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Technical Assessment of Wind Energy Potentiality in Malaysia Using Weibull Distribution Function

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ABSTRACT

In this paper, an assessment of the wind characteristics and wind power potentials in three different stations (Chuping, Kuantan and Melaka) in Malaysia has been analyzed at 80 m height. The assessment technique was based on the two-parameter Weibull distribution function over three recent consecutive years (2018-2020) while aiming to establish the potentiality of the wind as a source of power generation in these sites. The results demonstrate that the monthly highest mean wind speeds were 4.42 m/s, 2.96 m/s and 2.17 m/s at Melaka, Kuantan and Chuping, respectively. The highest most probable wind speed was 4.70 m/s and the wind speed carrying maximum energy was 1.74 m/ both speeds occurred at Maleka in 2019. The yearly highest Weibull shape parameter was 1.69 and the scale parameter was 2.96 m/s. Among the three stations, Melaka has shown the highest wind power potentials with an average value of 26.10 W/m^2 followed by Kuantan with 12.71 W/m^2 and Chuping with 6.80 W/m^2 wind power density. The corresponding wind energy densities were 595.58 kWh/m2/year, 111.37 kWh/m2/year and 228.65 kWh/m2/year for Chuping, Kuantan and Melaka station, respectively. The prevailing wind directions are northeast at both Kuantan and Melaka station, west and southwest direction at Chuping station. It is therefore concluded that the potentiality of the wind power of the sites covered in the present study is only feasible for small-scale power generations.

1. Introduction

Renewable energy sources such as solar, hydro, geothermal and wind are receiving more attention nowadays from researchers, manufacturers, policymakers and developers as they are becoming promising alternative sources of energy. They are being explored and considered globally in the effort to decrease the dependency on fossil fuels which are depleting, finite, producing GHG emissions and rising in price [1,2]. In particular, wind energy is considered one of the fastest-growing and used among the renewable energy sources which can produce electricity without any harm to

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the environment [3,4]. This is because wind energy is clean, renewable and possesses economically viable characteristics [5]. The current advancement in windmill technologies for design and development made the production of electricity through wind turbines more efficient than ever before with an economically viable process [6, 7]. Thus, in order to get the utmost benefits from the energy that comes from wind resources, further investigations are needed for the economic utilization of wind energy. Wind turbines have a good potential to be developed in the future as the wind flows continuously around us to make it a better choice compared to solar power generation and fossil fuel [8,9]. Wind turbines are a better solution for large-scale applications such as the national grid for commercial-scale power production. There are two common types of wind turbine designs which are horizontal-axis and vertical-axis wind turbine. The vertical axis wind turbine is claimed as the most economical wind turbine model because it is relatively efficient, quiet, suitable to set up at any place and it can operate well in the turbulent wind [10-12]. While another design which is the horizontal axis wind turbine is the most built wind turbine ever created. It can generate electricity more than a vertical axis wind turbine but has a heavier weight and may not able to operate well in the turbulent wind [13]. The factor of heavier weight can cost more to undergo maintenance and do the set-up process. Wind turbines basically generate electricity by converting kinetic energy to mechanical energy. Then, a generator will convert the mechanical energy to electric energy. Wind turbines can generate electricity when the rotors capture the wind flow [14]. As the wind flows, the rotor or blade will rotate continuously when the wind is present. A shaft that is connected to the rotor and generator will spin to generate electricity. Wind turbines can also be used at home, school, or office to supply electricity sufficiently in our daily lives.

In Malaysia, the primary energy demand is highly dependent on the technology utilized as well as the price of fuels used in providing the energy to the various sectors. Therefore, the energy demand is more sensitive due to the changes in energy type, price of fuels which are used at different industries or sectors and the pace of technological change which can impact directly or indirectly on the energy demand and supply. As such, the energy prices and government policies will influence the pace of deployment and development of new technologies and taking into account the global market conditions and economic factors.

The wind is a form of solar energy that made is of the uneven heating of the sun to the atmosphere, the irregularities of the earth's surface and rotation of the earth [15]. The amount of wind energy varies according to the cube of wind speed. Therefore, it is important to understand the characteristic of the wind source in every aspect of wind energy exploitation starting from the identification of suitable sites and the design of wind turbines for the prediction of the economic viability of wind farm projects. It is also important to understand their effect on electricity distribution networks and consumers [16]. The potential of wind energy for a site is typically determined by the strength of the wind in the site of interest. Wind speed persistence and wind speed frequency are varying significantly at the very same terrain due to wind regime characteristics and that may lead to varied power output. Malaysia has two different main seasons, which are the southwest monsoon (May to September) and northeast monsoon (October -March). In other words, Malaysia has a non-uniform flow of wind and experience low-speed wind. Only certain places or areas in Malaysia experiencing strong wind. The success of a wind power project before the start is related to two things; the proper site assessment and choosing the appropriate wind turbine for the particular site. There are numerous numerical and statistical methods used to evaluate the wind potentials of a site since the meteorological wind speed data alone not sufficient to give an accurate appraisal. Among the widely used techniques is the two-parameter Weibull distribution method for its simplicity, suppleness and accuracy to fit the meteorological data [17-20].

