Wind Energy Potential Investigation and Micrositting in Langkawi Island, Malaysia

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ABSTRACT

The aim of this study was to predict the wind energy potential over the Langkawi Island, Malaysia. The wind data for year 2009 was collected from Malaysia Meteorology Department (MMD) and then extrapolated to the hub heights of various turbines. Wind turbines with rated powers between 1 kW and 110 kW were chosen for annual energy production calculations and best fitted ones were used for the micrositting analysis. In this study, the turbine with 22 kW rated power with hub height 30 m was selected based on its best value of capacity factor. The wind speed frequency per year is highly peaked in the range 1–6 m/s, this indicate that most of the wind speed at Langkawi Island lies in this range. The 'WAsP' and 'WindPRO' softwares were used for the wind statistics and energy calculations. Calculated energy production of located 10 turbines with total capacity of 0.22 MW was 111.1 MWh. Suitable sites were selected according to the created wind power and energy maps. The future cost of maintenance and the status of area either its reserved or conserved by the government were the factors that be considered for selection of site area.

Keywords: Wind energy; Micrositting; Windpro; WasP; Annual energy production; Wind farm

1. INTRODUCTION

There is a growing awareness for renewable energy resources in Malaysia as a result of increasing population and industrial development. Electricity energy sector in Malaysia is forecasted growth, the demand for electricity is expected to increase from 91,539 GWh in year 2007 to 108,732 GWh in year 2011 [1, 2, 3, 4]. Accordingly, it is projected that by 2020, the final energy demand in Malaysia will reach 116 Mtoe based on an annual growth rate of 8.1% [5]. With the rapid economic development, Malaysia needs more and more resources to support the industrial development and to enhance the productivity of capital, labor and other factors to production.

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Wind speed in Malaysia depends on geographical and meteorological factor. Location of Malaysia near to the Earth equator inducing four climatic seasons experienced throughout the year. Consist of two monsoons and inter-monsoon respectively, their impact on windcreates seasonal pattern of wind speed. Northeast monsoon occurred from November to March gives highest wind speed each year that can reach 15 m/s compared to Southwest monsoon and inter-monsoon [6]. Lightest wind averagely 1–2 m/s occurred in April each year during Northeast monsoon transition to Southwest monsoon. Long distance traveled by wind from Indian Ocean to Langkawi reduces the wind speed during Southwest monsoon. This happens due to large frictional force on wind with water surface thus forming large waves. This explains the reason of high wind speed during Northeast monsoon in Langkawi despite its West Coast location [7].

In order to provide a broad wind resource assessment over Malaysia, the wind characteristics must be studied in detail. Wind resource assessments can be divided into two main areas: regional assessment and micrositting. Regional assessment is overall estimation of the mean energy content of the wind over a large area. Micrositting is to position one or more wind turbines on a land in order to maximize the overall yearly energy output of a wind farm.

During the last decade, advanced computational methods have been developed to gain the data to use in estimation of wind energy potential and micrositting [8, 9, 10, 11, 12]. A precise 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 [13] is a good example of this. Some other wind resource maps such as Wind Atlas of Russia [14] and the Irish Wind Atlas [15] also have been prepared.

The Windpro and WAsP Software were widely used by researchers for analyze the wind turbine and energy production [16, 17, 18]. Several studies have been done to estimate the wind potential in Malaysia [19, 20, 21, 22]. However, there are limited study about the wind energy and wind farm in Malaysia compare to the other countries. This article aims to provide a wind energy potential estimation and to perform micrositting study on Langkawi in order to bridge this gap.

2. MATERIAL AND METHOD

2.1. Meteorological station and proposed wind farm

Wind speed and, consequently, wind energy potential are heavily influenced by the surface roughness of the surrounding area of nearby obstacles such as trees or other buildings, and by the contours of the local terrain. The secondary data was collected from the Malaysia Meteorological Department (MMD) Station which located in coordinates 581022 E, 700601 N (in UTM coordinate system). The data were used for preliminary analysis of wind energy potential in Langkawi. The MMD station was located inside Langkawi International Airport.

