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A Study on Wind and Solar Energy Potentials in Malaysia

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Abstract- This paper discusses the wind and solar energy potentials in Malaysia. It first presents the Weibull density functions and compares the wind speed over several cities. Then, it shows the power density at the wind measurement device's height and compares it with the power density at the hub height of a certain turbine, followed by showing the probability of the turbines operating above 2.5m/s and their annual operating hours. The second part presents temperature and radiation over the same cities and compares the output energy of a specific PV module in each of the cities; to provide a fair comparison. All the data are from the Malaysian Meteorology Department, and they were taken from 2011-2012 on a daily basis. The significance of this research is that it lays the road for optimization studies and gives a glimpse on the energy potential of the wind and solar energies in Malaysia.

Keywords: Renewable energy; Solar energy potential; Wind energy potential.

1. Introduction

Renewable energy sources (RES) will in the near future be the heart of electricity generation worldwide. After the discovery of the oil resources, the world has gone energy crazy dissipating and using this source as if it is an endless source. But the awakening moment has come after receiving a huge shock from our planet; the global warming caused a drastic change in the earth climate and temperature. Moreover, the fact that the oil reservoirs are running low caused every country to seek an alternative source of energy especially the renewable sources. There are several RES but the wind turbine systems and the photovoltaic (PV) systems found part of the two fast growing technologies. By 2012, 282.5 GW of wind turbines had been installed [1], while electrical consumption generated from solar systems is about 93 TWh [2].

Malaysia is now exploring its options of renewable energy especially after the 8th plan, when the energy commission of Malaysia regulated the energy supply activities and enforced energy supply laws. In the period of 2001-2005 Malaysia had set a target for the energy supplied by RES of 5% of its total electricity demand. Then, during the 9th plan in the period of 2006-2010 Malaysia laid a target of 350 MW grid-connected to be generated from RES [3], but it was not achieved. However, Malaysia is still determined to increase the implementation of the RES which is clearly apparent from the 10th plan (2011-2015) that a target of 985MW has been set to be met by the end of that period [4].

Before starting to examine the energy potential from wind turbines and PV systems, it is a must to have a basic knowledge about the geographical location and climate conditions of Malaysia. Malaysia is an equatorial country located in 4.19° N, 103.7°E as shown in Fig. 1. It consists of thirteen states divided into two regions separated by the South China Sea, Peninsular Malaysia and Malaysian Borneo. Malaysia's temperature is generally uniform throughout the year, with high humidity and heavy rains.

Fig.1. Malaysia's Location.

Being a country close to the equator; makes the sky always covered with clouds, therefore, the average sunshine hours are 6 hours a day. Generally, there are two different monsoons over Malaysia: the Southwest monsoon and the Northeast monsoon. The Southwest monsoon is from the period of May/June till September, while the Northeast monsoon is in the period from November until the end of March. [5]. In general, Malaysia has a humble average wind speed and it varies between the two different monsoons. On the other hand the annual average daily solar radiation is in the range from 4.21 kWh /m2 to 5.56 kWh /m2 [6].

The scope of this research is to examine the wind and solar energy potential in Malaysia. All the required data were obtained from the Malaysian Meteorological Department from 2011 to 2012.

Daily wind speed, temperature and solar radiation over seventeen different cities were downloaded from Nasa Surface Meteorology and Solar Energy data base for two years. Cities that have a high wind speed or receive high solar radiation were chosen to be studied in this paper. For accuracy of data; solar radiation, temperature, and wind speed were requested from the Malaysian Meteorology Department for the same period (2011-2012). Table 1 shows the cities under study and their locations.

2. Methodology

Table 1. The selected cities with their locations.

