wind farm.

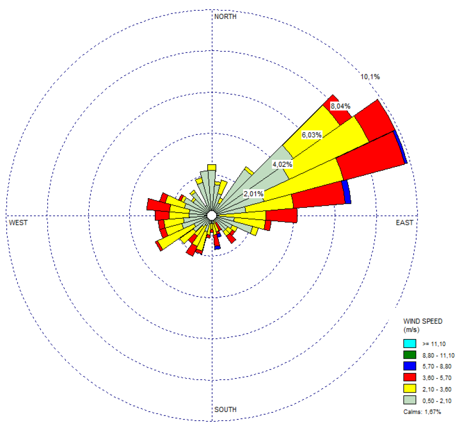

Fig. 12. Best Wind rose on the mount of Serra da Nogueira (April).

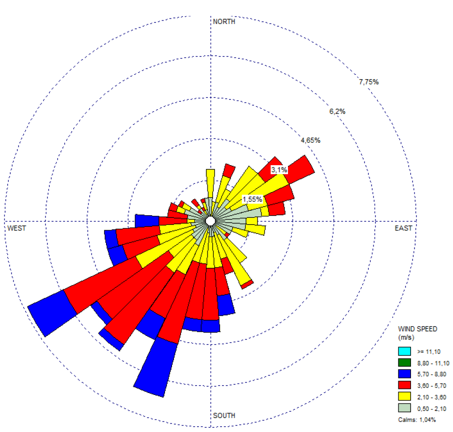

Fig. 13. Worst Wind rose on the mount of Serra da Nogueira (September).

D. Selection of the most appropriate wind turbine technology

The blades are located at the hub level, therefore the height of the wind turbine mast must be taken into account for the power calculations. Three types of wind turbines were chosen

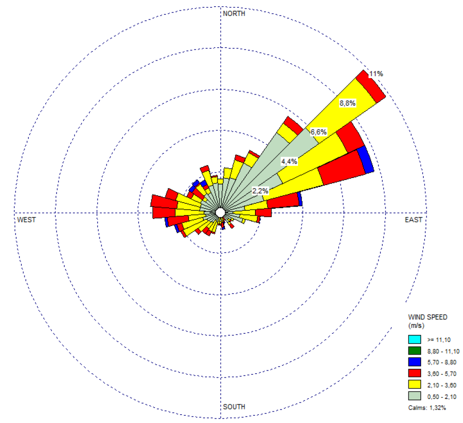

Fig. 14. Annual Wind rose on the mount of Serra da Nogueira.

in order to identify which type of wind turbine will produce more energy as presented in Table V.

TABLE V
TYPES OF WIND TURBINES SELECTED FOR THE PARK MODEL.

Characteristics \ Model	Fuhrländer	Ades	Enercon
Height - mast (m)	60	75	130
Power (kW)	100	200	2000
Diameter (m)	21	36	82
Vs (m/s)	2.5	3.5	2.5
Vn (m/s)	13	12	12.5
Va (m/s)	25	25	25

Fig.15 shows the variation in power density at heights of wind turbine hub as a function of the month for each generator type presented in Table V. It should be noted that the height of the machines is the sum of the height of the mountain and the height of the hub. The curves show the same pattern with the only difference being that the more altitude, the better density is obtained. The months of April, June, October, November, and December have the highest power density values. The interval of good wind fields corresponds to the period of load shedding, which is an advantage for the project.

The following Table VI. represents the values of the charge factor obtained according to Equation (15). The values obtained are adequate to build a wind farm site because they are higher than the limit margin of 25%, in fact, the best would be to opt for the generator Enercon, because of the considerable power that can be recovered at this height level, especially since the wind characteristics at this altitude are steady, as proved by the form factor specified in Table IV.

TABLE VI
CHARGE FACTOR ON THE HUB LEVEL.

Generator	Charge factor
Fuhrlander	39.64
Ades	49.18
Enercon	48.2

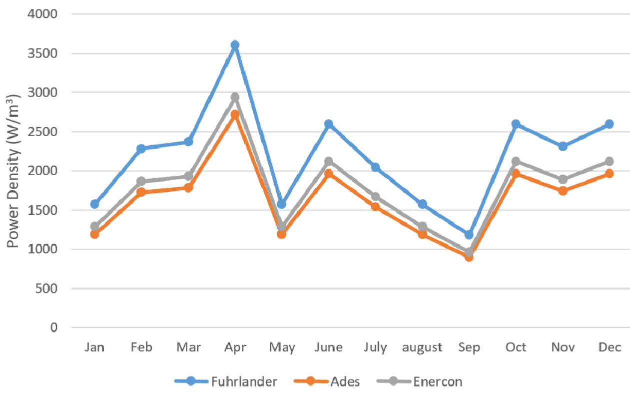

Fig. 15. Variations in monthly power density.

