

Evaluation of wind energy potential at four provinces in Morocco using two-parameter Weibull distribution function

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ABSTRACT

In the last years, the use of wind turbines for power generation has increase due to the advance's technology used and the stable cost. In this paper, due to the low investment in the desert regions of Fezouata, Oujjane, El Ouatia, and Taroudannt in Morocco, we have considered wind resources as an ideal option. Using meteorological statistics, Weibull's distribution function was able to estimate the wind power and potential of four various wind turbines for each site with various nominal powers, ranging from 250 kW to 2000 kW, for use in wind farms. 24 years of wind speed data to fit the Weibull distribution. For the four provinces examined, the annual mean value of wind speed and frequency distributions were collected. The desert province of El Ouatia shows that it is economically feasible to install a wind farm for the production of green energy.

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1. INTRODUCTION

Multiple economic, environmental, and social factors push most countries to develop programs to encourage the use of renewable energies [1], [2], consequently, the level of technological and industrial development of wind energy has reached an extraordinary level [3]–[5]. Currently, wind energy accounts for around 4% of global electricity consumption [6]–[8], which is dominated by the Chinese market with a total installed capacity of 114 GW according to the global wind energy council (GWEC) report, followed by the US market in second place, with a capacity of 65 GW, then from the German market with a capacity of 39 GW in third position. Expectations indicate that the cumulative installed capacity will reach more advanced levels due to the massive installation of new onshore and offshore wind turbines [9]. Morocco's energy bill weighs heavily on the trade balance. Indeed, the country depends almost entirely on foreign countries for its energy supply due to the limited resources of conventional renewable energies (95% is the energy dependency rate) [10]. This situation prompts the government to develop an energy strategy based on supply assurance and the diversification of energy sources, including the production of electricity through the use of national energy resources. The installation of wind farms for the production of green energy, according to the Morocco 2030 energy vision, made it possible to increase the capacity from 0.28 GW in 2010 to 2.0 GW in 2020 [11].

Wind projects are a long process, with slow administrative procedures, taking around 10 years from the start of prospecting on the site until the establishment of the park, then more than 20 years of wind turbine production. Wind projects represent a huge initial investment with a massive financial transaction. The financial component is based on the evaluation of the potential, which is the sum of an estimate of the average electricity production for the years of operation of the park, studied before the installation of the wind turbines from the wind measurements on site. This figure is applied to calculate the future profit from electricity sales, which gives an overall idea of the productivity of the project.

If the wind production is lower than expected after its installation, the question of the utility of the wind project begins to arise, especially if the production is different in the 20 years of operation of the park, and which risks blocking the expansion of the sector. Several potential studies have been carried out in many regions of Morocco on the feasibility and evaluation of wind power, for example [12]–[18]. Most of them are concentrated in the coastal areas of Morocco. However, this work focuses on four desert regions of Morocco, as shown in Figure 1, these lands are arid, inexpensive and have good wind speed capability, which can make it an interesting place to set up large wind farms.

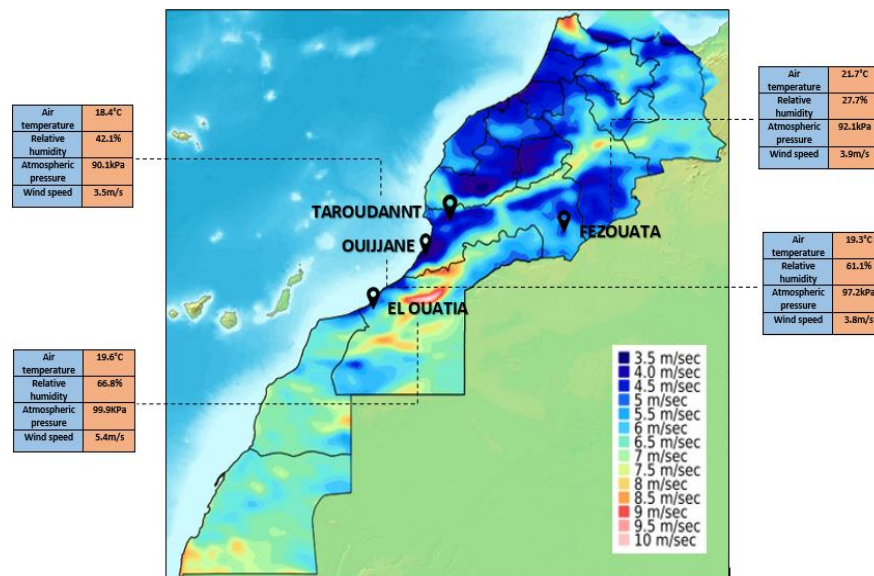


Figure 1. Wind speed in Morocco and annual average parameters for the provinces studied at 10 m

