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Keywords: wind atlas, power law index, Malaysia, capacity factor, wind energy

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This paper investigated the wind energy potential by analysing a certain amount of gathered 10-min measured data at four stations located at coastal sites in Malaysia, i.e., Kudat, Mersing, Kijal, and Langkawi. The wind data are collected from a total of four new wind measurement masts with sensors mounted at various heights on the tower. The measured data have enabled the establishment of wind resource maps and the power law indexes (PLIs) analysis. In addition, the dependence of PLI upon surface temperature and terrain types is studied, as they are associated to the form of exponential fits. Moreover, the accuracy of exponential fits is assessed by comparing the results with the 1/7 law via the capacity factor (CF) discrepancies. In order to do so, the wind turbine with a hub-height similar to the maximum height of the measured data at each site is selected to simulate energy production. Accordingly, the discrepancy of CF based on the extrapolated data by employing 1/7 laws and exponential fits, in spite of being computed using measured data, is determined as well. Furthermore, the large discrepancy of the wind data and the CF, which has been determined with the application of 1/7, is compared to the exponential fits. This is because; discrepancy in estimation of vertical wind speed could lead to inaccurate CF computation. Meanwhile, from the energy potential analysis based on the computed CF, only Kudat and Mersing display a promising potential to develop a medium capacity of wind turbine power, while the other sites may be suitable for wind turbines at a small scale.

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Article

Wind Energy Potential and Power Law Indexes Assessment for Selected Near-Coastal Sites in Malaysia

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Abstract: This paper investigated the wind energy potential by analysing a certain amount of gathered 10-min measured data at four stations located at coastal sites in Malaysia, i.e., Kudat, Mersing, Kijal, and Langkawi. The wind data are collected from a total of four new wind measurement masts with sensors mounted at various heights on the tower. The measured data have enabled the establishment of wind resource maps and the power law indexes (PLIs) analysis. In addition, the dependence of PLI upon surface temperature and terrain types is studied, as they are associated to the form of exponential fits. Moreover, the accuracy of exponential fits is assessed by comparing the results with the 1/7 law via the capacity factor (CF) discrepancies. In order to do so, the wind turbine with a hub-height similar to the maximum height of the measured data at each site is selected to simulate energy production. Accordingly, the discrepancy of CF based on the extrapolated data by employing 1/7 laws and exponential fits, in spite of being computed using measured data, is determined as well. Furthermore, the large discrepancy of the wind data and the CF, which has been determined with the application of 1/7, is compared to the exponential fits. This is because; discrepancy in estimation of vertical wind speed could lead to inaccurate CF computation. Meanwhile, from the energy potential analysis based on the computed CF, only Kudat and Mersing display a promising potential to develop a medium capacity of wind turbine power, while the other sites may be suitable for wind turbines at a small scale.

Keywords: wind energy; capacity factor; Malaysia; power law index; wind atlas

1. Introduction

Malaysia is situated in Southeast Asia, where it shares international borders with three countries: Thailand, Indonesia, and Brunei. In fact, Malaysia has the 29th longest coastline in the world, totalling up to 4675 km [1]. Like most countries worldwide, Malaysia has also acknowledged the significance of Renewable Energy (RE) as a complement to the conventional fuel that serves as a source for generating electricity. In line with that, Malaysia adopted the Small Renewable Energy Power Program (SREP) in year 2001 to further boost the development of RE. However, unsatisfactory results were obtained as the SREP scheme failed to increase the share of RE in the national power generation mix by 2010 [2]. After that, in 2011, a national energy policy known as Renewable Energy Act 2011 (Act 725) was introduced and passed in the Malaysian parliament for implementation [3,4]. Act 725 is comprised of detailed information and execution procedures pertaining to the Feed-in Tariff (FIT) scheme.

Other than that, the target for year 2015 was 985 MW, while 2020 and 2030 are projected to contribute 2080 MW and 4000 MW, respectively. However, as reported in 2014, the progress took a dramatic turn from the target when the cumulative capacity was less than 250 MW, while the projected capacity for year 2015 was a whopping 400 MW, which satisfied 50% of the original target [5]. On the other hand, [6] asserted that the target is still an impossible feat to achieve as the capacity of RE-based energy in year 2020 has been projected to only achieve 1464 MW even if all power plants are commissioned. Hence, it is obvious that the target for year 2030 is indeed an impossible achievement. Accordingly, one of the best solutions available is to introduce a new renewable energy technology, such as wind energy, into the Malaysian RE mix to enhance the generation of electricity [5].

In fact, wind energy is an RE resource that has yet to attain recognition as an eligible RE within the Malaysia Renewable Energy Act 2011 [7]. However, the Malaysian government has a positive outlook for such RE resource by offering research grants to generate more detailed and comprehensive researches especially to study the feasibility of wind for generating electricity in Malaysia [8].

As such, this paper presents the progress of wind energy application in Malaysia, as well as the evaluation of the potential of wind energy at four newly installed wind measurement masts. Even though numerous studies have looked into the notion of wind energy in the country, most of them displayed negative impressions by concluding that Malaysia has no potential for generating wind energy. Furthermore, many factors have been listed to support this negative finding, which are further discussed in detail in Section 2. Next, Section 3 presents the analysis and the evaluation of the recent wind data from the newly installed wind measurement masts at the four selected sites.

2. Wind Energy Potential in Malaysia

2.1. The Wind Resource Assessment

Studies pertaining to wind energy potential, especially those concerning Malaysia, began to emerge in the 1990s, where in 1995, Sopian et al., analysed a collection of wind speed data recorded from ten sites; Kota Kinabalu, Tawau, and Labuan in Sabah; Kuching in Sarawak; as well as Mersing, Kuala Terengganu, Alor Setar, Petaling Jaya, Cameron Highlands, and Melaka, in Peninsular Malaysia. In fact, the analysis took into account data accumulated from as far as ten years back (1982–1991), which were collected from a number of Malaysian Meteorological Department (MMD) stations. Besides, it is important to note that the wind speed data were standardized to 10 m (m.a.g.l) mainly due to the height variation observed at the measurement towers at each MMD station. As a result, the analysis revealed that Kuala Terengganu and Mersing exhibited the best wind energy potential, in comparison to the rest, with wind power densities (WPD) per year of 32.50 and 85.61 W/m^2, respectively [9].

Other than that, Koh and Lim [10] carried out an assessment that investigated the wind energy potential at Tawau, which is a district situated on the east coast of Sabah, Malaysia. They utilized the MMD data, as presented by [9], and concluded that the site was able to install 2740 MW capacity wind farm with a total land area of 5182 km^2. They also discovered that the average wind speed on the site was 4.82 m/s, which had been above the cut-in wind speed of the selected wind turbines (the normal speed is 3.0 m/s). Nevertheless, the average wind speed was rather doubtful because the value obtained was higher than the value that had been expected. In addition, the height of the anemometer tower that gave the obtained wind speed value was not revealed. Their claim was validated and the exact height with such value was determined by using the current MMD data on the site. The wind data were collected from 10 m (m.a.g.l) height station, while the mean value of wind speed was 1.70 m/s. Furthermore, for the study pertaining to power law index (PLI) for data extrapolation at Tawau then, 1/7 (0.143) was employed as the exponent to predict the hub height of data with a value of 4.82 m/s. Thus, the Hellman power law model as showed in the following Equation (3) was employed to calculate the height of wind mast, z_2, and the following value of parameters was utilized; v_1 is 1.70 m/s, v_2 is 4.80 m/s, z_1 is 10 m and α is 0.143. The result, nonetheless, had been rather perplexing as the hub height for wind speed at 4.82 m/s was indeed very high for a standard height wind measurement mast or hub height of wind turbine using the PLI at 0.143. On top of that, it is rather impossible to develop a wind farm with such huge capacity at a likely large area of land, as one should consider the factors that could decrease the actual available land area, such as existing residential areas, reserved forests, roads, etc.

In a different note, [11] employed the Weibull distribution model to determine the quality of three-year (2006–2008) wind data gathered from Labuan and Kudat. In fact, Weibull has been widely applied as a tool to assess the potential of wind energy by many researchers, including [12]. Malaysian researchers alike too have utilized wind data from MMD stations (10 m height) and extrapolated them to higher height using the standard 1/7 law as the value of power law exponent. The maximum wind speed and WPD for Kudat and Labuan were 5.55 m/s (67.40 W/m^2) and 4.75 m/s (50.81 W/m^2), respectively [11].

