Technical Feasibility Analysis of Wind Energy Potentials in two sites of East Malaysia: Santubong and Kudat

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Technical Feasibility Analysis of Wind Energy Potentials in two sites of East Malaysia: Santubong and Kudat

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Abstract: This study presents an analysis of wind power potentials for two meteorological stations in the eastern part of Malaysia using the statistical Weibull distribution method over a period of ten years stretching from 2010 to 2019. As the estimation of the resource potentials is crucial towards the planning of a wind energy project, the primary objective of this study is to reveal the characteristics and potentials of the two selected sites. The results show that the highest annual average wind speed was 3.4 m/s at Kudat station and 2.3 m/s at Santubong station. The maximum shape and scale parameters were respectively 1.68 and 2.88 m/s and both appeared at Kudat station. The wind power density ranged between 9.45 W/m^2 and 24.24 W/m^2. The maximum energy density at Kudat was 207.60 kWh/m^2/year and 106.01 kWh/m^2/year at Santubong. The most probable wind speeds and wind carrying maximum energy were predicted at 1.68 m/s and 4.59 m/s and both speeds were observed at Kudat in 2019. The maximum deviation between observed frequencies and Weibull frequency distributions was around 27%. While the wind power at each site differs considerably, both of these two stations fall outside of the category of pacific northwest national laboratory (PNNL) classifications due to their low mean wind speeds. Nevertheless, it can be categorized for a smaller scale of wind power generation at a wind turbine elevation of more than 10 m.

Keywords: wind resource assessment; wind energy potential; Weibull distribution function; Santubong; Kudat; East Malaysia

1. Introduction

Nowadays, renewable energy resources which are natural and continuously replenishing, are becoming attractive for socio-economic development in developing nations. Due to the present issues related to conventional energy resources such as increasing prices, global warming and greenhouse gas emissions, finding alternative, clean, sustainable and renewable source of energies is essential and has been regarded as the primary concern for many countries including Malaysia. Malaysia is one of the largest consumers of energy in Southeast Asia[1,2)]. The main source of energy consumption in Malaysia comes from crude oil and natural gas. Today, Malaysia generates approximately 2% only of its energy from renewable energy sources and it has announced in 2018 that a mix of energy target of 20% from renewable energy resources from the overall energy generation by 2025[3,4)]. Therefore, renewable energy will economically and environmentally become a new growth area for Malaysia. Malaysia has begun to consider the development of wind energy harnessing technology. This is due to the annual growth in energy consumption and the greenhouse effects as a result of burning fossil fuels which in return produce greenhouse gas emissions.

Wind energy can be considered one of the most environment-friendly and has limited distributiveness and geographical boundaries. It is harnessed from the wind kinetic energy, which generates electrical energy through the mechanical torque of the rotating shaft. It has vast potentials to satisfy the world's energy needs while reducing the amount of electricity generation from fossil fuels. During the operational process, wind energy generation creates almost zero carbon dioxide emissions, making it one of the most effective strategies for reducing environmental problems[5]. Since the wind turbine technology was internationally marketed in the 1980s, it has been economically competitive with traditional energy sources[6]. Malaysia is a developing country and spends heavily on constructing traditional power plants to cope with the country's increasing energy demands for electricity, despite the environmental effects that have become a major concern as the country continues to be dominated by thermal energy sources[7].

In terms of harvesting wind energy, there are two main devices. They are known as a horizontal axis wind turbine (HAWT) and vertical axis wind turbine (VAWT). In HAWT, the axis of rotation faces the direction of the flow stream as opposed to the VAWT, in which the rotational axis is perpendicular to the wind direction[8]. The HAWT is commonly utilized globally, primarily for higher output volumes compared to the VAWT [9][10]. However, HAWT involves numerous components and relatively heavier than the VAWT. The VAWT is favourable in the high turbulent sites such as urban environments and therefore it is typically found in the region with low wind speeds and high turbulence. The main advantages of VAWTs as compared to HAWTs are the generation of electricity at ground level and the simplicity of installation as compared to HAWT. Moreover, HAWT requires a high cost of investment as compared to VAWT. The VAWT also requires less space for installation than the HAWT[11]. However, there is a design limitation for VAWTs. One of the major challenges facing the VAWT is the dynamic blade stagnation because of the rapid variations of the attack angle. Moreover, the wide variations in terms of the force exerted on the blades as they rotate create more fatigue one the rotor. Thus, during each turn, the blades could be twisting and bending which will cause them to break up during the long operation.

