Journal of Optimization in Industrial Engineering
Vol. 16, Issue 2, Summer & Autumn 2023, 243-248
DOI: 10.22094/JOIE.2023.1997285.2104

Research Article

Assessment of Wind Energy Potential in Green-Mountain, Libya

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Received 28 September 2023; Revised 19 October 2023; Accepted 20 November 2023

Abstract

The annual capacity additions from renewable sources across the globe are growing at a rapid rate. Considering the efforts made by the international community to mitigate the effects of global warming, it is anticipated that it will continue to rise. As a result, many nations across the globe are increasing their installed capacities by capitalizing on renewable resources, such as wind resources, in order to satisfy the rising demand for electrical power. In the first part of this study, a wind resource assessment is carried out to determine the wind potential at several different places in the Green Mountain Province, which is in the northeastern part of Libya. The sites with valuable annual wind speed frequency distribution and power density are then evaluated further to determine the technological features required for a wind farm to be constructed there. Wind turbines are chosen based on their power characteristic curves, and those curves must match the resultant wind distribution. To determine the system's financial and technical parameters, the data from the most prominent site are analyzed using two different processing technologies, both of which implement the Weibull Distribution Model. The findings indicate the possibility of implementation at least at two locations, with hub heights of 10 and 50 meters, respectively.

Keywords: Wind power plants; Wind energy; Renewable energy systems; Weibull distribution.

1. Introduction

The fossil fuel remains for decades forming the major source of electricity production in Libya. After the political change during 2011 and afterwards, oil production has seriously dropped, which led to a severe shortage in electricity production. As a result of the required economic development, it is urgent to build a new infrastructure in this country after the massive destruction that occurred during the last decade. The remarkable annual growth in electrical demand brings back the attention of local government to the renewable energy resources available in the country. The location of Libya in the North African high solar radiation area as well as its long coastal line on Mediterranean Sea makes it a country of high potential for renewable energy sources. The growth of global renewable capacity is expected to accelerate in the next five years, accounting for almost 95% of the increase in global power capacity through 2026 according to International Energy Agency (IEC) [1]. Wind additions in 2021-2026 are planned to be 25% higher than in the previous five years with forecasts showing significant annual additions over this period, as shown in Figure 1.

In this research, the measured wind data was obtained from Statistics for Meteorological Stations in eastern Libya with an objective to assess the wind power class at several sites in this province. Wind data in this research was collected, for nine sites in the Green Mountain province from the Statistics for Meteorological Stations in Eastern Libya. The data were measured for a period of 10 years on an hourly basis.

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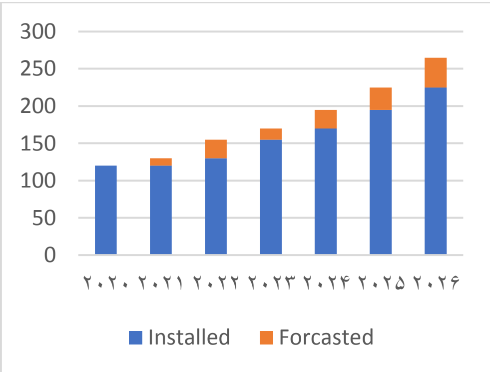

Fig .1. The Global Wind Capacity (GW), installed in 2020 and forecasted till 2026.

The objective was to determine the sites that show availability of best quality wind distributions and hence to forecast the annual energy production for certain sites after selecting suitable wind turbines. The structure of this paper is proceeded as follows: Section II provides the basics of theoretical aspects for wind power calculations; Section III describes the research method; Section IV gives the results and related discussions; and in Section V, authors give their conclusions and state any limitation. The structure of this paper has proceeded as follows: Section 2 provides the literature review for wind power topic; Section 3 describes the research method; Section 4 gives the results and related discussions; and in Section 5, the authors give their conclusions and state any limitation.