Meanwhile, wind data for the period from 1 January 2007 until 30 November 2009 (almost three years) at ten MMD stations in Peninsular Malaysia had been assessed by [13]. The stations were Alor Setar, Bayan Lepas, Cameron Highlands, Chuping, Ipoh, Kota Bharu, Kuantan, Melaka, Mersing, and Kuala Terengganu. Mersing is located at the coastal area, while Chuping is an inland, and Cameron Highland is situated in a hilly area. Besides, the other remaining seven stations are located at airports. The location of stations had been found to influence the value of wind speed. For instance, Mersing, which faces the ocean wind and has less surface roughness, has been discovered as the best location to generate the highest wind speed for 10 m height, compared to the others [13].

On the other hand, Pulau Pinang is a state located off the west coast of Peninsular Malaysia with a total of 293 km^2 area. Although geographically Pulau Pinang is an island, the location where the wind data had been recorded can be classified as an onshore site. With that, Tiang and Ishak (2012) utilized one-year (2008) wind data collected from the Bayan Lepas MMD station with 12.5 m (m.a.g.l) and 15.3 m (m.a.s.l) heights. The findings depicted that the greatest wind speed occurred during the Northeast monsoon (December, 3.2 m/s), while the calmest wind speed was recorded during the Southwest monsoon season (May, 1.9 m/s). Furthermore, the average annual WPD was estimated at 24.54 W/m^2 [14].

In a similar note, a general wind map of power density had been developed by Masseran et al., (2012) based on the data gathered from MMD stations [15]. They concluded that Mersing and Kudat emerged as the promising sites to develop the wind energy project. Nevertheless, a more in-depth and comprehensive study is needed to validate the statements concluded in the abovementioned studies.

Other than that, Khatib et al., performed a simulation of cost determination for remote housing electrification using a wind turbine [16]. Their study had been based on 2009 MMD station one-year data at nine selected coastal areas in Malaysia. The results indicated that the cost of energy through the proposed system was in the range of 0.38–0.83 USD/kWh (1.43–3.11 RM/kWh). This amount is, in fact, rather costly compared to that for solar energy. However, their results had been dependent on the quality of wind speed collected from the stations where the related data were measured, whereby the value of wind speed affected the calculation of energy cost. As such, calculation made at a windy area generated a lower cost for wind energy compared to that for solar energy, approximately 0.32 USD/kWh or 1.20 RM/kWh [6]. Furthermore, as the data were collected from MMD, most of the data derived from inside the airport, where airports are usually built in low wind speed area. Therefore, the data should be interpolated to other open or flat area where fewer obstacles are present and the degree of roughness is lower. Besides, the CFD flow modelling had been utilized to predict wind speed based on MMD data as reference. As a result, the annual average of wind speed on the sites fell into class 1 category, which reflected a low wind speed region [16].

Other than that, many prior studies have estimated the potential of wind energy only based on the average wind speed [17]. Nonetheless, some researchers indicated that wind energy potential is indeed based on the CF of wind turbine, as carried out by [18], whereby the energy produced by 21 kW wind turbine was simulated at the northern part of Kudat in Sabah. They also developed a wind atlas using the wind flow WAsP model after taking into consideration some essential factors, such as surface roughness, obstacles, elevation, and excluded areas.

2.2. The Study on Wind Turbine Pilot Test

Until recently, the wind turbines in Malaysia have been installed only for educational and research purposes. This is because, even though some projects have been devised to supply electricity to remote areas, the success of these projects is subject to doubts and has raised more questions.

In a similar vein, Najid et al., presented the success of a 150 kW wind turbine at Pulau Terumbu Layang-Layang located in Sabah, which had been claimed as the first wind turbine installed in Malaysia [19]. This particular project was spearheaded by Universiti Kebangsaan Malaysia (UKM). The wind turbine was hybridized with a diesel system to generate electricity supply to an army base and a nearby resort. Moreover, the installed wind turbine is an extension of a study related to wind speed that was conducted at the same site by [20], in which Pulau Terumbu Layang-Layang is discovered to possess the greatest wind energy potential compared to other places in Malaysia [20].

Furthermore, in 2007, the most well-known wind turbine project was carried out at Perhentian Island and pioneered by the Tenaga Nasional Berhad (TNB)—a national electricity utility company in the country. In that particular project, two units of 100 kW WTG were hybridized with a single 100 kW solar photovoltaic and a 100 kW diesel generator set. As a result, Darus et al., reported the power produced by the system, as well as the value of wind speed recorded at the site [21]. The results showed that the minimum and the maximum values for the wind speed recorded at the site were approximately 3.6 m/s and 15.6 m/s respectively. Furthermore, the monthly mean values of the wind speed for three years (2003–2005) had been in the range of 6.63–9.31 m/s. Unfortunately, their findings were not convincing enough as the common cut-in wind speed for a wind turbine, even for a large scale WTG, is only 3.0 m/s. Thus, if their result had been valid, it indicated the unlikely idea that those wind turbines had continuously rotated and produced endless electricity throughout the years. However, based on site observation, the wind turbine failed to rotate continuously, and besides, the result did not match the report published by [22], as the report claimed that the wind speed values in Terengganu are varied because of the two monsoon seasons that hit the state annually. Additionally, the failure of the wind turbine in generating the desired electricity was perhaps due to the inapt technology applied in the selected wind turbine. Hence, in-depth studies should be carried out to look into the WTG selection process, including the ranking of the existing latest technology of wind turbine using the wind turbine-site matching index.

In addition, some pilot tests were conducted by the Scientific and Industrial Research Institute of Malaysia (SIRIM) before year 2013 at Kudat, Kuching, Kuala Perlis, and Kuala Terengganu. These projects installed wind turbines with a capacity that ranged from 3.3 kW to 25 kW. However, the results of these projects were never published.

On the other hand, another pilot test was conducted by Universiti Malaysia Terengganu (UMT) in collaboration with a company in the aquaculture industry. In that project, a wind turbine with capacity 3.3 kW was installed in a shrimp farm in Setiu, Terengganu. The wind turbine was directly connected to the aeration and the water pump systems on the site. The application of the wind turbine to supply electricity had been expected to help the industry in reducing the high operation cost [23].

2.3. Summary of Wind Energy Progress in Malaysia

It had been observed that most prior studies had utilized meteorological data directly on their simulation without taking into consideration interpolating the data to other locations that could turn out to be more promising areas in generating maximum electricity. Nonetheless, one must note that the MMD wind data were not recorded for energy purposes. Those sites, of course, were not feasible for wind energy generation as it is common for airports to be built at low wind speed areas [24]. Other than that, it is a common practice among Malaysian researchers to use 1/7 (0.143) as the PLI to determine the value of wind speed on desired heights. The power law model using this value is also known as 1/7 Power Law, which was introduced by Frost in 1974 [25]. However, the accuracy of 1/7 (0.143) as the PLI has been argued in many studies, including the study on 39 different regions by [26]. They calculated 7082 wind PLIs, and found that 7.3% of the PLIs were distributed between 0 and 0.14, while 91.9% of them were above 0.143; and 0.8% of the PLIs displayed negative values [26]. Therefore, the value (0.143) has been either underestimated or overestimated to provide the exact value of wind speed at the desired height from the ground level, which leads to inaccuracy of the predicted data.

Hence, in order to reduce the uncertainty on wind energy assessment at the national level, the installation of more wind measurement masts at various heights should be carried out. In fact, the effort of measuring wind data at different heights had been initiated in year 2010 by Universiti Malaysia Terengganu (UMT) through the financial support offered by the Malaysian Ministry of Science and Technology (MOSTI) in the form of a grant. Next, in year 2013, UMT collaborated with the Sustainable Energy Development Authority (SEDA) of Malaysia, where ten more wind masts were installed by SEDA at some other selected sites. The following section presents the analysis of primary data from four wind measurement masts at the selected potential sites in Malaysia.

3. Evaluation of Selected Coastal Sites

This section presents the statistical analysis of the wind data measured by using a number of anemometer masts, which were installed at different heights at four selected sites. Other than that, the dependence of PLI with surface temperature and terrain types were also studied, which led to the associated form of exponential fit. The value of wind speeds on different heights may be different, because of the different terrain types or relevant land feature [27]. Moreover, the wind speed and power law index are also influenced by the weather and atmosphere stability, as well as the local temperature [28].