Thus, in this study, the two-parameter Weibull distribution function is adopted to establish the potentiality of the wind characteristics as a source of power generation in the three geographically different stations in Malaysia, namely Chuping station in the state of Perlis, Kuantan station in Pahang and Melaka station in the state of Melaka.

2. Data and Site Description

The data in this study are collected from the Department of Meteorology Malaysia. The data involves three meteorological stations located at three different geographical states in Malaysia. The Chuping station is located in the states of Perlis, meanwhile, Kuantan station and Melaka station are available at the states of Pahang and Melaka, respectively, as shown in Figure 1. These stations are chosen for study because of the existence of future potential renewable energy envisioned by the local government besides the population density and tourist attractions. Thus, the results achieved are of significant importance in showing stakeholders the potentials of these sites at different altitudes and the prevailing directions of the wind. The data was collected recently based on daily average data for a period of three consecutive years starting from 2018 and 2020. The details of the sites chosen for this study are shown in Table 1.

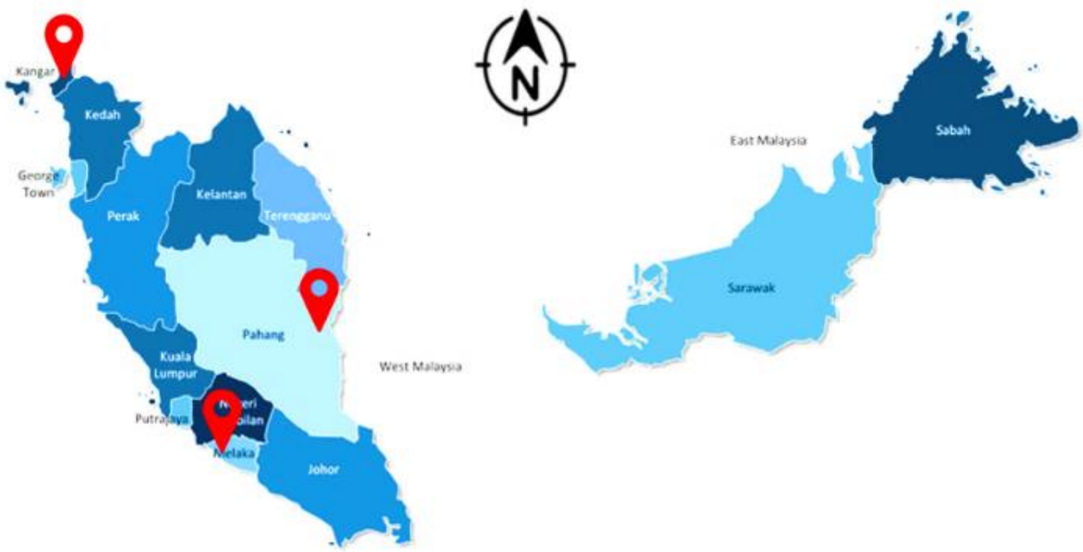

Fig. 1. Selected sites in the map of Malaysia

Table 1
Details of the stations

Station name	Station ID	Latitude	Longitude	Elevation
Chuping	48604	6° 29' N	100° 16' E	21.7 m
Kuantan	48657	3° 46' N	103° 13' E	15.2 m
Melaka	48665	2° 16' N	102° 15' E	8.5 m

Moreover, the data have been adjusted to cover the variations of wind velocity with altitudes using the 1/7th wind profile power law given in Eq. (1). This equation predicts that the wind velocity increases proportionally to the seventh root of the altitude. The present analysis was adjusted to cover wind speed at 80 m since most of the existing wind turbines are installed at higher altitudes.

$$v_z = v_0 \left(\frac{z}{z_0}\right)^{\propto} \tag{1}$$

where v_z is the desired wind speed at height z, v_0 is the available wind speed at height z, typically at 10 m altitude. Meanwhile, $\propto$ is a coefficient that varies based on the stability of the atmosphere. For neutral stable conditions, a value of 1/7 is used which has also been adopted in this study.

3. Data and Site Description

3.1 Weibull Distribution Function

The analysis procedures in this study involve the use of the statistical two-parameter Weibull distribution function. It is commonly used in the assessment of wind power potentiality of a site due to its renowned simplicity, suitability, flexibility and commendable accuracy to reveal the wind characteristics of the particular topography chosen for the study. This method estimates two main parameters which are the dimensionless shape function and scale function of the Weibull distribution which are responsible for the wind potentials characterizations of the site. The shape parameter which is shown in Eq. (2) reveals the stability and distribution of the wind at the potential site, while the scale parameter which is given in Eq. (3) indicates the strength of the wind at the site.

$$k = \left(\frac{\sigma}{\bar{v}}\right)^{-1.086} \quad (1 \leq k \leq 10) \tag{2}$$

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

where $\bar{v}$ is the average is wind speed, σ is the variance and Γ is the gamma function. The average wind speed and the variance are calculated through the expressions given in Eq. (4) and Eq. (5).

$$\bar{v} = \frac{1}{n}\left[\sum_{i=1}^{n} v_i\right] \tag{4}$$

$$\sigma = \left[\frac{1}{n-1}\sum_{i=1}^{n}(v_i - \bar{v})^{\frac{1}{2}}\right] \tag{5}$$

Moreover, the Weibull distribution function describes the frequency of wind speed distribution and wind energy density using the probability density function which is shown in Eq. (6) and the cumulative distribution function which is given in Eq. (7). These two functions also depict the variations of the wind speed of the site. The probability density function shows the probability where the wind speed prevails at a certain direction and the cumulative distribution function shows the probability whereby the wind velocity is equivalent to the average velocity or lower.