2. Literature Review

Many regions in developing countries are experiencing a shortage of energy supply which depends heavily on fossil fuels. Therefore, all possible renewable energy resources should be exploited to enhance energy security. Renewable Energy Authority of Libya (REAOL) developed a plan to be fulfilled up to 2030. This plan targets reaching 25% of renewable energies by 2025 with 2000 MW wind-based [2]. Thus, several studies analyzing the feasibility of wind data collected from different periods have been carried out in literature in different parts of Libya [3]-[5]. However, most of such studies focused on the Darna region, where a 60 MW wind farm project was planned [6]. The other studies were performed on different regions in this country, which were reported to have wind potential results [6]-[8]. However, more studies are required to help REAOL meet its scheduled plans, especially in the Green Mountain region, North-Eastern the country. Wind-based power projects start first with evaluating wind potentials in the sites under study. The variation of wind speed, as a function of altitude, is a key element in evaluating wind resources and predicting the energy generated in each wind farm. In general, wind speed data, measured at a predefined sensor height, are extrapolated to the desired level height using several algorithms [9]. One or more of these algorithms can be applied to determine Weibull scale and shape parameters [10]. The input data for this analysis is the data obtained from characterized wind data files. Thus, the extrapolated wind speeds and directions are used to determine wind speed distribution and wind energy density at any hub height.

The Weibull distribution concept is reported to be widely accepted in potential wind assessment due to the best informative role of its parameters on wind speed, variation, steadiness, and usable time-defined average values. A preferred site from an energy production viewpoint is the one which, through Weibull analysis, shows high values of shape (k) and scale (λ) parameters in addition to having recognized wind power density. Process of estimating the parameters is carried out by Weibull distribution using several algorithms, among which the MLM and the LSM are the most common. The values of scale and shape parameters from a method which best matches the original wind data's characteristics are used to make evaluations on wind class at a certain location. Also, wind speed interpolation can cope with various standard hub heights of wind turbines. Monthly wind analysis is performed on hourly-measured data to record the most productive months of the year, which are the months of highest wind speed.

Many authors during the last decade conducted case studies in different parts of the world [11] - [20] and recommend the monthly-based analysis of wind data for at least five years to obtain as accurate results as possible since the wind speed and direction vary continuously. This analysis is significant for wind power engineers to efficiently plan for an accurate mode of operation and schedule maintenance or procedural shutdowns. However, no previous studies were conducted to evaluate the wind data in Libya. Thus, this research aims to measure the wind data accurately and effectively, as the first study can be undertaken in Libya. Wind data in this research was collected for nine sites in the Green Mountain province from the Statistics for Meteorological Stations in Eastern Libya. The data were measured for 10 years on an hourly basis. The objective was to determine the sites that show the availability of best quality wind distributions and hence to forecast the annual energy production for certain sites after selecting suitable wind turbines.

3. Methodology

This research was carried out based on data obtained from the Statistics for Meteorological Stations in Eastern Libya to cover nine sites in Green-Mountain province located East-North Libya. The map of this region is shown in Figures 2 and 3.

Fig. 2. Map showing the location of Green Mountain district.

Fig. 3. Map showing locations for nine sites inside the Green Mountain district.

From this region, nine sites were selected, as pointed out by numbers in Figure 3 and Table 1. Upon these sites, two types of data were used; data from meteorological stations for long-term characterization (covers over 35 years) and the hourly data from NASA web database for the last decade. The wind files for the measured data were used in the initial stage to determine whether wind speeds and directions show a promising figure in these nine sites using the Weibull Distribution concept. Consequently, sites with the best results at a hub height of 10 m and a hub height of 50 m are selected for the next processing stage to determine the wind power results. The assessment proceeds in the following steps:

i) The first step defines the three geographical site descriptions: longitude, altitude, and latitude.
ii) Collection of measured data in which; wind speed, wind direction, ambient temperature, and atmospheric pressure, for a pre-defined time duration, preferably for a decade, with monthly average wind speeds (taken for hourly readings per day).
iii) Characterization of the wind resource for the selected sites to compare it monthly for an entire year. The comparison results in the selection of the most promising sites.
iv) Wind resource estimations are conducted from the available online database to compare it with measured data on the same time interval bases. The comparison results in the selection of the most promising site used for the wind farm proposal.
v) Prepare the wind resource data in the form of a weather file in SRW format suitable to be processed by the software simulating platforms. These files contain wind speed, wind direction, ambient temperature, and atmospheric pressure data at 10 and 50 meters above the site's ground to account for wind hub heights. This represents the wind resource over a period of one decade.
vi) The software modelling platform uses wind resource data (from the previous step) to provide the necessary record concerning the content of kinetic energy in the wind at the hub height of the turbine's location. This content of energy relies on parameters such as wind speed and air density and is time-dependable for one or more turbine hub heights.
vii) Specification of the wind turbine's ratings. This will decide the turbine's power curve, calculated from a set of turbine characteristics in the program database.
viii) The definition of the wind farm layout is an array of two dimensions that adjusts for each turbine's location and the required additional inputs used to account for losses.
ix) Calculation of the wind farm electrical output in kWh for each time span.
x) Calculation of the wind farm economic balance through calculating the electrical energy exported to the grid, the total capital and running costs, and finally, the electricity export revenue of the project.
Figure 4 visualizes the methodology flowchart.

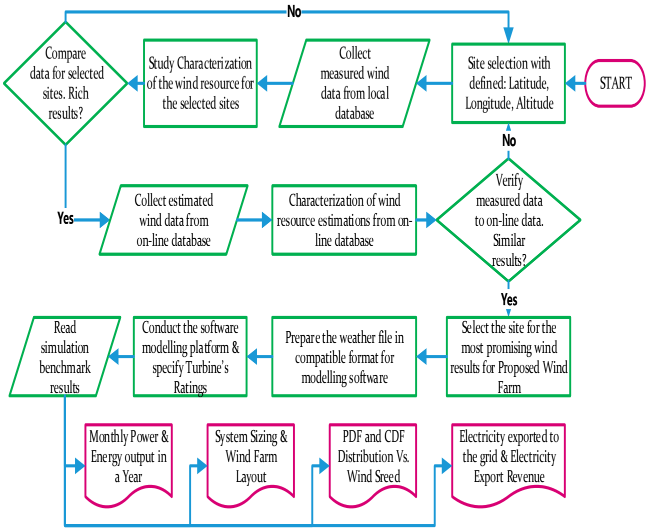

Fig. 4. Methodology flowchart

4. Results and Discussions

4.1 Elimination of some sites

The average wind speed values measured for a decade are compared for nine sites in the eastern province as shown in Figure 5. It shows that four sites could be considered eligible for more assessment which are: ALMERJ, SHAHAT, ALKUF, and TULMETHA. The locations of these sites are given in Table 1 and its average wind speed, measured, estimated at 10m and 50m is shown in Figure 6.

