IEEE Access
Multidisciplinary ⋮ Rapid Review ⋮ Open Access Journal

Received June 17, 2020, accepted June 27, 2020, date of publication June 30, 2020, date of current version July 20, 2020.

Digital Object Identifier 10.1109/ACCESS.2020.3006134

Comprehensive Review of Wind Energy in Malaysia: Past, Present, and Future Research Trends

FUAD M. NOMAN, (Member, IEEE), GAMAL ABDULNASER ALKAWSI, DALLATU ABBAS, AMMAR AHMED ALKAHTANI, (Member, IEEE), SIEH KIONG TIONG, (Member, IEEE), AND JANAKA EKANAYAKE, (Fellow, IEEE)

Institute of Sustainable Energy (ISE), Universiti Tenaga Nasional (UNITEN), Kajang 43000, Malaysia

Corresponding author: Ammar Ahmed Alkahtani (ammar@uniten.edu.my)

This work was supported by Universiti Tenaga Nasional (UNITEN), Malaysia, under Grant BOLD2025 fund.

ABSTRACT In recent years, wind energy has gained extensive attention in the recent years in various countries due to the high energy demand of energy and shortage of traditional electric energy sources. Because wind energy constitutes a cost effective and environmentally friendly source, it can significantly contribute toward the reduction of the ever-increasing carbon emissions. It is one of the fastest growing green technologies worldwide, with a total generation share of 564 GW as of the end of 2018. In Malaysia, wind energy has been a hot topic in both academia and green energy industry. In this paper, the current status of wind energy research in Malaysia is reviewed. Different contributing factors such as potentiality and assessments, wind speed and direction modeling, wind prediction and spatial mapping, and optimal sizing of wind farms are extensively discussed. This paper discusses the progress of all studies related to wind energy and presents conclusions and recommendations for improving wind energy research in Malaysia.

INDEX TERMS Renewable sources, sizing optimization, wind energy, wind farm design, wind mapping, wind potentiality, wind prediction.

LIST OF ACRONYMS

AEG	Annual Energy Generation
ANFIS	Adaptive Neuro-Fuzzy Inference System
ANN	Artificial Neural Network
COE	Cost of Energy
COP15	15th Conference of the Parties
DE	Differential Evaluation
DEM	Digital Elevation Model
DG	Didel Generator
FIS	Fuzzy Inference System
FiT	Feed in Tariff
GA	Genetic Algorithm
GIS	Geographic Information System
HANN	Hybrid Weibull Distribution with ANN
HAWT	Horizontal Axis Wind Turbine
HOMER	Hybrid Optimization Models for Energy Resources
IDW	Inverse Distance Weighted
KF	Kalman Filter
KLIA	Kuala lumper International Airport
LLS	Large-scale Solar
MAE	Mean Absolute Error
MAPE	Mean Absolute Percentage Error
MHP	Micro Hydropower
MMD	Malaysian Meteorological Department
mvMF	Mixture of von Mises Fisher
N/A	Not Available
NACA	National Advisory Committee on Airfoils
NEM	Net Energy Metering
NPC	Net Present Cost
NWP	Numerical Weather Prediction
PSO	Particle Swarm Optimization
PV	Photovoltaic
RM	Malaysian Ringgit (currency)
RMSE	Root Mean Square Error
SARIMA	Seasonal Autoregressive Integrated Moving Average
SIRIM	Scientific and Industrial Research Institute of Malaysia
SWT	Small Wind Turbine

The associate editor coordinating the review of this manuscript and approving it for publication was Ton Do.

T-FFNN	Topological Feedforward Neural Network
TNB	Tenaga Nasional Berhad
TSR	Tip Speed Ratio
UMT	Universiti Malaysia Terengganu
USD	United States Dollar (currency)
UTM	Universiti Teknologi Malaysia
VAWT	Vertical Axis Wind Turbine
vM	von Mises
VMWT	Vehicle-Mounted Wind Turbine
WGS	World Geodetic System
WT	Wind Turbine

I. INTRODUCTION

The increased energy demand globally has led Malaysia to recognizing the significance of renewable energy as a supplement to conventional sources of electricity generation. Malaysia has established several energy policies, which have made the country a leader in energy production in south-east Asia. The first National Energy Policy was coined in 1979, while the Renewable Energy Act was enforced in 2011. One of the objectives of the policy framework was to appropriately identify the energy needs, conserve resources as well as the environment, and promote sustainable development and low carbon technology [1], [2]. Malaysia pledged to the United Nations Climate Change Conference 2009, the 15th Conference of the Parties (COP15), to decrease carbon emissions by 40% [3] as well as to reduce its green house gas emissions by 45%, by 2030 compared to 2005 [4], [5]. The new net energy metering (NEM) mechanism, updated in 2019, proposes an equal tariff for buying and selling electricity for NEM members. This recent process is expected to engage more customers in adopting renewable technology, such as wind turbines and solar panels; however, the current NEM mechanism covers only the energy generated by solar panels [6]. Currently, renewable energy in Malaysia is mainly produced by biomass, biogas, solar, wind, and mini-hydro [6]. Figure 1 summarizes the installed electricity supply capacity mix for entire Malaysia (Peninsular Malaysia, Sabah, and Sarawak) as of December 2018 [7]–[9]. Figure 1(a) shows the total installed capacity of nonrenewable sources, dominated by fossil fuels, gas (43%), coal (37%), hydro plants larger than 100 MW (19%), and 1% of diesel generators. On the other hand, renewable sources (grid-tied only), as shown in Figure 1(b), include solar (67%), biomass (11%), biogas (10%), LSS & NEM (6%), mini-hydro (5%), and solid waste (1%). Renewable energy sources capacity provides a total of 625 MW, representing 2% of the total energy sources capacity in Malaysia. However, the Malaysian Green Technology Master Plan aims to increase the capacity of renewable sources mix to 20% by 2025.

Most of the wind power studies in Malaysia focus on the features and characteristics of wind speed. That is due to the challenges Malaysia faces in wind energy production, as it is located 5° on the north of the equator. Moreover, the sea and land air influence the wind circulation system. It has been observed that wind changes by area and month, and that it does not show a uniform behavior [10]. As per the statistics, Malaysia is known to have low wind speeds in comparison to countries such as Denmark and Netherlands. However, several locations in Malaysia are characterized by high wind speeds at a particular time of the year, especially during monsoon. There are two moonsoons seasons in Malaysia, the south-west monsoon (May–September) and the north-east monsoon (November–March). The average wind speed is usually below 3 m/s, which is not sufficient condition for continuous generation of wind energy, however, the maximum wind speed is in the range of 6–12 m/s, indicating the possibility to generate wind energy at certain times only [11].

A few review studies have been conducted on wind energy in Malaysia. However, these reviews are not recent and most of them generally concentrate on renewable sources and do not discuss the literature in depth [12]–[18]. Among the mentioned studies, only a few concentrated on wind energy. However, these studies investigated specific factors such as wind speed distribution and spatial models [19]; particular aspects such as political and regularity support [20], and technical issues [21], [22]. None of these studies contains a comprehensive review of all factors related to wind potentialities and other wind energy aspects, such as wind forecasting, mapping, turbine designs, and optimal sizing of hybrid renewable sources. Therefore, the present paper presents a comprehensive review of wind energy research progress in Malaysia. It includes all potentiality factors and wind predictions, as well as techno-economic and design factors, which are further discussed in detail in the following sections.

In this study, the search engines of Science-Direct, Scopus, and Web of Sciences were used to find wind-related studies in Malaysia. From the search queries, 177 articles were found. First, we performed a title check, where 27 entries were removed as duplicated articles. The rest of the articles were then subjected to a full abstract read. During this stage, 46 articles were removed as they were out of scope. The remaining 104 entries were entitled for a full text read and categorized as follows: feasibility and potentiality (54); mapping (6); design (7); prediction (8); sizing (18); and reviews (11).

II. POTENTIALITY

Learning the wind behavior is very important to assess the performance of wind farms. Location plays an essential role in wind frequency and speed. Therefore, wind turbines are located only in particular regions, on a global scale. To evaluate wind eligibility of a specific location for the management and design of a wind energy system, various statistical measures and analysis have to be performed, using historical wind data extracted from the geographical site [23]. This section reviews the energy potential and the statistical evaluation of wind characteristics studies in Malaysia. As shown in Table 1, the studies are categorized based on their objectives. Wind

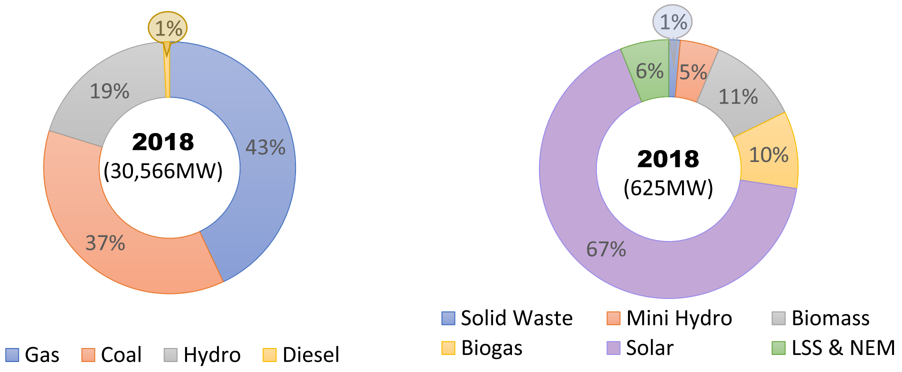


FIGURE 1. **Installed energy capacity in Malaysia by plant type (end of 2018). (a) non-renewable sources. (b) renewable sources. LSS: large scale solar, NEM: net energy metering.**

direction, wind speed distribution models, and geographical aspects are presented. Moreover, the techno-economic effects are reported.

A. WIND DIRECTION

Shamshad *et al.* [30] conducted statistical and power density analysis of wind direction and speed in Mersing. They studied the effects of area topography and roughness on wind energy, using various wind turbines. The results of the wind direction analysis showed that the south-west direction (240°) occurred in 27% of the cases. However, the analysis of projected wind speed at varying heights indicated that the 240° direction is related to the lowest wind speed.

On the other hand, different distribution models were applied to identify the best model for the determination of wind direction in Malaysia. For instance, Masseran *et al.* [70] found that the finite mixture model of von Mises (vM) distribution, indicating H amount of components, is the most suitable distribution model. In further investigations, the flexibility of the vM distribution model was proven to be advantageous in addressing wind directional data with several modes. Masseran [80] compared the circular model with the suitability of the vM model based on non-negative trigonometric sums. The findings showed that the Finite Mixture of von Mises Fisher (mvMF) model when the number of H components is ≥ 4 is the most appropriate model. Furthermore, Masseran and Razali [71] investigated the wind directions through the monsoon seasons. They used the data collected from five stations between January 1th, 2007 and November 30th, 2009, to fit the Finite Mixture model of vM distribution to the data of wind direction on an hourly basis. The results demonstrated the ability of the model to fit all different datasets with R^2 values ≥ 0.9. Similarly, Satari *et al.* [72] employed vM distribution. They noticed remarkable shifts in the wind direction within a period of 10 years. However, they stated that the wind direction did not impact the wind speed.

Sanusi *et al.* [41] used a unique combination of Gama and a finite mixture model of vM distributions for wind speed and direction, respectively, to assess the energy potential in Kuala Terengganu. The analysis of wind power density revealed that the existing uncertainty, resulting from the use of bivariate model compared to a univariate one, explains why the high-speed wind does not usually align with the most common direction of wind. The study concluded that the combination of Gama and a finite mixture of vM distributions is the perfect bivariate model regarding the clarification of wind data of Kuala Terengganu. Accordingly, Sanusi *et al.* [28] investigated the effects of wind direction on producing wind energy in Mersing. The mvMF and Weibull distributions were applied for modeling wind speed and wind direction and speed data respectively. The results show that within the studied time interval (2007–2013), the approximate power density (power equation) ranged from 18.2 to 25 W/m^2. Analysis of wind direction, it was also concluded that the south-southwest direction is the dominant wind direction in Mersing.

B. WIND SPEED DISTRIBUTION MODELS

Saberi *et al.* [65] used the Weibull distribution model to assess the quality of wind data that were collected in 2017 in Kuala Terengganu. Likewise, the Weibull distribution model has been extensively used as a method for determining the potentiality of wind energy as shown in Table 2 such as [28], [41], [63], [68], [69], [81]. In most of these studies, the use of the Malaysia Meteorological Department (MMD) wind data was found to be dominant. These data were collected from stations at 10 m height and mostly extrapolated to higher heights using the standard 1/7 power law. In Butterworth, the Weibull distribution function was analyzed using five wind turbines, to calculate the energy density. The calculated energy yield density was 288.23 and 315.10 kWh/m^2/year and 315.104 kW/m^2/year at a hub height of 100 m for 2008 and 2009, respectively [74]. Likewise, at a height of 100 m and according to the Weibull variables, the mean wind speed was calculated on an hourly basis, and then simulated using a joint sequential Monte Carlo simulation method, which yielded power densities of 84.59, 79.28 and 33.36 W/m^2 for Mersing, Kudat, and Terengganu, respectively [55]. For self-collected data, Albani *et al.* [64] collected

TABLE 1. Potentiality studies in Malaysia categorized according to their main objective denoted by * at each column. Geo.: Geographical aspects; WD: wind direction; TE: Techno-economic; Dist.: Distribution modeling; Energy: Energy measure method.