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

$$F(v) = 1 - e^{-\left(\frac{v}{c}\right)^{k}} \tag{7}$$

where *v*, is the average wind speed, *c* and *k* are the Weibull scale and shape parameters, respectively.

Furthermore, the most frequent or probable wind velocity and the wind velocity that carries the maximum energy can also be estimated using this shape and scale parameters of the Weibull functions. Thus, the most probable wind velocity and the wind velocity that carries the maximum energy are expressed as shown in Eq. (8) and Eq. (9).

$$v_{mp} = c\left(1 + \frac{1}{k}\right)^{\frac{1}{k}} \tag{8}$$

$$v_{max.E} = c\left(1 + \frac{2}{k}\right)^{\frac{1}{k}} \tag{9}$$

In terms of power, the theoretical wind power available in the air through a blade swept area, A is proportional to the cube of the velocity and it is given as in Eq. (10). However, the wind power density and wind energy density based on Weibull parameters are given as in Eq. (11) and Eq. (12).

$$P(v) = \frac{1}{2}A\rho v^3 \tag{10}$$

$$\frac{P}{A} = \int_0^\infty \frac{1}{2}\rho v^3 f(v)dv = \frac{1}{2}\rho c^3 \Gamma\left(\frac{k+3}{k}\right) \tag{11}$$

$$\frac{E}{A} = \frac{1}{2}\rho c^3 \Gamma\left(\frac{k+3}{k}\right) T \tag{12}$$

where ρ is the air density (1.225 kg/m^3) at sea level and T is the desired time.

4. Results and Discussion

4.1 Seasonal Variations of Wind Speed

The average wind speed variations throughout the different seasons of the year are discussed in this section. Figure 2 shows the seasonal wind speed variations at 80 m height above the ground over the three year-period studied in Melaka station. It is evident that the monthly average wind speed varies significantly from one season to another. The Southwest monsoon which is from May to September shows the lowest wind speed while the Northeast Monsoon which is from October to March exhibits the highest seasonal prevailing winds. This variation is in the range of about 1 m/s and 4.5 m/s. The lowest wind speed is found in the month of May and increases gradually until the highest wind occurs in January. However, the variation of the wind speed in terms of the different years covered is insignificant. A similar trend is observed for the Kuantan station with the highest wind velocity is noticed in the month of February, as shown in Figure 3. However, in Chuping station, the lowest and highest winds are observed in October and December, respectively with a decreasing trend starting from April until October, as shown in Figure 4. Furthermore, Figure 5 compares the seasonal variations of all sites over the three years under study. It is clear that Melaka station possesses the better potentiality of wind compared to the other stations with Chuping station displaying the weakest wind speeds. The yearly mean wind variation in Chuping is between about 1 m/s and 2.3 m/s and between 2.5 m/s to 2.9 m/s in Kuantan, for the lowest and highest wind speeds, respectively.