3.1. Methodology

3.1.1. Data collection

Some wind measurement masts with different heights (m.a.g.l) were installed at four selected sites; Kudat, Kijal, Langkawi, and Mersing. The recorded data were collected and temporarily stored in a field station. After that, each 10-min averaged data was transmitted to the monitoring station located at Universiti Malaysia Terengganu, where the data were processed and analysed. Moreover, the data that had been collected at 10-min averaged values displayed varied periods and number of data for different sites. Information pertaining to the sites, as well as the gathered data from sites is summarized in Table 1, while the map of the sites is shown in Figure 1.

3.1.2. Distribution Function

In order to illustrate the distribution of wind speed v, the Weibull model had been utilized. The Weibull distribution can be characterized by two parameters; k and c, the shape and the scale respectively [29,30]. The wind speed data were distributed as Weibull using the following equation:

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

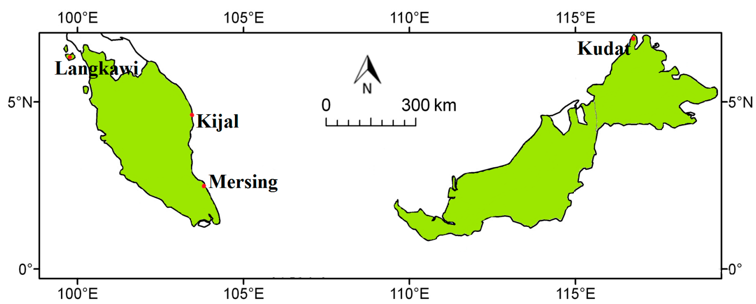


Figure 1. Map showing the selected sites.

Table 1. The coordinates, heights of the wind masts, and the period of data for every selected site.

Station Sites and Coordinates	Data Parameters, Heights and Accuracies	Measurement Periods, Number of Data and Data Recovery	Sites Descriptions
Kudat (7°1′45.33″ N, 116°44′47.98″ E)	Wind speed, 10 m, (±0.4 m/s) Wind speed, 35 m, (±0.4 m/s) Wind speed, 50 m, (±0.4 m/s) Wind speed, 70 m, (±0.4 m/s) Wind direction, 10 m, (±1°) Wind direction, 70 m, (±1°) Temperature, 10 m, (±0.5 °C) Pressure, 10 m, (±0.5 mbar)	May 2014–April 2015 (12 Months) 52,560 data Recovery: 99%	**Coastal, few buildings/trees** Located at a site facing the ocean wind from West (W) to South (S) direction. Few trees were observed on the North (N) and the East (E), where the surface wind speed was predominantly blowing from.
Kijal (4°20′50.70″ N, 103°28′34.74″ E)	Wind speed, 10 m, (±0.4 m/s) Wind speed, 15 m, (±0.4 m/s) Wind speed, 40 m, (±0.4 m/s) Wind speed, 55 m, (±0.4 m/s) Wind direction, 10 m, (±1°) Wind direction, 55 m, (±1°) Temperature, 10 m, (±0.5°C) Pressure, 10 m, (±0.5 mbar)	May 2013–April 2014 (12 Months) 52,560 data Recovery: 99%	**Coastal, few buildings/trees** Located at a site facing the ocean wind from North (N) to East (E) direction. However, a few trees and buildings were observed on the South (S) and the West (W), where the surface wind speed was predominantly blowing from.
Langkawi 6°21′37.92″ N, 99°41′16.62″ E	Wind speed 10 m (±0.4 m/s) Wind speed 30 m (±0.4 m/s) Wind speed 40 m (±0.4 m/s) Wind speed 70 m (±0.4 m/s) Wind direction 10 m (±1°) Wind direction 70 m (±1°) Temperature 10 m (±0.5°C) Pressure 10 m (±0.5 mbar)	May 2014–April 2015 (12 Months) 52,560 data Recovery: 99%	**Coastal, Many buildings/trees** Located at a site facing the ocean wind from West (W) to North (N) direction. Many trees were observed on the East (E) and the South (S), where the surface wind speed was predominantly blowing from.
Mersing 2°34′50.00″ N, 103°48′23.60″ E	Wind speed 10 m (±0.4 m/s) Wind speed 20 m (±0.4 m/s) Wind speed 40 m (±0.4 m/s) Wind speed 60 m (±0.4 m/s) Wind direction 60 m (±1°) Temperature 10 m (±0.5 mbar)	January 2014–December 2014 (12 Months) 52,560 data Recovery: 99%	**Coastal, flat** Located at a site facing the ocean wind from North (N) to East (E) direction. The location was flat with fewer obstacles surrounding the site.

3.1.3. The Wind Resource Mapping

The wind data had been used to develop a wind resource map using the Wind Atlas Analysis and Application Program (WAsP). In fact, the WAsP model considers the elevation and the roughness length, besides utilising linear components of Navier-Stokes equations to determine the wind speed at different sites [31]. Furthermore, in order to run the process of simulation, as presented in Figure 2, several files were prepared. The files are inclusive of the following:

a. *Imagery map*; many kinds of imagery maps are available for use, including topography map and extracted map from the Google Earth (GE) tool. The topography map is categorised into two; restricted and unrestricted topography maps. In Malaysia, both can be purchased from the Department of Survey and Mapping, Malaysia (JUPEM). Meanwhile, the restricted topography map is more expensive than the unrestricted topography map. Besides, free imagery map that comes with coordinates can be extracted from GE tool using the image overlay option.

b. *Elevation map*; the elevation map can be extracted from the Digital Elevation Model (DEM) and digitized using the ArcGIS tool. Another way is by downloading the elevation map, namely the Radar Topography Mission (SRTM) data with 1-arc second resolution (30 m) or 3-arc second resolution (90 m). Moreover, detailed information concerning the SRTM data can be obtained from the United States Geological Survey website [32].

c. *Roughness line map*; the roughness map is essentially a land-used map that contains the value of roughness length and class, as presented in Table 2. The roughness line map can be manually digitized on WindPRO tool based on the land-used image on a topography map. Meanwhile, the roughness map is also available online, namely the GlobCover 2009, which is a global land cover dataset with a 300 m spatial resolution, which can be downloaded using the WindPRO; in which more information can be obtained from the website of the European Space Agency [33]. However, this map should be carefully assessed and corrected to ensure that the roughness map really lies on the right land-used.

d. *Obstacle rose*; the obstacle rose was manually digitized by using the WAsP tool through the inclusion of the value of obstacle porosity, as shown in Table 3. Moreover, only obstacles with more than 5 m height had been considered in the simulation.

e. *Wind turbine power curve*; the wind turbine power curve contains a graph of power versus steady wind speed. The data can be added manually to the tools. Besides, WindPRO provides the datasets of WTG power curves from small- to large-scale wind turbine purchased from various manufacturers. On the other hand, the valid datasets also can be retrieved and viewed from the WindPower program; a tool developed by the PelaFlow Consulting [34].

Table 2. The values of roughness class and length [35].

Area Type	Roughness Class	Roughness Length
City	3.0	0.4000
Forest	3.0	0.4000
Farmland, pretty closed	2.5	0.2000
Farmland, partly open	2.0	0.1000
Farmland, rather open	1.5	0.0548
Farmland, open	1.0	0.0300
Water	0.0	0.0000

Table 3. The porosity of every obstacle [35].

Wind-Break Appearance	Porosity
Solid	0
Very dense	<0.35
Dense	0.35 to 0.50
Open	>0.50

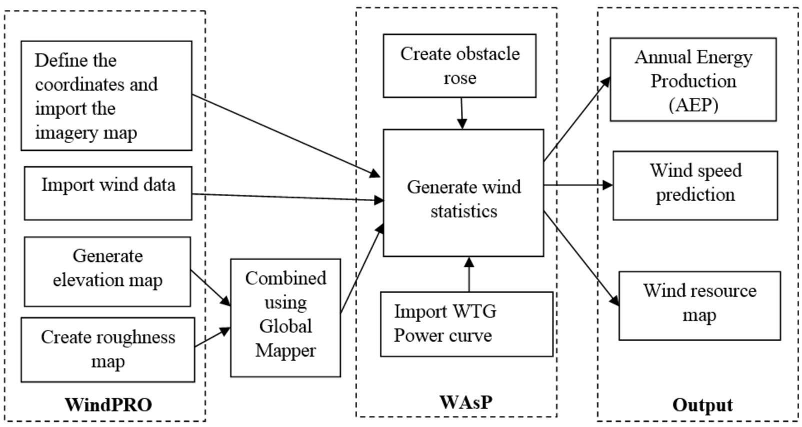


Figure 2. Methodology of the wind modelling using WAsP and WindPRO.