Article	Geo.	WD	TE	Dist.	Energy
[24]	-	-	-	-	Turbine
[25]	-	-	-	-	electrocorder
[26]	-	-	-	*	Power law
[27]	-	-	-	*	Power law
[28]	*	-	-	-	Power law
[29]	-	*	-	-	HOMOR
[30]	*	-	-	-	turbines
[31]	-	-	-	*	N/A
[32]	-	-	*	*	Power law
[33]	-	*	-	-	N/A
[34]	-	-	*	-	HOMER
[35]	-	-	*	-	HOMER
[36]	-	-	*	-	iHOGA tool
[37]	-	-	*	-	HOMER - Offshore
[38]	-	-	-	*	Power law
[39]	-	-	-	*	Power law
[10]	-	-	-	*	Power law
[40]	-	-	-	*	Power law
[41]	-	*	-	*	Power law
[42]	-	-	-	*	Power law & turbines
[43]	-	-	-	*	Power law
[44]	-	-	*	-	turbines
[45]	-	-	-	*	Power law
[46]	-	-	-	*	pdf
[47]	-	-	*	*	turbines
[48]	-	-	*	-	HOMER - Offshore
[49]	-	-	*	-	HOMER
[50]	-	-	*	-	Turbines, WindPRO and WaSP
[51]	-	-	*	-	N/A
[52]	-	-	*	-	Turbines - sitting
[53]	-	-	-	*	N/A
[54]	-	-	-	*	Power law
[55]	-	-	-	*	Power law, Sim. turbines
[56]	-	-	-	*	pdf
[39]	-	-	-	*	Turbines, WindPRO, WAsP
[57]	-	-	-	*	pdf
[58]	-	-	-	*	Sitting, turbines, power law
[59]	-	-	-	*	N/A
[60]	-	-	-	*	N/A
[61]	*	-	-	-	N/A
[62]	*	-	-	-	Turbines
[63]	*	-	-	-	N/A
[64]	*	-	-	-	power law indexes / Turbines
[65]	-	-	-	*	Weibull distribution
[66]	-	-	-	*	Electrocorder
[67]	-	*	-	*	Power law
[68]	-	-	-	*	Weibull distribution
[69]	-	-	-	*	Weibull distribution
[70]	-	*	-	-	N/A
[46]	-	*	-	-	Betz's law
[71]	-	*	-	-	N/A
[72]	-	*	-	-	N/A
[73]	*	-	-	-	HOMER
[74]	-	-	*	-	HOMER
[75]	-	-	*	-	HOMER
[76]	-	-	*	-	HOMER
[77]	-	-	*	-	HOMER
[78]	-	-	*	-	HOMER
[79]	-	-	*	-	HOMER

wind data at four locations, namely Kudat, Mersing, Kijal, and Langkawi. The authors installed masts and then embedded the sensors at different heights. The collected data were used to generate maps of wind resources and analyze the power law indexes. The results showed that, for a feasible project, a wind speed of 5 m/s can be reached only if the tower is higher than 60 m above ground level in all locations, excluding Kudat where the average wind speed surpasses 5 m/s at 50 m above ground level. Furthermore, they assessed the accuracies of exponential fits via matching the findings with the 1/7 law through the capacity factor discrepancies. As a result, the Mersing and Kudat regions present the potential to adopt medium-scale wind farms, while Kajil and Langkawi are suitable for small-scale wind farms.

Alternatively, other studies examined various distribution functions. Tiang and Ishak [67] employed the function of Rayleigh distribution to investigate the wind speed and density in Penang. They found that the annual average of power density was 24.54 W/m^2, and predicted the monthly annual mean of wind energy at 17.98 kW/m^2. In southern Sabah, Masseran *et al.* [53] used goodness-of-fit analysis to indicate that most of the analyzed stations showed a good fit with Gamma and Burr distributions. However, Gamma distribution was found to be the best for all stations. Similarly, Najid *et al.* [31] applied three probability distributions (Weibull, Gamma, and Burr) to evaluate the potentiality of wind energy in Kuala Terengganu. The study used a self-collected wind speed database recorded daily at an 18 m hub-height for two years (2005–2006) with an average speed of 2.78 and 2.81 m/s, respectively. They concluded that among the three proposed distributions, Burr distribution provided the best fit for the analyzed wind speed data. Meanwhile, Masseran *et al.* [82] evaluated wind speed persistence (stationarity and variability) in 10 wind stations (Kuala Terengganu, Alor Setar, Bayan Lepas, Kuantan, Chuping, Ipoh, Kota Bahru, Mersing, Malacca, and Cameron Highlands) during 2007–2009, using the data obtained from MMD. The wind speed duration curve was used to generate an accumulative distribution of wind speed through a specific duration. The findings demonstrated that the wind speed from Chuping station showed the lowest and most persistent variations regardless of the wind speed values (average speed of 1.03 m/s). However, considering the wind speed values and energy potential, Mersing showed the greatest potential for energy generation compared to other sites, with 18.2% of the wind speed exceeding 4 m/s for a period of three years. To further investigate modeling and statistical evaluation of wind power density, Masseran [46] utilized wind data from Cameron Highlands, Mersing, Malacca, Sandakan, Kudat, and Putrajaya stations obtained from MMD, to evaluate several modeling methods including Gamma, Weibull, and inverse Gamma density functions. The paper proposed the Monte Carlo integration method to better estimate the statistical parameters from the power density that was calculated from the distribution models. The findings indicated the efficiency and reliability of the integrated Monte Carlo method in delivering a good solution for defining the statistical attributes of wind power density. The results showed that the mean power per unit-area ranged between 2 and 24 W/m^2, and that Kudat and Mersing sites showed the greatest values compared to the other stations. Furthermore,

TABLE 2. Studies applying Weibull distribution model.

Study	Location	Power Density (W/m^2)	Wind Speed (m/s)	Energy Density
[65]	Kuala Terengganu	Average in 2017 was 43.42 W/m^2	2.01	N/A
[28]	Mersing	18.2 – 25 W/m^2	Average between 2 and 6	N/A
[10]	Kudat and Labuan	The highest power density was 67.40 W/m^2 in Kudat and 50.81 W/m^2 in Labuan	At Kudat, the average was 3.37, 3.36, and 3.00 for 2006, 2007, and 2008, respectively. At Labuan the average was 3.50, 3.81, and 2.67	The maximum is 590.40 kWh/m^2/year in Kudat and 445.12 kWh/m^2/year at Labuan
[39]	Langkawi	N/A	Mean speeds were 2.00 and 2.50 m/s, respectively, at 10 and 30 m	The range was 68.6–286.7 kWh/m^2/year
[40]	Perlis (Chuping and Kangar)	In Chuping, the result was 2.13 W/m^2 and in Kangar, it was 19.69 W/m^2 for hub-heights above 50 m	Average 1.2 & 2.5	N/A
[74]	Butterworth	32.61 and 35.65W/m^2 for 2008 and 2009 respectively	Average 2.86 m/s	288.23 and 315.10 kWh/m^2/year at hub height of 100 m
[55]	Mersing, Kudat and Terengganu	84.59, 79.28 and 33.36 W/m^2 at a height of 100 m	Annual mean is 2.82, 2.45, and 2.03	Annual 61.754, 57.877, and 24.356 kWh/m^2
[30]	Mersing	Average of 44 W/m^2	N/A	N/A
[26]	Perlis	1.1549	1.7133	N/A
[27]	Mersing, Kota Bharu, Miri, Kuala Terengganu, and Lingkawi	Mersing showed the highest 69.257 w/m^2 at hub-height of 65 m	2.74, 2.27, 2.18, 2.05, and 1.92	N/A
[38]	Kota Bharu, Kuala Terengganu, Langkawi, Mersing, and Miri	Mersing showed the highest 69.257 w/m^2 at hub-height of 65m followed Kota Bharu 45.174 w/m^2	Mersing showed the highest value of 3.97	N/A
[39]	Kudat	21 W/m^2	2.8 m/s	14.6 MWh/year
[41]	Kuala Terengganu	The univariate model showed a value of less than 4 W/m^2 and mostly higher than 4 W/m^2 for the bivariate distribution	The highest mean is 2.9201 m/s	N/A
[66]	Kangar, Perlis	The highest power density was 64.206 W/m^2	Average of 3.5	N/A
[56]	Peninsular Malaysia	The highest and lowest values of power density were 84.60 and 15.20 W/m^2, respectively	The monthly average wind speeds ranged from 2.00 to 5.20 m/s	N/A
[59]	Sarawak	The highest and lowest values of power density in Marudi were 3.93 and 18.67 W/m^2 and in Kula Baram were 3.73 and 18.02 W/m^2	The average annual wind speed was 2.0 m/s	The highest and lowest values of energy density in Marudi were 34.39 and 163.51 (kWh/m^2/year) and in Kula Baram were 32.66 and 158.82 (kWh/m^2/year)

Kudat and Mersing stations showed the greatest standard deviation, ranging from 4 to 45 W/m^2.

C. GEOGRAPHICAL ASPECTS

It is observed that many studies considered some geographical aspects regarding the determination of wind potentiality in Malaysia. Lawan *et al.* [24] proposed a methodology to evaluate wind energy without using direct wind speed measurements. The study covered some terrain areas in Sarawak (Kuching, Samarahan, Serian, and Lundu). A topological-feedforward neural network (T-FFNN) method was used to model the monthly wind speed profile using region-specific geographical, meteorological, and synthesized topological parameters. The study concluded that the wind power of all areas fell within the lower power density class ($\leq$100 W/m^2) with annual energy output in the range of 4–12 MWh/year. Meanwhile, Lawan *et al.* [59] studied wind power generation at Miri in Sarawak by analyzing the characteristics of wind speed at the height ranging from 10 to 40 m using the methods of ground wind station and T-FFNN. With nine meteorological, geographical, and topographical data as input parameters, the model used monthly wind speed as its output variable. The values of 5800–13,622 kWh/year for the annual energy output obtained from their micro-sitting analysis showed the possibility of harnessing wind energy for small-scale applications. In Peninsular Malaysia, Yanalagaran and Ramli [33] investigated the relation between wind flow and coastal erosion over 1984–2016, using the image layering technique on wind data acquired from MMD and coastal erosion data collected from newspaper articles, news videos, social media, and other relevant media. Using the equilibrium beach profile theory, the wind and coastal erosion analyses were investigated using wind direction data. The findings demonstrated the good correlation between the wind direction and erosion direction.

A few researchers employed satellite data to examine wind potentiality in offshore and onshore locations. Uti *et al.* [61] used a multi-mission satellite altimeter to study offshore location with wind potential. They extracted the wind speed data from nine different satellites between 1993 and 2016. In addition, they gathered data from buoys at the sea to compare it with satellite data for reliability validation purposes.

The findings of their study indicated that the wind speed values measured from satellites were slightly higher than those measured from the buoys. However, validation analysis conducted using satellite track analysis and the root mean square error (RMSE) computation showed a good correlation with positive values of 0.6148 and 0.7976 for Sarawak and Sabah respectively. Meanwhile, Albani *et al.* [50], investigated offshore wind resources in Kijal (Terengganu) using QuickSCAT satellite data obtained from WindPRO software [83] during 2000–2008 with a horizontal resolution of 12.5 km^2. WindPRO and WaSP software [84] were used to conduct the potentiality analysis of wind data along South China Sea in Kijal. The optimum feed in tariff (FiT) rate as proposed for offshore wind projects in Kijal was found to be approximately RM 0.81 to 1.38. The findings concluded that Malaysia has a potential for adopting medium- and small-scale wind turbines. Rizeei *et al.* [63] used the satellite data in onshore areas to derive solar irradiance estimation and MMD data to obtain daily wind speed over Peninsular Malaysia. Also, they applied the method of simple additive weighting in the geographic information system (GIS) platform to build a hybrid renewable energy suitability model. The analysis results indicated that the coastal areas at Hulu Terengganu showed a good potential for the photovoltaic–wind turbine (PV–WT) hybrid system.

D. TECHNO-ECONOMIC

From a techno-economic perspective, many studies have related the FiT rates with the feasibility of wind farms in Malaysia. For instance, Ibrahim and Albani [52] selected 22 kW rated-power wind turbines to perform an annual energy production analysis in Kudat. The analysis identified the best site to install wind turbines with a potential production ranging from 37.5 to 43.1 MWh/year with the FiT rates being approximately RM 0.46 to RM 0.80 per kWh. Moreover, Albani *et al.* [51] proposed a method for calculating the optimal FiT that would be suitable for wind energy generation in Malaysia. They selected Kudat as the case study, with real data collected at different heights and—with an average speed of 5 m/s when the hub-height exceeded 30 m. The base case results indicated an FiT between 0.9245 and 1.1313 RM/kWh for small-scale turbines and between 0.7396 and 0.9050 RM/kWh for utility-scale wind turbines. An analysis of the capacity factor using different wind turbines was conducted by Akorede *et al.* [32]. The findings showed that, at a height of 36.6 m, Mersing achieved a maximum capacity factor of 4.39% with wind turbines of 20 and 50 kW capacity. Mersing also showed the highest energy production of 378 MWh/y, followed by Chuping with an annual yield of 254 MWh. Mersing achieved the lowest production cost, approximately 21–35 cents, followed by Chuping with the highest cost of production being 70 cents for 600 kW turbines. On the other hand, offshore wind resources in Kijal (Terengganu) were assessed by Albani *et al.* [50]. The wind turbine capacity factor analysis showed that the turbine with a rated power of 850 kW was the most suitable one to be installed in Kijal, compared to other evaluated turbines, with a capacity factor of 26.8% (annual energy production of 3.653 MWh with a payback period of 7–10 years). The analysis showed that the optimal FiT rates were approximately RM 0.81 to RM 1.38. In another offshore site (near the Terengganu coast), a model of 2000 kW wind turbine was studied in terms of gross energy and economic feasibility. The sensitivity analysis of FiT ratio was found to be between 1 and 3 [37]. Notably, the FiT rate changed with the level of economic parameters.