City	Height above MSL (m)	Location	Coordination
Kota Bharu	4.6	East cost of Peninsular Malaysia	Lat. $6^{o}10$ N
			Long. $102^{o}17$ E
Kuala Terengganu	5.2	East cost of Peninsular Malaysia	Lat. $5^{o}23$ N
			Long. $103^{o}06$ E
Langkawi Island	6.4	Northwest of Peninsular Malaysia	Lat. $6^{o}20$ N
			Long. $99^{o}44$ E
Mersing	43.6	Southeast of Peninsular Malaysia	Lat. $2^{o}27$ N
			Long. $103^{o}50$ E
Miri	17	North cost of Sarawak	Lat. $4^{o}20$ N
			Long. $113^{o}59$ E

This article is divided into two parts: the first part examines the wind energy potential in the five aforementioned cities, while the second part studies the solar PV energy potential.

3. Wind Energy Potential

Wind is one of the most ancient techniques that have been in use in order to generate usable mechanical or electrical power. It moves from one location to another based on the pressure level between these two locations, and it abides the natural laws by flowing from high pressure regions to lower pressure locations. Wind speed is mainly affected by the wind pressure and hence it is noticeable that low pressure regions have lower wind speed compared to high pressure regions, Malaysia in turn is located in the low pressure belt and therefore, the wind speed over Malaysia in general is low. Figure 2 shows the global wind speed map.

Wind speed varies based on the geographical nature of the location under study. One of the most common functions in use to determine the probability of a certain wind speed is the Weibull distribution function, and is usually used due to its simplicity and the agreement of the values predicted by this method with the experimental data [7].

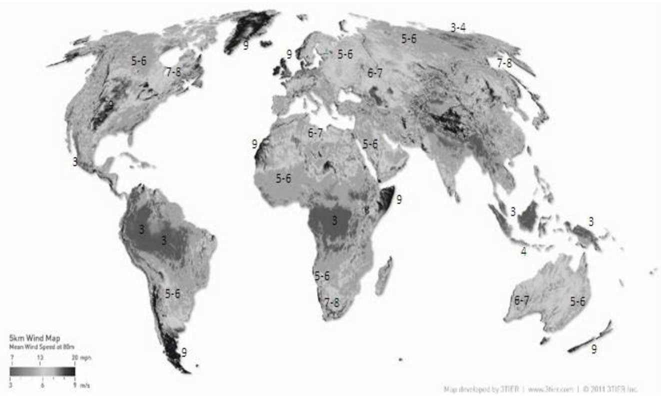

Fig. 2. Global wind speed map (m/s)

In general, the Weibull probability density function is described by [8]:

$$f(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} \exp-\left(\frac{v}{c}\right)^{k} \qquad (1)$$

Where v is the average wind speed in (m/s), c (m/s) is the scale parameter, and k (dimensionless) is the shape parameter.

Some notes about the c and k parameters are worth mentioning, that is as the shape parameter increases, the peak of the Weibull density function gets higher and the shape gets narrower, which means that the repetition of a certain value is high. Meanwhile, if the scale parameter is increased, the shape of the Weibull pdf would expand in width, which means that the wind speed varies largely [9].

Based on the knowledge of the variance and the mean of the wind speed the value of k and c can be obtained respectively using the following expressions

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

Where σ is the square root of the variance.

$$c = \frac{v}{\Gamma\left(1+\frac{1}{k}\right)} \quad \text{m/s} \tag{3}$$

Where Γ(x) is the gamma function of x.

Another factor that plays a major role in the wind speed is the height above ground; therefore, it is necessary to determine the wind speed at the height of the wind turbine's hub [10]:

$$v = v_0\left(\frac{z}{z_0}\right)^{\alpha} \tag{4}$$

Where α is the ground surface friction coefficient.

The power of the wind flowing at speed v (m/s) through a blade sweep area A (m^2) is given by [10]:

$$P(v) = \frac{\rho A v^3}{2} \quad \text{W} \tag{5}$$

Where ρ is the air density.