The proposed wind farm was located in around coordinates 591546 E, 715703 N (in UTM coordinate system). There were no obstacles detected around the area. Surface roughness was low due to low plant heights, which is important in wind shear. Site was directly open to the sea at North and East direction. The West directions were covered with small trees and bushes. Figure 1 shows the location of the meteorology station and proposed farm in Langkawi.

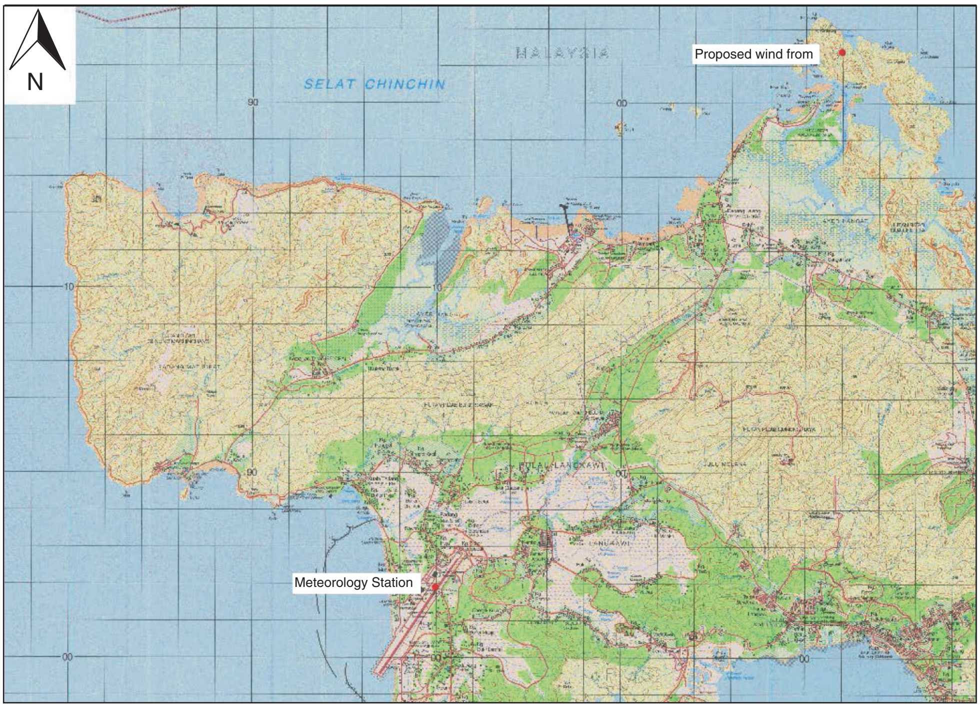

Figure 1: Location of the meteorology station and proposed wind farm in Langkawi.
Map Source: JUPEM.

2.2. Methodology

The data were collected from Malaysian Meteorological Department (MMD) station. Since the MMD station anemometer height varies with station, the wind speeds quoted here were all corrected to a standard height of 10 m by using the formula [23];

$$X_h = X_{10}\left(\frac{0.02337}{0.656\log_{10}(h+4.5)}\right) \tag{1}$$

The MMD station wind data are based on the 10 m height. However, the wind speeds at different heights can be extrapolated to assess the availability of wind resources. Vertical wind speed profile for each station was interpolated by the power law equation [24-27];

$$v = v_0\left(\frac{z}{z_0}\right)^{\alpha} \tag{2}$$

where v is 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 'WindPRO' and 'WAsP' softwares were played a key role to evaluate all collected data in order to make wind energy analysis and micrositting considering orography and topography at the site.

The expression of kinetic energy of air in wind is;

$$E_k = \frac{1}{2}mV^2 \tag{3}$$

where m is total mass of the air, V is wind speed. Since, $m = \rho AV\Delta t$ then,

$$E_k = \frac{1}{2}\rho AV^3\Delta t \tag{4}$$

where ρ is air density, A is area which air moves, Δt is period of time. The power of wind may be expressed as;

$$P = \frac{1}{2}\rho AV^3 \tag{5}$$

and the wind power density may be expressed as;

$$P_d = \frac{1}{2}\rho V^3 \tag{6}$$

The Weibull probability density distribution function used for wind speed is [28, 29, 30, 31, 32, 33];

$$p(V)_w = \left(\frac{k}{c}\right)\left(\frac{V}{c}\right)^{k-1}\exp\left[-\left(\frac{V}{c}\right)^k\right] \tag{7}$$

where k is a dimensionless shape factor and c is the scale factor. The linear approximation of the data is obtained by using the least square method.