In another avenue, Izadyar *et al.* [73] selected a list of potential locations to set the optimal configuration of a hybrid renewable systems. Other researchers have considered a techno-economic factor in assessing the wind potential of several locations and determining the optimal configurations of hybrid systems [49], [75], [77]–[79]. Based on the net present cost (NPC), Langkawi was found to be the location with the best potential for the PV-Wind configuration (NPC of 696,083 USD). Tioman and Borneo islands required an additional power source based on the micro- hydropower (MHP), where the best configurations that fit being PV-WT-MHP and PV-MHP, respectively [73]. By considering the cost of energy (COE), Ngan and Tan [35] conducted energy potential and economic analysis on using hybrid renewable sources combined with a diesel generator (DG) in a PV-WT-DG configuration, with and without a battery storage system in Johor Bahru using HOMER software [85]. Hybrid WT-DG without a battery system shows a very high excess of electricity production, for which they finally suggested to add battery storage. The hybrid WT-DG with battery storage showed COE values ranging from RM 1.365/kWh to RM 1.638/kWh. Likewise, Muda and Salleh [49] focused on evaluating a wave energy system in terms of its feasibility in the provision of electricity to Terengganu (Pulau Perhentian island) by proposing and analyzing a hybrid WT-PV-hydro-DG power system. The findings demonstrated that the hybrid wave energy system achieved a lower COE at RM 1.303/kWh, compared to the hybrid PV-battery system, which achieved a COE of RM 1.262/kWh. Moreover, the energy analysis showed 712,813 kWh/year (81 kWh) of generated power with only a 2.4% share from wind energy and a 0.76% share from wave energy. In another study conducted in Terengganu, a hybrid system (PV-WT-grid) connected to the households grid was evaluated. The findings showed that the most feasible configuration was the PV connected to the grid hybrid system (2 kW PV panels) with an energy cost of 0.001 USD/kWh. In other configurations, the total electricity produced by wind turbines constituted only 14% and 22% of total electricity production for the PV-WT-grid and wind-grid systems, respectively. The analysis showed that the best configuration was PV-WT-grid, with an average wind speed of 3.43 m/s and a FiT rate of 0.5169 USD/kWh [34]. In contrast, Anwari *et al.* [29] studied the case of Pemanggil Island (near Mersing), which has an annual wind speed of approximately 1.7–6.7 m/s. They found that the WT-DG hybrid system can be feasible in the case where the wind speed is higher 3 m/s and the diesel price is greater than 1.02 USD/L.

Elsewhere, at five locations in Malaysia (Kota Belud, Kudat, Langkawi, Gebeng, and Kerteh) Nor *et al.*) [47] conducted an economic-feasibility analysis of a 77 Leitwind wind-turbines installation of 1,000 kW each. The study showed that Kota Belud achieved the highest internal rate of return (21%) and the lowest payback period (4.25 years) [47]. In contrast, Suboh *et al.* [44] proposed a dispatch strategy for a micro-wind turbine farm combining storage, using the monthly average wind data for Mersing in 2009. The study considered 10 × 300 W wind turbines (Infiniti 300) with a cut-in speed of 2 m/s. According to the proposed strategy, the study concluded that a payback period of 20 years is required to reimburse the capital expenditure. As shown in Table 3, the PV-WT-DG configuration is an optimal setting for Berjaya, Kuala lumper International Airport (KLIA) Sepang, and Johor. However, a few studies found that it is not feasible to utilize wind energy in several locations in Sarawak and Terengganu for large-scale turbines, as the average wind speed falls below 4 m/s [42], [76].

TABLE 3. **Hybrid renewable systems.**

Article	Location	Optimal Configuration	COE-Cost
[49]	Pulau Perhentian Kecil	PV-DG	RM 1.262/kWh
[73]	Langkawi	PV-WT	N/A
[73]	Tioman island	PV-WT-MHP	N/A
[75]	Kerteh	PV-WT	USD 0.474/kWh
[77]	KLIA Sepang (Selangor)	PV-WT-DG	USD 0.625/kWh
[78]	KLIA Sepang (Selangor)	PV-WT-DG	USD 5.126 /kWh
[79]	Berjaya Tioman	PV-WT-DG	USD 0.279 /kWh
[35]	Johor	PV-WT-DG	RM 1.365 to RM 1.638/kWh

To summarize, most of the previous studies focused on wind potentiality in Malaysia, often based on theoretical studies with conflicting conclusions. However, some of them offered valuable contributions and analyses of wind energy in Malaysia using MMD data. Several wind assessment studies concluded that due to the equatorial location of Malaysia, the wind profile is relatively low in general. However, a few sites in Malaysia have been found to have acceptable wind profiles and can be further investigated for the actual development of wind farms. For instance, in many studies, Mersing (2.4309° N, 103.8361° E), showed the highest wind speed profile with an average speed of above 2.5 m/s, which suggests that small-scale wind turbines with low cut-in speed can be used. Nevertheless, based on the wind data collected over 10 years, Mersing showed a power density of above 50 W/m^2 [32], [54]. However, in other studies, Kudat (6.8831° N, 116.8466° E) [58] showed a slightly better wind profile compared to that of Mersing, with an average speed of above 2.8 m/s. The analysis of wind speed, measured at Chuping station (6.4985° N, 100.2580° E), by Masseran *et al.* [11] showed the lowest and the most persistent variations, regardless of the wind speed values. Note that, some studies considered the annual average of wind speed, which doesnot correctly reflect the actual power output as it is heavily dependent on the wind speed fluctuations.

III. WIND POWER PROJECTS IN MALAYSIA

Several wind turbine farms have been constructed in Malaysia, mainly for research purposes, some of which have been claimed to supply electricity for remote areas. However, conflicting reports of the success or failure of these projects have been mentioned in the literature [20], [58], which rises major doubts for the new wind projects to be installed in the future. Table 4 lists the well-known wind farms implemented in Malaysia.

TABLE 4. **Wind power plants in Malaysia.**

Project	Year	Location	Sponsor
150 kW	1995	Terumbu Layang-Layang (Sabah)	TNB
Two×100 kW	2007	Perhentian Island (Terengganu)	TNB UKM
3.3–25 kW	2009–2013	Kudat, Kuching, Kuala Perlis, and Kuala Terengganu	SIRIM
3.3 kW	2014	Setiu (Terengganu)	UMT

The first pilot hybrid wind power project in Malaysia was initiated in 1995 by Tenaga Nasional Berhad [86] and spearheaded by Universiti Kebangsaan Malaysia (UKM) [58]. This project comprises a 150 kW wind turbine unit installed at Pulau Terumbu Layang-Layang (Swallow Reef), Sabah. While this project was reported as successful after its installation citeNajid2009, a review conducted by Ho [20] claimed that the wind turbine stopped rotating. In 2007, a hybrid diesel-solar-wind project with a battery bank was implemented in Small Perhentian Island, Terengganu [87]. This hybrid project comprised two wind turbines of 100 kW, a 100 kW solar PV system, a single 100 kW diesel generator set, and a 480 kWh battery bank of 240 voltage direct current. Due to the improper wind data collection and analysis, as well as an inappropriate wind turbine selection for that particular location, the wind turbines have failed to continuously rotate within a year from the official launch of the project [58].

During 2009–2013, several pilot tests were conducted by the Scientific and Industrial Research Institute of Malaysia (SIRIM) at different locations in Malaysia (i.e. Kudat, Kuching, Kuala Perlis, and Kuala Terengganu). Small-scale wind turbines were used in these projects, with a capacity that ranged from 3.3 to 25 kW. However, the performance details of these projects were never published [58], [88]. In addition, in 2014, another pilot project, mainly conducted by Universiti Malaysia Terengganu (UMT), was implemented in a shrimp farm in Setiu (Terengganu) with a wind turbine of 3.3 kW. The turbine was connected directly to a water pump and the aeration system on the site and was estimated to cover almost 40% of the farm's energy consumption with an energy cost of 0.98 RM /kWh each year [89].

IV. WIND PREDICTION

An Optimal prediction of wind speed is an open research issue due to the need to foresee the feasibility of harnessing wind energy at specific sites. Wind speed forecasting has been extensively studied, with hundreds of articles found in the literature. Wind speed prediction methods can be categorized into five groups: persistent method, physical models, statistical models, artificial intelligence methods, and hybrid methods [90]. A brief summary of these methods can be given as follows.

1) The persistent method is the most common method used as a benchmark for comparisons with other methods. It assumes that the wind speed will remain constant over time, considering that the wind speed value in the future will be similar to the current value when a forecast is made. However, due to the intermittent nature of wind speed, this assumption fails when the prediction horizon increases.
2) The physical model is based on weather forecast data (e.g. temperature, pressure, surface roughness, and obstacles) and numerical weather prediction (NWP) models. NWP utilizes complex mathematical models for creating a terrain-specific weather condition that is used for wind speed predictions. NWP requires large computational resources with high time consumption, and hence, is not suitable for short-term wind speed predictions [90], [91].
3) The statistical methods are based on the learning of the correlations of historical wind speed data and/or other explanatory variables (i.e., the common meteorological parameters or NWPs). Statistical models are usually less complex than physical models and show accurate performance when used for short-term forecasting tasks. The conventional statistical techniques can be categorized into linear stationary models, nonlinear stationary models, and linear non-stationary models. Generally, statistical models are limited by the fact that the data underlying dynamics are constrained by a strict assumption of normality, linearity, or variable independence [92].
4) Artificial intelligence methods and supervised mechanisms that have been constituting the dominant fields of research in recent years, since they can represent any complex relation between data, regardless of the underlying dynamics [93]. Recent advances in deep learning methods have seen significant performance improvements in many practical forecasting tasks, sometimes surpassing the well-known strong statistical models' performance. This is attributed to the capability of deep learning methods to perform both feature extraction and modeling. This allows learning of complex data representations with the privilege of hierarchical levels of semantic abstraction via multiple stacked hidden layers, and hence, robust and accurate forecasting, even when it is based on raw data obtained from multiple exogenous or heterogeneous sources.
5) Hybrid models are based on the combination or integration of two or more models of different methodologies, in order to benefit from the advantages of each model and improve the prediction performance [90], [93].

In this study, we limit the review of wind speed forecasting methods to the studies that a) have been carried out in Malaysia and b) have used data collected in Malaysia. Only a few previous studies include efforts for the improvement of prediction performance, mostly using meteorological station data (i.e., MMD data). We conducted a thorough review of eight published articles related to wind data prediction in Malaysia during 2005–2018 in the analyzed database. Four prediction methods used an artificial neural network (ANN) [94]–[97], two deployed an adaptive neuro-fuzzy inference system (ANFIS) [98], [99], two used seasonal autoregressive integrated moving average (SARIMA) [81], and one used the Mycielski algorithm [100].

The first article regarding wind speed prediction for Malaysia was published by Shamshad *et al.* [96] who implemented a stochastic synthetic generation of wind data using Markov chain with wind data obtained from the MMD for two stations (Mersing and Kuantan) during 1995–2001. First and second-order matrices of the Markov process with 12 states were estimated using the wind speed data, which were then reversely used to predict future wind speed data. To assess the performance of Markov chain matrices, the Weibull distribution was estimated using the observed and predicted wind data. Both transition matrices showed comparable distribution parameters, namely of k and c. Autocorrelation and spectral power density were also used for performance evaluation in the case of using different correlation time lags. The RMSE values of the first and second order were 0.12 and 0.03 for Mersing and 0.03 and 0.03 for Kuantan, respectively. The Markov model is a type of statistical model that relies heavily on probabilistic theory, while higher orders show a better performance with increased state-space complexity.

Lawan *et al.* [95] proposed a topological ANN method for monthly wind speed prediction. The geographical and meteorological data were obtained from MMD for eight regions in Sarawak for a 10-years period from 2003 to 2012 (Kuching, Miri, Sibu, Bintulu, and Sri Aman) and a five-year period from 2008 to 2012 (Kapit, Limbang, and Mulu). Nine parameters were used as input to the ANN model including latitude, longitude, altitude, terrain elevation, terrain roughness, month, temperature, atmospheric pressure, and relative humidity. For each station, the data were split into 70%, 20%, and 10% for training, testing, and validation, respectively. All data were normalized to the interval of [-1, 1]. Monthly prediction results showed the minimum and maximum values of correlation coefficient R were 0.8416 and 0.9120, respectively, and the maximum mean absolute percentage error (MAPE) was 6.46%.