In the effort to improve the performance of conventional HAWTs and VAWTs, there have been numerous designs introduced by researchers and inventors which consists of improving the blade design, the generator and even including an additional rotor for maximizing the power output of the turbine which are known today as counter-rotating wind turbines (CRWT)[12–19]. The CRWT is a wind turbine with a coaxial dual-rotor system in which each one of the rotors spins in the opposite direction from the other on a similar rotational axis. It is a technique primarily used to improve the output of the conventional wind turbine system in both HAWT and VAWT. Numerous studies indicated its effectiveness in improving the performance substantially and the ability to potentially harness at a lower wind speed[20–22].

On the other hand, wind resources assessment is an essential and significant step before the development of a wind energy project. There are numerous methods and techniques available to estimate the wind speed characteristics at a site. Among the renowned methods used to fit the wind speed distributions over a period of time are such as the Rayleigh, Lognormal, the Weibull distribution functions. The two-parameter Weibull distribution functions however are among the widely used and acceptable techniques due to their simplicity and great flexibility. Through this statistical tool, a wind turbine could be chosen wisely with optimum cut-in and cut-out speeds through the indication of how frequently the variations of the wind speed at the desired site. Given that researches on assessing the potentiality of wind power in Malaysia are still quite limited, the two-parameter Weibull distribution method is selected in the present study for its renowned capacities and suitability in the assessment of wind power resources of a particular site[23–27].

2. Geographical condition of East Malaysia

In the east, the Malaysian part of Borneo (Fig. 1) is situated near the equatorial region with its climate categorized as being relatively humid and dry annually. There are two main different seasons namely the monsoon and the dry seasons. The eastern region of Malaysia, Sabah and Sarawak is warm all through the year with temperatures ranging from the low 21°C to maximum temperatures hover around 32°C. It is average 21°C during the night time and up to 32°C during the day. The wind over the country, in general, comprises of both the west region and the East region are light and variable. However, the wind flow patterns in the country prone to several uniform periodic changes due to the different seasons that occur in a year[28].

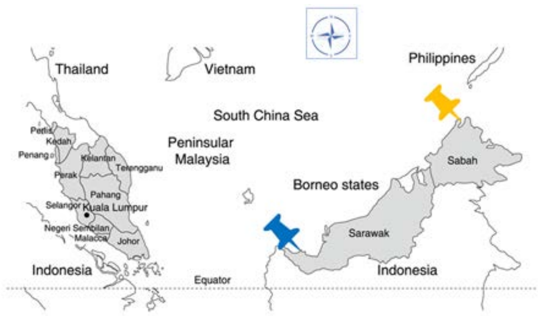

Fig. 1: Selected sites in the map of Malaysia.

2.1 Climate in Kudat, Sabah, Malaysia

Sabah is located in the Northeast of Malaysia, strategically located below the tropical typhoon belt. The area of study is situated in the Northern part of Kudat, located 190 km north of Kota Kinabalu city. It is situated at the coordinate of 6.8831° North latitude and 116.8466° East longitude, in the northern hemisphere, as shown in Table 1. Sabah has an equatorial climate and the mean temperature ranging from the minimum of 20°C up to a maximum of 32°C or even sometimes rarely rises above 32°C. The interior part of Sabah especially Ranau and

Tambunan which are at higher altitudes can be colder during the night. The average relative humidity in Kudat is ranging from 71% to 80% percent throughout the year. The wetter period of Sabah occurs during the North-East Monsoon from the month of October to February while the South West Monsoon when it comes to the drier season is from the month of March to September. Kudat division has a tropical rainforest climate as classified in the Köppen and Geiger climate system as Af[29]. It is hot, overcast and oppressive. In Kudat, the annual average temperature is 26.9°C, while the average rainfall is 189.2 mm which has a significant amount of rainfall throughout the year in the state of Sabah. The temperature in Kudat varies from 22.7°C up to 31.9°C and are rarely below 22°C or above 34°C.

Table 1. Details of the station.