Restricted topography map was used for background map. The height contour map was generated from Digital Elevation Model (DEM) by using ArcGIS function. Then the map was loaded into 'WindPRO' software for starting the analysis.

3. RESULTS

3.1. Selecting best fit turbines

Annual energy productions of eight turbines with different energy capacity were calculated by 'WindPRO' software using measured data. The turbine energy production was calculated at the same location, 591672 E, 715549 N (in UTM coordinate system). Rated powers of these turbines were 1, 3, 6, 11, 15, 22, 30 and 110 kW. Table 2 shows their nominal and estimated annual energy productions and capacity factors. Capacity factor is the ratio of estimated and

Table 1: Sectoral mean wind speeds and their frequencies at 10 m

Sector	Mean wind speed (m/s)	Frequency (%)
North (N)	1.16	4.6
North northeast (NNE)	2.22	23.3
East northeast (ENE)	1.61	21.5
East (E)	1.73	9.5
East southeast (ESE)	1.44	4.4
South southeast (SSE)	1.2	2.0
South (S)	1.53	1.4
South southwest (SSW)	2.18	2.4
West southwest (WSW)	2.35	9.9
West (W)	2.54	10.1
West northwest (WNW)	2.94	7.9
North northwest (NNW)	1.5	3.0
Mean	2.00	100.0

Table 2: Comparison of Turbines

Turbine Rated Power (kW)	Nominal annual energy production (MWh)	Estimated annual energy production (MWh)	Capacity factor (%)
1	8.76	0.2	2.3
3	26.3	0.4	1.5
6	52.6	0.7	1.3
11	96.4	4.9	5.1
15	131.4	3.5	2.7
22	192.7	11.2	5.8
30	262.8	11.4	4.3
110	963.6	20.1	2.1

nominal annual energy productions. Turbine with 22 kW nominal power has the highest capacity factor. The second highest capacity factor is achieved for a 30 kW nominal power turbine. Thus, turbine 22 kW nominal power was chosen as the most suitable wind turbines for the analysis of energy production at Langkawi Island.

3.2. Wind speed analysis

Mean wind speed and Weibull distribution are the most effective parameters in wind energy analysis. The wind speed collected from MMD station was extrapolated to the hub heights of various turbines. In this study, the wind speed was extrapolated to 30 m and the data analysis was shown in Table 3. Mean speeds were 2.00 and 2.50 m/s, respectively, at 10 and 30 m. However, this value was from MMD station and assumed that the true value of wind speed at selected proposed wind farm site was higher and more better.

The different between MMD station site and proposed wind farm site were on the obstacle and surface roughness. The obstacle and surface roughness will affect the value of wind speed.

Prevailing wind direction was North (N) and North northeast (NNE) on the site as showed in Figure 2 and Figure 3. Analysis of Weibull distribution showed that, 23.3% of the wind at MMD station blew from North northeast (NNE). The frequencies for East northeast (ENE) sector were 21.5%. There were strong wind blowing from west sectors, but their frequencies

Table 3: Sectoral mean wind speeds and their frequencies at 30 m

Sector	Mean wind speed (m/s)	Frequency (%)
North (N)	1.48	4.6
North northeast (NNE)	2.83	23.3
East northeast (ENE)	1.89	21.5
East (E)	2.18	9.5
East southeast (ESE)	1.72	4.4
South southeast (SSE)	1.58	2.0
South (S)	1.91	1.4
South southwest (SSW)	2.69	2.4
West southwest (WSW)	2.91	9.9
West (W)	3.18	10.1
West northwest (WNW)	3.69	7.9
North northwest (NNW)	1.86	3.0
Mean	2.50	100.0