2. THEORY

A detailed study is required in wind projects. In this article, the main criteria for estimating data are climatic characteristics and wind speed of past periods. Thus, to determine the wind potential, several techniques have been used in the literature [19]–[40].

In this study, meteorological data was used to calculate wind speed. Table 1 (see Appendix) presents the parameters related to the calculation of wind speed performance. These quantities were calculated over a 24-year period to describe the relationship between wind turbine performance, wind potential, and electricity production.

3. RESULTS AND DISCUSSION

3.1. Wind speed data

This study uses wind speed data obtained by measuring four different locations in central Morocco (Fezouata, Oujjane, El Ouatia, and Taroudannt) for 24 years (from 1997 to 2021). Measurements for all wind observatories are taken at a height of 10 m. Table 2 shows the geographic coordinates of the meteorological stations examined.

The wind is constantly changing. An underestimation of the potential at the start of the analysis can jeopardize the whole project. In order to have a good idea of the hypothetical sites with wind potential, it is imperative for the producers of wind farms to be able to describe the variation of the wind with the greatest possible pressure. This description provides the information necessary to optimize the production of electricity while taking maximum advantage of the wind resources of the region studied. It is found in the wind industry

that the two-parameter Weibull distribution is the most widely used function due to its ability to represent the frequency of wind speeds accurately and flexibly. Moreover, the Weibull distribution with two parameters (k , c), formulated by (1), unlike other distributions such as the Rayleigh distribution or the exponential distribution, has become the standard function in the wind industry. Calculated using (5), k is the Weibull form factor, it gives the shape of the distribution and admits values between 1 and 3. c is the Weibull scale factor expressed in m/s, it is proportional to the average wind speed and it can be formulated by (6). However, if we replace k with 1 or 2 in the expression for the Weibull distribution, we may end up with the exponential distribution or the Rayleigh distribution, respectively. The measured data are adjusted to $f(v)$ at the four locations, k & c parameters are indicated in Table 3, while Figure 2 illustrate the average monthly wind speed over the study period at 10 m altitude. El Ouatia recorded the maximum average monthly wind speed measured in July at 6.4 m/s, while Fezouata recorded the minimum in December with 3.2 m/s.

Table 2. Geographical location of the four sites analyzed

Site	Latitude (°)	Longitude (°)	Elevation (m)
FEZOUATA	30.2	-5.61	670
OUIJJANE	29.7	-9.7	393
EL OUATIA	28.3	-11.2	152
TAROUDANNT	30.5	-8.9	1035

Table 3. k and c parameters for the studied Moroccan sites at 10 m

Site	k (dimensionless)	c (m/s)
FEZOUATA	1.47	4.49
OUIJJANE	2.02	5.15
EL OUATIA	2.15	5.75
TAROUDANNT	1.43	6.28

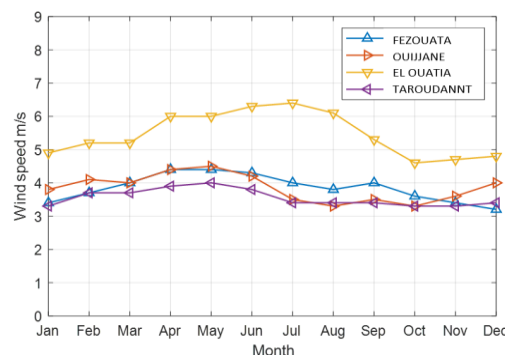


Figure 2. Monthly wind speed variation for the sites studied, Morocco

According to Table 3, at 10 m altitude, the parameter k varies between a minimum value of 1.43 at Taroudannt and a maximum value of 2.15 at El Ouatia, while the parameter c records values between 4.49 m/s at Fezouata and 6.28 m/s at Taroudannt. On the other hand, Figure 2, which illustrates the profile of the variation of the wind speeds, shows the need to extrapolate the values of the wind speed to higher altitudes. This necessity comes from the fact that the wind turbines are installed at a level higher than 10 m, which is justified by the fact that the wind becomes more important according to the altitude. The extrapolation of wind speeds and Weibull parameters can be calculated using (9), (10), (11) and (12). The prevailing wind speed level in the regions is determined by $f(v)$. The wind frequency distribution is based on the parameters found by analyzing the measured wind data, therefore, Figure 3 shows the Weibull probability distribution function for the four sites studied.

