SEMARAK ILMU PUBLISHING

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage: https://semarakilmu.com.my/journals/index.php/fluid_mechanics_thermal_sciences/index
ISSN: 2289-7879

Technical Assessment of Wind Energy Potentials in Bangladesh

Mithun Mondal[1], Djamal Hissein Didane[2,*], Alhadj Hisseine Issaka Ali[3], Bukhari Manshoor[2]

[1] Department of Mechanical Engineering, Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia (UTHM), Parit Raja, 86400 Batu Pahat, Johor, Malaysia
[2] Center for Energy and Industrial Environment Studies, Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia (UTHM), Parit Raja, 86400 Batu Pahat, Johor, Malaysia
[3] Department of Hydrocarbons Exploitation, Higher National Petroleum Institute of Mao Mao, Chad

ARTICLE INFO

Article history:
Received 18 February 2022
Received in revised form 5 May 2022
Accepted 10 May 2022
Available online 14 June 2022

Keywords:
Wind energy; wind conversion energy system; Weibull distribution; Bangladesh

ABSTRACT

Wind power has experienced very rapid growth over the past two decades as major technological advances have been made to reduce the cost of producing electricity through wind. It is also renowned for its low maintenance and negligible effect on environmental pollution. The main purpose of this study is to evaluate and compare the wind energy potential in seven major districts of Bangladesh including Barisal, Chittagong, Dhaka, Khulna, Rajshahi, Rangpur, and Sylhet. Data had been recorded on daily basis for the consecutive five years from 2015 until 2019 and analyzed using the Weibull distribution function for various essential parameters such as wind speed, wind power density and Weibull parameters. Results show that the monthly average wind speed varies between 0.5 m/s to 2.10 m/s for all the divisions except Chittagong which is in the range between 3 m/s and 4.5 m/s. Similarly, the maximum wind power density and wind energy density were also found in the Chittagong division with annual densities that range between 51.86967 W/m^2 to 84.01142 W/$m^2$and 454.3783 KWh/m^2 to 753.94 KWh/m^2, respectively. The shape and scale parameters (k and c) are varying between 0.774373 – 1.086069 and 0.684588 – 1.735511 m/s, respectively for all the divisions except Chittagong where it ranges between 1.463098 – 1.625881 and 3.131256 – 4.28601 m/s, respectively. Meanwhile, the prevailing wind directions vary from one division to another but mainly between the south and east. This, this study strongly recommends the Chittagong division for the utilization of the potentiality of wind energy typically for small-scale applications.

1. Introduction

The negative effects of fossil fuels on the environment have led scientists to consider the possibility of using renewable energy to generate electricity. The sources of electricity production such as coal, oil, and natural gas have contributed to one-third of global greenhouse gas emissions. It is essential to raise the standard of living by providing cleaner and more reliable electricity. The world has an increasing energy demand to fulfill the economic development plans that are being implemented. The provision of an increasing quantity of energy is a vital prerequisite for the

* *Corresponding author.*
E-mail address: djamal@uthm.edu.my

https://doi.org/10.37934/arfmts.96.2.1021

economic growth of the world [1,2]. Nonetheless, the depletion of conventional energy sources and associated environmental sustainability issues has put up new strategies for researchers and policymakers to explore and discover renewable energy sources such as solar, wind, geothermal, tidal, biogas, biofuels, etc. Among these, the usage of wind energy has become a promising resource due to its competitive nature as a clean, abundant, easily harvestable, inexhaustible, and affordable resource [3-6]. Certainly, irrespective of rampant irregularities existing in the global renewable energy market, overall installed capacity for wind power has rapidly increased by over 104% during the last decade which is clearly indicative of an increasing role of wind power in fulfilling future energy demands. Recently, China and the USA upgraded their installed capacity within one year by 23.328 GW and 8.203 GW, respectively, meanwhile the global wind power installed capacity showed a remarkable rise of 12.5% during the same period [7].

In Bangladesh, power generation is mostly dependent on natural gas, around 76.74 % of electricity is being produced from gas reserves and this percentage of electricity generation uses 37% of total gas consumption, while demand for gas consumption is increasing by about 8% per year [8]. Bangladesh is still far behind its expected growth of renewable energy, i.e., the target of 1000-1200 MW to ensure the electrification for all [9]. According to Bhuiyan *et al.,* [10], renewable energy is essential for economic growth, sustainable development of the country, and socio-economic development. Approximately 6% of power and energy belongs to renewable energy and the rest 94% are from fossil fuels [11]. Musial and Ram [12] mentioned about the possible potential of solar photovoltaic and wind energy are estimated at 50174 MW and 4614 MW, respectively, while the potential of energy from biomass and small hydropower plants is estimated to be 566 MW and 125 MW respectively.

Bangladesh already sets its goal for renewable energy to reduce the carbon footprints on the environment by avoiding the emission of greenhouse gasses. Wind, solar and biomass can be targeted as the source of renewable energy. Hydropower does not have much potential since the height of the land from sea level does not vary largely throughout the country. Since the available land area is mostly used for agriculture, hence the production of biomass on a large scale is not possible. Solar energy has great potential and has had a successful rollout so far. Nonetheless, the main drawback of solar energy is that it is difficult to produce solar energy at a large scale due to the requirement of the huge area to install the PV panels and hence, its use is limited mostly to the households of such areas where it is not possible to supply the grid power [13]. Therefore, like biomass energy, for solar energy also it is not possible to use the agricultural land in Bangladesh.

