Assessment of Wind Energy Potential based on METAR data in Malaysia

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Received: 04.11.2013 Accepted: 15.12.2013

Abstract- Wind energy is one of the fastest developing renewable energy technologies. This is due to the vast resource of wind and also a green technology which does not emit any pollutants to the environment. The type of wind data used in this study is METAR data with duration from year 2005 till 2011. In peninsular Malaysia, the METAR data are available at Kota Bharu, Johor Bharu, Langkawi and Kuala Terengganu, while in the state of Sabah and Sarawak are at Sandakan, Miri, Kota Kinabalu, Kuching and Kudat. The wind speed and direction is analyzed using WAsP to generate wind rose chart and Weibull distribution together with the wind power density . For wind power analysis, WindPRO software is used to determine annual energy production through simulation by using a single 22 kW rated power wind turbine, as well as the capacity factor and full load hour. The result for wind data at 10 m height indicated that Kudat has the greatest wind energy potential in Malaysia with the highest wind power density of 21 W/m^2 produced and Weibull scale parameter c of 2.8 m/s with shape parameter k of 1.74. The site also has the highest annual energy production at 14.6 MWh/year as well as highest capacity factor and full load hour at 7.6% and 661 hours/year respectively.

Keywords- Wind Energy, WindPRO, WAsP, METAR, Malaysia.

1. Introduction

Malaysia is currently looking for another alternative resource to generate electricity after so long dependent on coal and fuel. Coal and fuel is non-renewable resources as well as its prices rising in the global market due to decrement of its quantity and are only available in some countries. Malaysia has taken steps to exploring the resources of renewable energy as an alternative for generating electricity. Among the resources of renewable energy (RE), the wind energy was the fastest growing energy technology in the world and considered as one or resource that meet the needs of modern societies in reducing the dependence on coal and diesel whilst at the same time delivering substantial reduction in greenhouse gas emission.

Malaysia is comprises Peninsular Malaysia, Sabah and Sarawak which is the part of Borneo Island. Malaysia lies in the equatorial zone and the climate is governed by the regime of the Northeast and Southwest monsoons which blow alternately during the course of the year [1].

Peninsular Malaysia experiences four seasons which can be distinguished through monsoon seasons, which are the southwest monsoon, the northeast monsoon and two short inter-monsoon periods. These monsoons influenced the wind which blows across the peninsular. Rainy seasons occur during southwest monsoon, during May to September and northeast monsoon, during November to March. Severely most affected area is in the east and south due to later monsoon which brings heavier rainfall in the peninsular [2].

East Malaysia (Sabah and Sarawak) experiences heavy rains which runs between November and February. Due to the prevailing monsoon winds , it causes rainfall differs on the east and west coast. Hence, Sabah will experience wetter conditions due to the tail effect of typhoons which frequently traverse the Philippine Islands across the South China Sea. The southwesterly winds over the Northwest coast of Sabah and Sarawak region may strengthen to reach 10.30 m/s or more during the months of April to November where the typhoons frequently developed over the western Pacific and move westwards across the Philippines [3]. An average of 6-

7 tropical cyclones traverses over the Philippines and South China Sea per year. It occurred 7 times in 1996, 5 times in 1997, 4 times in 1998, 2 times in 1999, 7 times in 2000, 3 times in 2001, 5 times in 2002, 8 times in 2003, 12 times in 2004 and 4 times in 2005 [4].

This paper present about the wind energy potential at ten selected site in Peninsular and East Malaysia. The wind speed and energy analysis was conducted by using the WindPRO and WAsP softwares. The advanced computational methods have been developed to gain the data to use in estimation of wind energy potential and micrositing [5-8]. An accurate prediction of the wind speed at a given site is essential for the determination of regional wind energy resources. Because of aerodynamic reasons, the power output of a wind turbine is proportional to the third power of the wind speed.

It is a fact that, especially in complex terrain, wind energy content may vary significantly from one region to another. Therefore, wind data taken over many years are utilised to calculate wind climatology. European Wind Atlas is a good example of this. Some other wind resource maps such as Wind Atlas of Russia was prepared by [9], and the Irish Wind Atlas was prepared by [10]. The WindPRO and Wind Atlas Analysis and Application Program (WAsP) software were widely used by researchers for analyze the wind turbine and energy production and validate as the best software in this research field [11-13]. WindPRO and WAsP are softwares for predicting wind climates, wind resources and power productions from wind turbines and wind farms. The predictions are based on wind data measured at stations in the same region. The software function includes a complex terrain flow model, a roughness change model and a model for sheltering obstacles.

Several studies have been done to estimate the wind potential in Malaysia [14-16]. However, there are limited studies about the wind energy and wind farm in Malaysia compared to the other countries. This article aims to provide wind energy potential estimation and to perform micrositing study on Malaysia in order to bridge this gap.

2. Methodology

The flow chart is presented in Fig. 1 in order to outline the overall flow of procedures involved and notify the method works have been executed in a systematic manner.