Average power density per unit area is given by [10]:

$$P_{avg} = \frac{\rho}{2}\int_0^{\infty} v^3 f(v)dv \quad \text{W/m}^2 \tag{6}$$

If *f(v)* is the Weibull density function, the average power density can be expressed as [10]:

$$P_{avg} = \frac{\rho v^3 \Gamma(1+3/k)}{2[\Gamma(1+1/k))]^3} \quad \text{W/m}^2 \tag{7}$$

Air density is evaluated by 1.17 kg/m3. (As the average temperature over Malaysia and air pressure is 27^{o}C and 101.2 kPa respectively)

Power in general and power density can be determined by evaluating the value of the ground surface friction coefficient α to 0.25[11], then the power density at the hub height is estimated by the following expression [12]:

$$p = p_0\left(\frac{z}{z_0}\right)^{3\alpha} \quad \text{W/m}^2 \tag{8}$$

Where P is the power density at height z, and P_0 is the power density at height z_0 (Usually at the measurement's device height)

The probability of a wind speed to exceed a specific or a reference speed (*u*) was obtained by using the following expression [13]:

$$p(v \ge u) = \exp-\left(\frac{u}{c}\right)^k \tag{9}$$

The turbine operating hours is calculated by multiplying the total hours in a year (8760 hours) by the turbines operation probability.

3.1 Wind Energy Potential Results and discussion

All the data were collected from the Meteorology Department, wind measurements were taken from a 10 meters above ground height sensor. The data have been fitted using the data fit tool in MATLAB. Figure 3 shows the annual probability density of the chosen cities.

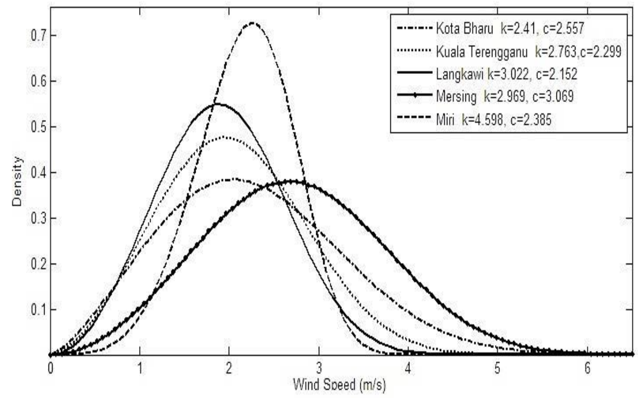

Fig. 3. Weibull probability density.

As mentioned earlier the shape parameter determines the peak of the curve, while the scale parameter determines the width. Miri has the highest k value and therefore, the shape of its probability density has the highest peak and the narrowest width. On the other hand, Mersing has the highest scale parameter and that is why it has wider range of wind speeds than any other city. However, Fig. 4 shows the monthly and annual wind regime over the cities.

Results reveal that Mersing has the highest wind speed of 2.74 m/s followed by Kota Bharu with an average speed of 2.27 m/s, Miri comes after with an average wind speed of 2.18 m/, then Kuala Terengganu with an average wind speed of 2.05 m/s, and the least average wind speed of 1.92 is measured over Langkawi island. During the Northeast monsoon the wind is high, wind reaches its maximum speed in all of the cities, while during the Southwest monsoon the wind speed starts to rise again but not as high as the speed during the Northeast monsoon due to the presence of obstacles toward the wind flow.

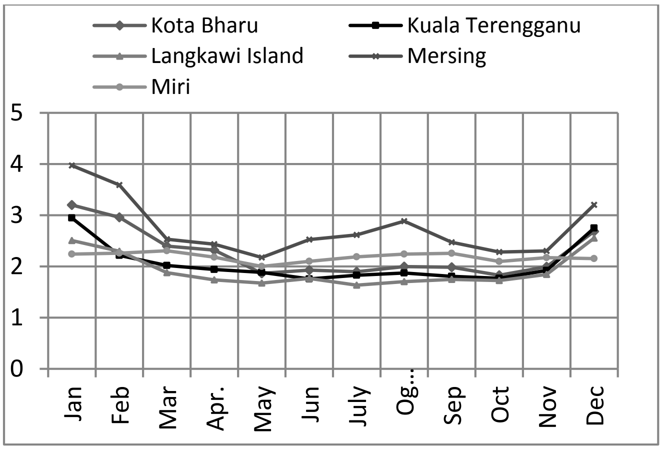

Fig. 4. Average wind speed over the cities under study.