Figures 3(a)–(d) show the estimated annual $f(v)$ wind speed at the four locations. In general, the widest $f(v)$ is calculated at the Taroudannt station, while the highest $f(v)$ is observed at the Fezouata and Oujjane stations as shown in these figures. The k & c coefficients, the different wind speed and climatic conditions for each station clarify these deviations.

The wind changes speed and direction. For optimal production from a wind farm, producers need to know the prevailing winds for hypothetical sites. Even though wind technology presents turbines capable of rotating in the direction of the wind, but this step remains important in the stage of prospecting and implementation of wind projects. The wind direction information at 10 m is provided by the wind rose diagram, as shown in Figures 4(a)–(d). The presentation of the results in a polar diagram, based on the wind

direction data, shows that the distributions of the prevailing wind direction at the locations studied are particularly diverse. For Fezouata, the East-North-East wind direction is the most frequently observed wind direction, while for Ouijjane, the prevailing wind directions come mainly from the North-West and West-South-West, then El Ouatia, North and North-North-East are the most frequently observed wind directions and finally for Taroudannt, and the prevailing wind directions are East-North-East and West-South-West.

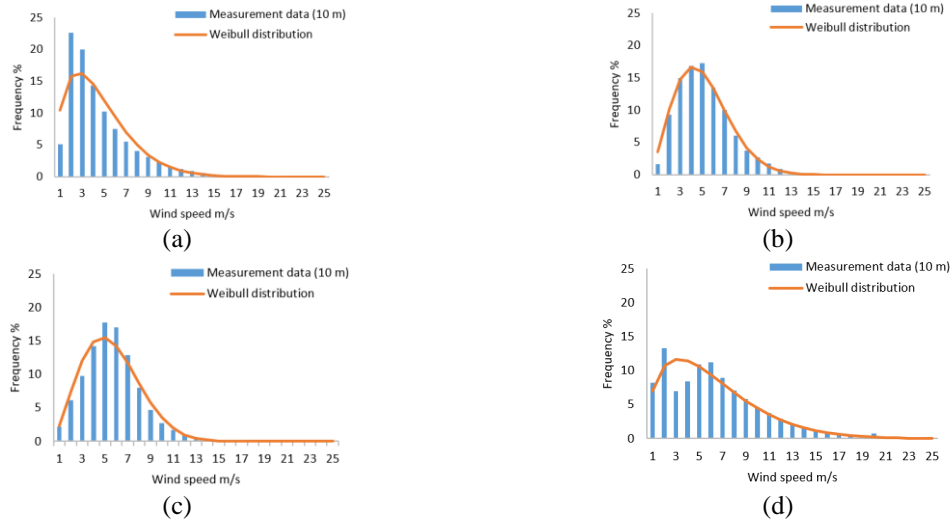


Figure 3. Distribution of wind speed frequencies for the four sites studied with (a) the frequency distribution of Fezouata, (b) the frequency distribution of Ouijjane, (c) the frequency distribution of El Ouatia, and (d) the frequency distribution of Taroudannt