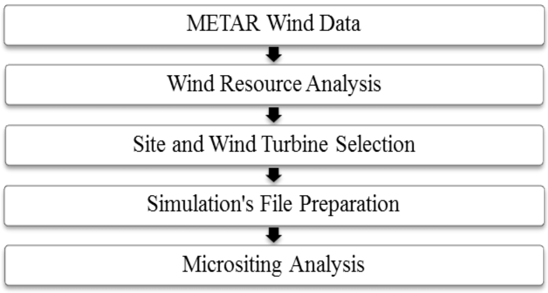


Fig. 1. Flow chart of energy simulation

2.1. METAR Data

METAR is the name of the international meteorological code for an aviation routine weather report. METAR observations are normally taken and disseminated on the hour [17].

Observed wind speeds from surface observing (METAR) stations are frequently used for long-term reference data [18]. If the proposed wind plant site is sufficiently close to the surface site, and the location is sufficiently representative of the on-site conditions, this can yield useful information regarding the wind variability [18].

METAR stations in Malaysia are located at airports and observations are usually collected at hourly increments at a height of 10 meters (m) Above Ground Level (AGL). The METAR data since year 2003 till 2013 are downloaded via WindPRO software. Only the data in year 2007 till 2011 are selected for potential analysis due to its quality which is no missing data compared to the other years.

The METAR stations are located at Kuala Terengganu, Johor Bahru, Kota Bahru, Langkawi Island in Peninsular Malaysia; Kota Kinabalu, Sandakan, Kudat in Sabah; and Miri, Kuching, Bintulu in Sarawak. Table 1 shows the location and elevation of the stations. The data consist of wind directions and wind speeds.

Table 1. The location and elevation for every selected site

Station	Latitude °N	Longitude °E	Height above mean sea level (m)
Bintulu	3° 12’	113° 02’	3.0
Johor Bahru	1° 38’	103° 40’	37.8
Kota Bharu	6° 10’	102° 17’	4.6
Kota Kinabalu	5° 56’	116° 03’	2.0
Kuala Terengganu	5° 23’	103° 06’	5.0
Kuching	1° 29’	110° 20’	26.0
Kudat	6° 55’	116° 50’	3.0
Langkawi Island	6° 20’	99° 44’	6.4
Miri	4° 20’	113° 59’	17.0
Sandakan	5° 54’	118° 04’	12.0

2.2. Extrapolation of Wind Data

Vertical wind speed profile for each station was extrapolated by the power law equation [19-20].

$$V = V_0 \left(\frac{z}{z_0} \right)^{\alpha}$$

Where V is the wind speed estimated at desired height, z; V_0 is wind speed measured at the reference height, z_0; α is the ground surface friction coefficient and calculated by the Counihan equation. The value of ground surface friction for every station is estimated at 1/7 or 0.143 as suggested by [21] for neutral stability conditions. However, it may underestimate wind speed at hub height in stable laminar flow situations and overestimate when there is mixing and convection in the wind speed extrapolation.

2.3. Micrositing Analysis

By employing the WindPRO Statgen module, the wind statistics of every site were generated. The Park module provided by WindPRO is used for energy simulation. The Park module is employed with the following parameters; open farmland, height contours from the extraction of Digital Elevation Model (DEM), surface roughness and the Wind Turbine Generation (WTG) file.

Malaysia has low wind speed and thus the small scale rated power wind turbine from 1 kW to 30 kW is suitable for installation in this country [22]. The 22 kW rated power wind turbine is chosen for the micrositing analysis at every selected site. Fig. 2 showed the power curve for wind turbine with 22 kW rated power. The important information about wind turbine that can be obtained from the power curves is rated wind speed, cut-in wind speed and cut-out wind speed [23]. The rated wind speed is defined as the value of wind speed at which the turbine reaches its rated power output or maximum power output [24]. The cut-in wind speed is the wind speed at which a turbine starts to operate and produce electricity, while the cut-out wind speed is the wind speed at which the turbine shut down [24]. At high enough wind speed the turbine shuts down to protect the rotor blades, the generator and other components from failure. No power is generated above the cut-out wind speed. For 22 kW wind turbine which used in the energy calculation, the cut-in wind speed is 2 m/s, the cut out wind speed is 25 m/s and the rated wind speed is 10 m/s.

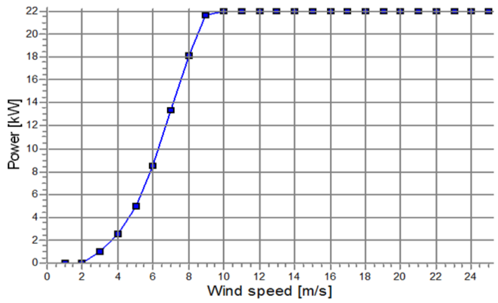


Fig. 2. The power curve of 22 kW wind turbine

3. Results and Discussion

3.1. Wind Speed Variation

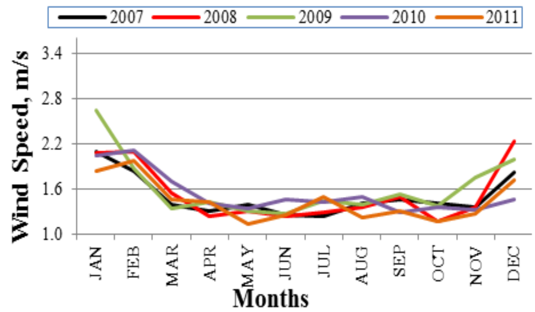
The potential of wind energy in peninsular Malaysia were investigated at Langkawi, Kota Bharu, Kuala Terengganu and Johor Bahru. The results presented that the corresponding annual mean wind speed at 10 m height from ground level in Langkawi within five years is approximately 2.2 m/s. Kuala Terengganu also has annual mean wind speed around 2.2 m/s. The highest annual mean wind speed at 10 m height from ground level is recorded at Kota Bharu with approximately 2.4 m/s and Johor Bahru obtaining the lower of annual mean wind speed which is about 1.8 m/s.