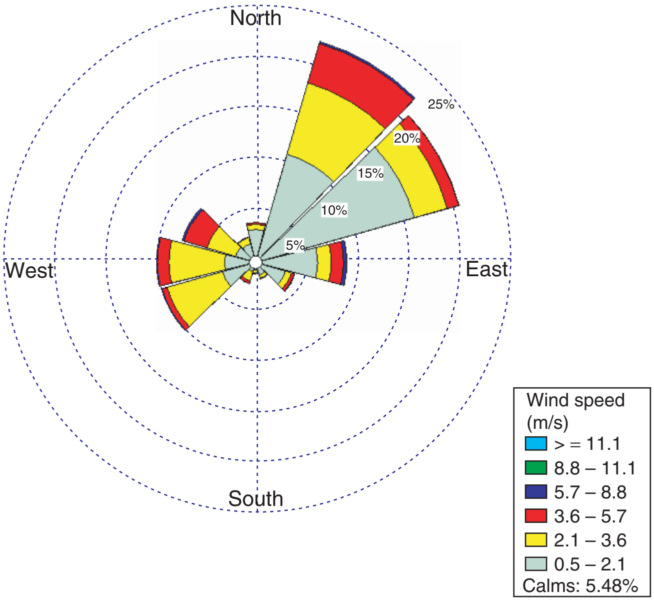

Figure 2: Wind rose of Langkawi Island at 10 m.

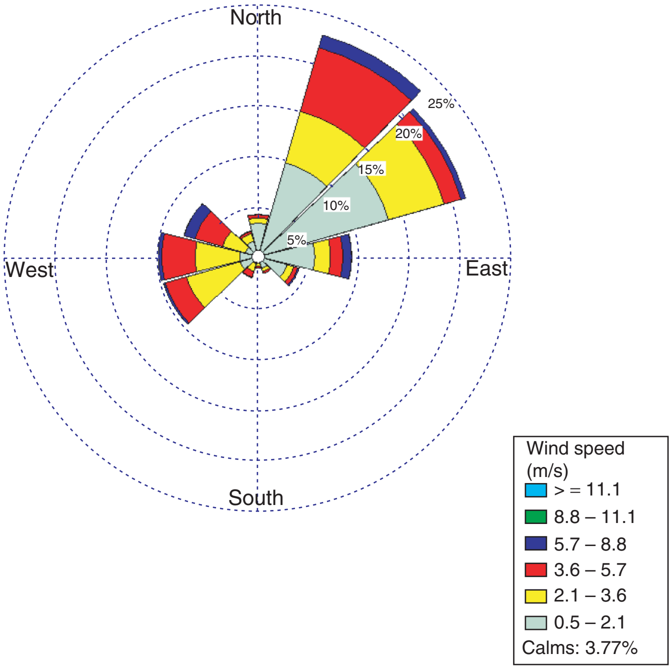

Figure 3: Wind rose of Langkawi Island at 30 m.

were quite low. Other sectors frequencies showed the small value. The sectoral mean wind speed values along with their frequencies are shown in Tables 1 and 2, respectively, at 10 and 30 m heights.

Figure 4 and Figure 5 showed the wind class frequency distribution at Langkawi Island. The frequency is highly peaked in the range 1–6 m/s, this indicate that most of the wind speed at Langkawi Island lies in this range. This distribution of wind speed is important in determining the percentage of time during a year, the power that could be generated from wind farm.