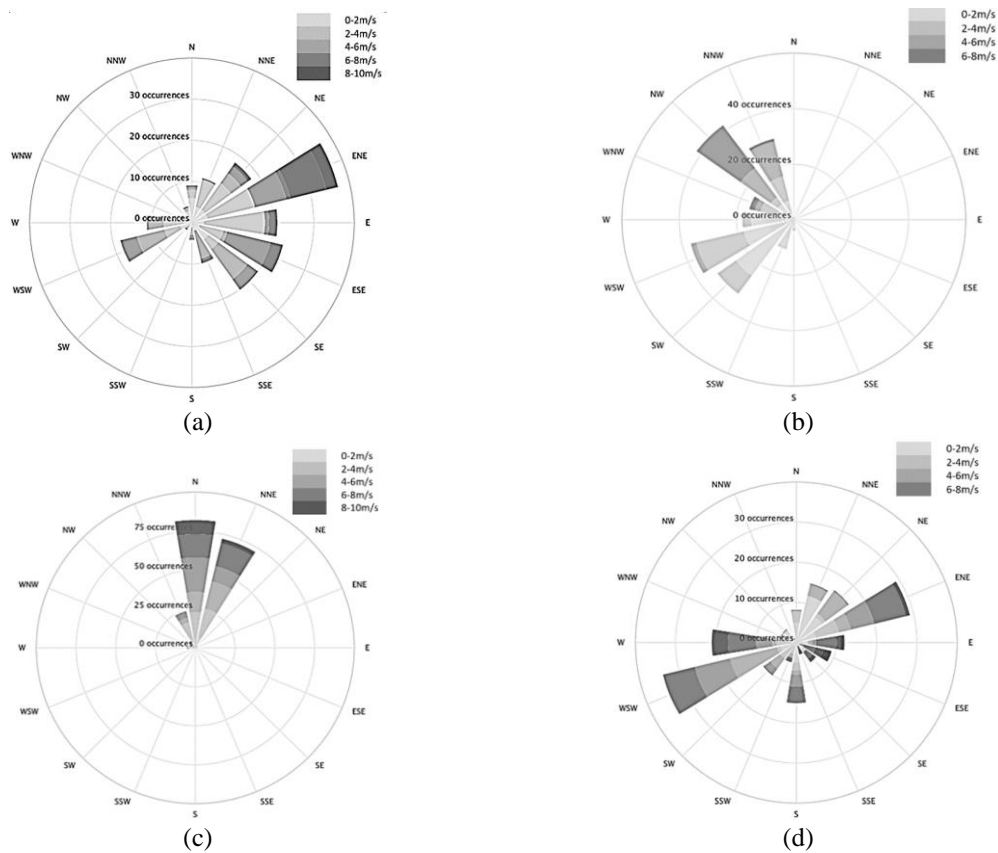


Figure 4. Wind direction for (a) FEZOUATA, (b) OUIJJANE, (c) EL OUATIA, and (d) TAROUDANNT

3.2. Wind generators

The technical specifications of the selected generators are presented in Table 4, with commercial models differing in power and altitude. Figure 5 illustrates the power curve of the four selected generators with nominal powers classified in ascending order of 250 kW, 500 kW, 800 kW, and 2000 kW. The selected wind machines are reliable with a useful life of about 20–years. Capacity factors refer to the power delivered during their lifetime, with which the properties of their respective locations correspond.

Table 4. Industrial characteristics of selected generators [41]–[43]

Wind turbine	Lagerwey 250 kW	EWT 500 kW	Gamesa 800 kW	Gamesa 2 MW
Hub height (m)	40	40	74	100
Swept area (m ²)	706.86	2123.72	2123.72	5026.55
Rotor diameter (m)	30	52	52	80
Cut-in wind speed V_C (m/s)	3	3	4	3
Cut-off wind speed V_D (m/s)	25	25	25	25
Rated wind speed V_r (m/s)	13	13	13	13
Rated power (kW)	250	500	800	2000

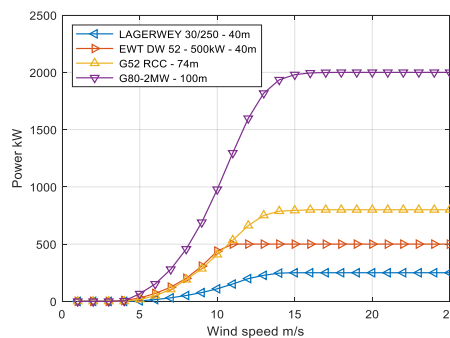


Figure 5. Power curves for selected generators

3.3. Energy delivered from turbines

Table 5 shows the energy supplied by the four wind turbines at each site. As shown in Table 5, the energy produced is related to the characteristics of the wind turbine (swept area, efficiency, altitude, electrical and mechanical performance, and type of manufacture), wind speed and geographic location. It is recommended that the capacity factor be greater than 25% for profitable investments in wind energy [44]. Based on this criterion, for EL OUATIA, only three models that could be suitable for grid integration (EWT 500 kW–40 m, Gamesa 800 kW–74 m, and Gamesa 2 MW–100 m), while for the rest of the sites, it has been proved that C_f is less than 25%, which is not economically feasible for the production of wind energy on the Oujjane, Taroudannt, and Fezouata sites.