Accordingly, the annual and monthly wind speed variation at Malaysia is showed in Fig. 3. The trend of annual monthly mean wind speed in 2007 until 2011 is similar respectively. It is established that the stronger mean wind speed at Kota Bharu was occurring during the Northeast monsoon season from November to February. The range was between 2 m/s to 4 m/s at 10 m height from ground level. The northeast monsoon wind speed is blowing in this region which also brings together with heavy rainfall. As a contrast, the low wind speed occurred from April until October. Mostly during the months, the mean wind speed remain constant between 1.68 m/s to 3.36 m/s. From this result, it can be seen that the annually and monthly mean wind speed at Kota Bharu is higher than other regions in Peninsular Malaysia.

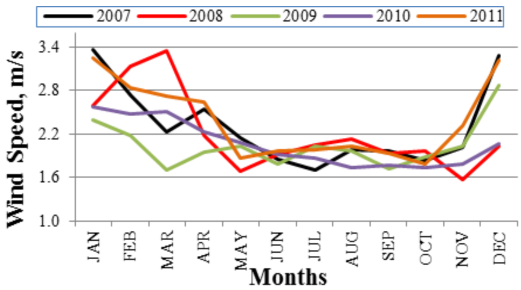
The potential of wind energy in Sabah and Sarawak were investigated at Sandakan, Kota Kinabalu, Kudat, Miri, Bintulu and Kuching. The results of wind speed showed that the highest annual mean wind speeds at 10 m height is occurred at Kudat with approximately 2.6 m/s and Bintulu showed the lower of annual mean wind speed which is about 2.0 m/s. The second highest annual mean wind speed in Sabah is at Sandakan with approximately 2.5 m/s, followed by Miri with annual mean wind speed around 2.4 m/s, Kota Kinabalu with 2.3 m/s annual mean wind speeds and Kuching at 2.1 m/s.

During April to September, the mean wind speeds remain constant between 1.78 m/s to 2.98 m/s. From this result, it can show that the annually and monthly mean wind speed at Kudat is higher than other sites in Sabah and Sarawak.