3.1.4. Vertical Extrapolation

The estimation of the amount of energy that could be generated by a wind turbine (WTG) requires wind speed data at a determined height from the ground level. Every commercial wind turbine has its unique hub height, which varies from 30 m to 100 m, depending on the capacity of WTG, as well as the rotor diameter. Furthermore, in order to obtain primary data at a level similar to the hub height for certain selected wind turbine, it is not feasible to install a new wind measurement mast with the desired height of cup anemometer mounted to the tower.

However, the common method used to determine the vertical wind data is by using the power law method, which is also known as the Hellmann power law (see Equation (3)). In this equation, the determination of an exponent or the power law index (PLI), α, is essential before predicting wind speed values, commonly via direct computation, if wind speed data at two or more heights (m.a.g.l) are available.

Hellmann Power Law

The most frequently used equation to determine PLI is the Hellmann power law that correlates wind speed data at two different heights for the available recorded data. The Hellmann power law, as expressed by [36,37], is given in the following:

$$\alpha = \frac{\ln\left(\frac{v_2}{v_1}\right)}{\ln\left(\frac{z_1}{z_2}\right)} \quad (2)$$

If the PLI is determined, the wind speed at the desired height can be predicted by using the following equation, which derives from Equation (2),

$$v_2 = v_1\left(\frac{z_2}{z_1}\right)^{\alpha} \quad (3)$$

In which v is the wind speed to height z, v_1 is the reference wind speed to reference height z_1 (frequently referred as 10 m height), v_2 is the desired wind speed to desired height z_2 and α is the PLI.

The 1/7 Power Law Method

The 1/7 power law, as depicted α = 0.143, has been proven to give a good approximation for wind profile in the neutral atmospheric boundary layer, which has been regularly assumed as a value for open land [38–40]. However, this method has been challenged because of its failure in considering the aspect of PLI for various roughness characteristics and atmospheric stability. Moreover, the 1/7 law has been believed to be only suitable for estimating vertical wind speed at almost neutral conditions (adiabatic).

3.1.5. Annual Energy Production and Greenhouse Gases (GHG) Saving

According to the best vertical extrapolation method, the value of wind speed obtained from the wind turbine hub height could be computed, and thus, the annual energy production of the selected site could be calculated. On top of that, the selection of wind turbine is significant in studies related to wind energy feasibility, especially in regions that generate low wind speed [41]. The selection of wind turbines in this work is depicted in Table 4 is based on the wind turbine hub height that matched the maximum height of available measured data.

Table 4. The specification of four selected wind turbines.

Sites	WTG	P_r (kW)	z (m)	RD (m)	v_c (m/s)	v_r (m/s)
Kudat	Dewind D4/48-600	600	70.0	48.0	3.0	12.0
Mersing	Unison U54-750	750	60.0	54.0	3.0	12.0
Kijal	Gamesa G58-850	850	55.0	58.0	3.0	12.0
Kudat	Dewind D4/48-600	600	70.0	48.0	3.0	12.0

WTG: Wind turbine model; P_r: Wind turbine rated power; z: The hub height of wind turbine; RD: Rotor diameter; v_c: Cut-in wind speed; v_r: Rated wind speed

The wind turbines are generally divided into two categories: pitch-regulated WTG and stall-regulated WTG [42–45]. As all the selected wind turbines in this study are the pitch-regulated type, thus, the power and the energy produced by WTG had been calculated by using the following equations:

Power:

$$p(v)_{pitch} = \mathrm{P_r} \times \begin{cases} 0 & v < v_c \text{ or } v > v_f \\ \left(\sum\limits_{i=0}^{n} a_i v^i\right)_{asc} & v_c \leq v \leq v_r \\ 1 & v_r \leq v \leq v_f \end{cases} \quad (4)$$

Energy:

$$AEP_{pitch} = \mathrm{P_r} \int_{V_c}^{V_r} \left(\sum_{i=0}^{n} a_i v^i\right) f(v)dv + \mathrm{P_r} \int_{V_r}^{V_f} f(v)dv \quad (5)$$

where $\mathrm{P_r}$ is the wind turbine rated power, v_c is the cut-in wind speed, v_r is the rated wind speed, v_f is the cut-out wind speed, $\sum\limits_{i=0}^{n} a_i v^i$ is the polynomial model and $f(v)$ is the wind speed distribution.

After determining the value of AEP, the annual reduction in greenhouse gases (GHG) emission could be computed. Besides, the emission factor of 660 g/kWh from the average Malaysian national electricity generation mix was used for this GHG emission calculation. This had been based on the estimated Carbon dioxide (CO_2) emission factors of 1.18, 0.85 and 0.53 kg/kWh for electricity generated from coal, oil, and gas, respectively [46]. Thus, the following equation had been employed to compute the reduction in GHG emission:

$$G = \frac{660 \times E}{1{,}000{,}000} \quad (6)$$

where G is the GHG emission reduction in Tonne CO_2/Year, and E is the annual energy production (AEP) in kWh/Year.

3.2. Results and Discussion

3.2.1. Overall Data Analysis

The statistics of 10-min averaged wind data, which had been measured by the wind measurement masts at the selected sites, are depicted in Table 5. The results revealed that the air density in Kudat (1.1608 kg/m^3) had been the highest compared to that of Kijal (1.1600 kg/m^3) and Langkawi (1.1363 kg/m^3). Furthermore, it is noteworthy to observe that ρ mean values for all the sites had been lower than the general standard value (1.225 kg/m^3).

The standard ρ value is generally assumed for any site without taking into consideration the elements of temperature and pressure. Thus, a minor wind energy overestimation should occur if this standard value (1.225 kg/m^3) is taken into consideration in the wind energy potential assessment. As Kudat displayed the highest ρ value, the wind speed and power density in Kudat had also been recorded as the highest, in comparison to other sites, in which the mean values for 10 m (m.a.g.l) had been 2.84 m/s and 29.4 W/m^2, followed by Mersing (2.63 m/s, 25.0 W/m^2), Kijal (2.47 m/s, 20.2 W/m^2), and Langkawi (1.51 m/s, 3.6 W/m^2). The wind power density was calculated directly using the measured wind data. Other than that, the Weibull distribution for all sites is presented in Figure 3. In fact, all the sites demonstrated quality of wind speeds categorised as wind class 1, where the value of the wind speed had been below 4.4 m/s, as mentioned by [47]. Sites grouped into wind class 1 are inappropriate for wind energy investment, but in reality, the hub height of the wind turbine had been in the range of 30 m to 100 m (m.a.g.l). Some locations in Kudat nevertheless did exhibit annual average wind speeds that exceeded 3.00 m/s, which reflected the minimum wind speed that was needed to rotate the wind turbine.

Table 5. The statistical parameters.

Sites	z, (m)	T, (°C)	P, (mbar)	ρ, (kg/m^3)	c, (m/s)	k	v, (m/s)	WPD, W/m^2
Kudat	10	28.11	1003.80	1.1608	3.20	1.84	2.84	29.4
	35				5.26	2.02	4.66	117.4
	50				6.08	2.19	5.39	168.0
	70				6.67	2.25	5.91	216.8
Mersing	10	27.08	n/a	n/a	2.95	1.73	2.63	25.0
	20				3.65	1.87	3.24	42.8
	40				4.58	2.21	4.05	70.9
	60				4.79	2.33	4.24	77.9
Langkawi	10	28.33	983.36	1.1363	1.59	1.83	1.41	3.6
	30				2.86	1.92	2.54	19.8
	40				3.47	1.85	3.08	37.3
	70				4.11	1.81	3.66	63.9
Kijal	10	26.89	999.08	1.1600	2.77	1.76	2.47	20.2
	15				3.44	1.78	3.06	38.2
	40				3.81	1.81	3.39	50.6
	55				4.57	1.78	4.07	89.2

z: Anemometer height; T: Temperature; P: Pressure; ρ: Air density; c: Scale parameter; k: Shape parameter; v: Mean wind speed; WPD: Wind power density.