As its seen from figure 4, Mersing has the highest wind speed among the other cities. Wind speed reaches maximum of 3.97 m/s in the middle of the northeast monsoon period and then drops to a minimum of 2.17 m/s in May. Mersing's height is the main factor contributing to the fact that it has the highest wind speed. Wind regime over Kota Bharu and Kuala Terengganu is almost the same, since both cities are located at the east cost of Peninsular Malaysia. Miri has almost a steady wind speed all over the year. Langkawi receives the lowest wind speed among the cities under study.

To determine the energy potential in each city, Weibull density function is used. With the knowledge of the values of the shape, scale parameters, and the average speed, annual power density can be determined from equation (7). The knowledge of the power density is not enough to determine the availability of wind power, turbine's operating hours per year is also required. The operation hours of the turbine is based on the probability of a certain cut in wind speed[1] that need to be exceeded. Most of the wind turbines have a cut-in speed range from 3-4 m/s, while some turbines have a cut-in speed of 2.5 m/s. Since the wind speed is generally low over Malaysia; one of ENERCON's wind turbine with a cut in speed of 2.5 m/s, rated power of 600kW at a rated speed of 13m/s, with a hub height and rotor diameter of 65m and 44 m respectively is considered.

Figure 5 shows the probability curves for each city. From the figure, it can be anticipated that wind turbines in Mersing have the highest operating hours (considering a cut in speed of 2.5 m/s); due to the shape of the Weibull probability curve. On the other hand, wind turbines in Langkawi have the lowest operating probability.

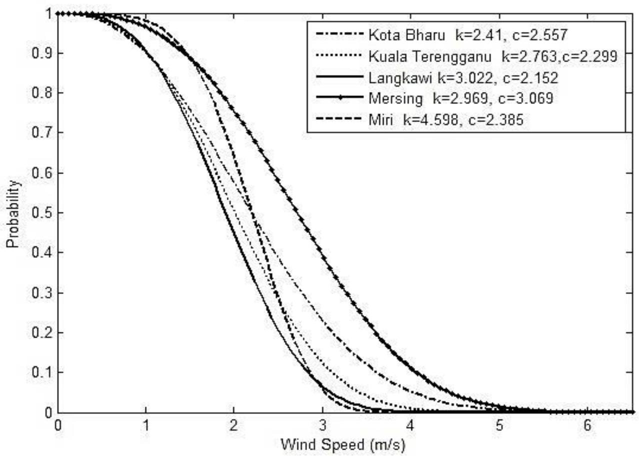

Fig. 5. Probabilities of the wind speed for or greater than a certain value.

Table 2 summarizes the power density and the turbines operating hours per year in each city.

Table 2. Results summary.

City	Power density w/m^2 at the measurement device height (10m)	Power density at hub height (65 m)	Probability of speed above 2.5 m/s	Turbine Operating hours
Kota Bharu	11.058	45.015	38.79%	3398
Kuala Terengganu	7.367	30	28.37%	2485
Langkawi Island	5.822	23.7	20.75%	1818
Mersing	17.013	69.257	58.04%	5084
Miri	7.197	29.298	28.85%	2527

4. Solar Energy Potential

Worldwide, there is a bright future for solar energy, as stated in [6] the land receives about 1700 TW worth of solar radiation and the use of only 1% of this power would not only be sufficient to supply the world's power needs but it will exceed that. The highest solar radiation is received between latitudes 30N and 15N, whereas the region between 15N and

[1] Cut-in speed is the speed at which the wind turbine starts to generate a usable power, any speed below that the turbine provides zero power.

0 comes second in term of the amount of solar radiation received [14]. Figure 6 shows the global solar radiation map.

Since Malaysia is located in the second largest solar radiation region, there is a huge PV energy potential. In order to estimate the annual energy production of a PV system, knowledge of its modules' efficiencies and the land coverage are required, however, most crystalline type modules have efficiency in the range of 11-18% [14].