Table 5 also shows the annual capacity of wind turbines produced at each site. Annual production capacity varies by location and turbine models. As shown, Oujjane provided the lowest annual energy production (almost equal to 0.2 GWh for generators with a hub height of 40 m and close to the value of 2.5 GWh for generators with a hub height of 100 m), on the other hand, Fezouata has an energy production (between 0.28 GWh and 3.05 GWh) against a production of between 0.21 GWh and 2.5 GWh at Taroudannt. El Ouatia can generally produce between 0.49 GWh and 5.53 GWh of wind power each year, respectively, using Lagerwey 250 kW–40 m and Gamesa 2 MW–100 m. Overall, the higher rate wind turbines generate, the higher output power can be. Exceptionally, for EWT 500 kW–40 m (with an altitude of 40 m and a nominal power of 500 kW) which recorded annual values higher than that of Gamesa 800 kW–74 m (with an altitude of 74 m and a nominal power of 800 kW).

Table 5. Annual values of capacity factor and output energy for the sites studied

Turbine	E_v (GWh/year); C_f (%)	Fezouata	Oujjane	El Ouatia	Taroudannt
LAGERWEY 250 kW–40 m	E_v	0.268	0.201	0.499	0.216
	C_f	11.06	8.29	20.61	8.89
EWT 500 kW–40 m	E_v	0.881	0.762	1.587	0.733
	C_f	18.15	15.72	32.72	15.10
Gamesa 800 kW–74 m	E_v	1.123	0.902	2.074	0.923
	C_f	14.47	11.62	26.71	11.89
Gamesa 2 MW–100 m	E_v	3.059	2.564	5.532	2.536
	C_f	15.76	13.21	28.51	13.07

4. CONCLUSION

Four hypothetical sites in Morocco were analyzed in order to estimate their wind potential. From a series of data recorded over a period of 24 years, a statistical analysis was made using the statistical distribution of Weibull. Thus, the following conclusions can be drawn: i) El Ouatia recorded the highest annual wind speed profile with a maximum wind speed of 6.4 m/s in July, against Fezouata which showed the lowest annual profile with a minimum value of 3.2 m/s in December. ii) Les paramètres de Weibull (k , c) varient d'un site à l'autre. Le paramètre de forme, k , enregistre des valeurs comprises entre 1,43 et 2,15, tandis que le paramètre d'échelle, c , enregistre des valeurs variant entre 4,49 m/s et 6,28 m/s. iii) For all selected generators, the highest energy production is calculated at El Ouatia, while the lowest energy production is at Ouijjane. The results revealed that El Ouatia is a good area to generate electricity from wind energy, followed by Fezouata. iv) The desert locations of Fezouata and Taroudannt have moderate wind energy potential, while Ouijjane is very poor in wind energy potential. A future study will be devoted to the socio-economic impact of the installation of the wind farm on the province of El Ouatia.

APPENDIX

Table 1. Summary analysis of the equations to measure the performance of wind power