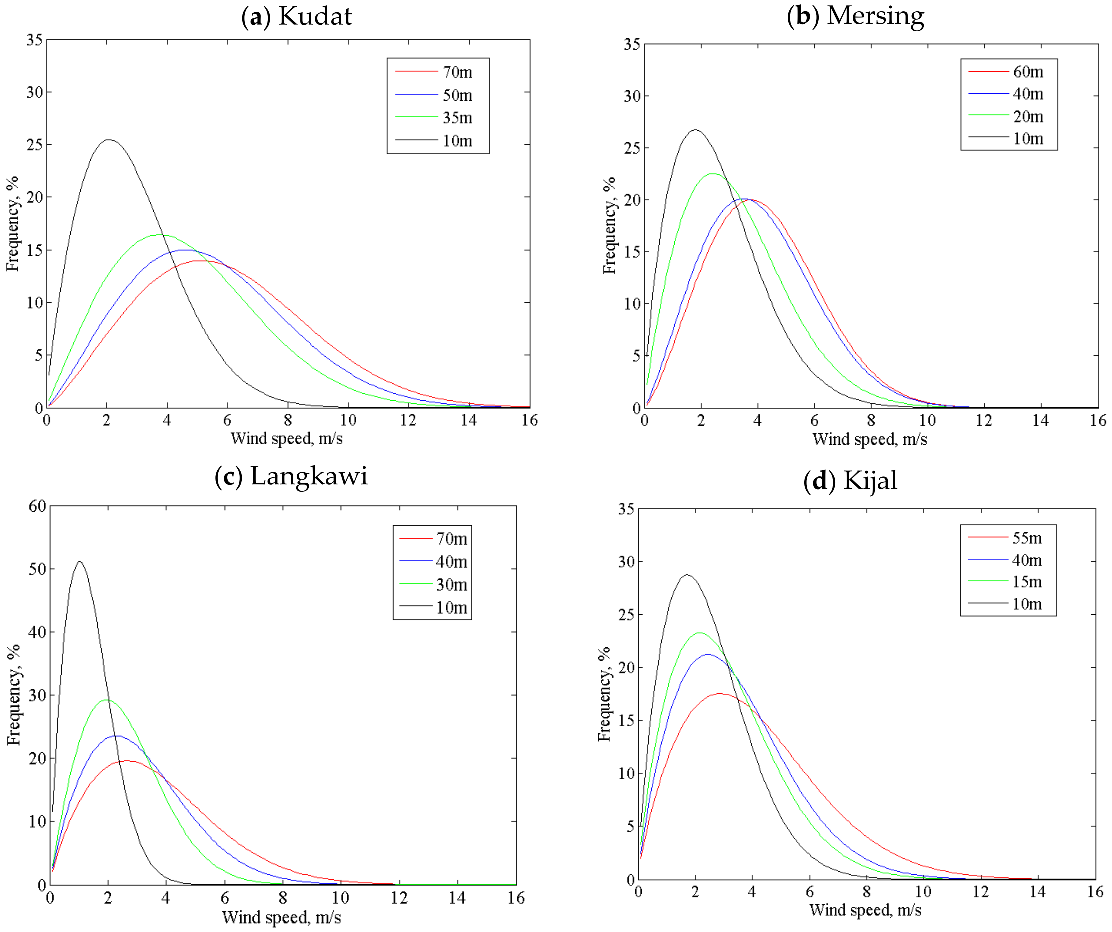


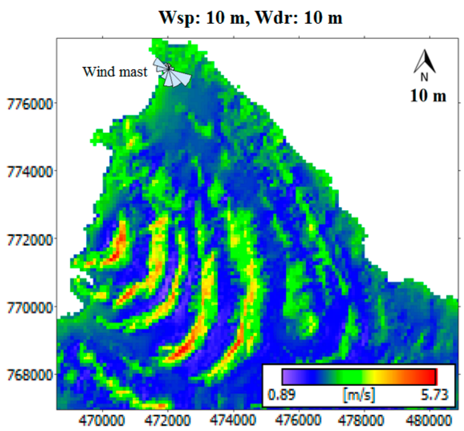
Figure 3. The Weibull distribution for every selected site, (**a**) Kudat; (**b**) Mersing; (**c**) Langkawi; (**d**) Kijal.

Nonetheless, the best wind speed for a profitable wind project is 5.00 m/s. As such, this value could only be achieved if the height of tower is more than 60 m (m.a.g.l) for all sites, except for Kudat, which recorded an average wind speed that exceeded 5.00 m/s at 50 m height (m.a.g.l). Generally, both the temperature and the pressure should decline with height (usually more than 100 m) due to the reduction observed in the mass of overlying air. The decrease in pressure, nonetheless, is closely related to the reduction in air density. However, this phenomenon is not discussed in this paper.

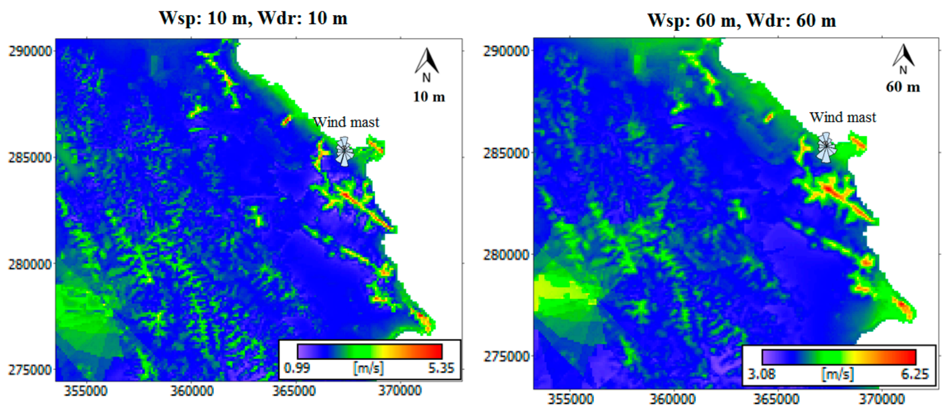
3.2.2. Wind Resource Map

The wind resources map had been developed based on the flow modelling of the wind speed by taking a number of aspects into consideration, for instance, obstacles, elevation, and roughness length. Usually, the wind speed is strong at high elevation, but weak against high obstacles and roughness length. In fact, many factors have been found to influence the results pertaining to wind resource map, including elevation, roughness length, obstacles, wind direction, as well as the height of anemometer, in order to determine reference wind speed.

Additionally, the 10 km^2 wind resource map is presented from the stance of the different colours projected by the wind speed, as illustrated in Figure 4. Hence, two wind maps with minimum and maximum heights (m.a.g.l) were developed for each selected site. The both axes of the wind maps represent the coordinates in UTM projection, while the header shows the height of both wind speed and direction utilized for WAsP flow modelling. The wind speed values are in the range of the lowest (purple) to the highest (red). In fact, red appears for high elevation at every site, while green (moderate value) reflects coastal areas, areas with fewer obstacles and roughness length, as well as open and flat regions; resulting from nil friction to the wind flow. On the other hand, the purple and blue colours refer to the lowest levels of wind speed on the map, whereby the existence of higher value of obstacles and roughness length might point towards residential area, city or forest.