Meanwhile, Shukur and Lee [97] suggested a hybrid method of ANN and Kalman filter (KF) to improve the performance of ANN models. However, the authors used daily wind speed data obtained from MMD for the Muar station during 2006–2010. Unlike the previous studies, which mostly used data-driven prediction models, state-space model parameters were estimated using the ARIMA model, and then used as input to ANN in order to predict the wind speed future data. The ARIMA (0,1,2) $(0,1,1)_1 2$ model was selected for state-space parameters estimation with MAPE of 19.27, while the hybrid ARIMA-KF achieved 17.20 MAPE and hybrid KF-ANN showed 11.29 MAPE. The results indicated that KF-ANN improved the prediction performance by almost 8% compared to the direct use of the ARIMA model. However, the state-space models are usually of high computational complexity and sensitive to the dynamics of data, especially that of a high sampling rate.

Kadhem *et al.* [94] proposed a short-term wind speed prediction hybrid model using Weibull distribution and ANN (HANN). Hourly wind speed data were obtained from MMD from three stations (Mersing, Kudat, and Kuala Terengganu) for a three-year period, from 2013 to 2015. Data were normalized in the interval [-1, 1], and then partitioned into 60% training, 20% validation, and 20% testing. Five parameters were used as input to the ANN model including wind speed of Weibull model, direction, hour, day, and month. The results showed that the proposed HANN method achieved a MAPE and RMSE of 6.06% and 0.048, respectively for Mersing data, which improved the prediction performance by a MAPE of 10.34% MAPE compared to the ANN model alone.

The suitability of using a hybrid ANFIS system and optimization methods for long-term (weekly and monthly) wind prediction in Malaysia was investigated by Hossain *et al.* [98]. Wind speed data were obtained from MMD for several locations, namely Mersing, Kuala Terengganu, Pulau Langkawi, and Bayan Lepas during the period 2004–2014. The data were adjusted to a hub-height of 50 m. Three optimization techniques, namely particle swarm optimization (PSO), genetic algorithm (GA), and differential evaluation (DE), were used to optimize the ANFIS membership function parameters. Method performance was analyzed using different train-test data partitioning: [70%,30%], [60%,40%], and [80%,20%]. Both ANFIS-PSO and ANFIS-GA can apparently provide an overall good power density prediction performance. The proposed hybrid ANFIS model was also used for daily wind data extrapolation of Tioman island, where no MMD station is available. Even though ANFIS is a combination of ANN and fuzzy inference system (FIS), it can supposedly to overcome the limitations of both methods and provide better performance.

Sahin and Erol [101] conducted a comparative analysis of both ANN and ANFIS concluding that the ANN approach performed better than the ANFIS model on predictions. Sarkar *et al.* [99] also conducted a comparative study of wind power prediction using the ANFIS model in Kuala Lumpur and Melaka. Wind data were obtained from MMD over the period of 2013 to 2015. Four input variables were used for prediction, namely humidity, pressure, wind speed, and temperature. Employing test data of one year, satisfactory results were obtained when using the ANFIS model to predict wind power data of Kuala Lumpur, compared to those for Melaka (RMSE = 1.82, MAE = 1.98, MAPE = 13.23 and R2 = 0.944) for Melaka and for Kuala Lumpur (RMSE = 1.65, MAE = 1.87, MAPE = 12.35 and R2 = 0.968).

The Mycielski algorithm is a simple, non-parametric, alternative approach for complex parametric models, which is mainly based on pattern matching [102]. Goh *et al.* [100] proposed a wind energy assessment comparing two methods (Mycielski algorithm and K-means clustering) for wind prediction in Kudat, Malaysia. Wind data were obtained from MMD over the period from 2002 to 2010. The data from 2002 to 2009 were used for training whilethose from 2010 were used for testing. The results showed that K-means clustering provides more accurate predictions compared to the Mycielski algorithm. Weibull distribution was used to assess the comparison of the predicted wind speed values with the actual ones, with the prediction RMSE of Mycielski being 1.875 and 1.391 for K-means.

The wind profile in Malaysia is highly dependent on monsoon seasons. Four main seasons alternate throughout the year, producing different wind speed and direction behaviors. Deros *et al.* [81] proposed a wind speed seasonal forecasting model using SARIMA with wind data obtained from MMD during 2000–2015 for Langkawi. Four monsoon seasons were analyzed, including north-east monsoon, April inter-monsoon, south-west monsoon, and October inter-monsoon. For variation analysis and determination of seasonal wind distribution, three distribution models were investigated, including Gamma, log-normal, and Weibull distributions. Forecasting results showed that SARIMA achieved RMSE = 0.3186, MAE = 0.265, and MAPE = 11.644%. Of the three tested distribution models, the log-normal distribution model produced the lowest gap value among all seasonal wind speed data in each monsoon season. The study concluded that the north-east monsoon shows the highest mean wind speed value with an average between 1.8 and 2.3 m/s, followed by October inter-monsoon, south-west monsoon, and April inter-monsoon, which showed the lowest wind speed, estimated to be between 0.9 and 1.3 m/s.

According to the reviewed articles on wind speed prediction, the lack of standardization between the proposed methods and wind database made technical or numerical performance comparisons difficult. It is important to understand the performance of these models and provide some degree of confidence. Fare analysis requires the prediction experiments to be conducted under similar environments and conditions, such as data sampling rate, train-test partition, prediction horizons, input variables, target area, and hub-heights. Hence, a benchmark study is required to test the generalization, universality, and transferability of these prediction models.

V. TURBINE DESIGN

Regarding the continuous search for the possibility of generating power from wind energy in a low-wind-speed region, several studies are available. The most prevailing subject is to design wind turbines specifically for a low-wind-speed region. Wen *et al.* [103] applied the blade element momentum theory to design a small wind turbine (SWT) blade as a partial solution to the low-wind-speed region of Malaysia. Based on Malaysia's average wind speed of 2–3 m/s, the authors chose the NACA4412 Airfoil profile with lower Reynolds numbers of $Re = 0.2$, $Re = 0.25$, $Re = 0.3$, $Re = 0.35$ and tip speed ratios (TSRs) of 5, 6, 7, and 8 to design an SWT of 4 m/s rated wind speed. A turbine blade that starts rotating at wind speed of 1.5 and 2.0 m/s, with the efficiency being approximately 49.31%, was realized. The annual energy generation (AEG) result obtained using the designed turbine's power curve and the Weibull distribution function with wind profiles of Kuching, Miri, Kangar, Labuan, and Kudat showed a better performance of $Re = 0.25$ and $Re = 0.3$.

Similar research was conducted by Wen *et al.* [104] in order to design and study the performance analysis of six constant-speed, horizontal-axis, wind turbines. Based on the Airfoils' low Reynolds numbers that fit the SWT blade design for application in low-wind-speed regions, six Airfoils—BW-3, FX63-137, NACA4412, S822, SG6040, and SG6043 with a specific Reynolds number ($Re < 500{,}000$) and tip speed ratios of 5 and 6—were chosen for the design. Their results showed that by increasing the Reynolds number, the aerodynamic performance of the Airfoils rapidly increased and in turn, resulted in a lower cut-in speed and higher power coefficient. A blade of 1.78 m/s cut-in wind speed and a higher power coefficient of 0.52 was obtained at the TSR of 5 and cut-in wind speed of 1.8 m/s, while a 0.51 power coefficient was obtained at the TSR of 6 with Airfoils SG6043 and FX63-137. A lower cut-in speed of 1.5 m/s was obtained with Airfoils BW-3 and FX63-137. The lowest cut-in speed achieved using Airfoils was recorded at the TSR of 5. The results of the computed AEG, when the designed turbine power curve was employed with the wind speed distribution of Kangar, showed that out of the six airfoiled turbines selected, SG6043 outperformed all with an AEG of 64 and 66 kWh for the 5 and 6 TSRs, respectively.

Misaran *et al.* [105] designed and developed a hybrid vertical axis wind turbine that can start rotating at a wind speed of 1.0 m/s and generate useful power from a low and intermittently high wind-speed region, such as Malaysia. The blade design was developed using CAD software [106] and the publicly available online Airfoil Tools [107] to generate the NACA0012 profile.

From another perspective, Johari *et al.* [108] used CATIA software [106] to design and compare the performances of three-blade horizontal axis wind turbines (HAWT) and Darrius-type vertical axis wind turbine (VAWT). The results of the HAWT and VAWT performance analyses showed that the HAWT produced higher voltage under stable wind condition, which became almost zero as the wind direction changed. In case of VAWT even though its output voltage is not as high as that of HAWT, it remained unaffected by the change in wind direction. Correspondingly, a vertical axis wind turbine's blade, based on the Aeolos-V1k model, was modified and redesigned in [109] using ANSYS software [110]. The modification, which was performed with teak wood material, reduced the blade's weight and cost and improved its efficiency. On the other hand, with respect to intellectual properties in Malaysia, only one patent can be found in the literature. This patent was filed by Mat [111], from UKM university and focuses on the design of vertical-axis wind turbine with an increased rotation torque of the turbine rotor. It was claimed that it could be used both vertically and horizontally for electrical power generation. However, through an online search, no updates could be found about this design and whether it was implemented on site.

Several articles that further explore the possibility of generating electricity from the wind energy sources of Malaysia are available. Awal *et al.* [112] designed a vehicle-mounted wind turbine that utilizes the speed of wind that passes the moving vehicle, in order to generates electricity. It uses a permanent-magnet DC motor as a generator and can produce 150–200 W of power as the vehicle moves. Likewise, Khai *et al.* [113] modified a rooftop ventilator in order for it to function as a wind turbine harvesting wind energy from the steady wind speed of the ventilation channel created due to the temperature difference between the indoor and outdoor spaces. The result of their testing conducted using a stand fan showed that the modified wind turbine could produce a minimum of 4.63 V and 21.44 mW power, which can light up a 5 V light-emitting diode bulb. Moreover, the design and implementation of a VAWT that utilizes the waste exhaust coming of a cooling tower was presented by Rahman *et al.* [114]. The design comprises a drag blade (C-type), a guide-vane to increase the inlet wind speed, and an enclosure to avoid the wind coming from the opposite direction. They recorded a voltage and a current of 1.97 V and 0.0041 A, respectively, and an average power of 0.0058 W, concluding that their system can generate 0.0081 W of electricity.

VI. OPTIMAL SIZING OF HYBRID ENERGY SYSTEMS

The integration of conventional into renewable energy sources and energy storage devices is common when developing hybrid energy systems to fulfill a particular load demand. However, the addition of an energy storage system is essential to moderate the supply demand mismatch. Moreover, conventional sources, such as diesel generators or fuel cells, can also be added to renewable sources in order to obtain a better energy balance. Hybrid systems are becoming more common nowadays, as they merge the advantages of both AC and DC, as well as flexibility, cost-effectiveness, and integration of different loads and sources based on their characteristics [115], [116]. However, no configuration can fit all solutions, and therefore; the suitability of a configuration must be considered based on the particular application and site.

The literature of wind energy in Malaysia shows two software tools that have been used to optimize hybrid renewable energy systems. The first software tool is HOMER, which has been mostly used as shown in Table 5, and the second is iHOGA [117], which was applied by Fadaeenejad *et al.* [36]. In contrast, other studies [118]–[120] have used MAT-

TABLE 5. Optimal sizing by using the HOMER software tool.

Study	Location	Energy Sources	Energy storage	Factors	Key factors
[49]	Small Pulau Perhentian	PV-DG	Batteries	NPC, COE	Second best combination is PV-WG-DG
[73]	Malaysia	PV-WT-MHP	Batteries	NPC	Tioman is the best location for PV-WT-MHP
[75]	Pontian, Kerteh and Teluk	BG-PV-WT	Batteries	COE	N/A
[77]	KLIA Sepang (Selangor)	PV-WT-DG	Batteries	NPC, COE, CO_2	N/A
[79]	Berjaya Tioman	PV-WT-DG	Batteries	NPC, COE, CO_2	N/A
[35]	Johor	PV-WT-DG	Batteries	NPC, COE, CO_2	N/A
[122]	Johor, Sarawak, Penang and Selangor	PV-WT-DG	Batteries	NPC, COE, CO_2	PV-WT proved to be cheaper and more environmentally friendly than DG
[125]	Tioman Island	PV-WT-FC	Batteries	NPC, COE, CO_2	N/A
[119]	Bintulu, Kota Kinabalu, Kuala Terengganu, Kuching, Kudat, Mersing, Sandakan, Tawau and Pulau Langkawi	PV-WT-DG	Batteries	COE	N/A
[126]	East coast of Peninsular Malaysia	PV-WT-EG	Batteries	NPC, COE, CO_2	N/A
[123]	Kuala Terengganu	PV-WT-DG	Batteries	COE, FiT	N/A

LAB simulation [121]. Energy systems, either connected to the grid or in standalone mode, involving conventional renewable sources and storage systems, can be optimized and simulated using the HOMER software. The optimization can be performed using historic meteorological data of each location. HOMER software has been used for determining the optimal configuration of hybrid energy systems for different locations in Malaysia. The Researchers' main objective was to reduce NPC, subjecting it to a few constraints, such as reliability and environmental conditions. Table 5 lists the studies from different locations in Malaysia that have used the HOMER software tool for size optimization of hybrid energy systems.