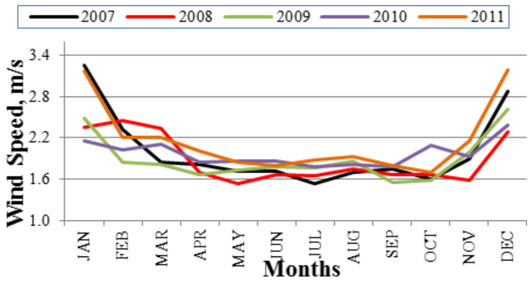
a. Johor Bahru



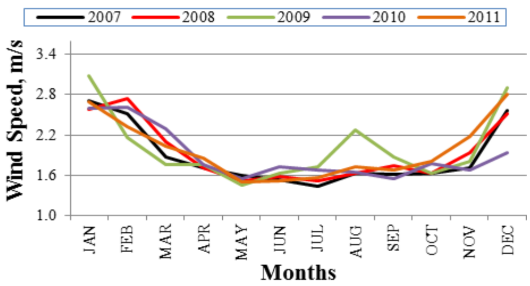
b. Kota Bahru



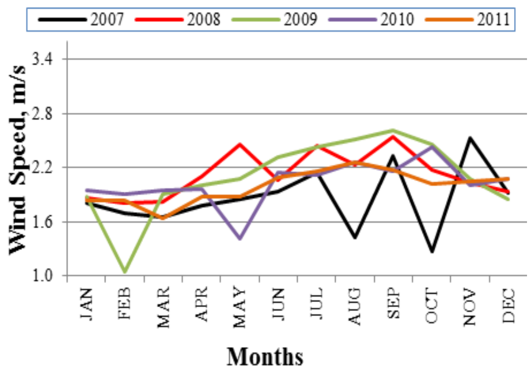
c. Kuala Terengganu



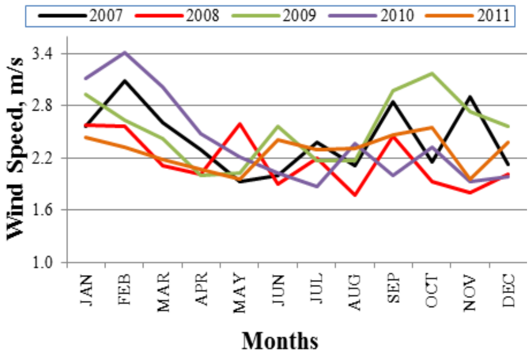
d. Langkawi



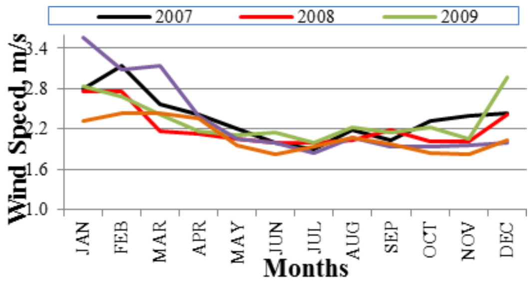
e. Kota Kinabalu



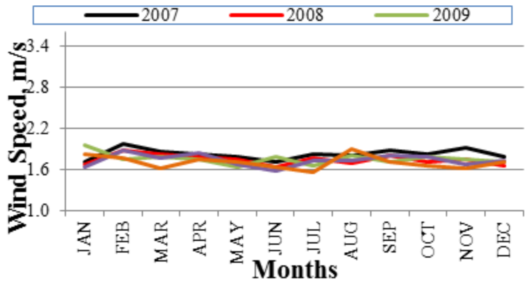
f. Kudat



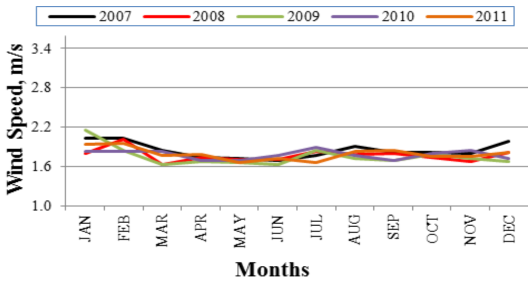
g. Sandakan



h. Bintulu



i. Kuching



j. Miri

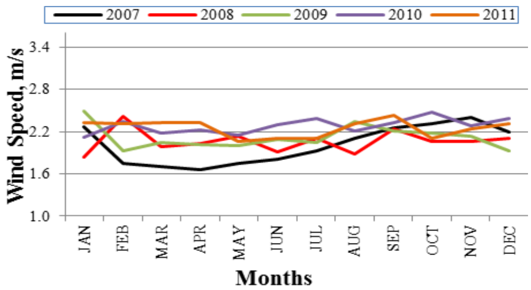


Fig. 3. The annual variation of mean speed at every selected site (a-j)

3.2. Weibull Distribution and Power Density

A statistical analysis is necessary to obtain a clear view of the available wind potential as simple knowledge of the mean wind speed at selected site is not sufficient enough [25]. The fraction of the time for which a wind speed possibly prevails in the study area will be indicated by the probability density function. The Weibull distribution models have been computed using WAsP software. Fig. 4 shows the probability density function of the annual wind speed distribution using Weibull models. Table 2 show the Weibull parameter (*k* and *c*) for wind data at 10 m height from ground level at every selected site in Malaysia.

Table 2. Monthly variation of Weibull parameter (*k* and *c*) for selected sites in Malaysia

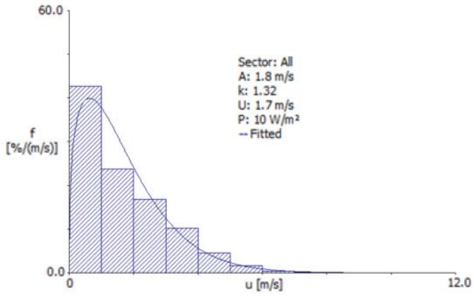
Location	Weibull Scale Parameter *c* (m/s)	Weibull Shape Parameter *k*
Bintulu	2.1	1.74
Johor Bahru	1.8	1.32
Kota Bharu	2.7	1.73
Kota Kinabalu	2.5	1.92
Kuala Terengganu	2.3	1.74
Kuching	2.1	1.56
Kudat	2.8	1.74
Langkawi	2.3	1.67
Miri	2.6	1.68
Sandakan	2.7	1.85

In Peninsular Malaysia, the highest value of Weibull shape parameter *k* from 2007 until 2011 is at Kuala Terengganu with the value of 1.74 which is followed by Kota Bharu with the value of 1.73. The lowest *k* value was in Johor Bahru with the value of 1.32. For scale parameter *c*, the highest was in Kota Bharu with 2.7 m/s while Johor Bahru has the lowest value of 1.8 m/s.

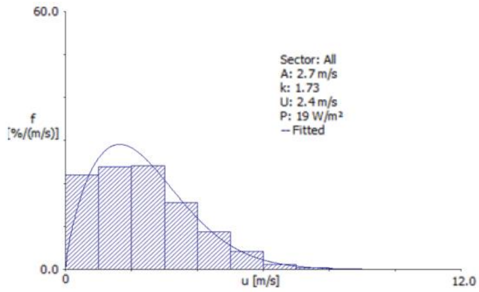
In Sabah and Sarawak, the highest value of Weibull shape parameter *k* from 2007 until 2011 is at Kota Kinabalu with the value of 1.92. The lowest k value is at Kuching with the value of 1.56. For scale parameter *c*, the highest value is at Kudat with 2.8 m/s while Kuching and Bintulu have the lowest value, 2.1 m/s.