Wind energy is an interesting option as it needs significantly less space and can easily be combined with agriculture [14,15]. The government of Bangladesh has set each year’s targets for renewable energy development through several technologies from 2015 to 2021 and it is known as “RE Development Targets” which require an extra capacity of 3,100 MW of renewable energy. This increased capacity must be completed by 2021 and it is a challenge. Most of the new capacity should be provided by solar (1,676 MW, or 54 percent) and wind (1,370 MW, or 44 percent). However, if the data from 2016 to 2018 are analyzed, then it seems that it is tough to achieve the target for wind energy [13].

Thus, from the existing literature it is clear that in Bangladesh, wind farms are still limited. In addition, the wind assessment for a longer duration is also unavailable for specified heights. Therefore, this study will help to establish a clear map of suitable areas for wind farms.

2. Materials and Methods

Current research is conducted using the Weibull Distribution Function. The distribution of Weibull is among the generally accepted methods to clearly determine the wind activity at a site statistically. This section, therefore, describes all the methods for evaluating Weibull's shape and scale parameters and working process flow in the analysis. In this matter, the Weibull distribution method was proposed to analyze the wind potential as discussed and planned before conducting the study.

2.1 Wind Data Collection and Site Description

The wind data for this study were collected from the Bangladesh Meteorological Department (BMD) and which is the national meteorological organization of Bangladesh. The geographical coordinates of seven major divisions across the country are furnished in Table 1. This data covers a wide range of five years (2015-2019) and has been reported on average every month, at a standard height of 10 m above ground level. These locations reflect distinct geographical and climatological conditions in seven divisions, namely the divisions of Rajshahi and Rangpur in the north-western part of Bangladesh; the divisions of Chittagong and Sylhet in the south-eastern part of Bangladesh; and the divisions of Dhaka in the central part of Bangladesh; the divisions of Barisal and Khulna in the south-western part of Bangladesh, as seen in Figure 1. Specifications and properties of materials, equipment, and other resources used in the current study should be described in this section.

Fig. 1. Division map of Bangladesh

Table 1
Physical features of the seven divisions

Name of Division	Coordinates				Elevation (m)
	Latitude (N)		Longitude (E)		
	Deg.	Min.	Deg.	Min.	
Barisal	22	42	90	22	1.22
Chittagong	22	54	91	29	29
Dhaka	24	09	90	24	4
Khulna	22	54	89	14	9
Rajshahi	25	00	89	00	18
Rangpur	25	44	89	14	34
Sylhet	24	53	91	52	35

2.2 Weibull Distribution Function

The characteristics of the wind speed and the wind power capacity of any given region can be calculated using several statistical methods, among which the Weibull distribution is the most commonly acceptable technique [16-19]. This approach consists of various techniques for estimating Weibull's scale and shape parameters based on the type of accessible data and the degree of complexity required. The Probability Density Function (PDF) and the Cumulative Distribution Function (CDF), respectively, are defined in Eq. (1) and Eq. (4) to describe the wind speed variations of this method. The PDF defines in a particular way the portion of time or the likelihood of which wind speed prevails. The CDF, on the other hand, reflects the likelihood that the wind speed is lower than or equal to its mean velocity.

Therefore, to statistically analyze the meteorological data, the two-parameter Weibull distribution function, which is versatile, simple, and can show good agreement with the data observed was implemented in this work [20-22]. By applying this approach, the density of wind energy and the characteristics of wind speed can be effectively studied. In addition, this two-parameter Weibull distribution function is used for the estimation of annual energy output (AEP) in most commercially available applications [23]. Eq. (5) and Eq. (6) show the two parameters of the Weibull distribution function, i.e., the dimensionless function of the form, k, and the function of the scale, c, in meters per second unit, indicating, respectively, the stability and strength of the wind at a given area [24].

$$f(v) = \left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1} \exp\left[-\left(\frac{v}{E}\right)^{k}\right]_1 \quad (1)$$

where V is the probability of observing the wind speed V. c is the Weibull scale parameter and k is the dimensionless Weibull shape parameter and they are given by [25] as follows

$$k = 0 \cdot 83\, \bar{V}^{0\cdot 5} \quad (2)$$

$$C = \frac{\bar{v}}{\Gamma\left(1+\frac{1}{k}\right)} \quad (3)$$

Γ is the gamma function and $\bar{V}$ is the average wind speed and can be expressed as

$$\bar{V} = \frac{1}{n}\left[\sum_{i=-1}^{n} v_i\right] \quad (4)$$

The cumulative distribution, as given in the below equation, is the integral of the probability density function

$$F(v) = 1 - e^{-\left(\frac{v}{c}\right)^k} \quad (5)$$

2.3 Wind Speed Carrying Energy

The equation for wind speed provides the shape and scale parameters of the Weibull distribution when maximum wind energy is transported at a given location and is presented in Eq. (6) [26]. The maximum wind speed indicates the strength, stability, and persistence of the wind at that given location and is not the same as the average and highest wind speed. It is, therefore, necessary to estimate the wind speed at the stated spot, which can carry the maximum energy. At the same time, this can also be used to calculate the appropriate wind turbine and the rated wind speed, since when the wind turbine runs at the rated speed, the maximum energy is produced by the wind speed

$$V_{max}E = c\left(1 + \frac{2}{k}\right)^{1/k} \quad (6)$$

2.4 Wind Power Density

Eq. (8) describes the formula of producing energy from wind's kinetic energy that is proportional to the cube of the velocity where it is considered that the wind flows through a blade of swept area, A. The generation of energy that is started by a wind turbine after starting its operation increases with the increasing wind speed and continues to increase up to the cut-out speed of the wind turbine. The power generation reaches its peak by running the wind turbine at the rated speed. Whereas a steady power generation is possible by operating the wind turbine at a speed in between the rated and cut-out speeds. The turbine stops working as a precaution of safety by avoiding any damage when the wind speed exceeds its cut-out speed.

$$P(v) = \frac{1}{2}A\rho v^3 \quad (7)$$

The wind power density based on Weibull distribution analysis is calculated using the following Eq. (8) [19].

$$\mathrm{P}(v) = \int_0^\infty \frac{1}{2}\rho v^3 f(v)dv = \frac{1}{2}\rho c^3 \Gamma\left(\frac{k+3}{k}\right) \quad (8)$$

where ρ defines the air density (1.225 kg/m3) at sea level with 1 atmospheric pressure and a mean temperature of 15°C.