Performance measures	Definition	Equation
Weibull probability density function $f(v)$	$f(v) = \left(\frac{k}{c}\right) \left(\frac{v}{c}\right)^{k-1} \exp\left[-\left(\frac{v}{c}\right)^k\right]$	(1)
Weibull cumulative density function $F(v)$	$F(v \leq v_0) = 1 - \exp\left[-\left(\frac{v}{c}\right)^k\right]$	(2)
Mean wind speed v_m	$v_m = c\Gamma\left(\frac{1}{k} + 1\right)$	(3)
Standard deviation σ	$\sigma = c\left[\Gamma\left(1 + \frac{2}{k}\right) - \Gamma^2\left(1 + \frac{1}{k}\right)\right]$	(4)
Weibull shape parameter k	$k = \left[\frac{\sum_{i=1}^n n_i v_i^k \ln(v_i)}{\sum_{i=1}^n n_i v_i^k} - \frac{1}{N} \sum_{i=1}^n n_i \ln(v_i)\right]^{-1}$	(5)
Weibull scale parameter c	$c = \left(\sum_{i=1}^n v_i^k P(v_i)\right)^{1/k}$	(6)
Wind power density $P(v)$	$P = \int_0^{\infty} \frac{P(v)}{A} f(v) = \frac{1}{2} \rho c^3 \Gamma\left(1 + \frac{3}{k}\right)$	(7)
Wind energy density $E(v)$	$E = \frac{1}{2} \rho A c^3 \Gamma\left(1 + \frac{3}{k}\right) \Delta T$	(8)
Extrapolation of the wind speed v	$v = v_0 \left(\frac{z}{z_0}\right)^\alpha$	(9)
Exponent α	$\alpha = \frac{0.37 - 0.088 \ln(v_0)}{1 - 0.088 \ln\left(\frac{z_0}{10}\right)}$	(10)
Extrapolation of k_z	$k_z = \frac{k_0}{1 - 0.088 \ln\left(\frac{z_0}{10}\right)}$	(11)
Extrapolation of c_z	$c_z = c_0 \left(\frac{z}{z_0}\right)^\alpha$	(12)

REFERENCES




- [1] F. Fazelpour, N. Soltani, and M. A. Rosen, "Economic analysis of standalone hybrid energy systems for application in Tehran, Iran," *International Journal of Hydrogen Energy*, vol. 41, no. 19, pp. 7732–7743, May 2016, doi:

- 10.1016/j.ijhydene.2016.01.113.
- [2] A. Tajeddin and F. Fazelpour, "Towards realistic design of wind dams: An innovative approach to enhance wind potential," *Applied Energy*, vol. 182, pp. 282–298, November 2016, doi: 10.1016/j.apenergy.2016.08.131.
 - [3] A. Dabaghyan, F. Fazelpour, M. D. Abnavi, and M. A. Rosen, "Evaluation of wind energy potential in province of Bushehr, Iran," *Renewable and Sustainable Energy Reviews*, vol. 55, pp. 455–466, March 2016, doi: 10.1016/j.rser.2015.10.148.
 - [4] K. Mohammadi and A. Mostafaeipour, "Using different methods for comprehensive study of wind turbine utilization in Zarrineh, Iran," *Energy Conversion and Management*, vol. 65, pp. 463–470, January 2013, doi: 10.1016/j.enconman.2012.09.004.
 - [5] D. Watts, N. Oses, and R. Pérez, "Assessment of wind energy potential in Chile: A project-based regional wind supply function approach," *Renewable Energy*, vol. 96, pp. 738–755, October 2016, doi: 10.1016/j.renene.2016.05.038.
 - [6] S. A. Abbasi, Tabassum-Abbasi, and T. Abbasi, "Impact of wind-energy generation on climate: A rising spectre," *Renewable and Sustainable Energy Reviews*, vol. 59, pp. 1591–1598, June 2016, doi: 10.1016/j.rser.2015.12.262.
 - [7] International Energy Agency, "Shaping a secure and sustainable energy future for all," March 2022, [Online]. Available: <https://www.iea.org/>.
 - [8] WWEA, "Technical report," 2013, [Online]. Available: <https://wwindea.org/>.
 - [9] Global Wind Energy Council, "Global Wind Statistics," 2016 [Online]. Available: <http://www.gwec.net/>.
 - [10] IRESEN, "Research Institute for Solar Energy and New Energies," 2019 [Online]. Available: <http://www.iresen.org/>.
 - [11] Ministry of Energy, Mines, Water and Environment, "Moroccan energy strategy: overview," [Online]. Available: <https://www.mem.gov.ma/>.
 - [12] M. E. Afilal and Z. Merzak, "Biogas Production from Anaerobic Digestion of Manure Waste: Moroccan Case," *Global Journal of Science Frontier Research Biological Sciences*, vol. 13, no. 1, pp. 0975-5896, 2013.
 - [13] A. Allouhi *et al.*, "Evaluation of wind energy potential in Morocco's coastal regions," *Renewable and Sustainable Energy Reviews*, vol. 72, pp. 311–324, May 2017, doi: 10.1016/j.rser.2017.01.047.
 - [14] M. Doukkali, "Water institutional reforms in Morocco," *Water Policy*, vol. 7, no. 1, pp. 71–88, February 2005, doi: 10.2166/wp.2005.0005.
 - [15] M. Enzili, A. Nayysa, F. Affani, and P. Simonis, "Wind energy in Morocco–Potential–state of the art–perspectives," *DEWI Magazin*, vol. 12, pp. 42–44, May 1998.
 - [16] A. Haddouche, "Renewable energy policy and wind energy in Morocco," *CDER–Center for Renewable Energies Development, Morocco*, October 2006.
 - [17] T. Kousksou *et al.*, "Renewable energy potential and national policy directions for sustainable development in Morocco," *Renewable and Sustainable Energy Reviews*, vol. 47, pp. 46–57, July 2015, doi: 10.1016/j.rser.2015.02.056.
 - [18] H. Nfaoui, J. Bahraui, A. S. Darwish, and A. A. M. Sayigh, "Wind energy potential in Morocco," *Renewable Energy*, vol. 1, no. 1, pp. 1–8, 1991, doi: 10.1016/0960-1481(91)90095-7.
 - [19] A. S. A. Shata and R. Hanitsch, "Electricity generation and wind potential assessment at Hurghada, Egypt," *Renewable Energy*, vol. 33, no. 1, pp. 141–148, January 2008, doi: 10.1016/j.renene.2007.06.001.
 - [20] T. R. Ayodele, A. S. O. Ogunjuyigbe, and T. O. Amusan, "Wind power utilization assessment and economic analysis of wind turbines across fifteen locations in the six geographical zones of Nigeria," *Journal of Cleaner Production*, vol. 129, pp. 341–349, August 2016, doi: 10.1016/j.jclepro.2016.04.060.
 - [21] M. A. Baseer, J. P. Meyer, Md. M. Alam, and S. Rehman, "Wind speed and power characteristics for Jubail industrial city, Saudi Arabia," *Renewable and Sustainable Energy Reviews*, vol. 52, pp. 1193–1204, December 2015, doi: 10.1016/j.rser.2015.07.109.
 - [22] L. Bilir, M. Imir, Y. Devrim, and A. Albostan, "An investigation on wind energy potential and small scale wind turbine performance at Incek region–Ankara, Turkey," *Energy Conversion and Management*, vol. 103, pp. 910–923, October 2015, doi: 10.1016/j.enconman.2015.07.017.
 - [23] F. Fazelpour, N. Soltani, S. Soltani, and M. A. Rosen, "Assessment of wind energy potential and economics in the north-western Iranian cities of Tabriz and Ardabil," *Renewable and Sustainable Energy Reviews*, vol. 45, pp. 87–99, May 2015, doi: 10.1016/j.rser.2015.01.045.
 - [24] M. Gökçek, A. Bayülken, and Ş. Bekdemir, "Investigation of wind characteristics and wind energy potential in Kirklareli, Turkey," *Renewable Energy*, vol. 32, no. 10, pp. 1739–1752, August 2007, doi: 10.1016/j.renene.2006.11.017.
 - [25] G. Gualtieri and S. Secci, "Methods to extrapolate wind resource to the turbine hub height based on power law: A 1-h wind speed vs. Weibull distribution extrapolation comparison," *Renewable Energy*, vol. 43, pp. 183–200, July 2012, doi: 10.1016/j.renene.2011.12.022.
 - [26] C. G. Justus, W. R. Hargraves, and A. Yalcin, "Nationwide assessment of potential output from wind-powered generators," *Journal of Applied Meteorology*, vol. 15, no. 7, pp. 673–678, July 1976, doi: 10.1175/1520-0450(1976)015.
 - [27] J. F. Manwell, J. G. McGowan, and A.L. Rogers, "Wind Energy Explained: Theory, Design and Application," *John Wiley & Sons*, 2010.
 - [28] D. Mohammed, A. Abdelaziz, E. Mohammed, and E. Elmostapha, "Analysis of wind speed data and wind energy potential using Weibull distribution in ZAGOURA, Morocco," *International Journal of Renewable Energy Development*, vol. 8, no. 3, pp. 267–273, 2019, doi: 10.14710/ijred.8.3.267-273.
 - [29] B. O. Bilal, M. Ndongo, C. M. F. Kebe, V. Sambou, and P. A. Ndiaye, "Feasibility study of wind energy potential for electricity generation in the northwestern coast of Senegal," *Energy Procedia*, vol. 36, pp. 1119–1129, 2013, doi: 10.1016/j.egypro.2013.07.127.
 - [30] S. Jerez, I. Tobin, M. Turco, P. Jiménez-Guerrero, R. Vautard, and J. P. Montávez, "Future changes, or lack thereof, in the temporal variability of the combined wind-plus-solar power production in Europe," *Renewable Energy*, vol. 139, pp. 251–260, August 2019, doi: 10.1016/j.renene.2019.02.060.
 - [31] J. Wohland, M. Reyers, J. Weber, and D. Without, "More homogeneous wind conditions under strong climate change decrease the potential for inter-statebalancing of electricity in Europe," *Earth System Dynamics*, vol. 8, no. 4, pp. 1047–1060, November 2017, doi: 10.5194/esd-8-1047-2017.
 - [32] P. L. M. Gonzalez, D. J. Brayshaw, and G. Zappa, "The contribution of North Atlantic atmospheric circulation shifts to future wind speed projections for windpower over Europe," *Climate Dynamics*, vol. 53, no. 7, pp. 4095–4113, May 2019, doi: 10.1007/s00382-019-04776-3.
 - [33] J. Peter, "How does climate change affect electricity system planning and optimal allocation of variable renewable energy?," *Applied Energy*, vol. 252, p. 113397, October 2019, doi: 10.1016/j.apenergy.2019.113397.
 - [34] M. Reyers, J. Moemken, and J. G. Pinto, "Future changes of wind energy potential over Europe in a large CMIP5 multi-model ensemble," *International Journal of Climatology*, vol. 36, no. 2, pp. 783–796, June 2015, doi: 10.1002/joc.4382.
 - [35] B. Pickering, C. M. Grams, and S. Pfenniger, "Sub-national variability of windpower generation in complex terrain and its correlation with large-scale meteorology," *Environmental Research Letters*, vol. 15, no. 4, p. 044025, 2020, doi: 10.1088/1748-