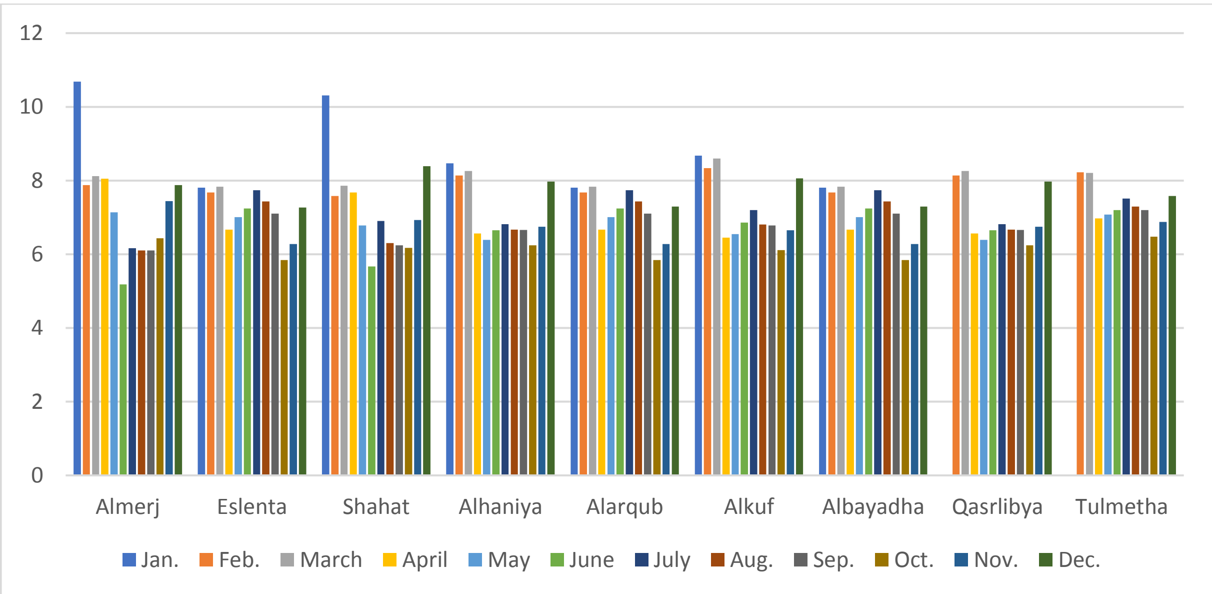

Fig .5. The Monthly Measured Wind Speed (m/s) Averaged over a Decade at 9 Sites

Table 1
Locations of the selected 4 sites

Site	Longitude	Latitude	Altitude
ALMERJ	21.88° E	32.50° N	391m
SHAHAT	21.87° E	32.81° N	620m
ALKUF	21.56° E	32.70° N	548m
TULMETH.	20.54° E	32.43° N	273m

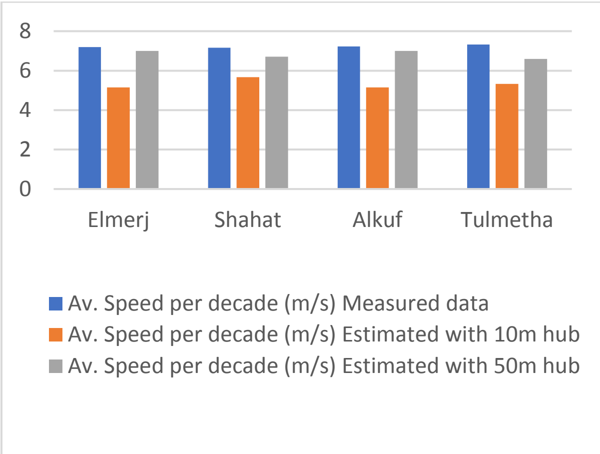

Fig .6. Average measured, estimated at 10m, and 50m wind speed.

4.2 Proceeded with Four Sites

The wind data files for these sites are processed using the Maximum Likelihood Algorithm and Least Square Algorithm to determine the Weibull parameters at two assumed hub heights. The obtained results, as shown in Tables 3 and 4, respectively, indicate a remarkably high convergence between the two algorithms. In case the results given by any algorithm are examined, the Maximum Likelihood, for instance, to evaluate Weibull parameters and WPD, it is seen that the ALMERJ site shows maximum shape parameter 'k' at both hub heights. As for the scale parameter 'λ', it is seen that the ALMERJ site shows the maximum result at 50m hub height, whereas the SHAHAT site shows the maximum at 10m hub height. For WPD results, SHAHAT shows the maximum result with (174.3 W/m^2) at 10m hub height also, whereas at 50m hub height ALKUF site shows a maximum of (343.9 W/m^2). This is evidence that higher Weibull parameters do not necessarily indicate better wind potential though the shape parameter is a significant indication of good wind distribution. The WPD is also a significant indication of the energy-enrichment of wind time series; both factors should enhance the wind potential evaluation.