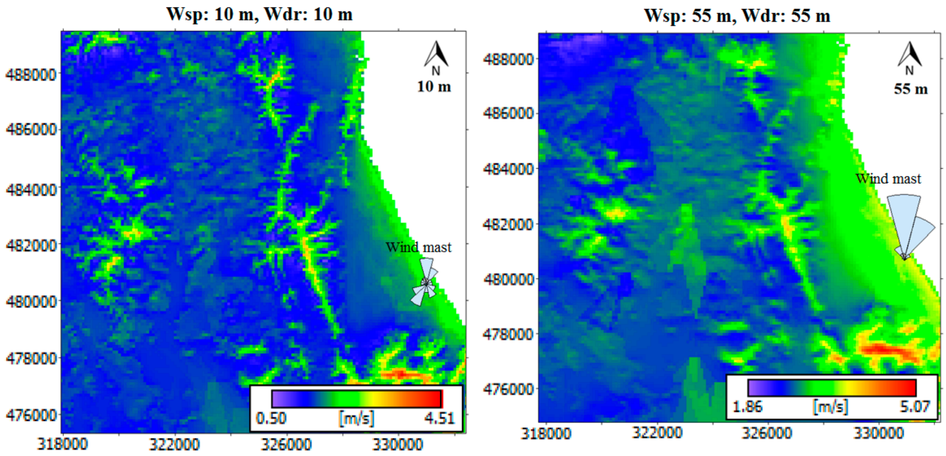


(**a**) Kudat

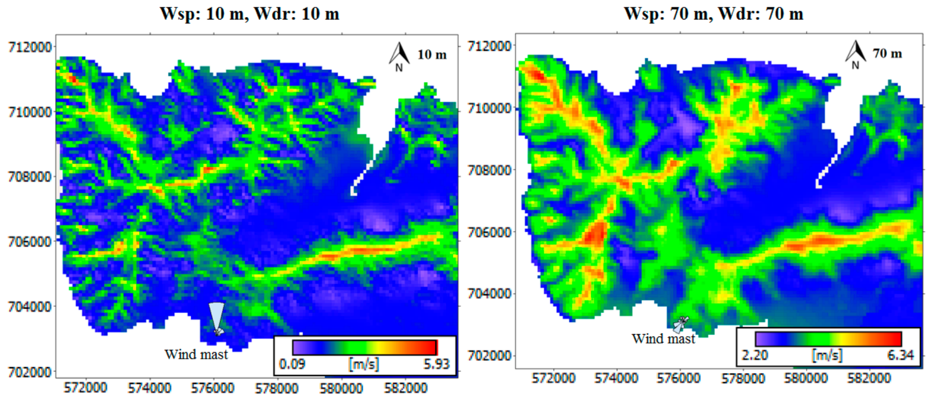


(**b**) Mersing

Figure 4. *Cont.*



(**c**) Kijal



(**d**) Langkawi

Figure 4. The 100 km^2 wind resource maps (**a**) Kudat; (**b**) Mersing; (**c**) Kijal; (**d**) Langkawi.

The accuracy of the developed wind resource maps were determined by comparing predicted wind data with the concurrent measured wind data from nearby meteorological station. Both data should correspond to the same coordinates and period of time to make sure there is no bias in the comparison. A similar study using the mean difference to identify the accuracy of WAsP model is reported by [48]. Only three sites were qualified for accuracy analysis as only those sites have nearby meteorological data. The sites are Kudat, Mersing and Langkawi. The errors vary in sign and are seen to be large in Langkawi (20.00%) and Mersing (19.18%). However, fair predictions are obtained for the wind resource map in Kudat (10.00%). The larger discrepancies in Langkawi may be caused by the ruggedness of the terrain as the wind mast is built on a complex terrain area.

3.2.3. Dependence of Power Law Index (PLI) Upon Temperature

The atmosphere functions like a fluid, where the boundary layer occurs when the fluid or the air is in touch with an underlying surface of the ground. Furthermore, the heat of the sunlight thus influences the movement of the atmospheric boundary layer and the value of PLIs. Moreover, the PLI that reduced during high temperature has been due to the higher air (wind) mixing above the ground, and less air (wind) mixing during low temperature. In fact, this phenomenon was reported in several studies [49–51].

The diurnal variation of PLI were illustrated in Figure 5. The PLI is higher during the night stable conditions, but it starts to reduce after sunrise. These lowest values remain all day, but begin to rise during the evening, as the air above the ground starts to cool with unstable conditions slowly turning into neutral and then, into stable ones. This scenario has been proven in several findings in the literature [52,53].

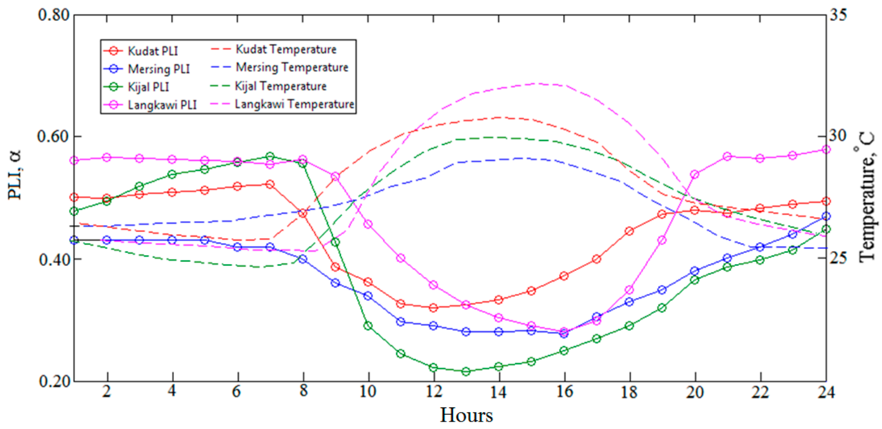


Figure 5. The diurnal variation of PLI at different sites.

In addition, the PLI is higher during the Northeast monsoon season (raining season), but the lowest during the Southwest monsoon season (summer season). This could be due to the summer season that projects higher air mixing above the ground; resulting in lower PLIs than that during raining season when the ground experiences less air mixing [49–51]. Besides, it is clear that the PLI is higher during the Northeast monsoon season, in which the recorded wind speed is higher as well. Furthermore, the PLI is higher during the low surface temperature, as shown in the preceding Figure 5. However, at night (cold temperature, low wind speed), the PLI is lower compared to that at night (hot temperature, high wind speed).

On top of that, the vertical thermal convection, as highlighted by [54], is not the only way to determine the characteristics of climate or wind, but it can also be determined by the horizontal movement, which is produced by thermal circulation of the ocean breeze [55,56]. The movement of wind speed that is predominant could be visualized by using wind rose, as presented in Figure 6.

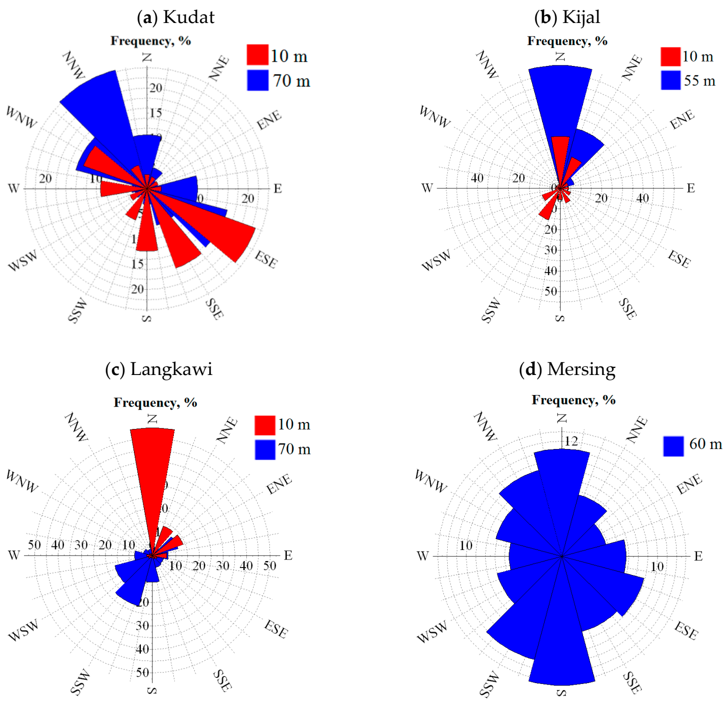


Figure 6. The wind rose for every selected site (**a**) Kudat; (**b**) Kijal; (**c**) Langkawi; (**d**) Mersing.

The direction of the wind speed can be used to determine th direction of the wind speed. Besides, it is measured (in degree units) by the wind vane located on the similar tower where the anemometer is mounted to. Furthermore, the data of the wind direction is measured at various heights. The wind masts that measured the direction of wind at two heights for minimum and maximum values are given in the following: Kudat (10 m, 70 m), Mersing (60 m), Kijal (10 m, 55 m), and Langkawi (10 m, 70 m). The prevailing wind direction at Kudat was Southeast (SE) for 10 m and Northwest (NW) for 70 m heights; Mersing at North (N) for 60 m; as well as Kijal at Northeast (NE) for both 10 m and 55 m. However, a significant predominance was discovered at Southwest (SW) for 10 m at Kijal; Langkawi at Northeast (NE) for 10 m, Northwest (NW) and Southwest (SW) for 70 m height. Besides, strong wind was found to blow from other sectors for every site, but their frequencies had been rather low. Moreover, the frequencies for other sectors displayed small values.