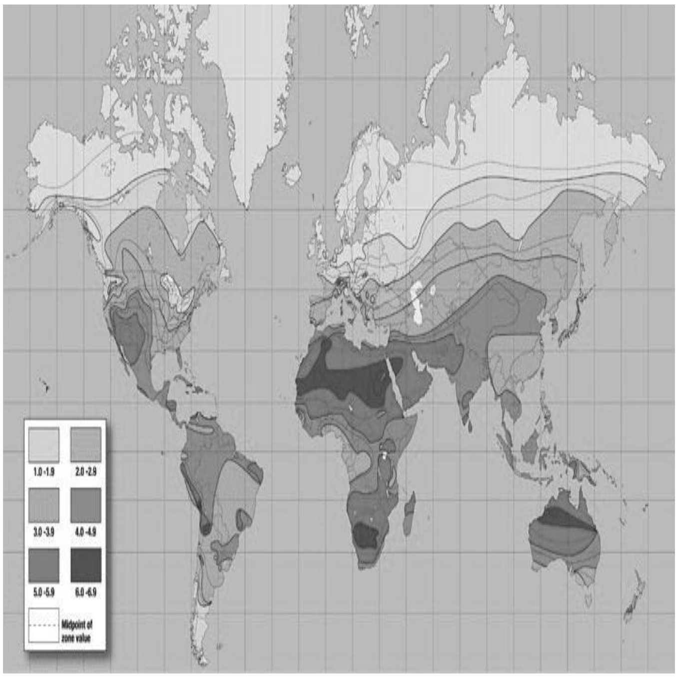

Fig. 6. Global surface solar radiation (W/m^2)

For a given PV system, the output power can be estimated by the following expression. This equation will take into account the temperature effect as well as the wiring and conversion losses [15]:

$$P = P_R \eta \left(\frac{G}{G_{STC}} \right) \left[1 + \gamma \left(T - 25^o \right) \right] \qquad (10)$$

Where PR is the module rated power, η is the de-rating factor which is considered here to be equal to 87%. This value takes into consideration the inefficiencies in the converters, transformers, and the wiring of the PV system. Typical de-rating values can be found in [16]. G is the incident global solar radiation in kW/m2, GSTC (1kW/m2) is the global radiation at standard test conditions, γ is the module power temperature coefficient (oC-1), and T is the module temperature in oC.

The global solar irradiation is the total solar irradiation received by a horizontal surface on the earth. It has two components, the direct and diffused irradiation. The direct irradiation is the direct beam that reaches a horizontal surface, while the diffused irradiation is the irradiation that has been scattered by the earth's atmosphere, clouds, and the reflected radiation from the ground [17]. Figure 7 illustrates the direct and diffused irradiation on a horizontal surface.

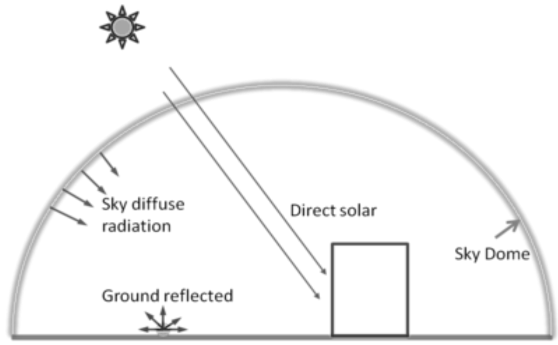

Fig. 7. Direct and diffused radiation.

In general the output power of the PV system is affected by several parameters, and these parameters are [18]:

1. The solar radiation, in which the power increases in a linear relationship with the increase of the solar radiation,
2. The area of the PV system, since the captured solar radiation is increased,
3. The operating temperature, which has a negative impact on PV system output.

All the mentioned parameters can be anticipated by examining equation (10).