Tables 2 & 3 give the Wind speed distribution analysis results by Maximum Likelihood Algorithm and Least Squares Algorithm respectively. Both algorithms give approximately similar results.

Table 2
Wind speed distribution analysis by Maximum Likelihood Algorithm

	Weibull *k*		Weibull λ (m/s)		Av. Speed (m/s)		Power density W/m^2		R^2	
Site	@10m	@50m	@10m	@50m	@10m	@50m	@10m	@50m	@10m	@50m
ALMERJ	2.465	2.879	5.616	7.664	4.982	6.832	120.7	280.8	0.97205	0.9670
SHAHAT	2.212	2.155	6.176	7.314	5.470	6.477	174.3	296.1	0.94653	0.9191
ALKUF	2.293	2.692	5.684	8.107	5.035	7.208	131.8	343.9	0.96687	0.9583
TULMETH.	2.377	2.403	5.865	7.321	5.198	6.490	141.0	272.1	0.96526	0.9378

Table 3
Wind speed distribution analysis by Least Squares Algorithm

	Weibull *k*		Weibull λ (m/s)		Av. Speed (m/s)		Power density W/m^2		R^2	
Site	@10m	@50m	@10m	@50m	@10m	@50m	@10m	@50m	@10m	@50m
ALMERJ	2.534	2.641	5.602	7.772	4.972	6.907	117.6	306.4	0.96997	0.94567
SHAHAT	2.427	2.358	6.125	7.247	5.431	6.422	158.2	267.5	0.94800	0.91630
ALKUF	2.322	2.370	5.676	8.251	5.029	7.312	130.1	393.4	0.96595	0.93934
TULMETHA	2.539	2.528	5.834	7.302	5.178	6.481	132.7	260.8	0.96665	0.94125

4.3 Wind power classification

According to the Pacific Northwest Laboratory (PNL) classification, wind energy potential is categorized into seven classes depending on the magnitude of power density and means of wind speed as shown in Table 4 [22]. Examining the resulted wind potential obtained in accordance with (PNL) classification, reveals the assessment of the results for the four sites obtained in this research. Table 5 shows the resulted assessment of the wind potential as obtained in this study. This assessment reveals remarkable wind class at SHAHAT, in the Green-Mountain province.

Table 4
Standard wind power classification [22]

Wind Speed (m/s)		Power Density W/m^2		Wind
@10m	@50m	@10m	@50m	Class
0 – 4.4	0 – 5.4	0 - 100	0 - 200	1 (Poor)
4.4 – 5.1	5.4 – 6.2	100 - 150	200 - 300	2 (Marginal)
5.1 – 5.6	6.2 – 6.9	150 - 200	300 - 400	3 (Moderate)
5.6 – 6.0	6.9 – 7.4	200 - 250	400 - 500	4 (Good)
6.0 – 6.4	7.4 – 7.8	250 - 300	500 - 600	5 (Excellent)
6.4 – 7.0	7.8 – 8.6	300 - 400	600 - 800	6 (Excellent)
> 7.0	> 8.6	> 400	> 800	7 (Excellent)

Table 5
Evaluation of wind class at 10m & 50m hub heights

	Wind Class		Wind Assessment	
Site	@10m	@50m	@10m	@50m
ALMERJ	2	2	Marginal	Marginal
SHAHAT	3	3	Moderate	Moderate
ALKUF	2	3	Marginal	Moderate
TULMETHA	2	2	Marginal	Marginal

As seen in Table 5, this evaluation at 10m hub height indicates that wind evaluation at the site SHAHAT is classified 'Moderate' with an annual average wind speed of 5.47 m/s, whereas wind at the remaining sites is classified as 'Marginal'. At 50m hub height, the wind potential at sites SHAHAT and ALKUF is classified as 'Moderate' with an annual average wind speed of 6.477 m/s and 7.208 m/s respectively, whereas at the remaining sites, the wind is classified as 'Marginal'.