Station name	Station ID	Latitude	Longitude	Elevation
Santubong	96413	1° 72' N	110° 31' E	21.7 m
Kudat	96477	6° 88' N	116° 85' E	3.5 m

2.2 Climate in Santubong, Sarawak, Malaysia

Santubong is a federal constituency located 35 km north of Kuching city, in the district of Kuching in the Sarawak state. The location is geographically facing directly to the South China Sea, as shown in Fig. 1. Moreover, the Kuching division has a tropical rainforest climate as classified in the Köppen and Geiger climate system as Af[30]. The area of the study is situated at the coordinate of 1.71937° North latitude and 110.31617° East longitude. Kuching in general is considered the wettest city in Malaysia throughout the year. Furthermore, Santubong is situated in the coastal area of Northern Kuching and thus the climate is tropical and one of the most promising potential for wind energy in Sarawak state. The state of Sarawak, in general, is hot, humid and wet weather all year-round and the average relative humidity in Santubong is ranging from 77% to 88% throughout the year[30]. The average annual rainfall level of some 341.1 mm around 250 days of rain annually.

Sarawak in general is an equatorial climate and the average annual temperature ranging from the minimum of 22.7°C early in the morning up to a maximum of 31.3°C during the day and is relatively uniform throughout the year. However, the temperature drops in the Kuching division with the coldest temperature ever recorded at 22.5°C and could be high at around 32.4°C. The wetter period of Sarawak occurs during the North-East Monsoon from the month of November to January and even prolonged to February while the South West Monsoon when the drier season hits Sarawak is from the month of June until August throughout the year. Based on the climate data, much of the weather in Sabah and Sarawak are the same, only that the wetter or drier months start one or two months later.

3. Data description

The present data were collected at the meteorology department in Malaysia at a 10-meter height. The meteorological wind data for Santubong was obtained from the meteorological department of the Sarawak branch. The climate section is located at the Kuching Airport approximately 26 km radius from Santubong. The data were from 2010 up to 2019. The weather station is located at the coordinates of 1.71937° North latitude and 110.31617° East longitude. Similarly, the data for Kudat was collected at the meteorology department of the Sabah branch, where the climate section is located at the Kudat meteorological station which is located inside the Kudat airport for a period of ten years (2010-2019). The station is located at coordinates 6.8831° North latitude and 116.8466° East longitude. All data has been processed and analysed to represent the monthly and yearly average wind speed variations for both stations which provides the essential basis for informed and effective decision-making process on renewable energy projects at the respected site.

3.1 Theoretical Formulation

In this research, the two-parameter Weibull distribution technique has been utilized for its effectiveness, flexibility and accuracy to fit the observed data. In this method, the probability density functions and the cumulative distribution functions describe the variations of the wind velocity and characteristics. The wind velocity probability function which is given in Eq. 1 shows the period of time the speed of the wind prevails in the region under study.

$$f(v) = \left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1} \exp\left[-\left(\frac{v}{c}\right)^{k}\right],$$
$$(k > 0, v > 0, c > 1) \qquad (1)$$

where v is the average velocity, k is the non-dimensional Weibull shape parameter and c is the Weibull scale parameter and it is given in m/s.

The cumulative distributions function, as shown in Eq. 2 shows the period of time where the velocity of the wind is identical to the average velocity or lesser by computing the difference in its values, thus, the wind turbine's functional time can be estimated. Hence, the integral of the probability density functions becomes the cumulative distribution functions and it is given as shown in Eq. 2;

$$F(v) = 1 - e^{-\left(\frac{v}{c}\right)^{k}} \qquad (2)$$

To find Weibull parameters c and k, it would be necessary to calculate the average wind speed, $\bar{v}$ and the standard deviation, σ beforehand. Thus, Eq. 3 and Eq. 4 are respectively used to calculate the average wind speeds and standard deviations.

$$\bar{v} = \frac{1}{n}\left[\sum_{i=1}^{n} v_i\right] \qquad (3)$$

$$\sigma = \left[\frac{1}{n-1}\sum_{i=1}^{n}(v_i - \bar{v})\right]^{1/2} \qquad (4)$$

Weibull scale parameter *(c)* and shape parameter, *(k)* are obtained, respectively based on Eq. 5 and Eq. 6, as shown below.

$$k = \left(\frac{\sigma}{\bar{v}}\right)^{-1.086} \quad (1 \leq k \leq 10) \qquad (5)$$

$$c = \frac{\bar{v}}{\Gamma\left(1+\frac{1}{k}\right)} \qquad (6)$$

where Γ is the gamma function. It is found as by Stirling approximation[31].