Evaluating the mean wind power density is another important aspect in wind analysis. The wind power density in selected regions in Malaysia from 2007 until 2011 has been calculated using WAsP softwares. The wind data is at 10 m height from the ground level. Kota Bharu has the highest wind power density (19 W/m^2) in Peninsular Malaysia. This is followed by Kuala Terengganu and Langkawi which have the similar power density with value is 12 W/m^2. Kota Bharu and Kuala Terengganu are experience stronger wind speed during Northeast monsoon. Meanwhile, Johor Bahru produces the lowest wind power density in Peninsular Malaysia (10 W/m^2). Most of the wind station usually operated inside the airport. The location of METAR data inside airport is effecting the value of mean speed. The airport in Kota Bharu and Kuala Terengganu located nearer to the coastal area which receives better wind speed due to less interference and obstacles. Meanwhile, the station located in Johor Bahru is surrounded by obstacles such as buildings and trees. This will result the lower wind speed was recorded. For Sabah and Sarawak, Kudat shows the highest wind power density at 10 m height wind data (21 W/m^2) followed by Miri and Sandakan at 18 W/m^2 and 17 W/m^2. Bintulu produces the lowest wind power density (9 W/m^2). Since Kudat is located nearer to the coast, it receives strong wind speed. The station located in Bintulu is surrounded by land cover especially trees due to its location near the forested areas.

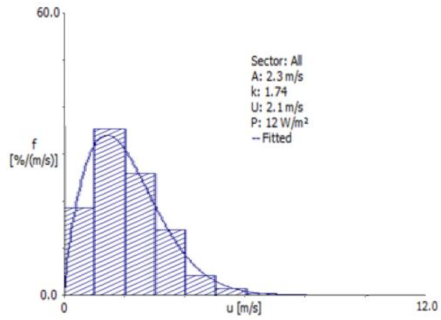
a. Johor Bahru



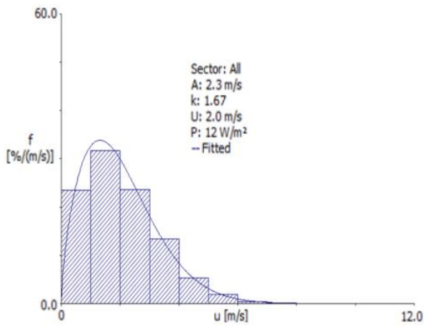
b. Kota Bahru



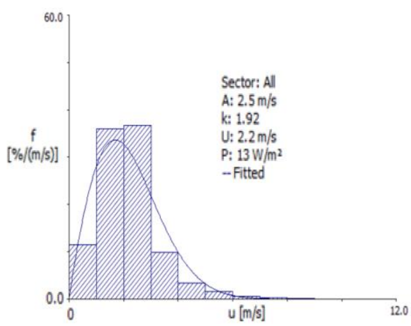
c. Kuala Terengganu



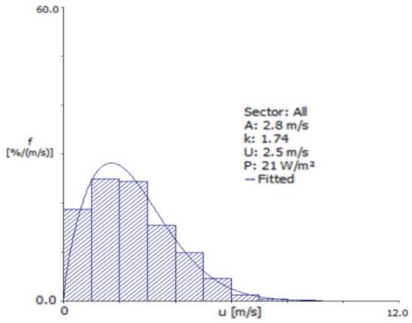
d. Langkawi



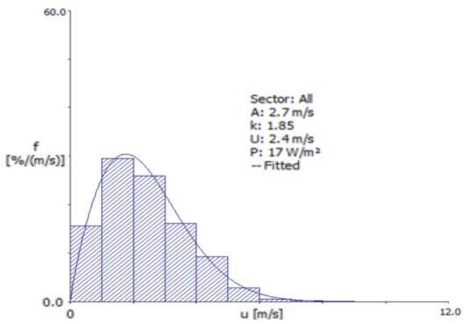
e. Kota Kinabalu



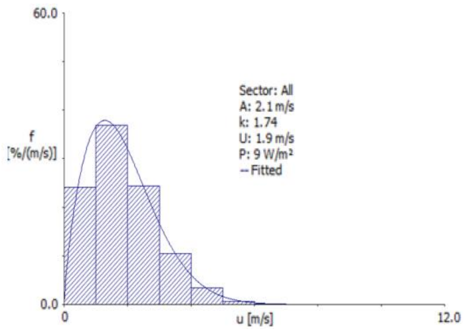
f. Kudat



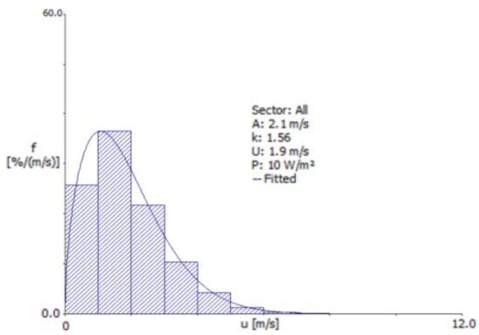
g. Sandakan



h. Bintulu



i. Kuching



j. Miri

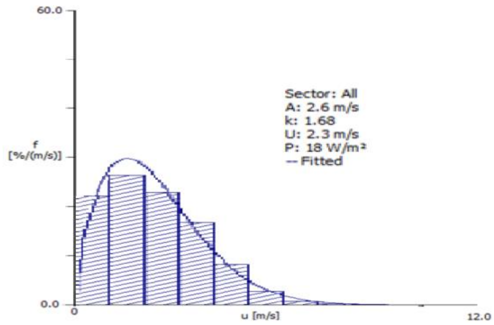


Fig. 4. The Weibull distribution and power density for wind data at 10 m height from ground level (a-j)

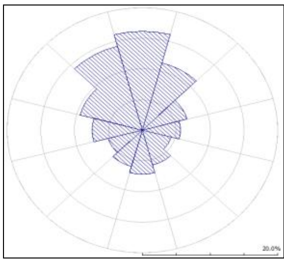
3.3. Wind Direction

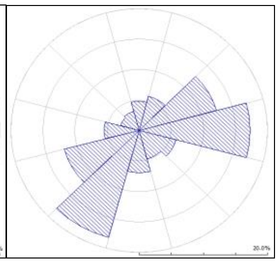
In order to use the energy power at optimum level, it is important to determine the wind direction. WAsP software is used to construct a polar diagram of wind data to identify the wind direction. The wind direction is in a form of polar diagram which is measured in a clockwise (°). The cycles are divided into 12 sectors and each sector covers an arc of 30°. The frequencies (%) are plotted in polar diagrams respects to the cardinal point to show the wind direction. Fig. 5 showed the direction of wind blow at each site. The most prevailing wind directions for annual years at each different sites are shown in Table 3.