2.5 Wind Energy Density

Wind energy density, a vital wind characteristic can be estimated if a site's wind power density is known for a particular period or duration. Eq. (9) is used to calculate the wind energy density for the chosen time duration

$$\frac{E}{A} = \frac{1}{2}\rho c^3 \Gamma(\frac{k+3}{k})T \quad (9)$$

where T is the chosen time duration, e.g., 720h or 8640h can be considered as T, for the wind energy density of one month or a year time, respectively.

3. Results and Discussion

The seasonal wind speed behavior comprises the mean wind speed, two parameters of Weibull, wind power density, wind energy density and frequency were considered over the span of the five years of the study period as mentioned in the methodology of the study.

3.1 Monthly Wind Speed Variation

The monthly variations in mean wind speed are shown in Figure 2. It is observed that the values of the monthly average wind speed during the period of the study (five years), do not vary too much and it was almost in the range of 0.5 m/s to 2.10 m/s for all the divisions except Chittagong. The range of average wind speed for the Chittagong division was between 3 m/s and 4.5 m/s. The highest average wind speed for the Chittagong division was in April (4.5m/s) and the lowest was in October (2.5m/s). The average wind speed for the Sylhet division was nearly the same all over the year, only a bit higher in March and April than in other months and it had the second-highest average wind speed compared to other divisions. November showed the lowest mean wind speed for Barisal and Khulna division of value 0.4 m/s. The analysis also reveals that the lowest and highest wind speeds prevailed due to the dry winter and hot summer from October to February and March to June, respectively for the complete study period.

The highest mean speed of different divisions is not at the same time, even not in the same year. For example, the highest mean wind speed was observed in Barisal in May 2019 whereas the same in Chittagong was in April 2016. It is also evident from the five-year analysis that the range of the wind speed does not vary much for most of the divisions, except Chittagong which is 3.60 m/s to 5.70 m/s unlike others, i.e., 0.5 m/s to 2.10 m/s. The analysis also reveals that the lowest and highest wind speed prevailed due to the dry winter and hot summer from October to February and April to August, respectively for the complete study period.

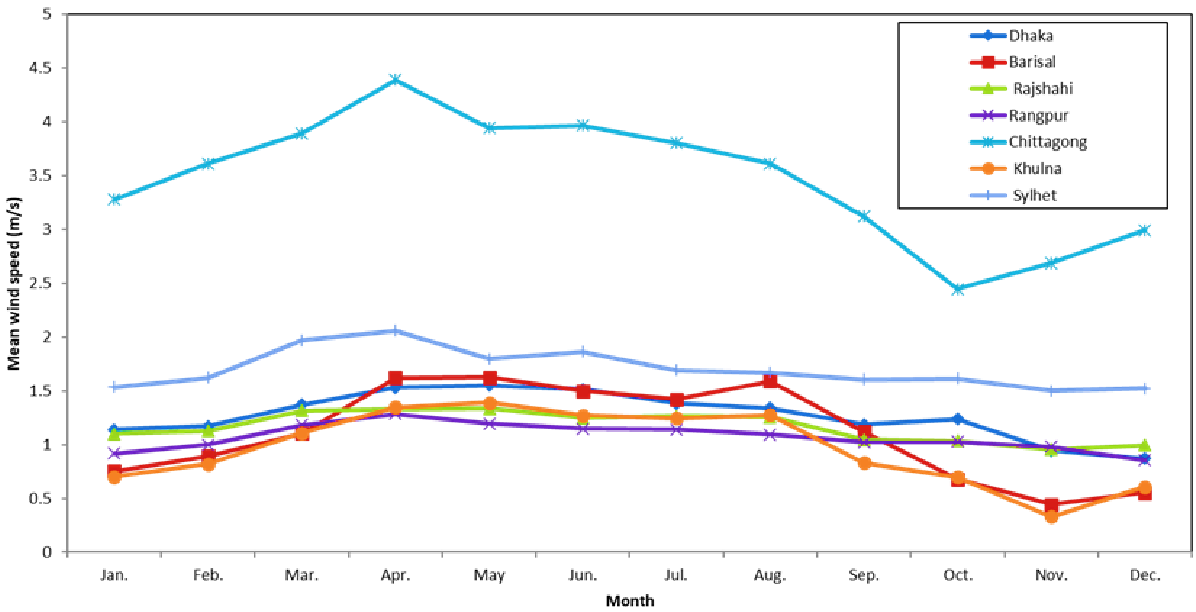

Fig. 2. Monthly variation of wind speeds for all division

3.2 Wind power and wind power density

The wind power density and wind energy density were also found at their high values for all the years in the Chittagong division and they are quite high than any other division of Bangladesh. Annual wind power density and wind energy density are ranged between 51.86967 W/m^2 to 84.01142 W/$m^2$and 454.3783 KWh/m^2 to 753.94 KWh/m^2. In April 2017, the wind power density was the highest during the studied period (see Figure 3&4).