4.1. Solar PV Potential Results and Discussion

Some of the requested solar radiation data were missing and these data are the solar radiation of Kuala Terengganu and Mersing. The missing data were recovered from Nasa Surface Meteorology and Solar Energy, but Mersing's data were only accessible from 2004 until the end of June 2005.Table 3 shows the average annual temperature and solar radiation, and Fig. 8 shows the average monthly solar insolation.

Table 3. Average annual temperature and solar radiation.

City	Average Temperature (°C)	Average Irradiation (kWh/m^2/d)
Kota Bharu	27.1	5.22
Kuala Terengganu	27.3	5.41
Langkawi	28	5.06
Mersing	26.5	4.54
Miri	27	4.94

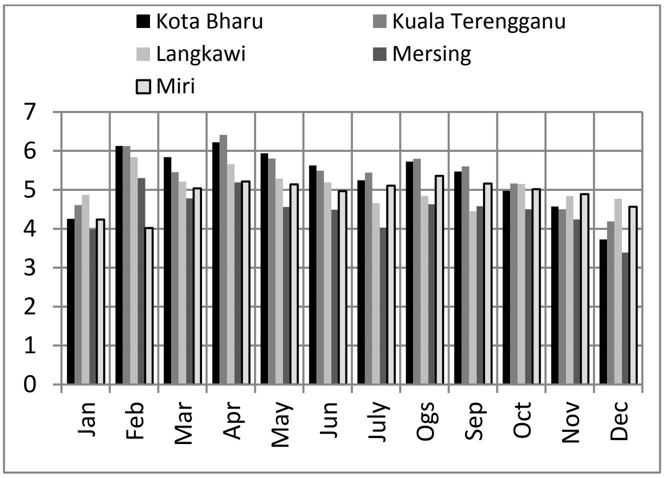

Fig. 8. Average solar irradiation (kWh/m^2/d).

To compare between the five cities in term of electrical power generation, a 300Wp PV module will be considered. The module will be placed in each city and the output power from each city will be listed in Table (5) . The PV module that have been considered is a SUNTECH module rated at 300Wp with a power tolerance of 0/+5%, temperature coefficient of power of -0.44%/oC, and an efficiency of 15.5%. The results in the table can be obtained by substituting the required parameters into Eq. 11.By substituting the solar radiation and temperature data given in Table 4 into equation (11) the results in Table 4 will be obtained.

Table 4. Expected annual power output per module.

City	Annual average power (kW/module)
Kota Bharu	492.688
Kuala Terengganu	510.168
Langkawi	475.678
Mersing	429.649
Miri	466.468

Since Kuala Terengganu receives the highest solar radiation; highest output power will be generated from the PV module if it is placed there. On the other hand, lowest power generation is from Mersing due to the low solar radiation received in Mersing.

5. Conclusion

This paper has presented a study on the wind and solar energy potential in Malaysia. Weibull probability density function was used to determine the average wind speed and the operating hours of the turbines in each city. The results showed that Mersing has the highest wind speed. Wind turbines in Mersing with a cut-in speed of 2.5 m/s would operate for 5084 hours a year. Results also revealed that he highest wind speed occurs during the northeast monsoon.

Solar energy potential on the other hand was determined by evaluating the annual output power of a 300W PV module in each city. Based on that the highest solar energy potential was found to be in Kula Terengganu followed with a small difference by Kota Bharu, but the main drawback of the Kuala Terengannu solar energy potential is that its data were taken from the internet, meanwhile Kota Bharu data were obtained from the Meteorology Department.

Acknowledgment

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Response to Reviewers

<u>Reviewer B</u>

1. Miri is added to the figure

2. T is the module temperature, it has been added in the content

3, 4, and 5. It has been modified to Kwh

<u>Reviewer C</u>

1. A daily basis (it has been stated in the Abstract)

2. The average temperature over Malayisa and air pressure are 27 degrees Celsius and 101.2 kPa respectively, by substituting these values into the air density equation you will get 1.17 Kg/m3

3. All of the equations are standard equations and have been referenced, the numbering of the equations has been modified.