Table 3. Prevailing wind directions for annual years at each different site

Sites	Angle (°)	Sector	Frequency (%)
Bintulu	120	ESE	19.2
Johor Bahru	0	N	16.2
Kota Bharu	210	SSW	18.2
Kota Kinabalu	120	ESE	26.3
Kuala Terengganu	210	SSW	21.2
Kuching	150	SSE	13
Kudat	240	WSW	22.9
Langkawi	30	NNE	23.1
Miri	90	E	12.1
Sandakan	210	SSW	15.9

a. Johor bahru b. Kota bharu





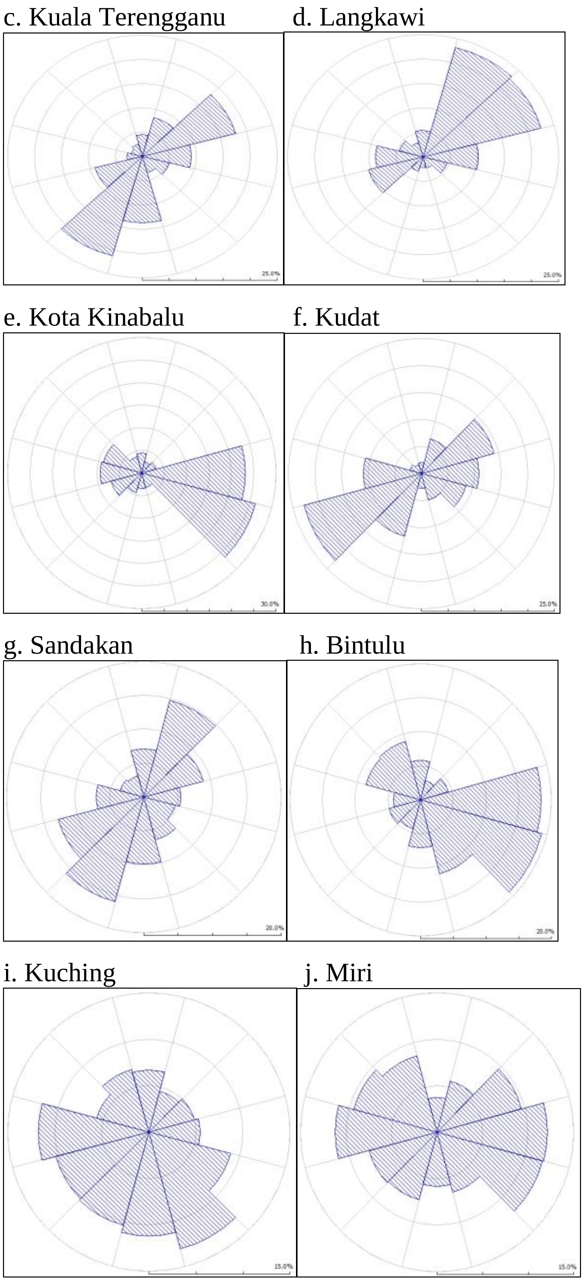


Fig. 5. The wind rose for every selected site (a-j).

3.4. Extrapolation of wind data

The METAR wind data is recorded at 10 m height from ground level. Mostly the hub height of wind turbine is more than 10 m. In this study, the 22 kW wind turbine with 30 m hub height was chosen for simulation analysis. Therefore, the available 10 m wind data is extrapolated to determine the wind speed at 30 m hub height. Fig. 6 show the extrapolation of wind data from 10 m to 100 m at every selected site.

3.5. Sectoral Energy Production

Energy produced at each sector of wind direction was calculated and a graph of energy against sectoral area was produced to show the best direction to install the wind turbines. The energy is simulated by using a single 22 kW wind turbine with rotor diameter and hub height are 15 m and 30 m respectively. Thus, the 30 m extrapolated wind data was used in the simulation. Fig. 7 showed that the potential site with the highest annual energy production in peninsular Malaysia is Kota Bharu with energy production of 8 MWh/year due to east direction. Johor Bahru shows the lowest annual energy production with energy production between 0.2 to 2.4 MWh/year, where the most preferable direction is located in North northeast (NNE). This is due to the location of METAR station in Kota Bharu is located near the coastal area, which receives direct wind from the South China Sea. Since the METAR station in Johor Bahru located near the area with obstacles such as buildings, it affects the wind speed and direction of the prevailing winds.