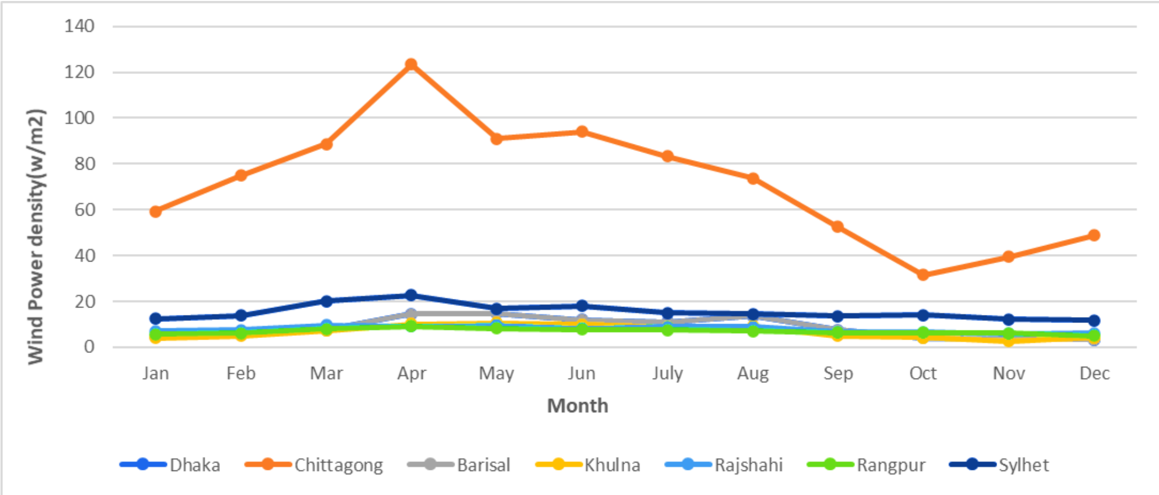

Fig. 3. Monthly variation of the wind power density in seven divisions of Bangladesh

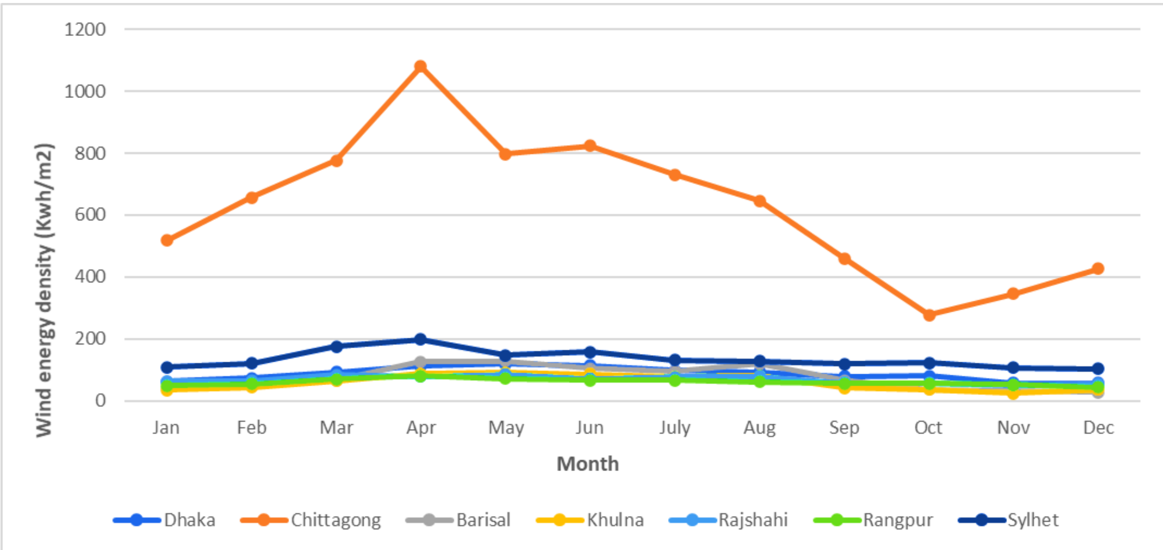

Fig. 4. Monthly variation of the wind energy density in seven divisions of Bangladesh

3.3 Weibull Distribution

For all the stations under analysis, the monthly mean scale parameter c (m/s) and form parameter k (dimensionless) of the Weibull distribution have been calculated and they are tabulated in Table 2. For almost all the divisions, the monthly values of parameter k ranged between 0.27 and 1.18, except for Chittagong, where it was between 1.28 and 1.73. This indicates that this division has high stability and high persistence compared to the others. The scale parameter c, which was slightly greater than the average wind speed, ranged from 0.54 to 2.18 m/s for nearly all the divisions and from 2.61 to

4.91m/s for the Chittagong division. The highest and lowest values of the dimensionless shape parameter k were observed as 1.73 and 0.27, respectively, at Chittagong and Barisal. This is because the Chittagong division is near the Bay of Bengal Sea with lots of open and flat areas and hence, these higher values of the scale parameter denote that these sites are windy.

The shape and scale parameters (k and c) of Weibull are varying from 0.774373 – 1.086069 and 0.684588 – 1.735511 m/s, respectively for all the divisions of Bangladesh except Chittagong. The same for Chittagong ranges between 1.463098 – 1.625881 and 3.131256 – 4.28601 m/s, respectively which shows that both the parameters are quite high in Chittagong than in other divisions.

Figure 5 reveals that the frequency curve behaves almost similarly for all the divisions except Chittagong and it was observed that only at 1 m/s wind speed, the frequency was lower at Chittagong than others whereas, for any other wind speed range, the frequency was high at Chittagong.