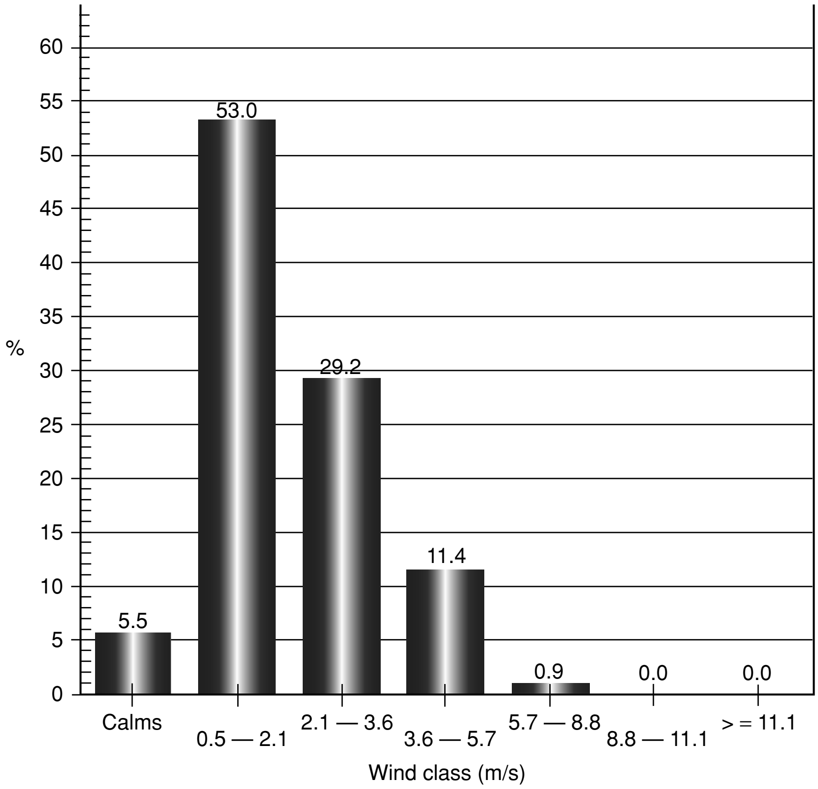

Figure 4: Wind class frequency distribution at Langkawi Island at 10 m.

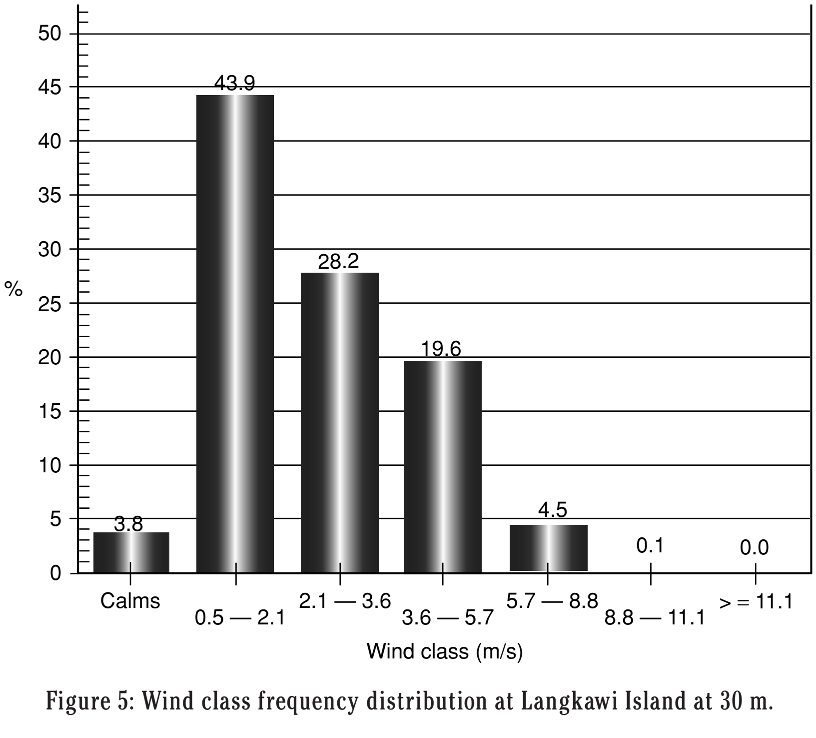

Figure 5: Wind class frequency distribution at Langkawi Island at 30 m.