The potential site with the highest annual energy production in Sabah and Sarawak by using a single 22 kW wind turbine is at Sandakan with energy production of 7.4 MWh/year due to North northeast (NNE) direction. Kudat has two high readings which is in West southwest (WSW) direction of 6.4 MWh/year and East northeast (ENE) direction, 5.7 MWh/year. Kuching shows the lowest annual energy production with energy production between 0.3 to 1.6 MWh/year, where the most preferable direction is located at the North (N) and North northwest (NNW). Table 4 shows the best sectoral area for annual energy production at every selected site.

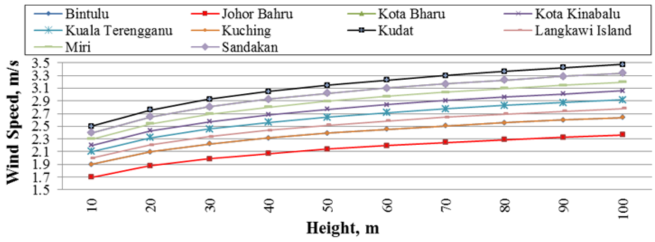
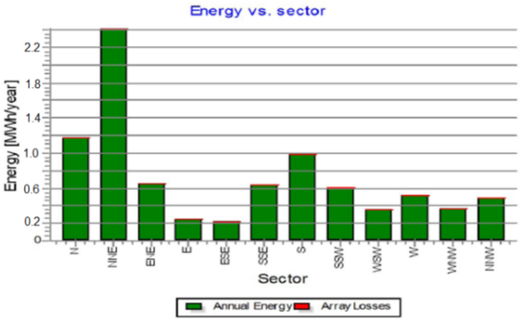


Fig. 6. The extrapolation of wind speed at different height

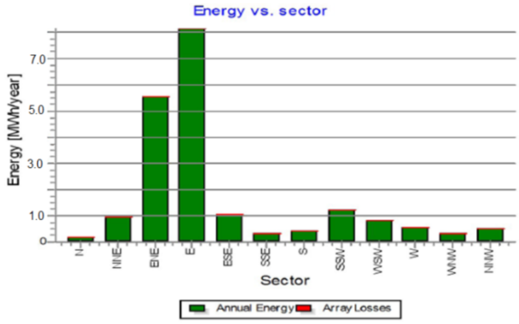
Table 4. Best sectoral area for Annual Energy Production (AEP)

Location	Annual energy production (MWh/year)	Sectoral
Bintulu	2.0	WNW
Johor Bahru	2.4	NNE
Kota Bharu	8.0	E
Kota Kinabalu	3.0	SSW
Kuala Terengganu	5.8	ENE
Kuching	1.6	NNW
Kudat	6.4	WSW
Langkawi	3.2	NNE
Miri	3.0	W
Sandakan	7.4	NNE