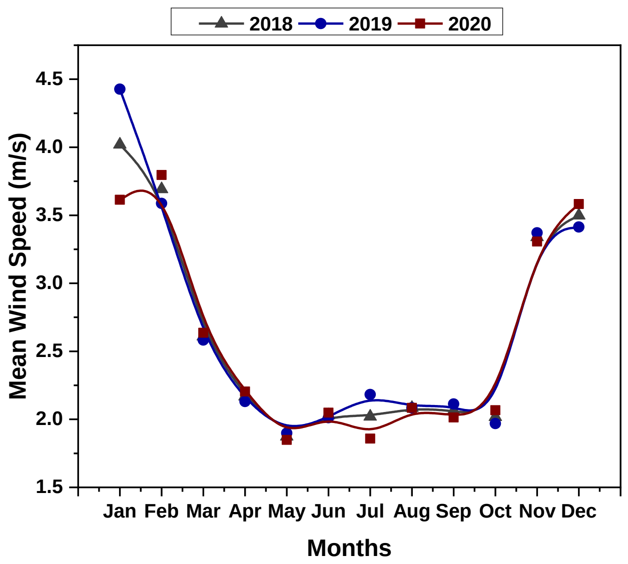

Fig. 2. Yearly seasonal variation in Melaka

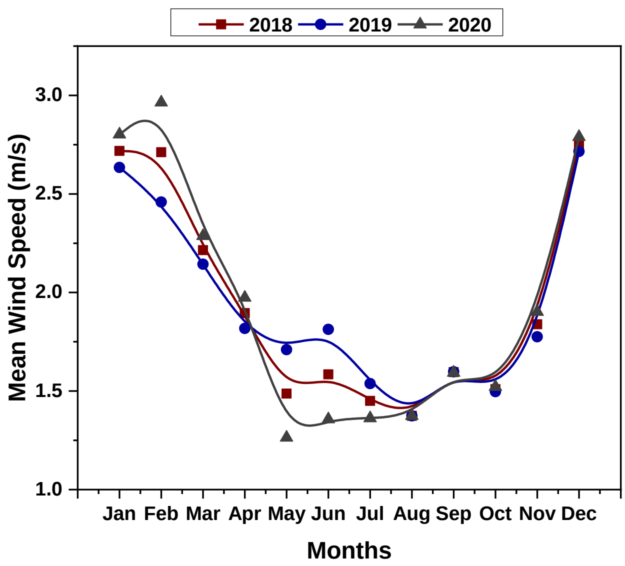

Fig. 3. Yearly seasonal variation in Kuantan

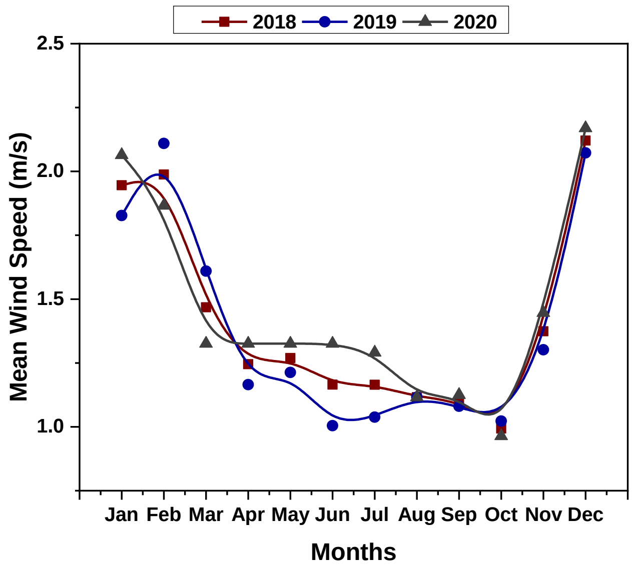

Fig. 4. Yearly seasonal variation in Chuping

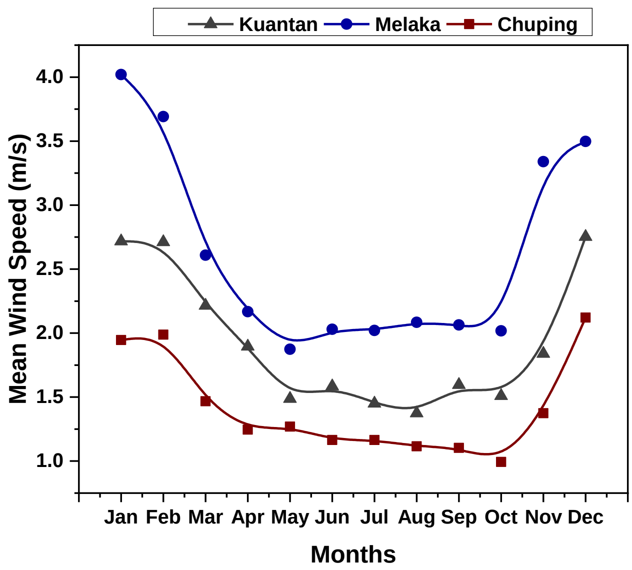

Fig. 5. Seasonal variation for all sites

4.2 Variations of Monthly Shape and Scale Weibull Parameters

In this section, the Weibull dimensionless shape parameter, *k* and scall parameter, *c* for all the stations through the three-year are presented, as shown in Table 2. The shape parameter describes the stability and distribution of the wind at the site and the scale parameter indicates the strength of the wind at the site under study. As expected, the monthly shape parameter and scale parameter variations in Melaka were the highest followed by Kuantan and Chuping. The shape parameter variations in Melaka, Kuantan and Chuping are between 1.43 and 2.21, 1.18 and 1.81 and 1.02 and 1.55, respectively, which signifies that the distributions of the wind in Melaka are more stable compared to the other two stations. In terms of the scale parameter which has a velocity unit and it is always greater than the average wind velocity, it ranges between 2.03 m/s and 5.00 m/s in Melaka and between 1.34 m/s and 3.33 m/s in Kuantan and between 0.98 m/s and 2.41 in Chuping, respectively for the lowest and highest, which again indicates that the wind Melaka is stronger than Kuantan and Chuping wind.

Table 2
Monthly Weibull parameters (k, c)