3.2 Maximum energy-carrying wind speed

The maximum wind energy carried by the wind speed is determined from the scale and shape parameters of the Weibull distribution functions[32]. The maximum energy the wind speeds carries can be defined as in Eq. 7.

$$V_{max.E} = c\left(1 + \frac{2}{k}\right)^{\frac{1}{k}} \qquad (7)$$

3.3 Most probable wind speed

With the calculation of the scale parameter and shape parameter, the most probable wind speed can be directly found to estimate wind energy. The most probable wind speed is the most frequent wind speed at the site and is expressed by Eq. 8[26];

$$V_{mp} = c\left(1 - \frac{1}{k}\right)^{\frac{1}{k}} \qquad (8)$$

3.4 Wind power density

The wind power density is calculated in this study as it is a useful and effective indicator while evaluating the resources of any location under study. It demonstrates the accessible amount of energy at the wind turbine conversion site and is measured in (W/m^2). The air density for both Kudat and Santubong is taken at sea level altitude with 1.225 kg/m^3 wind density and an average temperature of 25°C. The wind power density flowing at a wind speed, *v* over a swap area of the blade, *A* is calculated as in Eq. 9.

Through the wind power equation, the wind energy density can be estimated for any period of time, T by referring to Eq.10;

$$\frac{P}{A} = \int_0^{\infty} \frac{1}{2}\rho v^3 f(v)dv = \frac{1}{2}\rho c^3 \Gamma\left(\frac{k+3}{k}\right) \qquad (9)$$

$$\frac{E}{A} = \frac{1}{2}\rho c^3 \Gamma\left(\frac{k+3}{k}\right)T \qquad (10)$$

4. Results and discussion

4.1 Wind speed variation in Kudat and Santubong

The potentials of wind power have been studied for a period of ten years at Kudat and Kuching weather stations. The knowledge of the monthly wind variations at a site is vital in showing the seasonal behavior of the wind speed at that particular location. Such variations are essential while designing and selecting a suitable wind energy conversion system, energy storage system and load scheduling. These variations are presented in Fig. 2 and Fig. 3. The monthly and yearly average wind speeds at Kudat station, as in Fig. 2 and Santubong station as in Fig. 3, show that the trends of both sites display quite similar patterns. Most of the average wind speeds for Kudat are between 2 m/s and 2.9 m/s and only a few were below 2 m/s, as pictured in Fig. 2. Based on the Figure, the month of February has shown the highest average wind speed throughout the years and the highest value recorded was 3.4 m/s and it occurred in 2010. Meanwhile, the minimum was recorded from April through May. Similarly, Santubong station has also shown the minimum wind speed value during the same months with average wind speeds of around 1.5 m/s as described in Fig. 3. Moreover, it is observed that the wind speeds tend to rise moderately during dry weather condition that takes place during the southwest monsoon (June to early September) and declines noticeably when the weather condition is generally wet during the first month and second month of the wet season in Kudat (end of October to November). However, in recent years, the rainy season annually starts to hit by November.

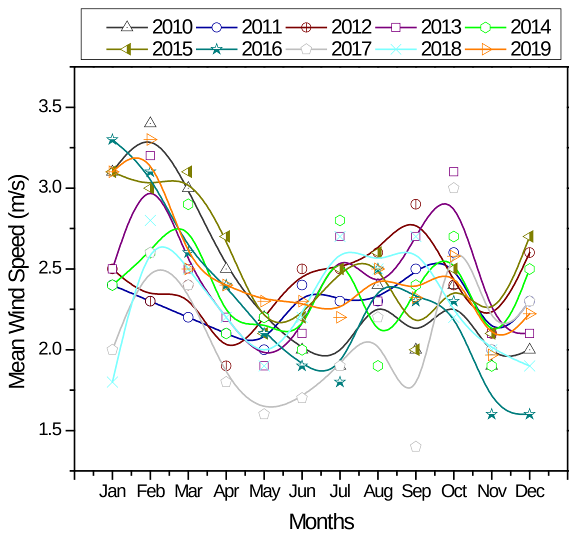

Fig. 2: Monthly variation of wind speeds at Kudat station.