3.3. Wind energy analysis

Wind energy were analyzed by using collected data, orography and roughness maps. The wind energy map, Figure 6, was determined in kWh/m^2 per year. This map considers whole values of Weibull histogram. The location which show the best value of wind

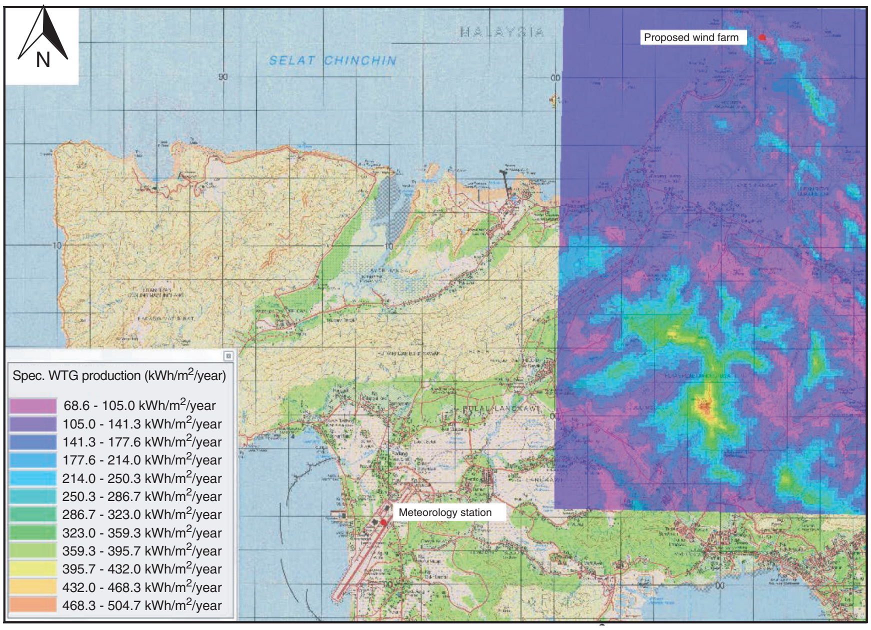

Figure 6: Wind energy map of Langkawi Island in kWh/m^2/year for 22 kW nominal power turbine.

energy was at highland area with range 468.3–504.7 kWh/m^2 per year. However, proposed site to develop wind farm must take account the future cost of maintenance and the status of area either its reserved or conserved by the government. The proposed site for developing wind farm in Langkawi Island shows range 68.6–286.7 kWh/m^2 per year. This site also located at northeast end of the island which the most prevailing wind were recorded.

Wind speed and wind energy maps were used to select suitable sites to locate wind turbines. Ten sites were selected to install the turbines. The wind speed frequency per year is highly peaked in the range 1–6 m/s based on MMD wind data and enough area to locate these

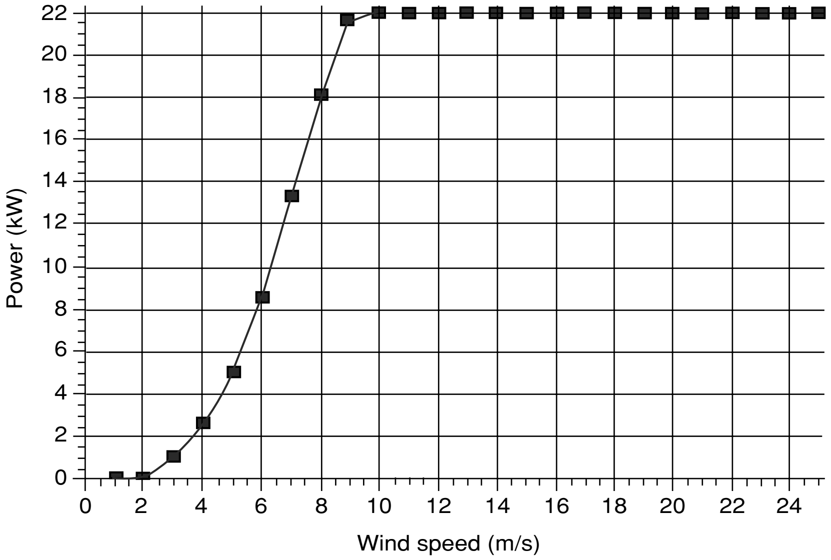

Figure 7: Power curve of 22 kW wind turbine used in windpro calculation.