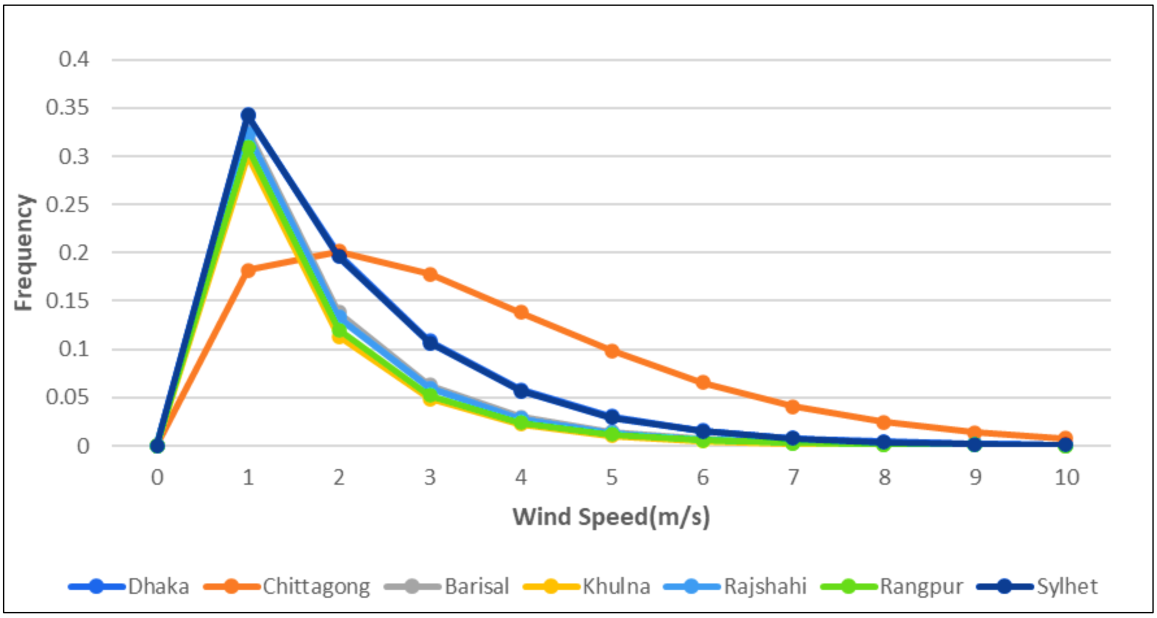

Fig. 5. Weibull wind speed frequencies of seven divisions in 2019

Table 2
Monthly Weibull parameters (k, c)

Division	Param-eter	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Barisal	k	0.71	0.77	0.86	1.04	1.04	1.01	0.98	1.04	1.61	1.04	0.52	0.27
	c	0.62	0.78	1.02	1.65	1.65	1.50	1.41	1.61	1.11	0.67	0.44	0.54
Chittagong	k	1.50	1.57	1.63	1.73	1.64	1.64	1.61	1.57	1.46	1.28	1.35	1.42
	c	3.63	4.01	4.34	4.91	4.40	4.43	4.24	4.01	3.44	2.61	2.91	3.27
Dhaka	k	0.88	0.89	0.96	1.02	1.02	1.01	0.96	0.95	0.89	0.91	0.82	0.79
	c	1.07	1.11	1.35	1.54	1.56	1.52	1.36	1.31	1.13	1.19	0.92	0.86
Khulna	k	0.69	0.74	0.87	0.96	0.97	0.92	0.92	0.93	0.75	0.67	0.48	0.62
	c	0.55	0.69	1.03	1.32	1.37	1.23	1.19	1.23	0.69	0.54	0.16	0.47
Rajshahi	k	0.86	0.88	0.95	0.93	0.95	0.90	0.93	0.92	0.84	0.84	0.81	0.82
	c	1.02	1.06	1.28	1.23	1.30	1.13	1.22	1.21	0.96	0.94	0.85	0.89
Rangpur	k	0.79	0.82	0.90	0.93	0.90	0.88	0.88	0.86	0.83	0.83	0.81	0.76
	c	0.80	0.90	1.12	1.24	1.13	1.08	1.07	1.01	0.93	0.93	0.87	0.72
Sylhet	k	1.02	1.05	1.16	1.18	1.11	1.13	1.07	1.07	1.04	1.05	1.01	1.01
	c	1.54	1.65	2.07	2.18	1.86	1.94	1.74	1.71	1.63	1.64	1.50	1.48

3.4 Prevailing wind direction

Polar diagram represented in Figure 6 to 12 the wind direction of all the seven divisions in Bangladesh. It can be inferred from these diagrams that the divisions on the north and north-eastern side, the wind directions are prominent on the eastern side, such as in Rangpur, Rajshahi and Sylhet. However, the rest of the divisions have a strong wind direction in the south. It is also evident from these images that except for Chittagong, for all 6 divisions the maximum wind speed varies from 2.10 – 3.60 m/s whereas in Chittagong the maximum wind speed was within the range of 5.70 – 8.80 m/s.

The above analysis reveals that all the parameters considered for wind behavior were quite high in the Chittagong division than in any other division of Bangladesh and hence, this study strongly recommends to Chittagong division for the utilization of wind energy potential.