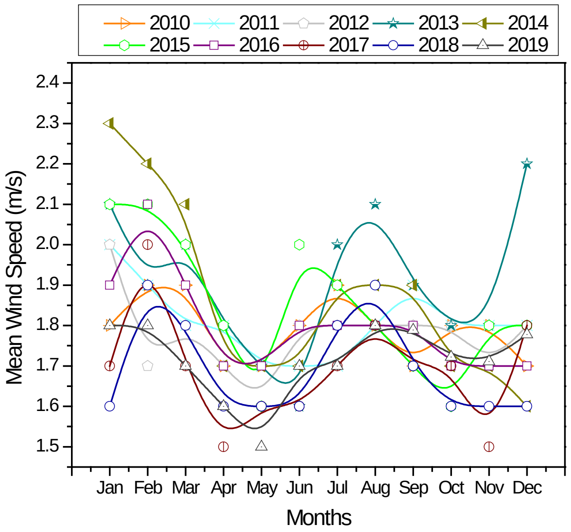

Fig. 3: Monthly variation of wind speeds at Santubong station.

Moreover, it was noticed that the wind speed gradually increases significantly for both Kudat and Santubong during the wettest month (December to February). This happened when the Northeast Monsoon hits, generally between December and February annually. Furthermore, the most promising wind speed for Kudat is by February during the end of the rainy season and October during the first month of the rainy period. Santubong, on the other hand, showed the more promising wind speed annually from December throughout January with the highest average wind speeds of 2.3 m/s in January 2014. Comparing the two stations, Kudat has shown the highest potentials throughout the month of the year compared to Santubong station, as shown in Fig. 4. However, according to the wind power classifications available, both of the stations in Kudat and Santubong fall outside of the categories of the annual mean wind speeds basis. Nevertheless, the development of a wind turbine system in East Malaysia needs to be continually considered for large-scale applications only at higher altitudes as the energy harnessing from the wind will be promising.

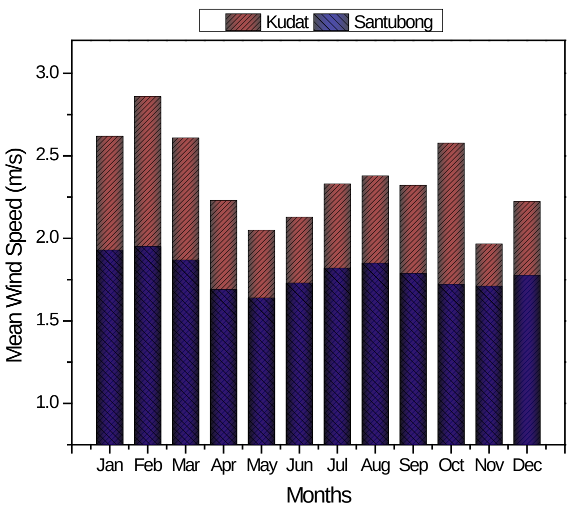

Fig. 4: Comparison of wind speed variations at Kudat and Santubong station.

4.2 Wind power density and energy density

Even though the characteristics of wind speed are crucial to drawing a clear image of a site's wind potential, it is assumed that the wind power densities could also be better indicators of the potentials of the resources. Thus, wind power densities and wind energy densities are evaluated and tabulated in Table 2 for Kudat and Table 3 for Santubong station. Moreover, the comparison of the yearly average wind speeds with respect to power density are presented in Fig. 5 and Fig. 6 for Kudat and Santubong station, respectively.