Most of the previous studies have reported that PV-WT-DG energy systems are feasible as they provide the minimum NPC and COE with the lowest CO_2 emissions [35], [77], [79], [119], [122], [123]. Nevertheless, Khatib *et al.* [124] examined the energy sources in nine locations in Malaysia to determine the cost of energy for every power system as a standalone system. They found that the average cost of a wind energy system is 1.6–7.29 USD/kWh. In comparison, solar, diesel generator, and grid power average costs are 0.35–0.5, 0.27-0.30, and 0.11 USD/kWh, respectively. The findings concluded that using wind energy as a standalone system is not feasible in the case of Malaysia. In accordance with the previous study, Haidar *et al.* [122], used the HOMER software to study the feasibility of wind energy within a hybrid system in four locations: Pinang, Johor Baharu, Sarawak, and Selangor. The results showed that the cost of wind energy was 1.054–1.457 USD/kWh. These findings indicate that PV-DG is an optimal configuration in Malaysia.

VII. WIND MAPPING

A comprehensive onshore or offshore wind resource mapping is necessary to assess wind feasibility, especially for Malaysia since it has a low wind profile. It is well known that wind speed varies depending on the terrain conditions, such as temperature, wind direction, height from the ground, surface roughness, day time, and year seasons [127]. Wind resource geographical maps can be generated using either spatial prediction or altimetry wind data for those unobserved or uncovered by MMD stations locations. The development of wind energy in Malaysia is still in its early stages, with majority studies using secondary meteorological wind data collected by weather stations mainly located in airports [128]. These wind data were obtained from MMD and mainly used in airports for weather forecasting. Hence, only a few studies have highlighted this issue and conducted nationwide wind energy planning using spatial interpolation methods to create wind maps for Malaysia [129].

Masseran *et al.* [11] conducted a study to generate a wind resource map for all of Malaysia using statistical and geo-statistical analysis, including semivariogram and inverse distance weighted (IDW) methods for spatial correlation, estimation, and interpolation. A total of 10 years of wind speed data, from 2000 to 2009, from 67 stations were obtained from MMD to create a nationwide spatial map. First, the study determined the best suitable wind speed distribution. Nine types of wind speed statistical distributions were examined, namely Weibull, Burr, Gamma, inverse Gamma, inverse Gaussian, exponential, Rayleigh, log-normal, and Erlang. The goodness-of-fit tests conducted indicated that only five distributions can be used to derive the power distribution for each station, namely Gamma, Burr, Weibull, Erlang and inverse Gamma. Raw moment and Monte Carlo approach were used to determine the mean power. The spatial correlations and dependencies were investigated using the semivariogram method, while the IDW method was used to estimate/interpolate wind power in the spatial dimension for mapping reasons. Finally, the spatial maps were created. Spatial mappings of mean power density revealed that the north-east, north-west, and south-east of peninsular Malaysia as well as southern region of Sabah, are the locations with greatest potential for wind energy development.

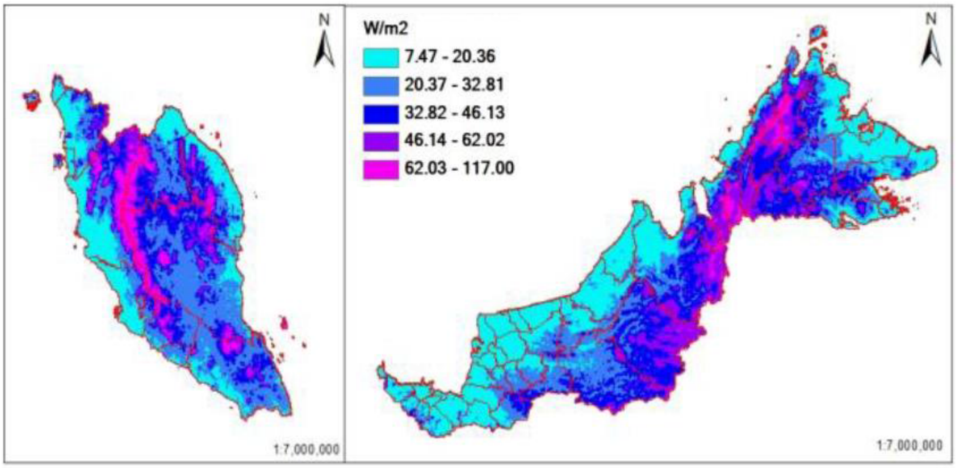


FIGURE 2. Malaysian onshore wind power density map at 10 m height [129].

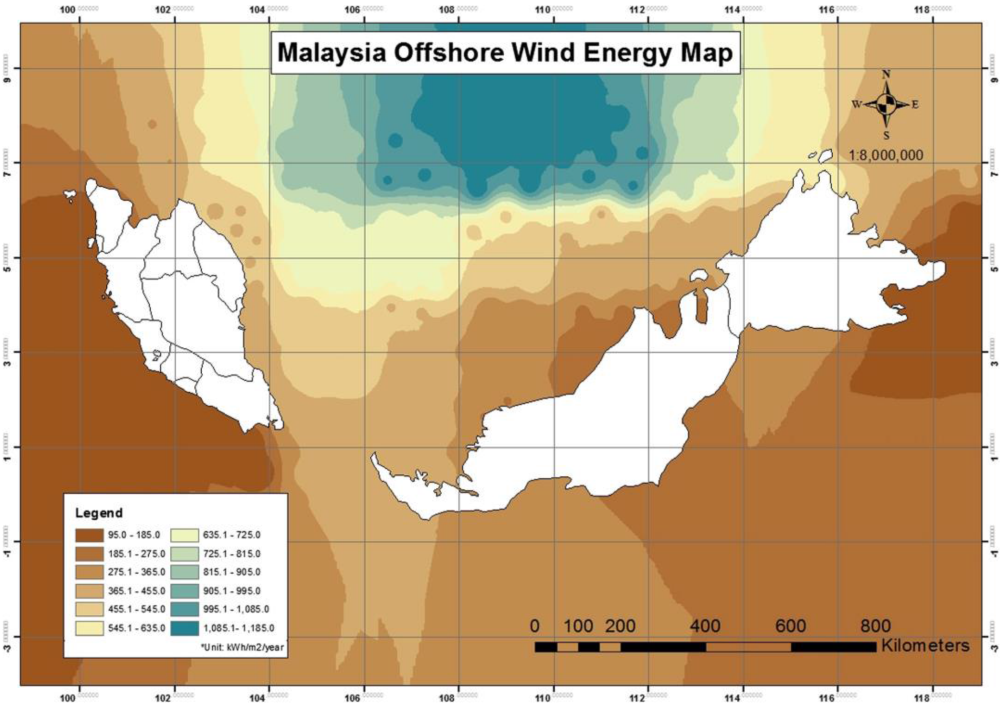


FIGURE 3. Offshore wind energy map of Malaysia. Extracted from [133].

In 2014, another wind mapping study was conducted by Ibrahim *et al.* [128] covering only nine sites (Mersing, Kuala Terengganu, Pulau Langkawi, Sandakan, Kudat, Kota Kinabalu, Bintulu, Kuching, and Tawau) with only one-year wind data obtained from MMD for 2009. Weibull distribution and IDW interpolation methods were used for the mapping. The study concluded that Mersing and Kudat are considered the sites with the best potential, showing an average of 3 m/s above 60 m height. The IDW spatial wind mapping method showed that the area located in the southern part of peninsular Malaysia had better wind resources. These conclusions were proved by Weibull distributions of each area. In that study, further analysis of wind speed distribution and direction was conducted. However, the study lacks an extensive spatial analysis in terms of data and locations compared to Masseran *et al.* [11]. The same authors in [130] studied the spatial interpolation and mapping of wind distribution in Malaysia with wind data obtained from MMD, considering more sites related to 12 stations (Langkawi, Kuala Terengganu, Mersing, Kuching, Bintulu, Kota Kinabalu, Kudat, Sandakan, Tawau, Cameron Highland, Kuantan, and Kapit).

For mapping reasons, the wind extrapolation, power law, and the digital elevation model (DEM) were used in combination, in order to create an onshore spatial wind distribution for Malaysia. Then, the ordinary Kriging method was used for spatial wind data interpolation, which was then combined with DEM maps via the power law to produce the final wind map. The results showed monthly maps variations with accuracies of ±1.1143 and ±1.4949 m/s respectively, for Kriging interpolation and wind map. The study had a limited selection of sites to be used for mapping reasons, the wind direction was excluded in the analysis, and the produced wind map was limited to 10 m height only. The authors published another article in [129] following similar methodology and wind data from their previous study [128]. Power density spatio-temporal maps were generated using extrapolated wind data of different heights, from 10 to 100 m. The study concluded that the wind power of Malaysia falls into Class 1, showing 1.5232 MW/m^2 at 100 m height.

A partial wind map of the eastern part of Malaysia (i.e., Sarawak) was studied by Lawan *et al.* [95] using wind data obtained from MMD, from four stations. The proposed topological ANN wind speed prediction method was utilized to predict the wind data for the uncovered areas in Sarawak, in order to generate a more precise spatial map. Two ready-made software (i.e. GEPlot [131] and Google Earth [132]) were utilized to build a DEM model. The target site-sampled locations including the longitudes and latitudes were generated using the world geodetic system (WGS 84). These sampled locations were then used to extract the DEM with a terrain zonum solution tool. The last element, the surface roughness class was developed using the GEPlot software. The study proposed for the first time an Isovent wind atlas map of Sarawak at heights ranging from 10 to 40 m. The study revealed that the north-east, south-west, and coastal regions of Sarawak have better wind potential.

The main focus of the previous articles was wind resources mapping in order to explore the wind potential in onshore sites. Ahmad Zaman *et al.* [133] studied the mapping and sectorization of offshore locations with wind energy potential in Malaysia, using multi-mission satellite altimetry data. The satellite altimetry (Jason-1, Jason-2, and Envisat) data were obtained from Radar Altimeter Database Systems located at GNSS and Geodynamics Laboratory, Universiti Teknologi Malaysia (UTM), for a period of 19 years, from 1993 to 2011. In addition, buoy measurements from two offshore sites were used for validation reasons. Comparing the satellite with buoy data, the average error was found to be 14% with a correlation of 0.835 and an RMSE of 1.99. The ArcMap 10.2.2 software using raster interpolation with IDW function was deployed to generate the annual wind energy maps. Figure 3 shows the produces offshore wind energy density map for Malaysia. The study concluded that areas C4 (Terengganu coastline), C9 (Labuan), and D11 (Sabah) have high annual wind speed and wind energy density.

VIII. FUTURE RESEARCH RECOMMENDATIONS

1) For onshore wind farms, several studies have recommended a few sites with the potential for wind energy harvesting in Malaysia. However, most of these studies use the MMD database along with interpolation and extrapolation methods to measure the wind energy projects' feasibility. To assess the actual wind speed in these sites, it is important to collect wind data from these sites by installing masts with different heights.
2) Although few studies have conducted offshore wind energy-related analysis mainly using satellite data, the lack of actual offshore wind data makes it difficult to validate the recommendations of these studies. Hence, we also recommend installing wind data collection instruments at the sites that were previously highlighted in the literature.
3) For the optimal sizing of hybrid energy systems, most of the studies used the HOMER software tool. An increasing trend toward the use of modern optimal sizing methods is observed, as they offer realistic and promising size optimization. Thus, the use of modern methods is recommended namely, teaching-learning-based optimization, the hybrid flower pollination algorithm, simulated annealing algorithm, and non-dominated sorting particle swarm optimization.
4) The turbine height is shown to significantly influence the wind speed and optimization results. Based on this factor, it is neccessary to take into account the constraints in turbine installment, design, and optimization, instead of using wind speed extrapolation to higher heights, which may not reflect the correct wind speeds for different terrains and provide wrong estimates of the turbine power output.
5) Most of the studies concentrate on the reliability and cost of hybrid systems, as discussed previously. Few studies focus on environmental factors, such as CO_2 emissions. These factors should be considered especially if the energy system includes a conventional source.
6) According to the analyzed MMD wind data, as mentioned in the previous studies, the low wind profile in Malaysia requires a customized wind turbine design that can operate at low cut-in wind speeds. Therefore, researchers can concentrate more on designing rotor blades that will reach higher rated power at lower wind speed, which on the other hand will increase the AEG.
7) The insufficiency of wind turbines in producing the expected power was probably related to the inappropriate technology used. Therefore, it is recommended to conduct an in-depth research on the wind turbine generator selection process.
8) The effect of a different airfoils profile on the performance of vertical-axis wind turbines must be examined by the National Advisory Committee on Airfoils (NACA), since the current studies have only considered a single NACA 0012 profile.

IX. CONCLUSIONS

The main objective of this study was to review previous literature on wind energy in Malaysia. We discussed all wind-related studies in Malaysia. A comprehensive study was carried out based on some identified factors, in order to give the reader a complete summary of the past, present, and future wind energy research in Malaysia. These factors included in the analysis include the potentiality of wind energy, speed and direction modeling; wind speed forecasting; spatial mapping; and optimal sizing of wind farms.