Month	Parameters	Chuping			Kuantan			Melaka		
		2018	2019	2020	2018	2019	2020	2018	2019	2020
Jan	k	1.46	1.42	1.51	1.73	1.70	1.76	2.11	2.21	2.00
	c	2.15	2.01	2.29	3.05	2.95	3.15	4.54	5.00	4.08
Feb	k	1.48	1.52	1.43	1.73	1.65	1.81	2.02	1.99	2.05
	c	2.20	2.34	2.05	3.04	2.75	3.33	4.17	4.05	4.29
Mar	k	1.27	1.33	1.21	1.56	1.54	1.59	1.70	1.69	1.70
	c	1.58	1.75	1.41	2.46	2.38	2.55	2.92	2.89	2.95
Apr	k	1.17	1.13	1.21	1.45	1.42	1.48	1.55	1.53	1.56
	c	1.32	1.22	1.41	2.09	2.00	2.18	2.41	2.37	2.45
May	k	1.18	1.16	1.21	1.28	1.37	1.18	1.44	1.45	1.43
	c	1.34	1.28	1.41	1.60	1.87	1.34	2.06	2.09	2.03
Jun	k	1.13	1.05	1.21	1.32	1.41	1.22	1.50	1.49	1.50
	c	1.22	1.02	1.41	1.72	1.99	1.45	2.25	2.23	2.27
Jul	k	1.13	1.07	1.19	1.26	1.30	1.23	1.49	1.55	1.43
	c	1.22	1.07	1.37	1.56	1.67	1.46	2.24	2.43	2.05
Aug	k	1.11	1.11	1.11	1.23	1.23	1.23	1.52	1.52	1.52
	c	1.16	1.16	1.16	1.47	1.47	1.47	2.31	2.31	2.31
Sep	k	1.10	1.09	1.11	1.33	1.33	1.33	1.51	1.53	1.49
	c	1.14	1.12	1.17	1.73	1.74	1.73	2.29	2.35	2.23
Oct	k	1.05	1.06	1.03	1.29	1.28	1.30	1.49	1.47	1.51
	c	1.01	1.05	0.98	1.63	1.62	1.65	2.23	2.18	2.29
Nov	k	1.23	1.20	1.26	1.42	1.40	1.45	1.92	1.93	1.91
	c	1.47	1.38	1.56	2.02	1.95	2.10	3.76	3.80	3.73
Dec	k	1.53	1.51	1.55	1.74	1.73	1.75	1.96	1.94	1.99
	c	2.35	2.30	2.41	3.09	3.05	3.13	3.95	3.85	4.04

4.3 Wind Power and Energy Density

In this section, the wind power density, wind energy density, most probable wind velocity and the wind velocity which carries the maximum energy are discussed. The figures which present the power densities for all the stations tend to show similar trends to the wind velocity figures. This is because the wind power rises proportionally with the cube of the wind velocity. Thus, the highest power densities in Melaka were observed during the northeast monsoon and the lowest in the southwest monsoon with corresponding power values of 72 W/m^2 and 12 W/m^2, respectively, as shown in Figure 6. Meanwhile, these values are 28 W/m^2 and 6 W/m^2 in Kuantan and about 15 W/m^2 and 3 W/m^2 in Chuping for the highest and lowest power densities, respectively, as shown in Figure 7 and Figure 8. Comparing the average power densities with respect to all stations covered, Melaka stations demonstrate the highest power density in all months of the year and Chuping shows the lowest potentiality of wind power, as shown in Figure 9.

Moreover, Table 3 shows a summary of all Weibull parameters based on annual average values. It is perceived that the annual average most probable wind speed in Chuping varies between 3.26m/s and 3.33 m/s and between 3.86 m/s and 3.89 m/s in Kuantan and between 4.63 m/s and 4.70 m/s in Melaka station. Furthermore, the corresponding highest wind energy density was 228.64 kWh/m^2 per year and it is found in Melaka station, while the lowest was 54.42 228.64 kWh/m^2 per year and it is observed in Chuping station. This indicates that Melaka station could possibly be promising for small-scale power generation using small-scale wind turbines which will add more economic benefits compared to the other two stations.