It is observed that the highest value of the wind power density at Kudat was 24.24 W/m^2 in 2019 and the lowest was in the year 2017 with an average power density of about 15 W/m^2, as shown in Table 2 and Fig. 5. Meanwhile, the yearly variations at Santubong station are minor compared to Kudat station with a maximum wind power density value of about 12 W/m^2, as could be seen in Table 3 and Fig. 6. However, the wind energy density has ranged from 130.56 to 212.32 kWh/m^2 per year for Kudat. While the wind energy density for Santubong was in the range from 82.83 to 106.008 kWh/m^2 per year. The highest values of the most probable wind speeds were 1.68 m/s and wind speeds carrying maximum energy were 4.59 m/s at Kudat, as demonstrated in Table 2. Santubong, however, shows the value of 1.9 m/s for the most probable wind speeds and 3.82 m/s for the most wind speeds carrying max energy in Santubong, as shown in Table 3. As wind speeds are higher during the Northeast Monsoon compare to the other times during the year, similarly, the related wind power density and wind energy density during the Northeast Monsoon season is also higher. This clearly shows that a wind power converter will generate promising power for both Kudat and Santubong regions during this period.

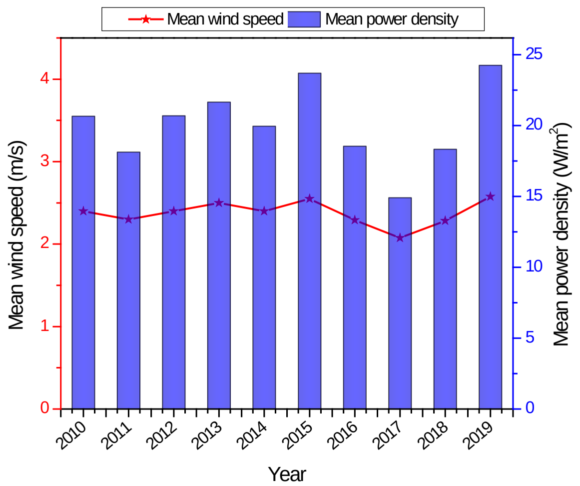

Fig. 5: Yearly mean wind speeds and mean power density at Kudat.

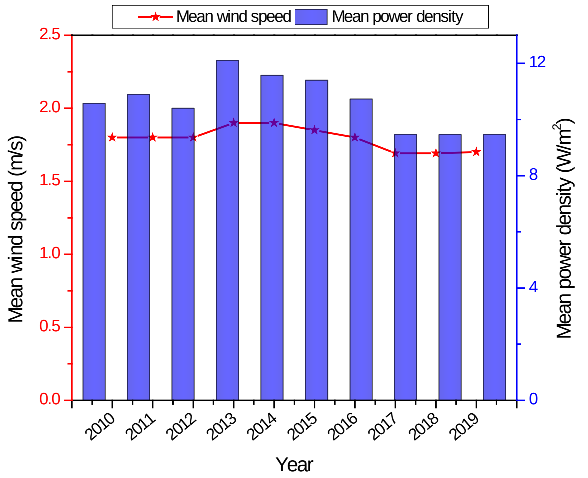

Fig. 6: Yearly mean wind speeds and mean power density at Santubong.

Table 2. Wind characteristics at Kudat station.

Year	Parameter						
	$\bar{v}$ (m/s)	V_{maxE} (m/s)	V_{mp} (m/s)	k (-)	c (m/s)	$\frac{P}{A}$ (W/m^2)	$\frac{E}{A}$ (kWh/m^2)
2010	2.4	4.40	1.48	1.62	2.68	20.66	180.96
2011	2.3	4.24	1.36	1.59	2.54	18.13	158.81
2012	2.4	4.40	1.50	1.63	2.69	20.69	181.22
2013	2.5	4.46	1.54	1.64	2.74	21.65	189.68
2014	2.4	4.36	1.44	1.61	2.64	19.94	174.71
2015	2.55	4.57	1.65	1.67	2.85	23.70	207.60
2016	2.29	4.28	1.35	1.58	2.55	18.54	162.39
2017	2.08	4.05	1.11	1.50	2.30	14.90	130.56
2018	2.28	4.26	1.35	1.58	2.54	18.32	160.49
2019	2.58	4.59	1.68	1.68	2.88	24.24	212.32

Table 3. Wind characteristics at Santubong station.