In most of the studies, wind speed has been reported to have an average value of 2 - 8 m/s and can vary according to the monsoon conditions and site where the measurements took place. The lacking of standardization and representation of wind data has led researchers to use hybrid power systems that include other renewable energy sources (i.e., solar and hydropower) along with wind, which was highlighted in this review as well. Other studies have been conducted on wind power energy conversion using various methods such as power law, computer software (e.g., HOMER), wind turbine power curve, or by using wind power or speed density distributions. Different statistical distributions of wind data have been reported and evaluated for Malaysia, with most of the studies suggesting Weibull distribution for wind speed data.

In general, wind prediction has been another a subject of interest, with a limited number of studies that focus on this issue in Malaysia. After a thorough review of these studies, it was found that various proposed methods achieved various degrees of uncertainty. This is due to the lack of a generalized prediction approach that can tackle seasonal and annual wind variations for both short and long-term horizons. Additionally, the extrapolation of wind speed to different heights can impose significant errors, producing false estimations of wind power. The topographic parameters should be considered for both vertical extrapolation and spatial interpolation in order to produce a more accurate wind potentiality assessment analysis. Spatial prediction and mapping of all or part of Malaysia have been studied in the literature, offering valuable preliminary maps and highlighting several potential sites. This is very beneficial for future research, since before any actual wind turbine installation decision, the wind data need to be measured to confirm the project feasibility for the identified site.

Though most of the previous studies concluded that wind power generation for commercial purposes is not feasible in Malaysia, different methodologies were proposed and further analysis of turbine design, optimal sizing, and hybrid power systems was suggested to overcome the barriers of wind energy development for low-potential wind areas. Most of the wind turbines in the market have cut-in speed above 3 m/s, which is beyond the average annual wind speed in Malaysia. The vertical-axis wind turbines were highlighted and analyzed in several studies since they can operate regardless of any sudden change in wind direction. With the rapid growth of wind turbine design technology, a fully customized wind turbine designs are still required for the wind profile of Malaysia. In this context, a hybridization of two or more renewable power sources seems to provide a partial solution to this issue. Many studies have investigated this option and highlighted the effectiveness of such hybrid systems.

REFERENCES

[1] T. H. Oh, M. Hasanuzzaman, J. Selvaraj, S. C. Teo, and S. C. Chua, "Energy policy and alternative energy in Malaysia: Issues and challenges for sustainable growth—An update," *Renew. Sustain. Energy Rev.*, vol. 81, pp. 3021–3031, Jan. 2018.

[2] P. H. Shaikh, N. B. M. Nor, A. A. Sahito, P. Nallagownden, I. Elamvazuthi, and M. S. Shaikh, "Building energy for sustainable development in Malaysia: A review," *Renew. Sustain. Energy Rev.*, vol. 75, pp. 1392–1403, Aug. 2017.

[3] Malaysian Energy Commission. (2017). *Peninsular Malaysia Electricity Supply Industry Outlook*. [Online]. Available: https://www.st.gov.my/web/download/listing/106

[4] R. Kardooni, S. B. Yusoff, and F. B. Kari, "Renewable energy technology acceptance in peninsular Malaysia," *Energy Policy*, vol. 88, pp. 1–10, Jan. 2016.

[5] A. X. Y. Mah, W. S. Ho, C. P. C. Bong, M. H. Hassim, P. Y. Liew, U. A. Asli, M. J. Kamaruddin, and N. G. Chemmangattuvalappil, "Review of hydrogen economy in Malaysia and its way forward," *Int. J. Hydrogen Energy*, vol. 44, no. 12, pp. 5661–5675, Mar. 2019.

[6] W. S. W. Abdullah, M. Osman, M. Z. A. A. Kadir, and R. Verayiah, "The potential and status of renewable energy development in Malaysia," *Energies*, vol. 12, no. 12, p. 2437, Jun. 2019.

[7] Malaysian Energy Commission. (2019). *Sabah Electricity Supply Industry Outlook*. [Online]. Available: https://www.st.gov.my/web/download/listing/106

[8] Malaysian Energy Commission. (2019). *Peninsular Malaysia Electricity Supply Industry Outlook*. [Online]. Available: https://www.st.gov.my/web/download/listing/106

[9] Sarawak Energy. (2018). *Energising Tomorrow Today*. [Online]. Available: https://www.sarawakenergy.com/investors/annual-reports

[10] M. R. Islam, R. Saidur, and N. A. Rahim, "Assessment of wind energy potentiality at Kudat and Labuan, Malaysia using Weibull distribution function," *Energy*, vol. 36, no. 2, pp. 985–992, Feb. 2011.

[11] N. Masseran, A. M. Razali, K. Ibrahim, and W. Z. W. Zin, "Evaluating the wind speed persistence for several wind stations in peninsular Malaysia," *Energy*, vol. 37, no. 1, pp. 649–656, Jan. 2012.

[12] M. H. M. Ashnani, A. Johari, H. Hashim, and E. Hasani, "A source of renewable energy in Malaysia, why biodiesel?" *Renew. Sustain. Energy Rev.*, vol. 35, pp. 244–257, Jul. 2014.

[13] A. Y. Azman, A. A. Rahman, N. A. Bakar, F. Hanaffi, and A. Khamis, "Study of renewable energy potential in Malaysia," in *Proc. IEEE Conf. Clean Energy Technol. (CET)*, Jun. 2011, pp. 170–176.

[14] K. Y. Foo, "A vision on the opportunities, policies and coping strategies for the energy security and green energy development in Malaysia," *Renew. Sustain. Energy Rev.*, vol. 51, pp. 1477–1498, Nov. 2015.

[15] F. M. Hossain, M. Hasanuzzaman, N. A. Rahim, and H. W. Ping, "Impact of renewable energy on rural electrification in Malaysia: A review," *Clean Technol. Environ. Policy*, vol. 17, no. 4, pp. 859–871, 2015.

[16] S. E. Hosseini and M. A. Wahid, "The role of renewable and sustainable energy in the energy mix of Malaysia: A review," *Int. J. Energy Res.*, vol. 38, no. 14, pp. 1769–1792, 2014.

[17] H. C. Ong, T. M. I. Mahlia, and H. H. Masjuki, "A review on energy scenario and sustainable energy in Malaysia," *Renew. Sustain. Energy Rev.*, vol. 15, no. 1, pp. 639–647, Jan. 2011.

[18] S. M. Shafie, T. M. I. Mahlia, H. H. Masjuki, and A. Andriyana, "Current energy usage and sustainable energy in Malaysia: A review," *Renew. Sustain. Energy Rev.*, vol. 15, no. 9, pp. 4370–4377, Dec. 2011.

[19] S. M. Lawan, W. A. Abidin, W. Y. Chai, A. Baharun, and T. Masri, "Recent progress and development of wind energy potential in Malaysia: A review," *World Appl. Sci. J.*, vol. 28, no. 9, pp. 1222–1232, 2013.

[20] L.-W. Ho, "Wind energy in Malaysia: Past, present and future," *Renew. Sustain. Energy Rev.*, vol. 53, pp. 279–295, Jan. 2016.

[21] D. H. Didane, A. A. Wahab, S. S. Shamsudin, and N. Rosly, "Wind as a sustainable alternative energy source in Malaysia—A review," *ARPN J. Eng. Appl. Sci.*, vol. 11, no. 10, pp. 6442–6449, 2016.

[22] C. Palanichamy, M. Nasir, and S. Veeramani, "Wind cannot be directed but sails can be adjusted for Malaysian renewable energy progress," in *Proc. IOP Conf. Ser., Mater. Sci. Eng.*, Apr. 2015, vol. 78, no. 1, Art. no. 012028.

[23] G. Li and J. Shi, "Application of Bayesian model averaging in modeling long-term wind speed distributions," *Renew. Energy*, vol. 35, no. 6, pp. 1192–1202, Jun. 2010.

[24] S. M. Lawan, W. A. W. Z. Abidin, T. B. H. Masri, W. Y. Chai, and A. Baharun, "A methodology for wind energy evaluation in complex terrain regions of Sarawak," *Int. J. Electr. Eng. Informat.*, vol. 7, no. 2, pp. 264–283, 2015.

[25] Y. M. Irwan, I. Daut, I. Safwati, M. Irwanto, N. Gomesh, and M. Fitra, "A new technique of photovoltaic/wind hybrid system in Perlis," *Energy Procedia*, vol. 36, pp. 492–501, 2013.

[26] I. Daut, A. R. N. Razliana, Y. M. Irwan, and Z. Farhana, "A study on the wind as renewable energy in Perlis, Northern Malaysia," *Energy Procedia*, vol. 18, pp. 1428–1433, Jan. 2012.

[27] A. Belhamadia, M. Mansor, and M. A. Younis, "A study on wind and solar energy potentials in Malaysia," *Int. J. Renew. Energy Res.*, vol. 4, no. 4, pp. 1042–1048, 2014.

[28] N. Sanusi, A. Zaharim, S. Mat, and K. Sopian, "A Weibull and finite mixture of the von Mises distribution for wind analysis in Mersing, Malaysia," *Int. J. Green Energy*, vol. 14, no. 12, pp. 1057–1062, Sep. 2017.

[29] M. Anwari, M. I. M. Rashid, H. T. M. Muhyiddin, and A. R. M. Ali, "An evaluation of hybrid wind/diesel energy potential in Pemanggil island Malaysia," in *Proc. Int. Conf. Power Eng. Renew. Energy (ICPERE)*, Jul. 2012, pp. 1–5.

[30] A. Shamshad, M. A. Bawadi, W. M. A. Wan Hussin, and A. M. Taksiah, "Analysis of prevailing wind speed and direction for wind energy potential at windy site in Malaysia," *Int. J. Ecodyn.*, vol. 2, no. 1, pp. 10–23, 2007.

[31] S. K. Najid, A. Zaharim, A. M. Razali, M. S. Zainol, K. Ibrahim, and K. Sopian, "Analyzing the east coast Malaysia wind speed data," *Int. J. Energy Environ.*, vol. 3, no. 2, p. 8, 2009.

[32] M. F. Akorede, M. I. M. Rashid, M. H. Sulaiman, N. B. Mohamed, and S. B. Ab Ghani, "Appraising the viability of wind energy conversion system in the peninsular Malaysia," *Energy Convers. Manage.*, vol. 76, pp. 801–810, Dec. 2013.

[33] R. Yanalagaran and N. I. Ramli, "Assessment of coastal erosion related to wind characteristics in peninsular Malaysia," *J. Eng. Sci. Technol.*, vol. 13, no. 11, pp. 3677–3690, 2018.

[34] W. M. W. Muda and R. Umar, "Assessment of economic feasibility for grid-connected renewable energy system for a household application in Terengganu," *Int. J. Energy Prod. Manage.*, vol. 1, no. 3, pp. 223–232, 2016.

[35] M. S. Ngan and C. W. Tan, "Assessment of economic viability for PV/wind/diesel hybrid energy system in southern peninsular Malaysia," *Renew. Sustain. Energy Rev.*, vol. 16, no. 1, pp. 634–647, Jan. 2012.

[36] M. Fadaeenejad, M. A. M. Radzi, M. Z. A. AbKadir, and H. Hizam, "Assessment of hybrid renewable power sources for rural electrification in Malaysia," *Renew. Sustain. Energy Rev.*, vol. 30, pp. 299–305, Feb. 2014.

[37] S. Mekhilef and D. Chandrasegaran, "Assessment of off-shore wind farms in Malaysia," in *Proc. IEEE Region 10 Conf. (TENCON)*, Nov. 2011, pp. 1351–1355.

[38] A. Belhamadia, M. Mansor, and M. A. Younis, "Assessment of wind and solar energy potentials in Malaysia," in *Proc. IEEE Conf. Clean Energy Technol. (CEAT)*, Nov. 2013, pp. 152–157.

[39] A. Albani, M. Z. Ibrahim, and M. H. Hamzah, "Assessment of wind energy potential based on METAR data in Malaysia," *Int. J. Renew. Energy Res.*, vol. 3, no. 4, pp. 959–968, 2013.

[40] M. Irwanto, N. Gomesh, M. R. Mamat, and Y. M. Yusoff, "Assessment of wind power generation potential in Perlis, Malaysia," *Renew. Sustain. Energy Rev.*, vol. 38, pp. 296–308, Oct. 2014.

[41] N. Sanusi, A. Zaharim, S. Mat, and K. Sopian, "Bivariate probability model for wind power density analysis: Case study," *ARPN J. Eng. Appl. Sci.*, vol. 13, no. 2, pp. 656–659, 2018.

[42] J. Ahmadian, M. J. Ghorbanian, S. Shams, F. Goodarzvand, and J. Selvaraj, "Kuala Terengganu, Malaysia wind energy assessment," in *Proc. IEEE Conf. Clean Energy Technol. (CEAT)*, Nov. 2013, pp. 214–219.

[43] N. Sanusi, A. Zaharim, S. Mat, and K. Sopian, "Comparison of univariate and bivariate parametric model for wind energy analysis," *J. Adv. Res. Fluid Mech. Therm. Sci.*, vol. 49, no. 1, pp. 1–10, 2018.

[44] S. M. Suboh, N. H. Baharudin, and O. A. Basheer, "Dispatch strategy for grid-connected micro-wind turbine generators with battery: Case study in Malaysia," *Universal J. Electr. Electron. Eng.*, vol. 6, no. 5A, pp. 139–144, Dec. 2019.