On top of that, in order to understand the relationship between PLI and temperature, least squares fitting was utilized by using the data of hourly PLI versus hourly temperature. The data were resampled by using the 10-fold cross validation resampling method [57]. The data were sorted into two groups, the training data (90% of the data) and validation data (10% of data). In the analysis, there are 11 training dataset, 10 of them is 90% of turn dataset, and 1 is the entire dataset. From the 11 trained dataset, the 11 individual fits training model was derived for every site. The best model was determined by computing the root mean square error. The accuracy is evaluated using validation datasets with ten times iterations. The collective exponential fits are derived from the combination of datasets from the sites with similar terrain type, see Table 1. The process of cross validation for collective exponential fits derivation is repeated and their accuracy is re-evaluated. The equation of exponential fits is as follows:

$$\alpha = Ae^{-bT} \quad (7)$$

where A and b are fit constants, which had been applied to predict α from the surface temperature that differ for various sites and terrain types. The approach to differentiate the PLI analysis based on the different terrain types was also performed by [58], where they studied the data extrapolation performance at three different terrain types, includes the flat, coastal and rugged area. As a result, the model derived from entire datasets is showing the best RMSE compared to the rest models, see Table 6. However, the model derived from entire dataset would lead to the over-fitting problem. To avoid the over-fitting, in the early stage of analysis, the data was validated by eliminating the error and outliers. It also confirmed by consistency of the result of overall RMSE for all validation datasets of every site. Thus, the final individual and collective exponential fits is presented in Table 7.

Table 6. The RMSE for every training models.

Sites	Training Models										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Entire**
Kudat	0.3998	0.4000	0.3999	0.4001	0.4002	0.4001	0.3997	0.4000	0.3998	0.3999	0.3997
Mersing	0.6393	0.6362	0.6366	0.6359	0.6360	0.6372	0.6367	0.6391	0.6362	0.6367	0.6358
Kijal	0.6017	0.6017	0.6020	0.6020	0.6017	0.6017	0.6035	0.6019	0.6017	0.6029	0.6017
Langkawi	0.5489	0.5490	0.5499	0.5491	0.5490	0.5490	0.5491	0.5494	0.5490	0.5492	0.5489

Table 7. The exponential fit for every site with different terrain types.

Sites	Mean PLI	Terrain Type	Individual Fit	Collective Fit
Langkawi	0.47	Coastal, many buildings/trees	$\alpha = 4.2470e^{-7.6000\times10^{-2}\mathrm{T}}$	$\alpha = 4.2470e^{-7.6000\times10^{-2}\mathrm{T}}$
Kijal	0.25	Coastal, few buildings/trees	$\alpha = 7.3660e^{-1.0880\times10^{-1}\mathrm{T}}$	$\alpha = 8.9270e^{-1.1240\times10^{-1}\mathrm{T}}$
Kudat	0.38	Coastal, few buildings/trees	$\alpha = 3.7120e^{-7.9600\times10^{-2}\mathrm{T}}$	$\alpha = 8.9270e^{-1.1240\times10^{-1}\mathrm{T}}$
Mersing	0.20	Coastal, flat	$\alpha = 32.5400e^{-1.8360\times10^{-1}\mathrm{T}}$	$\alpha = 32.5400e^{-1.8360\times10^{-1}\mathrm{T}}$

Figure 7 shows the graph of PLI versus temperature and the equation formed by its exponential fit. Thus, the wind speed at the desired height could be predicted by using the following equation, which derives from the substitution of Equation (7) to Equation (3):

$$v_2 = v_1 \left(\frac{z_2}{z_1} \right)^{Ae^{-bT}} \tag{8}$$

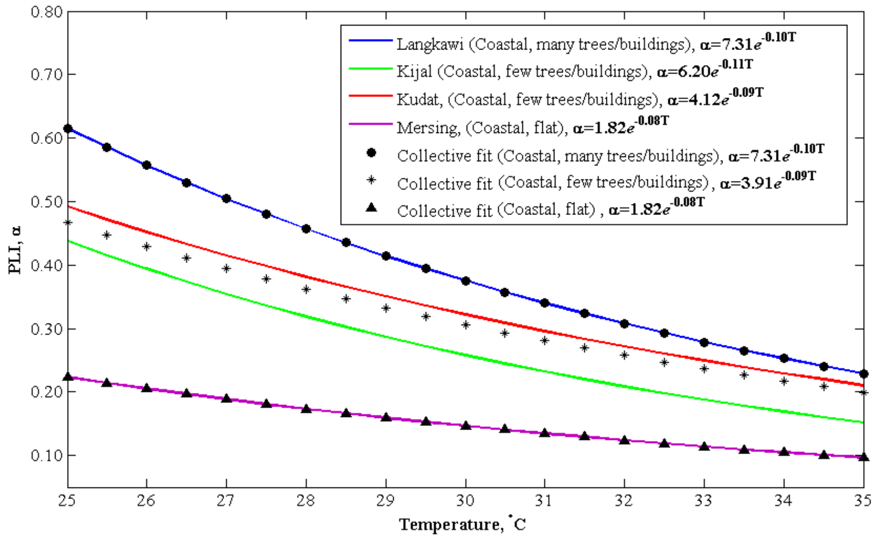


Figure 7. The exponential fit of hourly PLI versus hourly surface temperature.

3.2.4. The Comparison between PLI Models

In order to compare the accuracy of PLI models, the capacity factor discrepancy metric was adopted. The exponential fits and the 1/7 law model had been applied to predict the wind speed at the maximum height for each site: Kudat (70 m), Kijal (55 m), Mersing (60 m), and Langkawi (70 m).

Capacity Factor Discrepancies Analysis

The Annual Energy Productions (AEP) for the selected wind turbines was simulated at the same coordinate location where the wind measurement masts were installed. After the value of AEP had been determined, the CF was then calculated and computed in percentage. Furthermore, the notion of capacity factor (CF) is a measure of the frequency of a wind turbine that rotates and produces electricity for a specific period of time. Moreover, CF compares the amount of electricity a wind turbine actually produces at its maximum in continuous full-power operation within the same period. In other words, CF refers to the ratio of estimated and nominal annual energy productions. Besides, the best CF that is feasible and promising for an energy project is 20% and above. In fact, CF at 20% has been decided as the best CF to attain the profitability of wind energy project [59]. Nonetheless, lower CF is also considered if there is an incentive or subsidy provided by the government to pay more feed-in tariff rates to the power producers. Some of the factors that have been found to affect the energy produced by a wind turbine are given in the following:

(a) The quality of wind speed at a hub height of a wind turbine determines the amount of energy that could be produced. Hence, in order to generate a more profitable amount of energy, the average wind speed should exceed the cut-in wind speed of the wind turbine or the average wind speed at 5 m/s and above.

(b) The rated power of a wind turbine has an insignificant correlation with the CF produced. Usually, it is estimated that the larger the rated power of a wind turbine, the lower the value of CF; in comparison to the smaller rated power wind turbine, especially those installed at low wind speed region. However, in reality, some of the larger rated powers of the wind turbine are more efficient, in comparison to the smaller ones.

(c) A different manufacturer would develop and sell different specifications of wind turbines even if they share similar rated power. Therefore, the efficiency and the energy produced also could differ for every different manufacturer. Therefore, careful selection should be done before a wind energy project is begun.

The annual GHG emission reduction depends on the annual energy production. Hence, in this analysis, the computed GHG had been based on a unit of the wind turbine, thus, the value depended on the amount of rated power and the units of simulated wind turbines. The more the rated power and unit of the wind turbine, the more the GHG emission could be reduced, thus saving the environment.

Furthermore, the assessment of wind resource and annual energy production at 70 m (Kudat and Langkawi), 60 m (Mersing), and 55 m (Kijal) had been performed. In particular, by any location, three computation options were considered as a function of used wind data, i.e.,: (i) measured at maximum heights; (ii) extrapolated from 10 m data by using 1/7 law; and (iii) extrapolated from 10-m data using individual and collective exponential fits. This was performed to quantify the mistake(s) made in AEP simulation if options (ii) or (iii) had been opted, in spite of (i). As a matter of fact, similar comparisons performed by [60,61] proved a slight difference in PLI and thus, in the values of mean wind speed, to result in a dramatic annual energy production discrepancy.

Table 8 summarizes the parameters for energy production calculated at 70 m at the Kudat site by using a single 600-kW rated power Dewind D4/48-600 turbine. The measured data displayed promising scores for CF (22.01%). Besides, the use of data extrapolated through the 1/7 law, compared to the actual 70 m observed, led to inaccurate prediction of wind speed lesser by 37.62%; resulting in a noticeable CF underestimation (65.47%). Conversely, when data were extrapolated by using collective individual fit ($\alpha = 8.9270e^{-1.1240\times10^{-1}\mathrm{T}}$), a vividly lower discrepancy was observed than that of individual fit ($\alpha = 3.7120e^{-7.9600\times10^{-2}\mathrm{T}}$) and 1/7 law, as CF was over predicted by about 2.22%. Meanwhile, the CF for individual fit was 7.22% less than the measured data.