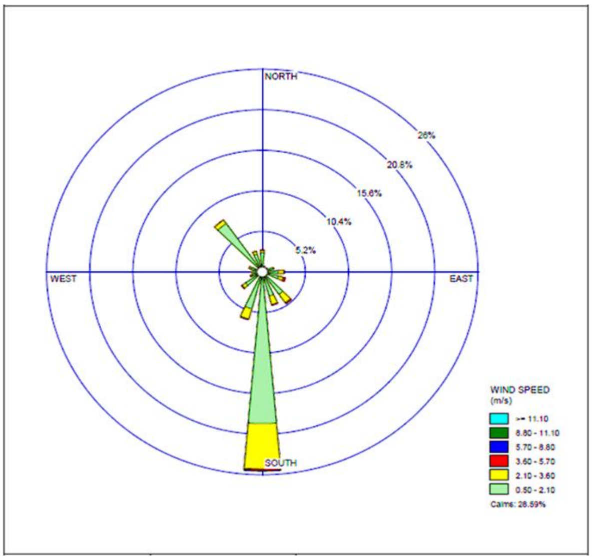

Fig. 6. Wind directions of Barisal

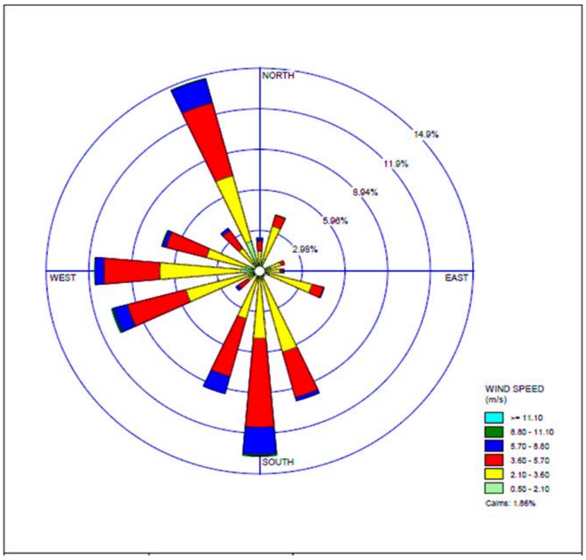

Fig. 7. Wind directions of Chittagong

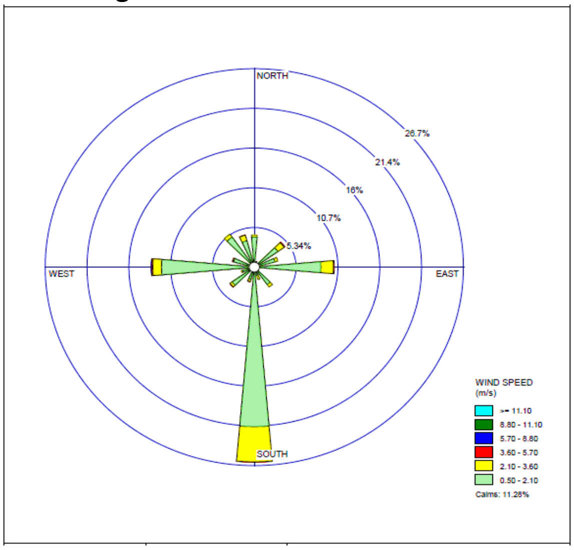

Fig. 8. Wind directions of Dhaka

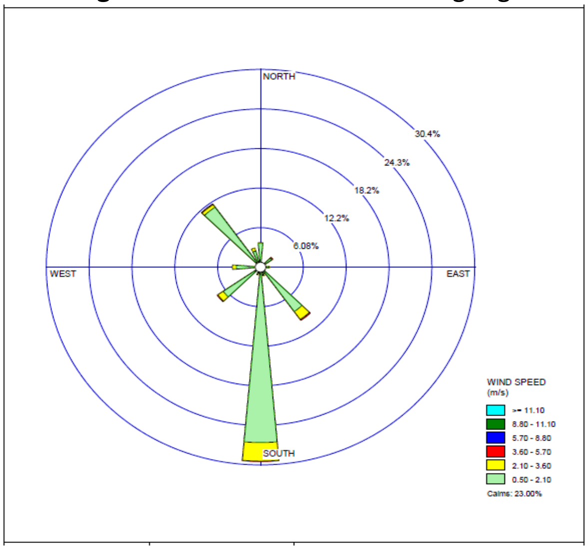

Fig. 9. Wind directions of Khulna

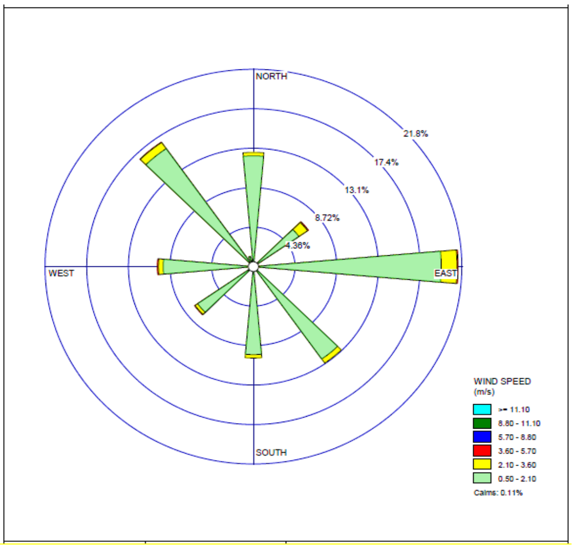

Fig. 10. Wind directions of Rajshahi

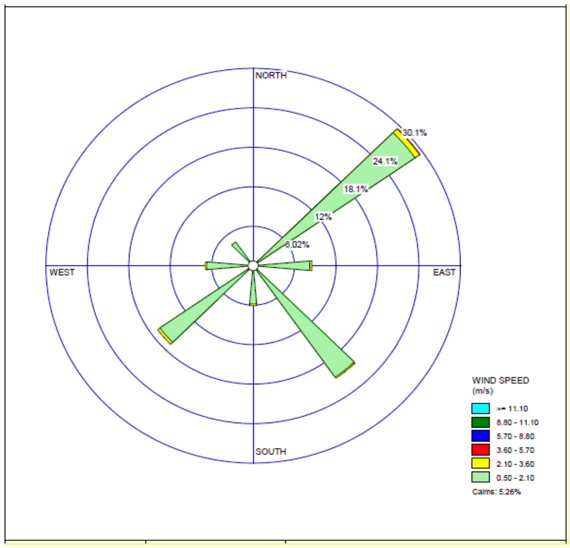

Fig. 11. Wind directions of Rangpur

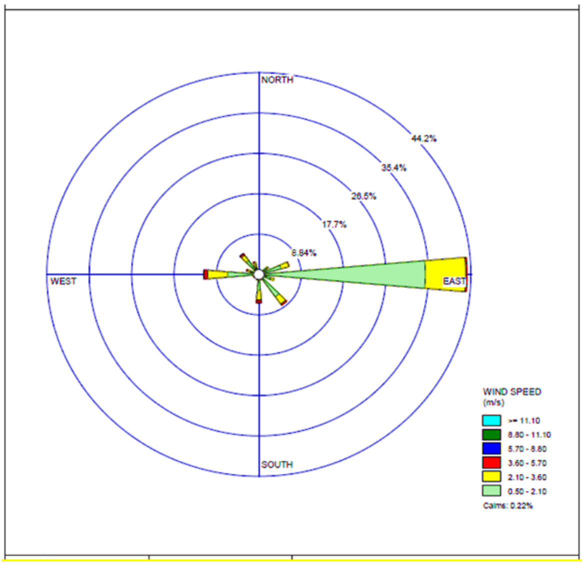

Fig. 12. Wind directions of Sylhet

4. Conclusion

The Weibull distribution function was used in this study for statistical analysis to assess the potentiality of wind energy in Bangladesh. Altogether, six parameters were used in this work and they are namely mean wind speed, two parameters of Weibull distribution, wind speed variation, wind power density and wind energy density. Comparing the potential of wind energy in the seven divisions of Bangladesh, the objectives of this study were achieved through the analysis of the results and comparing the tables, figures, and graphs. The results show that the monthly average wind speed during the five years of the study is in the range of 0.5 m/s to 2.10 m/s for all the divisions except Chittagong where it was between 3 m/s and 4.5 m/s. Accordingly, the wind power density and wind energy density were also found in the Chittagong division with annual values that ranged between 51.86967 W/m^2 to 84.01142 W/$m^2$and 454.3783 KWh/m^2 to 753.94 KWh/m^2, respectively.

In terms of Weibull parameters, the shape and scale parameters (k and c) are varying between 0.774373 – 1.086069 and 0.684588 – 1.735511 m/s, respectively for all the divisions except Chittagong where it ranges between 1.463098 – 1.625881 and 3.131256 – 4.28601 m/s, respectively.

Moreover, it was also found that the prevailing wind directions vary from one division to another. This assessment reveals that all the parameters considered for wind behavior were quite high in the Chittagong division than in any other division of Bangladesh and hence, this study strongly recommends the Chittagong division for the utilization of the potentiality of wind energy projects. Chittagong division is more suitable for small-scale wind farms due to the specific range of wind speeds.