[45] S. K. Najid, A. M. Razali, K. Ibrahim, K. Sopian, and A. Zaharim, "Estimating wind energy using extrapolated data of cameron highlands," in *Proc. 5th Int. Conf. Appl. Math., Simulation, Modelling*, Athens, Greece, 2011, pp. 151–154.

[46] N. Masseran, "Evaluating wind power density models and their statistical properties," *Energy*, vol. 84, pp. 533–541, May 2015.

[47] K. M. Nor, M. Shaaban, and H. A. Rahman, "Feasibility assessment of wind energy resources in Malaysia based on NWP models," *Renew. Energy*, vol. 62, pp. 147–154, Feb. 2014.

[48] S. Mekhilef, A. Safari, and D. Chandrasegaran, "Feasibility study of off-shore wind farms in Malaysia," *Energy Sci. Res.*, vol. 28, no. 2, pp. 877–888, 2012.

[49] W. M. W. Muda and N. A. S. Salleh, "Feasibility study of renewable energy system for an island in Terengganu," in *Proc. IOP Conf. Ser., Mater. Sci. Eng.*, Jun. 2018, vol. 366, no. 1, Art. no. 012002.

[50] A. Albani, M. Ibrahim, and K. Yong, "The feasibility study of offshore wind energy potential in Kijal, Malaysia: The new alternative energy source exploration in Malaysia," *Energy Explor. Exploitation*, vol. 32, no. 2, pp. 329–344, 2014.

[51] A. Albani, M. Z. Ibrahim, C. M. I. C. Taib, and A. A. Azlina, "The optimal generation cost-based tariff rates for onshore wind energy in Malaysia," *Energies*, vol. 10, no. 8, p. 1114, Jul. 2017.

[52] M. Z. Ibrahim and A. Albani, "The potential of wind energy in Malaysian renewable energy policy: Case study in Kudat, Sabah," *Energy Environ.*, vol. 25, no. 5, pp. 881–898, Jul. 2014.

[53] N. Masseran, A. M. Razali, K. Ibrahim, A. Zaharim, and K. Sopian, "The probability distribution model of wind speed over east Malaysia," *Res. J. Appl. Sci., Eng. Technol.*, vol. 6, no. 10, pp. 1774–1779, Jul. 2013.

[54] K. Sopian, M. Y. H. Othman, and A. Wirsat, "The wind energy potential of Malaysia," *Renew. Energy*, vol. 6, no. 8, pp. 1005–1016, Nov. 1995.

[55] A. A. Kadhem, N. I. A. Wahab, and A. N. Abdalla, "Wind energy generation assessment at specific sites in a peninsula in Malaysia based on reliability indices," *Processes*, vol. 7, no. 7, p. 399, Jun. 2019.

[56] W. B. W. Nik, M. F. Ahmad, M. Z. Ibrahim, K. B. Samo, and A. M. Muzathik, "Wind energy potential at east coast of peninsular Malaysia," *Int. J. Appl. Eng. Res.*, vol. 4, no. 1, pp. 9–16, 2019.

[57] N. Sanusi, A. Zaharim, and S. Mat, "Wind energy potential: A case study of Mersing, Malaysia," *J. Eng. Appl. Sci.*, vol. 11, no. 12, pp. 7712–7716, 2016.

[58] A. Albani and M. Ibrahim, "Wind energy potential and power law indexes assessment for selected near-coastal sites in Malaysia," *Energies*, vol. 10, no. 3, p. 307, Mar. 2017.

[59] S. M. Lawan, W. A. W. Z. Abidin, T. Masri, W. Y. Chai, and A. Baharun, "Wind power generation via ground wind station and topographical feedforward neural network (T-FFNN) model for small-scale applications," *J. Cleaner Prod.*, vol. 143, pp. 1246–1259, Feb. 2017.

[60] A. S. Ahmad, M. A. M. Yusuf, M. S. Majid, H. A. Rahman, and M. Y. Hassan, "Wind power harnessing based on Senai meteorological data, Malaysia," *Int. J. Comput. Intell. Control*, vol. 10, no. 1, pp. 7–16, 2018.

[61] M. N. Uti, A. H. Din, and A. H. Omar, "Reliability of wind speed data from satellite altimeter to support wind turbine energy," *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.*, vol. 42, no. 4W5, pp. 215–224, 2013.

[62] S. C. Lim, T. J. Meng, C. Palanichamy, and G. T. Eng, "Feasibility study of wind energy harvesting at TELCO tower in Malaysia," *Int. J. Energy Econ. Policy*, vol. 9, no. 6, pp. 277–282, Oct. 2019.

[63] H. M. Rizeei, B. Pradhan, and T. M. Mahlia, "GIS-based suitability analysis on hybrid renewal energy site allocation using integrated MODIS and ASTER satellite imageries in Peninsular Malaysia," in *Proc. 39th Asian Conf. Remote Sens. Remote Sens. Enabling Prosper (ACRS)*, vol. 1, Oct. 2018, pp. 358–368.

[64] A. Albani, M. Z. Ibrahim, and K. H. Yong, "Influence of the ENSO and monsoonal season on long-termwind energy potential in Malaysia," *Energies*, vol. 11, no. 11, pp. 1–18, 2018.

[65] Z. Saberi, A. Fudholi, and K. Sopian, "Potential evaluation of wind energy in Kuala Terengganu, Malaysia through Weibull distribution method," in *Proc. IOP Conf. Ser., Earth Environ. Sci.*, Jul. 2019, vol. 268, no. 1, Art. no. 012074.

[66] A. R. N. Razliana, Y. M. Irwan, M. Irwanto, and Z. Farhana, "Generation of wind power in Perlis, northern Malaysia," in *Proc. IEEE Symp. Comput. Informat. (ISCI)*, Mar. 2012, pp. 136–139.

[67] T. L. Tiang and D. Ishak, "Technical review of wind energy potential as small-scale power generation sources in Penang island Malaysia," *Renew. Sustain. Energy Rev.*, vol. 16, no. 5, pp. 3034–3042, Jun. 2012.

[68] I. Daut, M. Irwanto, S. Suwarno, Y. M. Irwan, N. Gomesh, and N. S. Ahmad, ''Potential of wind speed for wind power generation in Perlis, Northern Malaysia,'' *Telkomnika*, vol. 9, no. 3, pp. 575–582, 2011.

[69] A. N. Syafawati, I. Daut, S. S. Shema, M. Irwanto, Z. Farhana, N. Razliana, and C. Shatri, ''Potential of wind and solar energy using Weibull and Hargreaves method analysis,'' in *Proc. 5th Int. Power Eng. Optim. Conf. (PEOCO)*, Jun. 2011, pp. 144–147.

[70] N. Masseran, A. M. Razali, K. Ibrahim, and M. T. Latif, ''Fitting a mixture of von Mises distributions in order to model data on wind direction in Peninsular Malaysia,'' *Energy Convers. Manage.*, vol. 72, pp. 94–102, Aug. 2013.

[71] N. Masseran and A. M. Razali, ''Modeling the wind direction behaviors during the monsoon seasons in Peninsular Malaysia,'' *Renew. Sustain. Energy Rev.*, vol. 56, pp. 1419–1430, Apr. 2016.

[72] S. Z. Satari, Y. Z. Zubairi, A. G. Hussin, and S. F. Hassan, ''Some statistical characteristic of Malaysian wind direction recorded at maximum wind speed: 1999–2008,'' *Sains Malaysiana*, vol. 44, no. 10, pp. 1521–1530, Oct. 2015.

[73] N. Izadyar, H. C. Ong, W. T. Chong, J. C. Mojumder, and K. Y. Leong, ''Investigation of potential hybrid renewable energy at various rural areas in Malaysia,'' *J. Cleaner Prod.*, vol. 139, pp. 61–73, Dec. 2016.

[74] J. Ahmadian, M. J. Ghorbanian, S. Shams, F. Goodarzvand, and J. Selvaraj, ''Butterworth, Malaysia wind energy potential assessment,'' in *Proc. IEEE Conf. Clean Energy Technol. (CEAT)*, Nov. 2013, pp. 13–18.

[75] S. S. A. Wahid, Y. Z. Arief, and N. Mubarakah, ''Optimization of hybrid renewable energy in Malaysia remote rural area using HOMER software,'' in *Proc. 3rd Int. Conf. Electr., Telecommun. Comput. Eng. (ELTICOM)*, Sep. 2019, pp. 111–115.

[76] Y. Z. Arief, N. A. A. A. Halim, and M. H. I. Saad, ''Optimization of hybrid renewable energy in Sarawak remote rural area using HOMER software,'' in *Proc. Int. UNIMAS STEM 12th Eng. Conf. (EnCon)*, Aug. 2019, pp. 1–5.

[77] S. A. Shezan, S. Julai, M. A. Kibria, K. R. Ullah, R. Saidur, W. T. Chong, and R. K. Akikur, ''Performance analysis of an off-grid wind-PV (photovoltaic)-diesel-battery hybrid energy system feasible for remote areas,'' *J. Cleaner Prod.*, vol. 125, pp. 121–132, Jul. 2016.

[78] S. K. Shezan, R. Saidur, A. Hossain, W. T. Chong, and M. A. Kibria, ''Performance analysis of solar-wind-diesel-battery hybrid energy system for KLIA Sepang station of Malaysia,'' in *Proc. IOP Conf. Ser. Mater. Sci. Eng.*, 2015, vol. 88, no. 1, pp. 2–8.

[79] M. Hossain, S. Mekhilef, and L. Olatomiwa, ''Performance evaluation of a stand-alone PV-wind-diesel-battery hybrid system feasible for a large resort center in south China sea, Malaysia,'' *Sustain. Cities Soc.*, vol. 28, pp. 358–366, Jan. 2017.

[80] N. Masseran, ''Modeling a multi-modal distribution of wind direction data in Kudat, Malaysia,'' *Pakistan J. Stat. Oper. Res.*, vol. 11, no. 2, pp. 195–212, 2015.

[81] S. N. M. Deros, A. Asmat, and S. Mansor, ''Seasonal temporal distribution of forecasted wind speed data in Langkawi, Malaysia,'' *Pertanika J. Sci. Technol.*, vol. 25, no. S4, pp. 7–18, 2017.

[82] N. Masseran, A. M. Razali, and K. Ibrahim, ''An analysis of wind power density derived from several wind speed density functions: The regional assessment on wind power in Malaysia,'' *Renew. Sustain. Energy Rev.*, vol. 16, no. 8, pp. 6476–6487, Oct. 2012.

[83] EMD International A/S, Aalborg, Denmark. (2019). *WindPRO, Version 3.3.289*. [Online]. Available: https://www.emd.dk/

[84] DTU Wind Energy, Roskilde, Denmark. (2020). *Wind Atlas Analysis and Application Program (WaSP), Version 12.4.42*. [Online]. Available: https://www.wasp.dk/

[85] HOMER Energy LLC, CO, USA. (2020). *Hybrid Optimization Models for Energy Resources (HOMER), Version 3.13.8*. [Online]. Available: https://www.homerenergy.com/

[86] Tenaga National Berhad (TNB). (May 30, 2020). *Annual Report 2011*. [Online]. Available: https://www.tnb.com.my/assets/annual_report/AR11.pdf

[87] Z. M. Darus, N. A. Hashim, S. A. Manan, M. A. A. Rahman, K. A. Maulud, and O. A. Karim, ''The development of hybrid integrated renewable energy system (wind and solar) for sustainable living at Perhentian island, Malaysia,'' *Eur. J. Social Sci.*, vol. 9, no. 4, pp. 557–563, 2009.

[88] O. N. Aini and W. Q. Chiang, ''Pre-feasibility study on the suitability of the installation of wind solar hybrid energy system in Peninsular Malaysia,'' *J. Mater. Sci. Appl. Energy*, vol. 6, no. 3, pp. 200–204, 2017.

[89] K. Ibrahim, M. Z. Albani, A. Azhar, and S. Yong, ''The green technology for sustainable aquaculture industry: An application of low wind speed wind turbines in isharp shrimp farm, Setiu, Terengganu,'' in *Proc. Himpunan Abstrak Persidangan Kebangsaan Kedua Program Pemindahan Ilmu (KTP), Pelan Strategik Pengajian Tinggi Negara*, 2014, p. 11.

[90] M. Khodayar, O. Kaynak, and M. E. Khodayar, ''Rough deep neural architecture for short-term wind speed forecasting,'' *IEEE Trans. Ind. Informat.*, vol. 13, no. 6, pp. 2770–2779, Dec. 2017.

[91] E. C. Eze and C. R. Chatwin, ''Enhanced recurrent neural network for short-term wind farm power output prediction,'' *J. Appl. Sci.*, vol. 5, no. 2, pp. 28–35, 2019.

[92] S. Mishra and P. Palanisamy, ''Multi-time-horizon solar forecasting using recurrent neural network,'' in *Proc. IEEE Energy Convers. Congr. Expo. (ECCE)*, Sep. 2018, pp. 18–24.

[93] W.-Y. Chang, ''A literature review of wind forecasting methods,'' *J. Power Energy Eng.*, vol. 2, no. 4, pp. 161–168, 2014.

[94] A. A. Kadhem, N. Wahab, I. Aris, J. Jasni, and A. Abdalla, ''Advanced wind speed prediction model based on a combination of Weibull distribution and an artificial neural network,'' *Energies*, vol. 10, no. 11, p. 1744, Oct. 2017.