Table 4: Energy produced by individual unit of 22 kW turbines

	Location (in UTM coordinate system)	Power rated (kW)	Rotor diameter (m)	Hub height	Annual Energy (MWh)
Turbine 1	591672 E 715549 N	22	15	30	11.2
Turbine 2	591591 E 715606 N	22	15	30	11.1
Turbine 3	591509 E 715606 N	22	15	30	11.4
Turbine 4	591509 E 715663 N	22	15	30	11.4
Turbine 5	591346 E 715778 N	22	15	30	11.0
Turbine 6	591743 E 715619 N	22	15	30	10.9
Turbine 7	591661 E 715677 N	22	15	30	11.2
Turbine 8	591580 E 715734 N	22	15	30	10.8
Turbine 9	591498 E 715791 N	22	15	30	11.2
Turbine 10	591416 E 715849 N	22	15	30	10.9

turbines. Turbines were located 100 m distance apart each other to prevent energy production loses of park effect.

22 kW rated power wind turbine was selected for energy calculation in this study due to its best capacity factor value. The turbine hub height and rotor diameter were, 30 m and 15 m respectively. Figure 7 showed the power curve of 22 kW wind turbine which used in windpro software calculation. The turbines cut in wind speed was 3 m/s and the rated wind speed was 10 m/s. Ten unit 22 kW wind turbine were located in different location on the southwest of Langkawi Island as shown in Table 4. Calculated energy production of located 10 turbines with total capacity of 0.22 MW was 111.1 MWh.

4. CONCLUSION

The aim of this study was to estimate wind energy potential and to perform the most suitable micrositting study.

The wind power parameters were evaluated by using a great deal of measured data. The wind speed frequency per year is highly peaked in the range 1–6 m/s, this indicate that most of the wind speed at Langkawi Island lies in this range. North northeast (NNE) and East northeast (ENE) were found as prevailing wind direction.

In addition to wind characteristics, wind energy map was created. The most suitable turbines were located at the most convenient sites in order to produce the optimum energy. The annual energy productions of the ten micrositted turbines with 22 kW rated powers was 111.1 MWh/year. From this study, it is concluded that these sites are unsuitable for the large-scale wind energy generation. However, small-scale wind energy can be generated or hybrid with photovoltaics (PV) system for produce more electricity.

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REFERENCES

[1] Khamis, A., Alamshah, A., Ahmad, A., Rahman, A.A. and Hairi, M.H. Energy and electricity consumption analysis of Malaysian power demand. *Power Engineering and Optimization Conference (PEOCO)*, 2010, 463–467.

[2] Koh, S.L. and Lim, Y.S. Meeting energy demand in developing economy without damaging the environment – a case study in Sabah, Malaysia, from technical, environment and economic perspectives. *Energy Policy*, 2010, 38, 4719–4728.

[3] The Malaysia Economic in Figures 2010. Economic planning unit. Prime Minister Department. http://www.epu.gov.my/malaysianeconomyfigures2009.

[4] Chandran, V.G.R., Sharma, S. and Madhavan, K. Electricity consumption-growth nexus: the case of Malaysia. *Energy Policy*, 2010, 38, 606–612.

[5] Keong, C.Y. Energy demand, economic growth, and energy efficiency – the Bakun dam-induced sustainable energy policy revisited. *Energy Policy*, 2005, 33, 679–689.

[6] Siti, M.R.S., Norizah, M. and Syafrudin, M. The Evaluation of Wind Energy Potential in Peninsular Malaysia, *International Journal of Chemical and Environmental Engineering*, 2011, 2, 284–291.

[7] Deros, S.N.M., Asmat, A. And Mansor, S. Wind power estimation from forecast wind data. *6th International Symposium on Advances in Science and Technology (SASTech) Kuala Lumpur*, 2012, 6-11-30–193.

[8] Brown, B.G., Katz, R.W. and Murphy, A.A. Time series models to simulate and forecast wind speed and wind power. *Journal of Applied Meteorology and Climatology*, 1984, 23, 1184–1195.

[9] Blanchard, M. and Desrechors, G. Generation of auto-correlated wind speeds for wind energy conversion system studies. *Solar Energy*, 1984, 33, 571–579.