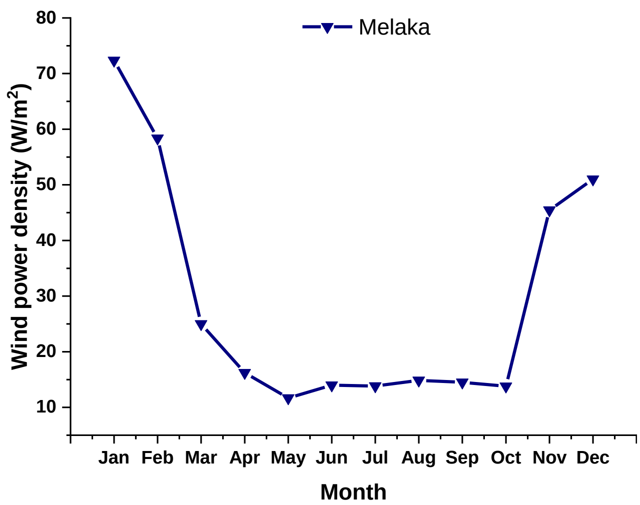

Fig. 6. Wind power density at Melaka

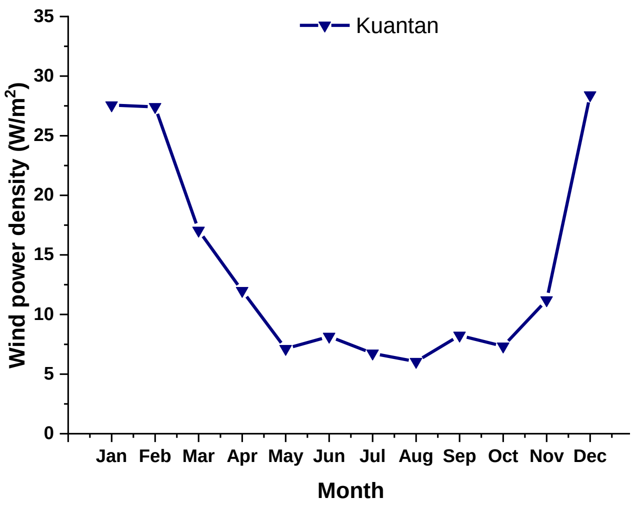

Fig. 7. Wind power density at Kuantan

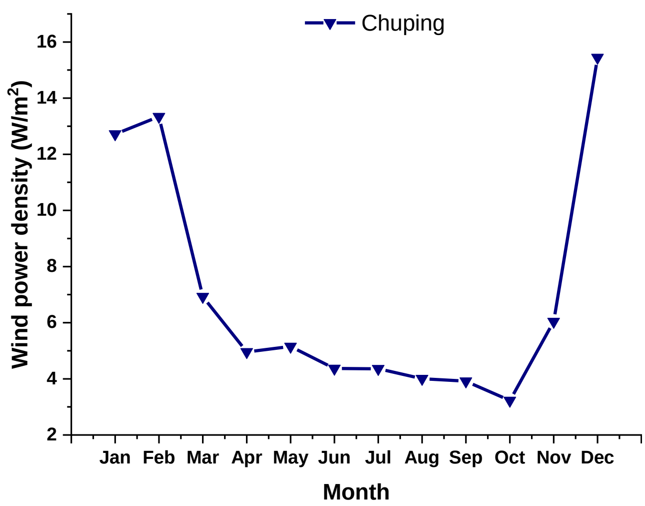

Fig. 8. Wind power density at Chuping

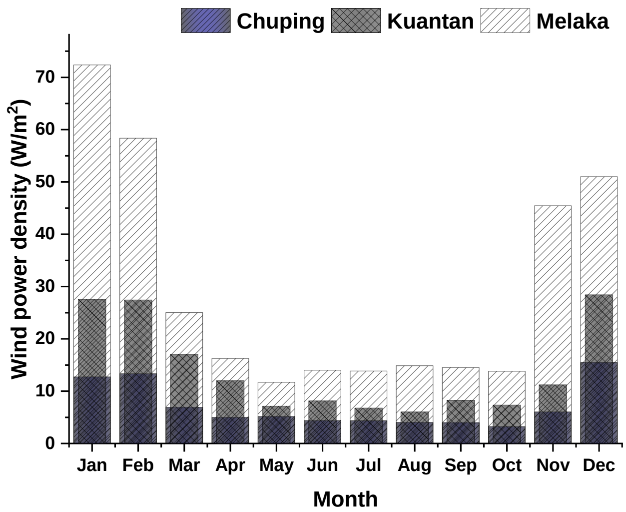

Fig. 9. Wind power density comparison

Table 3
Yearly mean site characteristics at 80 m height

Parameters	Chuping			Kuantan			Melaka		
	2018	2019	2020	2018	2019	2020	2018	2019	2020
$\overline{v}$	1.41	1.38	1.45	1.93	1.92	1.93	2.62	2.65	2.59
σ	0.39	0.41	0.38	0.53	0.46	0.63	0.79	0.84	0.76
k	1.24	1.22	1.25	1.45	1.45	1.44	1.68	1.69	1.67
c	1.51	1.47	1.55	2.12	2.12	2.13	2.93	2.96	2.89
V_{mp}	3.29	3.26	3.33	3.87	3.86	3.89	4.66	4.70	4.63
$V_{max, E}$	0.4	0.36	0.43	0.94	0.94	0.94	1.71	1.74	1.68
P/A	6.49	6.21	6.80	12.59	12.48	12.71	25.40	26.10	24.73
E/A	5688	5442	5955	1102	1093	1113	2225	2286	2166
	9.09	8.55	8.15	59.77	39.59	74.79	37.97	49.38	04.69

4.4 Weibull Distribution and Cumulative Distribution

The annual mean values of the Weibull shape parameter and scale parameter for all stations are presented in Table 2. The variation of these two parameters over the years within the same station is not significant but between the different stations is tremendous. Thus, the highest shape parameter value obtained is 1.69 and it has occurred in Melaka station and the lowest was obtained in Chuping and it is 1.22. similarly, the highest and lowest scale parameters were obtained within the same stations with the corresponding values of 2.96 m/s and 1.47 m/s, respectively. Moreover, Figure 10 and Figure 11 show the Weibull probability distribution function and the Weibull cumulative distribution function of all stations under study. The frequency figure illustrates that all stations have a similar trend of frequency against the wind velocity. The highest frequency of wind velocity occurs in the ranges of 1 – 2.5 m/s, which signifies the range of potentiality of wind speeds in these sites.