According to the Equations (16), (17), (18), and the dimensions of the site shown in Fig16. the number of turbines per row (N1) is 3 rows, the total number of rows (N2) is 5 rows, the total number of turbines on the site is 15 turbines, and finally, the wind farm is approximated to a total power of 30 MW.

Fig. 16. Site dimensions.

E. Power prediction from the selected model

To assess the site's potential in terms of recoverable power, this study will be concluded with an annual power estimation providing an insight into the efficiency of the Serra da Nogueira for the implementation of a wind farm.

Fig.17 shows the annual electricity production of the Enercon wind turbine at the site at the hub heights. This power is highest in the months of April, June, October, November, and December. It is low in May and September. The annual balance of power production is 8.31 MW minimum and 19.03 MW maximum. The average is 11.57 MW.

VII. Conclusion and Future Works

The work presented in this paper investigates the wind potential and evaluates the energy production of Serra da Nogueira Mountain. It was found that the wind at the site is regular and propagates in a North-North-East (NNE) direction, with stable average wind speeds between 2 m/s and 3 m/s at an altitude of 10 m. The best average wind speeds of 3 to 5 m/s, favorable to better electricity production, are

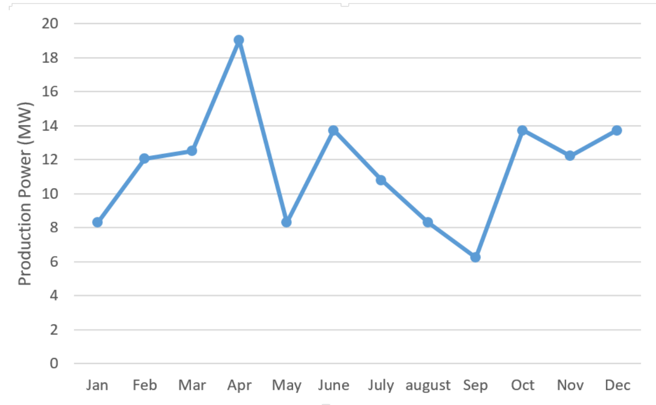

Fig. 17. Variation of monthly power produced by the wind turbine for each month of the year.

obtained by extrapolation to altitudes of 50 m, 100 m, 150 m, and 200 m corresponding to the heights of wind turbines. This study predicts the wind energy of the wind farm in question, based on a judicious choice of machine, taking into account the dimensions of the site, the wind turbine type Enercon is chosen. The wind potential of this 130 m high site has an average speed of 4,88 m/s and an energy density of 1788,31 W/m^2 in the preferred direction. The installation of 15 machines on the site gives a power of 30 MW for an average annual production power of 11.57 MW. This wind farm is designed as part of the microgrid system for the municipality of Braganca, in continuity, this wind farm will be used to carry out the sizing of the microgrid system which also includes a photovoltaic park, an energy storage system, and a microturbine as a backup system.

References

[1] Pata, Ugur Korkut, Mehmet Metin Dam, and Funda Kaya. "How effective are renewable energy, tourism, trade openness, and foreign direct investment on CO2 emissions? An EKC analysis for ASEAN countries." Environmental Science and Pollution Research (2022): 1-17.
[2] Harris, Jonathan, Shreepath Jain, and Anne-Marie Codur. "Climate Conference COP27: Focus on Agriculture and Forests." (2022).
[3] Guinto, Renzo R., et al. "Achieving climate justice, safeguarding planetary health: Diagnosis and demands from next generation leaders for COP27 and beyond." PLOS Global Public Health 2.11 (2022): e0001304.
[4] Sachs, Jeffrey, et al. Sustainable development report 2022. Cambridge University Press, 2022.
[5] Igliński, Bartłomiej, et al. "The assessment of renewable energy in Poland on the background of the world renewable energy sector." Energy 261 (2022): 125319.
[6] Perez, Marc, and Richard Perez. "Update 2022–A fundamental look at supply side energy reserves for the planet." Solar Energy Advances 2 (2022): 100014. .
[7] APREN. Portuguese Association for Renewable Energy [Online]. Available at: https://www.apren.pt/en/ (Accessed: November 25, 2022).
[8] Raza, Muhammad Amir, Krishan Lal Khatri, and Arslan Hussain. "Transition from fossilized to defossilized energy system in Pakistan." Renewable Energy 190 (2022): 19-29.
[9] Saia, Artjom, et al. "Techno-economic assessment of CO2 capture possibilities for oil shale power plants." Renewable and Sustainable Energy Reviews 169 (2022): 112938.