4.4 Selection the class of the wind turbine

To calculate the electrical energy produced for the system simulated, the type of wind turbine is to be specified initially. The power curve characteristics of the selected turbine should have a cubic region (defined as the region in which wind speed ranges between the cut-in speed and the speed of the transition point) that fits the resulting wind speed distribution. The International Electrotechnical Commission (IEC) sets international standards for turbine wind speeds each wind class must withstand [23], as in Table 6.

Table 6
IEC Wind Class for Turbines Selection [23]

Annual Average Wind Speed (m/s)	10	8.5	7.5	6
Wind Turbine Class	I	II	III	IV

For annual average wind speed of (≥ 7.5 m/s) at the sites under study, a turbine of wind class III is to be selected. Thus, a 250 kVA wind turbine with the specifications listed in Table 7 is suggested. The proposed wind farm rated power is selected at 2 MW, which consists of 8 turbines, each rated at 250 kVA.

Table 7
Ratings of Proposed Wind Turbine

Rated Power	Hub Height	Rotor Diameter	Shear Coefficient	Cut in Speed	Rated speed	Cut out Speed
250 kVA	50m	54m	0.14	2.5 m/s	7.5 m/s	25 m/s

5. Conclusions

In this research, the Weibull distribution concept is used to evaluate wind data collected from several site locations. Wind data is analyzed using MLM and LSM algorithms at hub heights 10m and 50m. Results show that both algorithms give similar distribution compared to each other, and both give slightly lower simulation to the measured data at 10m hub height and slightly higher than measured data at 50m height. Four sites have proceeded where Weibull distribution results are used to evaluate wind class according to international standards. The evaluation shows that at least one adapted site, namely SHAHAT, has a wind class of 'Moderate' at both hub heights, while other sites have 'Marginal' evaluation class. Results also showed that at 10m, Weibull shape and scale parameters as well as wind speed and power density were best at SHAHAT. Whereas at 50m, site ALKUF outcomes showed similarly motivative results for Weibull parameters and wind density. Accordingly, the wind turbine type is selected with rated 250 kVA, 50m hub, and 54m in diameter. With its cut-in speed of 3.5 m/s and rated speed of 7.5m, it fits the wind speed distribution at these sites. Resulted wind classes characterize the size of the proposed wind farm. 2MW farm, which consists of 8 wind turbines, is an appropriate small-scale system for wind classes 2 and 3. This assessment for the wind potential at the selected sites in the province indicates that investment in wind farm projects for wind power plants is affordable in at least two sites in Green-Mountain province.

Limitations:

The simulation assumed that all wind farm turbines are at the same height. Hence, the air density is assumed constant during the computations. Terrain type, which specifies the wind shear coefficient, is also assumed to be the same for all turbines, which is quite acceptable for small-size wind farms.

Acknowledgments

Measured wind data for this work was offered by Meteorological Stations in Eastern Libya. The authors would like to acknowledge their contribution in this research.

References

[1] International Energy Agency, (2021) *Renewables 2021 Analysis and forecast to 2026*.

[2] Elmabruk A. et al, *Estimation of wind energy in Libya*, the 5th international renewable energy conference. Hammamet, Tunsia, 2014.

[3] Ahwide F. et al, *Estimation of Electricity Generation in Libya Using Processing Technology of Wind Available Data: The Case study in Derna*. ICESD 2013, Dubai, UAE.

[4] Elansari A. et al, *Impact of New Wind Farms on Power Distribution Networks (Derna Wind Project Case Study)*. 2012 International Conference on Renewable Energies for Developing Countries (REDEC), Beirut, Lebanon, Nov. 2012.

[5] Rajab Z. et al, *Modeling Approach To Evaluate Wind Turbine Performance: Case Study For a Single Wind Turbine of 1.65 MW In Dernah, Libya*. The 8th International Renewable Energy Congress (IREC 2017).