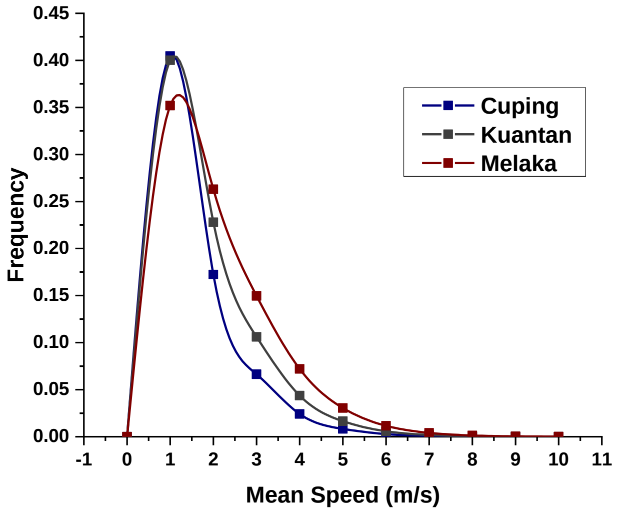

Fig. 10. Frequency for all sites

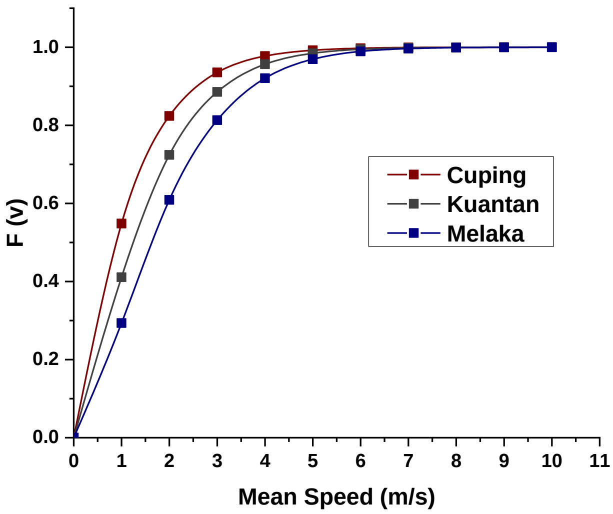

Fig. 11. Cumulative frequency for all sites

4.5 Polar Diagrams

Figure 12 to Figure 14 show the prevailing wind directions at 10 m height at Melaka, Kuantan and Chuping meteorological stations, respectively. It is noticeable that Melaka and Kuantan stations have a similar trend in terms of the prevailing wind direction. The wind in these two stations mostly blows in the northeast direction. However, at Chuping station, the wind diverges in several directions while dominating slightly in the west and southwest direction. It is also observed that the wind speed at Melaka and Kuantan station is stronger and covered more ranges of wind speed compared to Chuping station.