Acknowledgement

The authors would like to acknowledge the financial support provided by the Universiti Tun Hussein Onn Malaysia through the H919 grant.

References

[1] Al-Ghriybah, Mohanad, Mohd Fadhli Zulkafli, Djamal Hissein Didane, and Sofian Mohd. "The effect of spacing between inner blades on the performance of the Savonius wind turbine." *Sustainable Energy Technologies and Assessments* 43 (2021): 100988. https://doi.org/10.1016/j.seta.2020.100988

[2] Al-Ghriybah, Mohanad, Mohd Fadhli Zulkafli, Djamal Hissein Didane, and Sofian Mohd. "Review of the recent power augmentation techniques for the Savonius wind turbines." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 60, no. 1 (2019): 71-84.

[3] Didane, Djamal Hissein, Muhammad Amir Zafran Saipul Anuar, Mohd Faizal Mohideen Batcha, Kamil Abdullah, Mas Fawzi Mohd Ali, and Akmal Nizam Mohammed. "Simulation study on the performance of a counter-rotating savonius vertical axis wind turbine." *CFD Letters* 12, no. 4 (2020): 1-11. https://doi.org/10.37934/cfdl.12.4.111

[4] Halmy, Muhammad Syahmy Mohd, Djamal Hissein Didane, Lukmon Owolabi Afolabi, and Sami Al-Alimi. "Computational Fluid Dynamics (CFD) Study on the Effect of the Number of Blades on the Performance of Double-Stage Savonius Rotor." *Cfd Letters* 13, no. 4 (2021): 1-10. https://doi.org/10.37934/cfdl.13.4.110

[5] Didane, Djamal Hissein, Siti Masyafikah Maksud, Mohd Fadhli Zulkafli, Nurhayati Rosly, Syariful Syafiq Shamsudin, and Amir Khalid. "Performance investigation of a small Savonius-Darrius counter-rotating vertical-axis wind turbine." International Journal of Energy Research 44, no. 12 (2020): 9309-9316. https://doi.org/10.1002/er.4874

[6] Loutun, Mark Jason Thomas, Djamal Hissein Didane, Mohd Faizal Mohideen Batcha, Kamil Abdullah, Mas Fawzi Mohd Ali, Akmal Nizam Mohammed, and Lukmon Owolabi Afolabi. "2D CFD Simulation Study on the Performance of Various NACA Airfoils." *CFD Letters* 13, no. 4 (2021): 38-50. https://doi.org/10.37934/cfdl.13.4.3850

[7] G. W. E. Council. "GWEC global wind report." 2018.