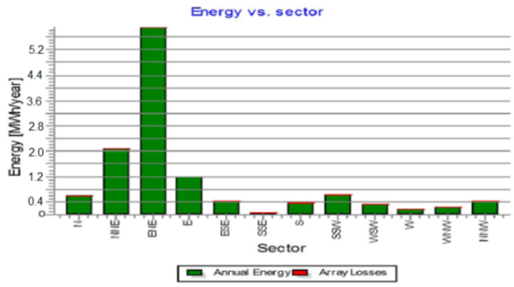
a. Johor Bahru



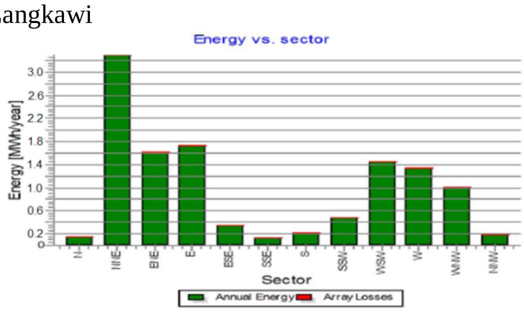
b. Kota Bharu



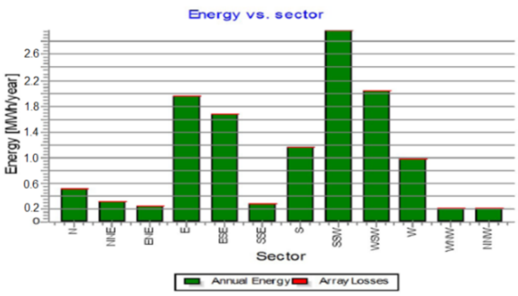
c. Kuala Terengganu



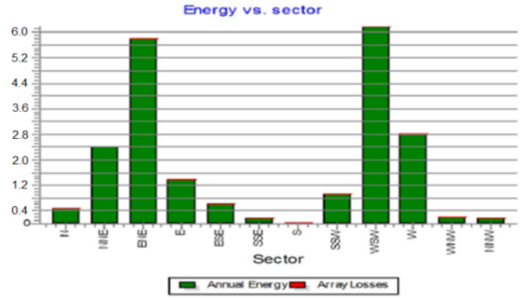
d. Langkawi



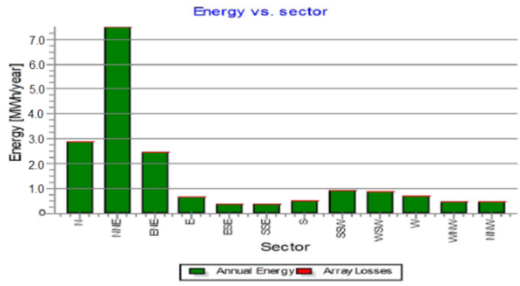
e. Kota Kinabalu



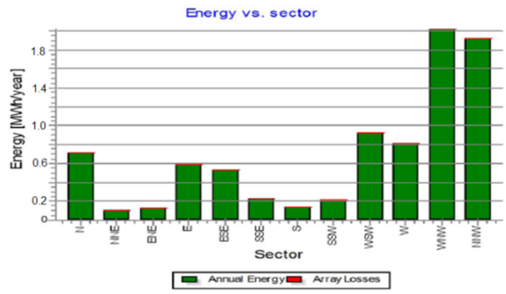
f. Kudat



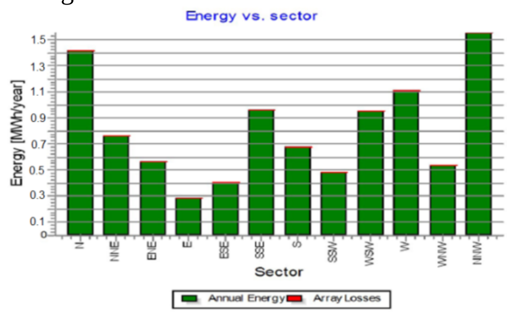
g. Sandakan



h. Bintulu



i. Kuching



j. Miri

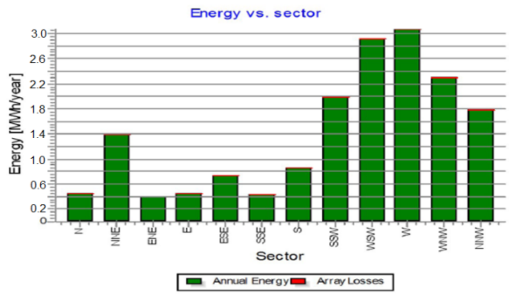


Fig. 7. Sectoral area energy production for every selected site.

3.6. Annual Energy Production (AEP)

The Annual Energy Production (AEP) for each site is calculated using WindPRO software based on a single 22 kW wind turbine. The ratio of estimated and nominal annual energy productions is called the capacity factor.

Full load hours refers to the operational time for the wind turbine. The longer the operational time, the higher the AEP produced. Fig. 8 and Table 5 shows the Annual Energy Production, Capacity Factor and Full Load Hour for every selected site.

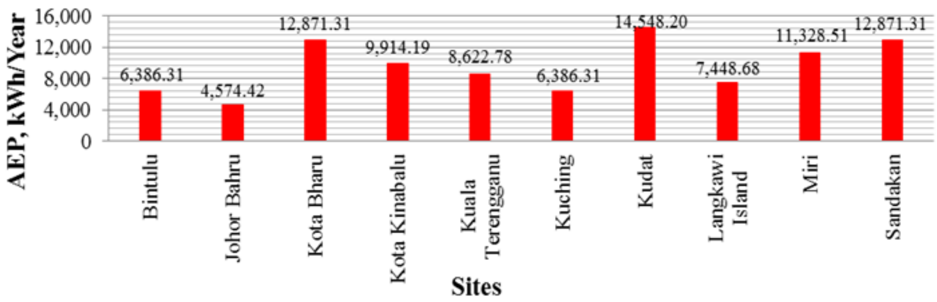


Fig. 8. The Annual Energy Production for every selected site

Table 5. The Annual Energy Production, Capacity Factor and Full Load Hour.

Sites	Annual Energy Production, (kWh/Year)	Capacity factor, (%)	Full Load Hour, (Hour/Year)
Bintulu	6,386.31	3.31	290.29
Johor Bahru	4,574.42	2.37	207.93
Kota Bharu	12,871.31	6.68	585.06
Kota Kinabalu	9,914.19	5.14	450.64
Kuala Terengganu	8,622.78	4.47	391.94
Kuching	6,386.31	3.31	290.29
Kudat	14,548.20	7.55	661.28
Langkawi Island	7,448.68	3.87	338.58
Miri	11,328.51	5.88	514.93
Sandakan	12,871.31	6.68	585.06

4. Conclusion

The most recommended sites with the highest wind energy potential for peninsular Malaysia is at Kota Bharu while for Sabah and Sarawak is at Kudat. The east coast especially in Kota Bharu is the best site for wind energy development in peninsular Malaysia due to strong Northeast monsoon. The Northeast monsoon brings the strong wind speed because there're no obstacles present in South China Sea before it reaches the coastal area. Hence, higher wind speeds is happened during the Northeast monsoon season from November to March, while slower wind speed is during the Southwest monsoon season from April to October due to Sumatera island acts as an impediment to the wind before it reaches the West coast. Since the inland areas receive the wind after it reaches the coastal areas, the wind quality is lower compared to the area nearer to the coastal area.

In the future, it is recommended to develop the wind mast with height more than 10 m from ground level at the coastal area for every selected site. The measured wind data from wind mast at coastal area is predicted showing more better results compare to the wind data which measured inside the METAR station. The measured data from wind mast then can be used for developing the wind map for Malaysia and encourage the development of wind energy project in this country.

Acknowledgements

The authors would like to thank to Ministry Of Science, Technology and Innovation of Malaysia (MOSTI) and School of Ocean Engineering, Universiti Malaysia Terengganu (UMT) for providing supervision and financial support.

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