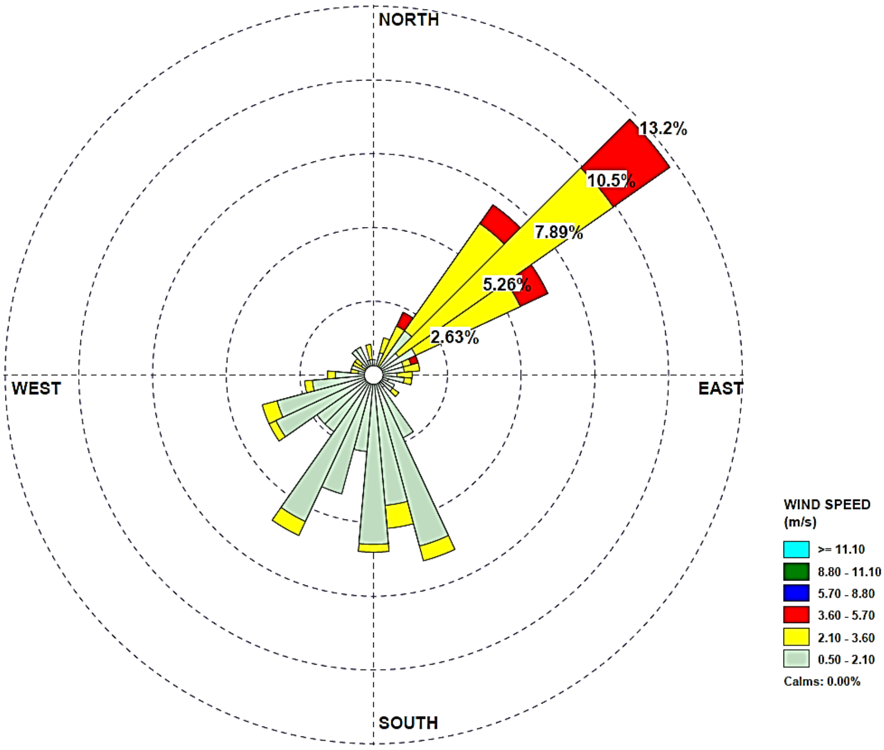

Fig. 12. Wind direction for the year 2019 in Melaka

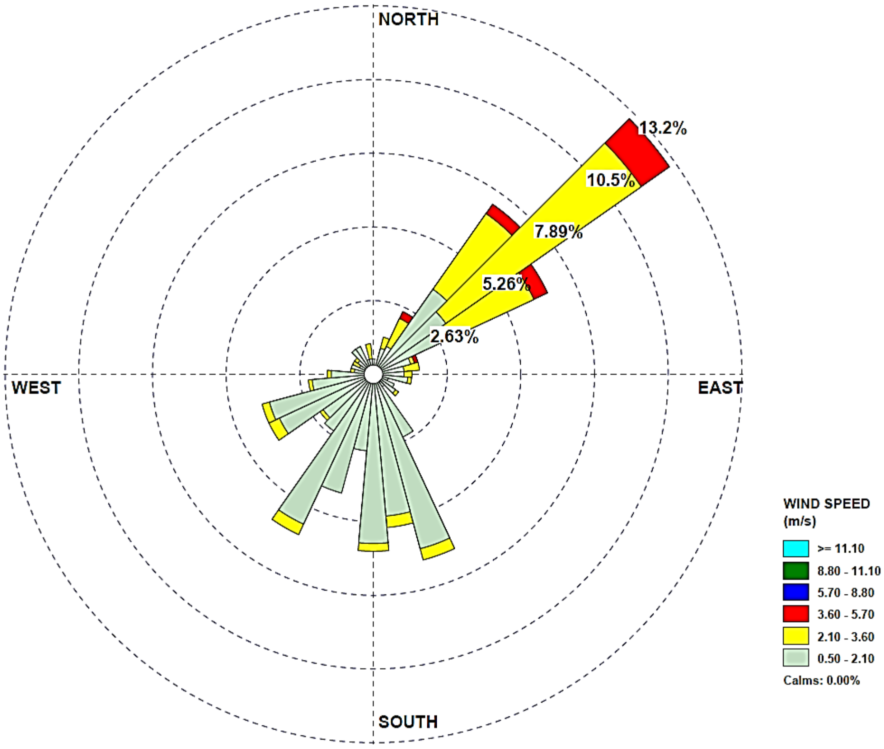

Fig. 13. Wind direction for the year 2019 in Kuantan

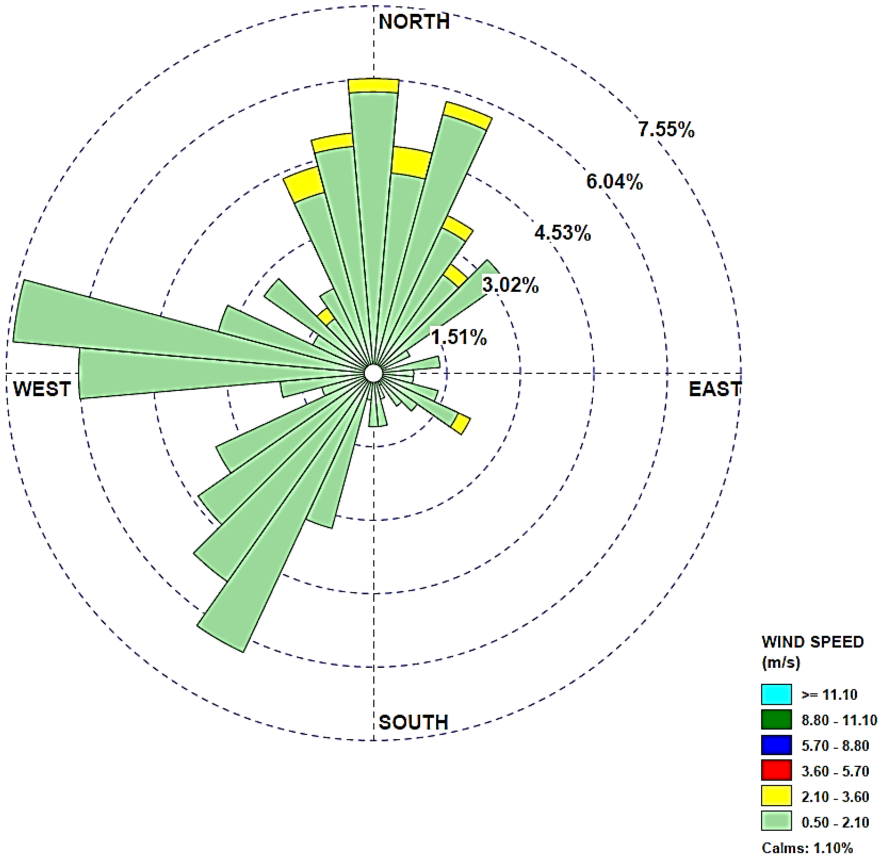

Fig. 14. Wind direction for the year 2019 in Chuping

4. Conclusions

In this study, the assessment of wind energy potentials of three different stations located in three major states in Malaysia has been analyzed. The evaluation was performed based on the two-parameter Weibull distribution function for a period of three years of daily-averaged data. The main concluding points are summarized as below

i. The analysis has shown that the monthly mean wind speed is higher during the northeast monsoon and lowest during the southwest monsoon throughout all stations. The highest mean wind speeds were found in Melaka followed by Kuantan and Chuping with a wind velocity of 4.42 m/s, 2.96 m/s and 2.17 m/s, respectively.
ii. The annual mean wind velocity throughout the three years studied at the three stations is 1.41 m/s, 1.92 m/s and 2.62 m/s, respectively for Chuping, Kuantan and Melaka. This indicates that a small-scale vertical axis wind turbine could be effective for small power generation at Melaka station. Thus, the most probable wind speed and wind speed carrying maximum energy were found both at Melaka station with 4.70 m/s and 1.68 m/s in the year 2019 and 2020, respectively.
iii. The annual maximum wind power density was 6.80 W/m^2 in Chuping, 12.71 W/m^2 in Kuantan and 26.10 W/m^2 in Melaka. Meanwhile, the annual maximum wind energy density was 595.58 kWh/m^2/year, 111.37 kWh/m^2/year and 228.65 kWh/m^2/year for Chuping, Kuantan and Melaka station, respectively.
iv. The prevailing wind direction is northeast at both Kuantan and Melaka station, while it diverges in several directions while dominating slightly in the west and southwest direction at Chuping station.

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