- 9326/ab70bd.
- [36] W. H. Press, B. P. Flannery, S. A. Teukolsky, and W. T. Vetterling, "Numerical recipes in C (2nd ed): the art of scientific computing," *Cambridge University Press*, St. New York, NY United States, p. 994, December 1992.
- [37] Z. R. Shu, Q. S. Li, and P. W. Chan, "Investigation of offshore wind energy potential in Hong Kong based on Weibull distribution function," *Applied Energy*, vol. 156, pp. 362–373, October 2015, doi: 10.1016/j.apenergy.2015.07.027.
- [38] E. L. Skidmore and J. Tatarko, "Stochastic wind simulation for erosion modeling. Trans," *Transactions of the ASAE*, vol. 33, no. 6, pp. 1893–1899, 1990, doi: 10.13031/2013.31555.
- [39] J. V. Seguro and T. W. Lambert, "Modern estimation of the parameters of the Weibull wind speed distribution for wind energy analysis," *Journal of Wind Engineering and Industrial Aerodynamics*, vol. 85, no. 1, pp. 75–84, March 2000, doi: 10.1016/S0167-6105(99)00122-1.
- [40] D. Mohammed, A. Abdelaziz, E. Mohammed, and E. Elmostapha, "Statistical Analysis of Wind Speed & Wind Direction in Tantan Province, Morocco," *International Journal of Recent Technology and Engineering*, vol. 8, no. 4, pp. 3955–3959, November 2019, doi: 10.35940/ijrte.D8444.118419.
- [41] Ewtdirect wind turbines, 2021, [Online]. Available: <https://ewtdirectwind.com/>.
- [42] Lagerwey wind turbines, 2021, [Online]. Available: <https://www.lagerwey.com/>.
- [43] Siemens Games, "Siemensgamesa wind turbines," 2021, [Online]. Available: <https://www.siemensgamesa.com/>.
- [44] A. Chauhan and R. P. Saini, "Statistical analysis of wind speed data using Weibull distribution parameters," *2014 1st International Conference on Non Conventional Energy (ICONCE 2014)*, 2014, pp. 160-163, doi: 10.1109/ICONCE.2014.6808712.

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