[8] Khatun, Dr Fahmida. "CPD-CMI Research Colloquium, FDI in the Energy and Power Sector in Bangladesh: Revisiting Policies and Contribution." (2013).

[9] Ahmed, Ferdous, Abul Quasem Al Amin, M. Hasanuzzaman, and R. Saidur. "Alternative energy resources in Bangladesh and future prospect." *Renewable and sustainable energy reviews* 25 (2013): 698-707. https://doi.org/10.1016/j.rser.2013.05.008

[10] Bhuiyan, M. M. H., M. Ali Asgar, R. K. Mazumder, and M. Hussain. "Economic evaluation of a stand-alone residential photovoltaic power system in Bangladesh." *Renewable energy* 21, no. 3-4 (2000): 403-410. https://doi.org/10.1016/S0960-1481(00)00041-0

[11] Sharif, I. Renewable energy development in Bangladesh, PPT Presentation on Executive Exchange on the use and integration of Renewable Energy in the Power Sector Madrid, Spain (2016).

[12] Musial, Walter, and Bonnie Ram. *Large-scale offshore wind power in the United States: Assessment of opportunities and barriers*. No. NREL/TP-500-40745. National Renewable Energy Lab.(NREL), Golden, CO (United States), 2010. https://doi.org/10.2172/990101

[13] "Rijksdienst voor Ondernemend Nederland - Wikipedia." https://www.rvo.nl

[14] Didane, D. H., S. M. Maksud, M. F. Zulkafli, N. Rosly, S. S. Shamsudin, and A. Khalid. "Experimental Study on the Performance of a Savonius-Darrius Counter-Rotating Vertical Axis Wind Turbine." In *IOP Conference Series: Earth and Environmental Science*, vol. 268, no. 1, p. 012060. IOP Publishing, 2019. https://doi.org/10.1088/1755-1315/268/1/012060

[15] Al-Ghriybah, Mohanad, Mohd Fadhli Zulkafli, Djamal Hissein Didane, and Sofian Mohd. "Performance of the Savonius Wind Rotor with Two Inner Blades at Low Tip Speed Ratio." *CFD Letters* 12, no. 3 (2020): 11-21. https://doi.org/10.37934/cfdl.12.3.1121

[16] Siti, M., M. Norizah, and M. Syafrudin. "The evaluation of wind energy potential in Peninsular Malaysia." *International Journal* 2, no. 4 (2011).

[17] Al-Ghriybah, Mohanad, Mohd Fadhli Zulkafli, Djamal Hissein Didane, and Sofian Mohd. "Wind energy assessment for the capital city of Jordan, Amman." *Journal of Applied Engineering Science* 17, no. 3 (2019). https://doi.org/10.5937/jaes17-20241

[18] Didane, Djamal Hissein. "Wind and solar assessment in the sahelian zone of chad." *International Journal of Integrated Engineering* 10, no. 8 (2018). https://doi.org/10.30880/ijie.2018.10.08.026

[19] Tchinda, Réné, and Ernest Kaptouom. "Wind energy in Adamaoua and North Cameroon provinces." *Energy Conversion and Management* 44, no. 6 (2003): 845-857. https://doi.org/10.1016/S0196-8904(02)00092-4

[20] Islam, M. R., Rahman Saidur, and N. A. Rahim. "Assessment of wind energy potentiality at Kudat and Labuan, Malaysia using Weibull distribution function." *Energy* 36, no. 2 (2011): 985-992. https://doi.org/10.1016/j.energy.2010.12.011

[21] Shata, AS Ahmed, and Rolf Hanitsch. "Evaluation of wind energy potential and electricity generation on the coast of Mediterranean Sea in Egypt." *Renewable energy* 31, no. 8 (2006): 1183-1202. https://doi.org/10.1016/j.renene.2005.06.015

[22] Keyhani, A., M. Ghasemi-Varnamkhasti, Mt Khanali, and R. Abbaszadeh. "An assessment of wind energy potential as a power generation source in the capital of Iran, Tehran." *Energy* 35, no. 1 (2010): 188-201. https://doi.org/10.1016/j.energy.2009.09.009

[23] Celik, Ali Naci. "A statistical analysis of wind power density based on the Weibull and Rayleigh models at the southern region of Turkey." *Renewable energy* 29, no. 4 (2004): 593-604. https://doi.org/10.1016/j.renene.2003.07.002

[24] Akpinar, E. Kavak, and S. Akpinar. "An assessment on seasonal analysis of wind energy characteristics and wind turbine characteristics." *Energy conversion and management* 46, no. 11-12 (2005): 1848-1867. https://doi.org/10.1016/j.enconman.2004.08.012

[25] Jaramillo, O. A., and M. A. Borja. "Bimodal versus Weibull wind speed distributions: an analysis of wind energy potential in La Venta, Mexico." *Wind Engineering* 28, no. 2 (2004): 225-234. https://doi.org/10.1260/0309524041211404

[26] Jamil, M., S. Parsa, and M. Majidi. "Wind power statistics and an evaluation of wind energy density." Renewable energy 6, no. 5-6 (1995): 623-628. https://doi.org/10.1016/0960-1481(95)00041-H