Year	Parameter						
	$\bar{v}$ (m/s)	V_{maxE} (m/s)	V_{mp} (m/s)	k (-)	c (m/s)	$\frac{P}{A}$ (W/m^2)	$\frac{E}{A}$ (kWh/m^2)
2010	1.8	3.7	0.82	1.46	1.97	10.57	92.59
2011	1.8	3.7	0.83	1.44	1.99	10.90	95.44
2012	1.8	3.7	0.80	1.47	1.95	10.40	91.14
2013	1.9	3.8	0.94	1.36	2.1	12.10	106.0
2014	1.9	3.8	0.88	1.34	2.05	11.57	101.4
2015	1.9	3.8	0.88	1.38	2.04	11.40	99.90
2016	1.8	3.7	0.82	1.42	1.98	10.73	94.00
2017	1.7	3.6	0.70	1.43	1.85	9.46	82.80
2018	1.7	3.6	0.70	1.40	1.85	9.46	82.80
2019	1.7	3.6	0.72	1.38	1.86	9.46	82.80

4.3 Weibull frequency distribution and cumulative distribution

The yearly average scale parameters and the dimensionless shape parameters of the Weibull distribution functions at Kudat and Santubong are presented in Table 2 and Table 3. Based on the results, it is evident that the shape parameters have smaller variations compare to scale parameters. The range of shape and scale parameter variations is from 1.50 – 1.68 and 2.30 – 2.88 m/s, respectively. Meanwhile, their average values were between 1.61 and 2.64 m/s, respectively, as shown in Table 2. However, for the Santubong station, the Weibull shape parameters and scale parameters are ranging between 1.36 – 1.45 and 1.85 – 2.10 m/s, accordingly with an average value of 1.40 shape parameter and 1.96 m/s scale parameter, as indicated in Table 3. The lowest value of the scale parameters within ten years from 2010 throughout 2019 is 1.79 m/s and is seen at Santubong station and the peak value during the ten years is 3.21 m/s and is appeared at Kudat. Thus, it can be deduced that the potentials at Kudat station are greater than Santubong station.

Based on the frequency distribution shown in Fig. 7 and Fig. 8, it is noticeable that at both Kudat and Santubong stations, more than 50 percent of the frequency is around 1 m/s to 4 m/s of wind speed. The Weibull cumulative frequency distributions pattern is observed to be similar to the observed cumulative distributions for both Kudat and Santubong stations showed in Fig. 9 and Fig. 10. The maximum percentage of error occurs at 2 – 3 m/s in Kudat and 1 – 2 m/s in Santubong between Weibull wind speed frequencies and observed frequencies with the highest error value being 26%. On the other hand, the deviation between the Weibull and the observed density functions is more significant for wind speeds of less than 2 m/s in Kudat station and 1 m/s in Santubong with the highest error of about 27%.

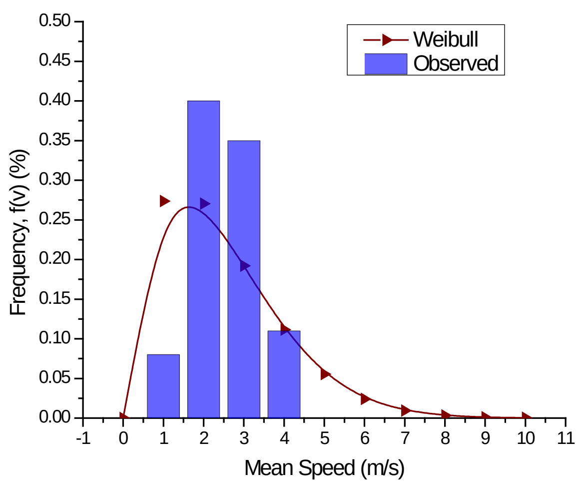

Fig. 7: Observed and Weibull wind speed frequency at Kudat.

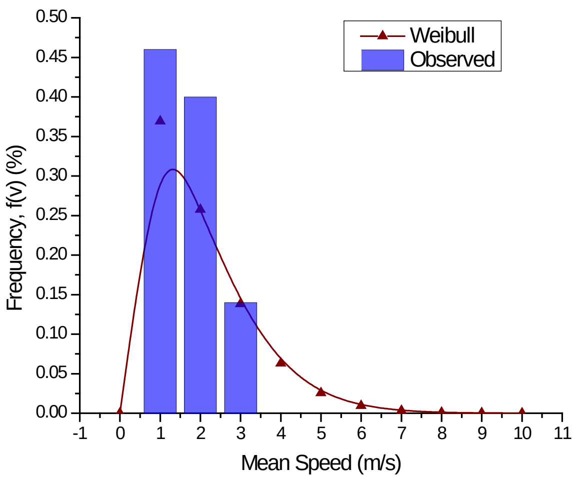

Fig. 8: Observed and Weibull wind speed frequency at Santubong.