Table 8. Wind resource and energy yield parameters calculated at 70 m by the Kudat site using a single 600-kW rated power Dewind D4/48-600 wind turbine.

Parameters	Wind Data			
	Measured	**1/7 Law, ff = 0.143**	**Individual Fit, ff = $3.7120e^{-7.9600\times10^{-2}\mathrm{T}}$**	**Collective Fit, ff = $8.9270e^{-1.1240\times10^{-1}\mathrm{T}}$**
v, m/s	6.06	3.78	6.22	6.11
AEP, MWh/year	1156.85	399.46	1240.42	1182.60
CF, %	22.01	7.60	23.60	22.50
FLH, hour/year	1928.08	665.76	2067.36	1971.00
GHG, Tonne CO_2/Year	763.52	263.64	818.68	780.52

v: Mean wind speed; AEP: Annual Energy Production; CF: Capacity factor; FLH: Full load hours; GHG: Greenhouse gases emission saving.

The calculation of energy production in Mersing is given in Table 9 with the use of a 750-kW Unison U54-750 turbine. In comparison to the actual 60-m measured data, the discrepancy discovered in turbine CF had been proven to be dramatic if the data extrapolated with 1/7 law PLI were used. In particular, an underestimation of 14.09% in wind speed resulted in underestimation of 41.13% for CF, FLH, and GHG. On contrary, if the data had been extrapolated with exponential fit ($\alpha = 32.5400e^{-1.8360\times10^{-1}\mathrm{T}}$), a slight CF overestimation (2.16%) occurred.

The 850 kW rated power Gamesa G58-850 wind turbine had been applied to estimate the AEP in Kijal at 60 m hub heights (Table 10). The individual fit had been found to be more precise, compared to collective fit and 1/7 law, as the wind speed was overestimated by individual fit (3.53%) and collective fit (11.23%), but underestimated by 1/7 law by 33.26%.

Table 9. Wind resource and energy yield parameters calculated at 60 m by the Mersing site using a single 750-kW rated power Unison U54-750 wind turbine.

Parameters	Wind Data			
	Measured	**1/7 Law, ff = 0.143**	**Individual Fit, $\mathbf{ff = 32.5400}e^{-1.8360\times10^{-1}T}$**	**Collective Fit, $\mathbf{ff = 32.5400}e^{-1.8360\times10^{-1}T}$**
v, m/s	5.89	5.06	6.07	6.47
AEP, MWh/year	1517.67	893.52	1550.52	1819.89
CF, %	23.10	13.60	23.60	27.70
FLH, hour/year	2023.56	1191.36	2067.36	2426.52
GHG, Tonne CO_2/Year	1001.66	589.72	1023.34	1201.13

v: Mean wind speed; AEP: Annual Energy Production; CF: Capacity factor; FLH: Full load hours; GHG: Greenhouse gases emission saving.

Table 10. Wind resource and energy yield parameters calculated at 55 m by the Kijal site using a single 850-kW rated power Gamesa G58-850 wind turbine.

Parameters	Wind Data			
	Measured	**1/7 Law, ff = 0.143**	**Individual Fit, $\mathbf{ff = 7.3660}e^{-1.0880\times10^{-1}T}$**	**Collective Fit, $\mathbf{ff = 8.9270}e^{-1.1240\times10^{-1}T}$**
v, m/s	4.81	3.21	4.98	5.35
AEP, MWh/year	1109.45	416.98	1399.85	1615.78
CF, %	14.90	5.60	18.80	21.70
FLH, hour/year	1305.24	490.56	1646.88	1900.92
GHG, Tonne CO_2/Year	732.24	275.21	923.90	1066.42

v: Mean wind speed; AEP: Annual Energy Production; CF: Capacity factor; FLH: Full load hours; GHG: Greenhouse gases emission saving.

The wind speed in Langkawi had been the lowest among all stations. The wind energy parameters calculated at Langkawi (Table 11) confirmed that the site is indeed less suitable for medium to large wind turbine with the application of the 600-kW rated power Dewind D4/48-600 turbine, in which a poor CF was achieved (10.30%). Even though Langkawi has been perceived as infeasible, the preceding wind resource map shows that the other locations on the site exhibited more potential and encouraging wind energy. Nonetheless, one must note that the energy simulation was only on a coordinate point, thus, in order to perform a fair judgement on the potential of the site; the wind resource map should be used as reference. Compared to the 70 m measured data, the extrapolation by 1/7 law led to a very large CF underestimation at approximately 87.38%.

Table 11. Wind resource and energy yield parameters calculated at 70 m by the Langkawi site using a single 600-kW rated power Dewind D4/48-600 wind turbine.

Parameters	Wind Data			
	Measured	**1/7 Law, ff = 0.143**	**Individual Fit, $\mathbf{ff = 4.2470}e^{-7.6000\times10^{-2}T}$**	**Collective Fit, $\mathbf{ff = 4.2470}e^{-7.6000\times10^{-2}T}$**
v, m/s	4.41	2.23	4.51	4.31
AEP, MWh/year	541.37	68.33	646.49	578.16
CF, %	10.30	1.30	12.30	11.00
FLH, hour/year	902.28	113.88	1077.48	963.60
GHG, Tonne CO_2/Year	357.30	45.10	426.68	381.59

v: Mean wind speed; AEP: Annual Energy Production; CF: Capacity factor; FLH: Full load hours; GHG: Greenhouse gases emission saving.

4. Conclusions

The onshore wind energy is one of the many highlighted new resources for generating electricity in many countries, including Malaysia, as the target of RE within the national energy mix has yet to be achieved. The existing and acknowledged eligible RE resources are solar photovoltaic, micro-hydro, biomass, and biogas. The following is a list of conclusion and recommendations for future works:

(a) A critical review of prior studies pertaining to onshore wind energy in Malaysia has been highlighted, including the related weaknesses and suggestions for improvement.
(b) The meteorological wind data, which were measured in low wind speed areas, such as airport runways, are unsuitable to represent the wind energy potential. The best way to do so is by measuring wind data at an open and flat area, where fewer obstacles and surface roughness are present. However, installing a new wind measurement masts is not only costly, but also requires undivided support from the government, especially monetary in the form of research grants.
(c) Kudat presents a higher potential for wind energy development compared to other areas in Malaysia, whereby the medium rated power of a wind turbine (600 kW) could generate electricity with its CF exceeding 20%. The other site also has the potential, as presented by wind resources map, but most of the sites are located at high elevation areas as they are far from access to the grid transmission line. This is also seen as non-feasible as it will increase the initial cost, except for the higher generation of electricity or the provision of an incentive or probably subsidy by the authority and the government in the form of Feed-in Tariff bonuses.
(d) The PLI, which is associated to temperature, displayed exponential fit for all the stations tested under the present study. Besides, parameters A and b depend on the location. The individual and the collective fit were found to offer good estimation of PLI. Meanwhile, the 1/7 law showed larger discrepancy of wind speed value prediction; leading to a huge error in energy estimation.
(e) As for future work, the installation of more wind measurement masts at other sites is recommended in order to study the PLIs with various roughness characteristics in Malaysia. In addition, the exponential fit model could be further improvised and tuned to be more precise through the use of more varied data derived from many other locations.
(f) The production of wind energy is feasible and practical only at certain locations in Malaysia. Therefore, the mesoscale of wind map should be produced by employing data from many stations involved in wind measurement, especially to identify the most apt location(s) in Malaysia and vice versa.
(g) Lastly, the application of Light Detection and Ranging (LIDAR) and Sound Detection and Ranging (SODAR) measurements is also suggested as they could determine wind speeds at up to 200 m or more in height (m.a.g.l). On the other hand, such added applications offer vertical resolution that is less than 10 m.

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Abbreviations

AEP	Annual Energy Production, kWh/Year
CF	Capacity factor of wind turbine, %
FiT	Feed-in Tariff
FLH	Full load hours, hour/year
GHG	Greenhouse gases saving, Tonne CO_2/Year
m.a.g.l	Mean above ground level

MMD	Malaysian Meteorological Department
PLI	Power Law Index
RE	Renewable Energy
RMSE	Root mean square error
SREP	Malaysian Small Renewable Energy Power Program
SRTM	Radar Topography Mission
WAsP	Wind Atlas Analysis and Application Program
WTG	Wind turbine generation

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