[95] S. M. Lawan, W. A. W. Z. Abidin, A. M. Lawan, M. Mustapha, and S. L. Bichi, ''ANN and GIS-assisted methodology for wind resource assessment (WRA) in Sarawak,'' *Jurnal Teknologi*, vol. 77, no. 12, pp. 75–80, Nov. 2015.

[96] A. Shamshad, M. Bawadi, W. Wanhussin, T. Majid, and S. Sanusi, ''First and second order Markov chain models for synthetic generation of wind speed time series,'' *Energy*, vol. 30, no. 5, pp. 693–708, Apr. 2005.

[97] O. B. Shukur and M. H. Lee, ''Daily wind speed forecasting through hybrid KF-ANN model based on ARIMA,'' *Renew. Energy*, vol. 76, pp. 637–647, Apr. 2015.

[98] M. Hossain, S. Mekhilef, F. Afifi, L. M. Halabi, L. Olatomiwa, M. Seyedmahmoudian, B. Horan, and A. Stojcevski, ''Application of the hybrid ANFIS models for long term wind power density prediction with extrapolation capability,'' *PLoS ONE*, vol. 13, no. 4, pp. 1–31, 2018.

[99] M. R. Sarkar, M. J. Nahar, A. Nadia, M. A. Halim, S. M. S. H. Rafin, and M. M. Rahman, ''Proficiency assessment of adaptive neuro-fuzzy inference system to predict wind power: A case study of Malaysia,'' in *Proc. 1st Int. Conf. Adv. Sci., Eng. Robot. Technol. (ICASERT)*, May 2019, pp. 1–5.

[100] H. H. Goh, S. W. Lee, Q. S. Chua, K. C. Goh, and K. T. K. Teo, ''Wind energy assessment considering wind speed correlation in Malaysia,'' *Renew. Sustain. Energy Rev.*, vol. 54, pp. 1389–1400, Feb. 2016.

[101] M. Sahin and R. Erol, ''A comparative study of neural networks and ANFIS for forecasting attendance rate of soccer games,'' *Math. Comput. Appl.*, vol. 22, no. 4, p. 43, Nov. 2017.

[102] C. Croonenbroeck and D. Ambach, ''An implementation of the mycielski algorithm as a predictor in R,'' *J. Fundam. Renew. Energy Appl.*, vol. 6, no. 1, p. 2, 2015.

[103] T. W. Wen, C. Palanichamy, and G. Ramasamy, ''Small wind turbines as partial solution for energy sustainability of Malaysia,'' *Int. J. Energy Econ. Policy*, vol. 9, no. 2, pp. 257–266, 2019.

[104] T. W. Wen, C. Palanichamy, and G. Ramasamy, ''Performance optimization of constant speed-small horizontal axis wind turbine (CS-SHAWT) for wind energy development in Malaysia,'' *Int. J. Energy Econ. Policy*, vol. 9, no. 3, p. 280, 2019.

[105] M. S. Misaran, M. M. Rahman, W. K. Muzammil, and M. A. Ismail, ''Assessment of C-type Darrieus wind turbine under low wind speed condition,'' *IOP Conf. Ser., Mater. Sci. Eng.*, vol. 217, no. 1, Jul. 2017, Art. no. 012019.

[106] Dassault Systemes, Paris, France. (2020). *Computer-Aided Three-Dimensional Interactive Application (CATIA), Version V5-6R2016*. [Online]. Available: https://www.3ds.com/

[107] *Airfoil Tools*. Accessed: May 29, 2020. [Online]. Available: http://www.airfoiltools.com/

[108] M. K. Johari, M. A. A. Jalil, and M. F. M. Shariff, ''Comparison of horizontal axis wind turbine (HAWT) and vertical axis wind turbine (VAWT),'' *Int. J. Eng. Technol.*, vol. 7, no. 4, pp. 74–80, 2018.

[109] L. Z. Yi and C. Y. Teoh, ''Modal analysis of vertical wind turbine blade,'' in *Proc. MATEC Web Conf.*, vol. 217, 2018, p. 5.

[110] ANSYS, PA, USA. (2020). *Analysis System (ANSYS), Version 2020-R1*. [Online]. Available: https://www.ansys.com/

[111] S. Mat, ''A wind turbine,'' Malaysia Patent 2013/109 133 Al, Jul. 25, 2013.

[112] M. R. Awal, M. Jusoh, M. N. Sakib, F. S. Hossain, M. R. C. Beson, and S. A. Aljunid, "Design and implementation of vehicle mounted wind turbine," *ARPN J. Eng. Appl. Sci.*, vol. 10, no. 19, pp. 8699–8706, 2015.

[113] X. L. Khai, L. L. Pei, J. J. Jamani, R. Arsat, A. A. A. Abdeltawab, S. S. Rahman, N. H. A. Khalid, A. Mohamed, and I. A. Khalid, "Harvesting electrical energy from rooftop ventilator," *Int. J. Integr. Eng.*, vol. 10, no. 4, pp. 68–72, 2018.

[114] A. A. A. Rahman, N. A. Yahaya, R. Bahsan, and U. K. Ahmad, "Energy harvesting from cooling tower by vertical axis wind turbine (VAWT)," *Jurnal Teknologi*, vol. 76, no. 5, pp. 37–41, Sep. 2015.

[115] R. Hosseinalizadeh, H. Shakouri, M. S. Amalnick, and P. Taghipour, "Economic sizing of a hybrid (PV-WT-FC) renewable energy system (HRES) for stand-alone usages by an optimization-simulation model: Case study of Iran," *Renew. Sustain. Energy Rev.*, vol. 54, pp. 139–150, 2016.

[116] S. Sanajaoba and E. Fernandez, "Maiden application of cuckoo search algorithm for optimal sizing of a remote hybrid renewable energy system," *Renew. Energy*, vol. 96, pp. 1–10, Oct. 2016.

[117] University of Zaragoza, Zaragoza, Spain. (2020). *Improved Hybrid Optimization by Genetic Algorithms (iHOGA), Version 2.5-EDU*. [Online]. Available: https://www.ansys.com/

[118] T. Khatib, A. Mohamed, K. Sopian, and M. Mahmoud, "Optimal sizing of hybrid PV/Wind systems for Malaysia using loss of load probability," *Energy Sour. A, Recovery, Utilization, Environ. Effects*, vol. 37, no. 7, pp. 687–695, Apr. 2015.

[119] T. Khatib, K. Sopian, A. Mohamed, and M. Z. Ibrahim, "Sizing of a wind charger at minimum cost for remote housing electrification: A case study for nine coastal sites in Malaysia," *Energy Buildings*, vol. 51, pp. 185–190, Aug. 2012.

[120] Y. D. An and B. S. Mahinder, "Sustainable solar-wind hybrid power plant for implementation in Malaysia," *J. Appl. Sci.*, vol. 11, no. 7, pp. 1121–1128, Jul. 2011.

[121] T. MathWorks, Natick, MA, USA. (2020). *Matrix Labratory Software (MATLAB), Version 2020a*. [Online]. Available: https://www.mathworks.com/

[122] A. M. A. Haidar, P. N. John, and M. Shawal, "Optimal configuration assessment of renewable energy in Malaysia," *Renew. Energy*, vol. 36, no. 2, pp. 881–888, Feb. 2011.

[123] A. Mohamed and T. Khatib, "Optimal sizing of a PV/wind/diesel hybrid energy system for Malaysia," in *Proc. IEEE Int. Conf. Ind. Technol. (ICIT)*, Feb. 2013, pp. 752–757.

[124] T. Khatib, K. Sopian, and M. Z. Ibrahim, "Assessment of electricity generation by wind power in nine costal sites in Malaysia," *Int. J. Ambient Energy*, vol. 34, no. 3, pp. 138–144, Sep. 2013.

[125] M. H. Ashourian, S. M. Cherati, A. A. Mohd Zin, N. Niknam, A. S. Mokhtar, and M. Anwari, "Optimal green energy management for island resorts in Malaysia," *Renew. Energy*, vol. 51, pp. 36–45, Mar. 2013.

[126] M. H. Alsharif, R. Nordin, and M. Ismail, "Green wireless network optimisation strategies within smart grid environments for long term evolution (LTE) cellular networks in Malaysia," *Renew. Energy*, vol. 85, pp. 157–170, Jan. 2016.

[127] O. N. Laban, C. M. Maghanga, and K. Joash, "Determination of the surface roughness parameter and wind shear exponent of Kisii region from the on-site measurement of wind profiles," *J. Energy*, vol. 2019, pp. 1–12, Jul. 2019.

[128] M. Z. Ibrahim, K. H. Yong, M. Ismail, A. Albani, and A. M. Muzathik, "Wind characteristics and gis-based spatial wind mapping study in Malaysia," *J. Sustain. Sci. Manag.*, vol. 9, no. 2, pp. 1–20, 2014.

[129] M. Z. Ibrahim, K. H. Yong, M. Ismail, and A. Albani, "Spatial analysis of wind potential for Malaysia," *Int. J. Renew. Energy Res.*, vol. 5, no. 1, pp. 201–209, 2015.

[130] M. Z. Ibrahim, K. H. Yong, M. Ismail, and A. Albani, "Wind speed modeling for Malaysia," *Int. J. Renew. Energy Res.*, vol. 4, no. 4, pp. 912–923, 2014.

[131] E. Srl, Concorezzo, Italy. (2020). *Google Earth Plot Software (GEPlot), Version 2.1.31.0*. [Online]. Available: https://www.enviroware.com/

[132] G. LLC, CA, USA. (2020). *Google Earth, Version 7.3*. [Online]. Available: https://www.google.com/earth/

[133] A. A. A. Zaman, F. E. Hashim, and O. Yaakob, "Satellite-based offshore wind energy resource mapping in Malaysia," *J. Mar. Sci. Appl.*, vol. 18, no. 1, pp. 114–121, Mar. 2019.

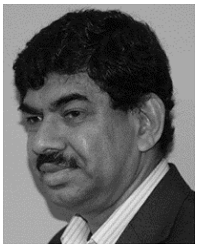
FUAD M. NOMAN (Member, IEEE) received the B.S. degree in electronics from the University of Sudan for Science and Technology, the M.S. degree in electronics engineering (telecommunication system) from the Universiti Teknikal Malaysia Melaka, in 2011, and the Ph.D. degree in biomedical engineering from the Universiti Teknologi Malaysia, Skudai, in 2019. He is currently a Postdoctoral Fellow with the Institute of Sustainable Energy (ISE), University Tenaga National (UNITEN). His research interests include signals and biosignal processing, machine learning applications, and biometrics.

GAMAL ABDULNASER ALKAWSI was born in Yemen. He received the B.S. degree in software engineering and the master's degree in management information systems from Coventry University, INTI, Malaysia, and the Ph.D. degree in information communication technology from The Energy University (UNITEN), Malaysia, in 2019. He is currently a Postdoctoral Researcher with The Energy University (UNITEN). He has published in journals and conferences. His research interests include emerging technology acceptance, user behavior, adoption of information systems in organizations, the IoT, artificial intelligence, and machine learning.

DALLATU ABBAS was born in Fadan Chawai, Nigeria. He received the B.S. degree in physics from Bayero University Kano, Nigeria, and the M.S. degree in physics from Kaduna State University, Nigeria. He is currently pursuing the Ph.D. degree with the Universiti Tenaga Nasional, Malaysia. He is also a Lecturer with the Physics Department, Kaduna State University, and a Research Assistant with the Institute for Sustainable Energy, Universiti Tenaga Nasional. His research interest includes wind energy generation.

AMMAR AHMED ALKAHTANI (Member, IEEE) received the bachelor's degree (Hons.) in electronics (telecommunications) from Multimedia University (MMU), the master's degree in electronics engineering (telecommunication system) from Universiti Teknikal Malaysia Melaka, in 2011, and the Ph.D. degree from the College of Engineering (COE), Universiti Tenaga Nasional (UNITEN), Malaysia, in 2015. He is currently a Senior Lecturer with The Energy University (UNITEN), Malaysia, where he is also the Head of the Wind Energy Unit. His research interests include signal processing, renewable energy, failure analysis, and applied machine learning.

SIEH KIONG TIONG (Member, IEEE) received the B.Eng. (Hons), M.Sc., and Ph.D. degrees in electrical, electronic, and system engineering from the Nasional University of Malaysia (UKM), in 1997, 2000, and 2006, respectively. He is currently a Professor with the College of Engineering. He is also the Director of the Institute of Sustainable Energy (ISE), Universiti Tenaga Nasional. His research interests include renewable energy, artificial intelligence, data analytics, microcontroller systems, and communication systems. He is currently a Professional Engineer registered with the Board of Engineers Malaysia (BEM).



JANAKA EKANAYAKE (Fellow, IEEE) was born in Matale, Sri Lanka, in October 1964. He received the B.Sc. degree in electrical engineering from the University of Peradeniya, Sri Lanka, and the Ph.D. degree from UMIST, U.K. He is currently with the Chair Professor of electrical and electronic engineering with the University of Peradeniya. He is also a Visiting Professor with Cardiff University, U.K., and the Universiti Tenaga Nasional, Malaysia. He has published more than 75 articles in refereed journals and has coauthored six books. His main research interests include renewable energy generation and its integration and smart grid applications. He is a fellow of IET.

• • •