[10] Khatiwada, Dilip, Rohan Adithya Vasudevan, and Bruno Henrique Santos. ”Decarbonization of natural gas systems in the EU–costs, barriers, and constraints of hydrogen production with a case study in Portugal.” Renewable and Sustainable Energy Reviews 168 (2022): 112775.
[11] Leiria, Andre, and Paulo Martins. ”A transdisciplinary perspective about climate change: A case of Portugal.” Transdisciplinary Journal of Engineering and Science 13 (2022).
[12] “Endogenous energies of Portugal,” e2p. [Online]. Available: https://e2p.inegi.up.pt/ (Accessed: 25-Nov-2022).
[13] Wade, Robert, and Geraint Ellis. ”Reclaiming the Windy Commons: Landownership, Wind Rights, and the Assetization of Renewable Resources.” Energies 15.10 (2022): 3744.
[14] Mahmood, Faleh H., Ali K. Resen, and Ahmed B. Khamees. ”Wind characteristic analysis based on Weibull distribution of Al-Salman site, Iraq.” Energy reports 6 (2020): 79-87.
[15] Teimourian, Hanifa, et al. ”A Comparative Study on Wind Energy Assessment Distribution Models: A Case Study on Weibull Distribution.” Energies 15.15 (2022): 5684.
[16] Saeed, M. Khalid, et al. ”Comparison of six different methods of Weibull distribution for wind power assessment: A case study for a site in the Northern region of Pakistan.” Sustainable Energy Technologies and Assessments 36 (2019): 100541.
[17] Carrillo, Camilo, et al. ”An approach to determine the Weibull parameters for wind energy analysis: The case of Galicia (Spain).” Energies 7.4 (2014): 2676-2700.
[18] Rocha, Paulo Alexandre Costa, et al. ”Comparison of seven numerical methods for determining Weibull parameters for wind energy generation in the northeast region of Brazil.” Applied Energy 89.1 (2012): 395-400.
[19] Aukitino, Tiaon, M. G. M. Khan, and M. Rafiuddin Ahmed. ”Wind energy resource assessment for Kiribati with a comparison of different methods of determining Weibull parameters.” Energy Conversion and Management 151 (2017): 641-660.
[20] Hadi, Firas A. ”Diagnosis of the best method for wind speed extrapolation.” International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering 4.10 (2015): 8176-8183.
[21] Gualtieri, Giovanni, and Sauro Secci. ”Extrapolating wind speed time series vs. Weibull distribution to assess wind resource to the turbine hub height: A case study on coastal location in Southern Italy.” Renewable Energy 62 (2014): 164-176.
[22] Li, Muyuan, et al. ”An assessment of observed wind speed and wind power density over China for 1980–2021.” Wind Energy 25.12 (2022): 2052-2070.
[23] Matip, Michel Jessy Nkeng, et al. ”Estimation of wind power in coastal areas using a Model based on the learning of a Multilayer Perceptron: Case of Douala, Cameroon.” E3S Web of Conferences. Vol. 354. EDP Sciences, 2022.
[24] Barber, Sarah, Florian Hammer, and Adrian Tica. ”Improving Site-Dependent Wind Turbine Performance Prediction Accuracy Using Machine Learning.” ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part B: Mechanical Engineering 8.2 (2022): 021102.
[25] Tuy, Soklin, Han Soo Lee, and Karodine Chreng. ”Integrated assessment of offshore wind power potential using Weather Research and Forecast (WRF) downscaling with Sentinel-1 satellite imagery, optimal sites, annual energy production and equivalent CO2 reduction.” Renewable and Sustainable Energy Reviews 163 (2022): 112501.
[26] Cetinay, Hale, Fernando A. Kuipers, and A. Nezih Guven. ”Optimal siting and sizing of wind farms.” Renewable Energy 101 (2017): 51-58.