[6] Al-Hashimi S. et al, *The Future of Renewable Energy in* Libya. University Bulletin – ISSUE No.19- Vol. (3) – July - 2017.

[7] Mrehel O. et al, *Design and Simulation of Wind Farm in Tarhuna Region with Economic Analysis*. 2019 19th international conference on Sciences and Techniques of Automatic control & computer engineering (STA), Sousse, Tunisia, March 24-26, 2019.

[8] Aldricy M. et al, *Practical Design and Performance Evaluation of Micro-Wind Turbine in Libya*. The 9th international renewable energy congress (IREC 2018).

[9] Miu L. et al, *Evaluation of Wind Energy Resources at Unmonitored Micro-Wind Application Sites from Public Weather Station Records.* 6th International Conference on Clean Electrical Power (ICCEP), 2017.

[10] Belu B. , *Assessment and Analysis of Offshore Wind Energy Potential*. A book chapter, Web of Science. DOI: http://dx.doi.org/10.5772/intechopen.95346

[11] Samal R. K. et al., *Wind Resource Assessment and Energy Analysis for Wind Energy Projects*, 2017.

[12] Bloch M. et al, *A Research on Electricity Generation fromWind Corridors of Pakistan (Two Provinces): A Technical Proposal for Remote Zones.* Sustainability 2017, 9, 1611; doi:10.3390/su9091611

[13] Berrezzek F. et al., *Estimation of wind energy potential and Weibull parameter extrapolation of the city of Annaba, Algeria*. International Conference on Advanced Electrical Engineering (ICAEE), 2019.

[14] Sharma A. et al., *Estimation of Weibull Parameters and Wind Power Density at Different Heights for Akal Site at Jaisalmer in Rajasthan*. International Conference On Smart Technologies for Smart Nation (SmartTechCon), 2017.

[15] Waewsak J. et al, *An Analysis of Wind Speed Distribution at Thasala, Nakhon Si Thammarat, Thailand*. Journal of Sustainable Energy & Environment 2 (2011) 51-55.

[16] Tareka E. et al, *Statistical Assessment of Potential Wind Energy Sites in Coastal and Southern Part of Namibia*, International SAUPEC/RobMech/PRASA Conference, 2020.

[17] T. P. Chang, *Performance comparison of six numerical methods in estimating Weibull parameters for wind energy application*. Applied Energy, Vol. 88, No.1, pp. 272-282, 2011.

[18] Teyabeen A. A. et al., *Power Curve Modelling for Wind Turbines*. UKSim-AMSS 19th International Conference on Computer Modelling & Simulation (UKSim), 2017.

[19] Moorthy C. B. et al., *Assessment of wind power potential in a region of Goa, India*. IEEE Intern. Confer. on Power Electronics, Drives, and Energy Systems (PEDES), 2016.

[20] H. S. Bagiorgas, M. Giouli, S. Rehman and L. M. Al-Hadhrami, *Weibull Parameters Estimation using Four Different Methods and Most Energy-Carrying Wind Speed Analysis*. International Journal of Green Energy, Vol. 8, No. 5, pp. 529-554 , 2011.

[21] Freeman, J.; Jorgenson, J.; Gilman, P.; Ferguson, T., Reference Manual for the System Advisor Model's Wind Power Performance Model. Technical Report AC36-08GO28308, National Renewable Energy Lab. (NREL), United States, 2014.

[22] Elliott, D., and Schwartz, M., Wind Energy Potential in the United States. Progress report NTIS No. DE94001667, Pacific Northwest Laboratory (PNL), Richland, WA, September 1993.

[23] Gipe P., IEC Wind Turbine Classes, June 2006. Wind-Works: IEC Wind Turbine Classes.

[24] Wind was second-largest source of U.S. electricity generation on March 29, Today in Energy, April 2022, U.S. Energy Information Administration. U.S. Energy Information Administration - EIA - Independent Statistics and Analysis