[10] Chou, K.C. and Corotis, R.B. Simulation of hourly wind speed and array wind power. *Solar Energy*, 1981, 26, 199–212.

[11] Bernard, J.C. An evaluation of three models designed for sitting wind turbines in areas of complex terrain. *Solar Energy*, 1991, 46, 283–94.

[12] Landberg, I., Mortensen, N.G. and Petersen, E.L. Wind resource assessment and sitting—a wider perspective. *World directory of renewable energy suppliers and services*, 1995, 170–176.

[13] Troen, I. And Petersen, E.L. European Wind Atlas. Roskilde: *Riso National Laboratory*, 1989.

[14] Starkov, A. and Landberg, L. Wind Atlas of Russia. In: Petersen EL, editor. *Proceedings of the European wind energy conference*, Nice-France, 1999, 1128–1131.

[15] Watson, R. and Landberg, L. The Irish Wind Atlas. In: Petersen EL, editor. *Proceedings of the European wind energy conference*, Nice, France, 1999, 1097–1100.

[16] Ozerdem, B. and Turkeli, H.M. Wind energy potential estimation and micrositting on Izmir Institute of Technology Campus, Turkey. Renewable Energy, 2005, 30, 1623-1633.

[17] Wizelius, T. Design and Implementation of a Wind Power Project. Comprehensive Renewable Energy. 2012, 2, 391-430.

[18] Jewer, P., Iqbal, M.T. and Khan, M.J. Wind energy resource map of Labrador. Renewable Energy. 2005, 30, 989-1004.

[19] Exell, R.H.B. and Cheong, T.F. The wind energy potential of Malaysia. *Solar Energy*, 1986, 36, 281-289.

[20] Sopian, K., Hj. Othman, M.Y. and Wirsat, A. The wind energy potential of Malaysia. *Renewable Energy*, 1995, 6, 1005-1016.

[21] Islam, M.R., Saidur, R. And Rahim, N.A. Assessment of wind energy potentiality at Kudat and Labuan, Malaysia using Weibull distribution function. *Energy*, 2011, 36, 985-992.

[22] Exell, R.H.B. The wind energy potential of Thailand. *Solar Energy*, 1985, 35, 3-13.

[23] Hussain, M. Dependence of powerlaw index on surface wind speed. *Energy Conversion and Management*, 2002, 43, 467-472.

[24] Ahmed, S.A. Wind energy as a potential generation source at Ras Benas, Egypt. *Renewable and Sustainable Energy Reviews*, 2010, 14, 2167-2173.

[25] Safari, B. Modeling wind speed and wind power distribution in Rwanda. *Renewable and Sustainable Energy Reviews*, 2011, 15, 925-935.

[26] Ohunakin, O.S. Wind resources in North-East geopolitical zone, Nigeria: An assessment of the monthly and seasonal characteristics. *Renewable and Sustainable Energy Reviews*, 2011, 15, 1977-1987.

[27] Arni, S.R. and Srinivasa, R. On joint Weibull probability density functions. *Applied Mathematics Letters*, 2005, 18, 1224-1227.

[28] Yeliz, M.K. and Ilhan, U. Analysis of wind speed distributions: Wind distribution function derived from minimum cross entropy principles as better alternative to Weibull function. *Energy Conversion and Management*, 2008, 49, 962-973.

[29] Carta, J.A. and Ramírez, P. Analysis of two-component mixture Weibull statistics for estimation of wind speed distributions. *Renewable Energy*, 2007, 32, 518-531.

[30] Tian, P.C. Estimation of wind energy potential using different probability density functions. *Applied Energy,* 2011, 88, 1848-1856.

[31] Weisser, D. A wind energy analysis of Grenada: an estimation using the 'Weibull' density function. *Renewable Energy,* 2003, 28, 1803-1812.

[32] Seyit, A.A. and Ali, D. A new method to estimate Weibull parameters for wind energy applications. *Energy Conversion and Management*, 2009, 50, 1761-1766.

[33] Ali, N.C. A statistical analysis of wind power density based on the Weibull and Rayleigh models at the southern region of Turkey. *Renewable Energy*, 2004, 29, 593-604.