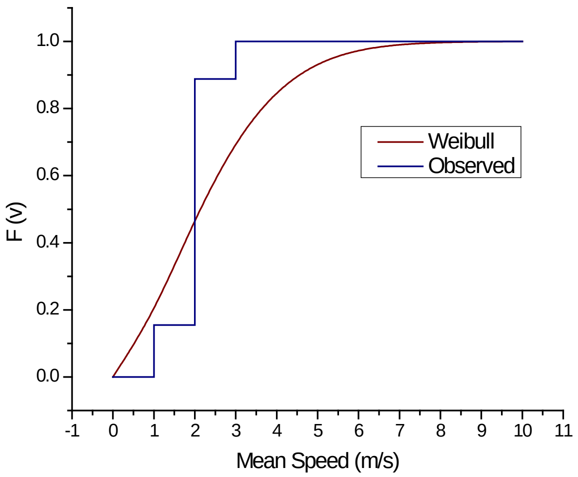

Fig. 9: Observed and Weibull cumulative distributions at Kudat.

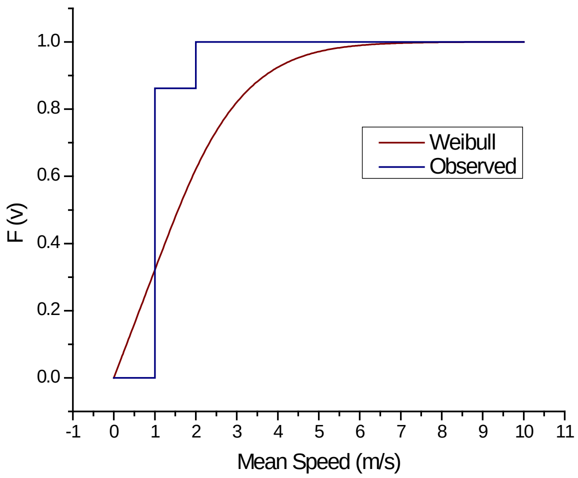

Fig. 10: Fig. 10: Observed and Weibull cumulative distributions at Santubong.

4. Conclusion

The present study describes the feasibility analysis of wind energy potentiality in Santubong, Sarawak and Kudat, Sabah in East Malaysia. Ten consecutive years stretching from 2010 up to 2019 data has been analysed in this assessment. The analyses were performed using the Weibull two-parameter distribution function while aiming to establish a preliminary analysis of the potential output of the wind energy at these two sites which could become a comprehensive wind database for stakeholders while designing and installing wind energy conversion systems in the region. The main findings summarized as follows:

Two types of wind speeds were found with regard to monthly mean wind speeds. Wind speeds in December through February are higher than the rest of the month in a year at both stations. Moreover, the maximum average wind speeds per month were 3.4 m/s and 2.3 m/s, in Kudat and Santubong, respectively. The annual average wind speeds were found to be about 2.0 m/s in Kudat and 1.8 m/s in Santubong. Furthermore, the variability between the mean wind speeds is found to be very low from the annual mean wind speeds at both stations, except for the year 2017 at Kudat station where the variability is noticeable from the rest of the years. The most probable wind speeds and wind speeds carrying maximum energy in Kudat were 1.68 m/s and 4.59 m/s, respectively. Meanwhile, in Santubong station, they were 0.88 m/s and 3.8 m/s, respectively. A maximum of 27% difference between observed frequencies and the Weibull frequency distributions was observed.

The maximum wind power density obtained was 24.24 W/m^2 in Kudat and it was 12.10 W/m^2 in Santubong. The corresponding maximum wind energy density was estimated as 207.60 kWh/m^2/year in Kudat and 106.01 kWh/m^2/year in Santubong. Based on the outcome of this work, it is suggested that only a small-scale vertical axis wind turbine (VAWT) could be feasible harness wind power in these two sites due to the low wind speed.

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