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FORECASTING WEIBULL PARAMETERS WITH A NOVEL ALTERNATIVE GRAPHICAL TECHNIQUE FOR LOW WIND SPEEDS

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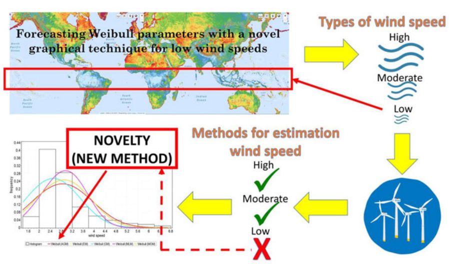
Graphical abstract



Abstract

This paper analyses wind speed estimation for Weibull distribution using various methods. According to a previous study, the existing methods primarily target areas with moderate to high-velocity rates, and Malaysia is a tropical country with pleasant breezes all year. As a result, this research aims to devise the most efficient method of forecasting wind speeds in low-speed areas. The researcher compared existing methods such as the Moment of Method, Empirical Method, Graphical Method, Maximum Likelihood Method and the newly proposed Alternative Graphical method. The finding indicates that the novel proposed approach, the Alternative Graphical Method, is superior regarding Goodness of Fit, Kolmogorov Smirnov and Chi-Square. For Kolmogorov Smirnov, the Alternative Graphical Method is 3.4 % better than the second-best method. At the same time, the usage of Chi-Square is again at a top position, with a 61 % disparity between it and the second and third best places. However, the Alternative Graphical Method is in second place for Anderson Darling, but the forecast performance with a minimum difference of 0.3 %. These findings imply that the Alternative Graphical Method capable of making more precise predictions than current methods.

Keywords: Wind speed, Weibull, histogram, alternative graphical method, goodness of fit

Abstrak

Kajian ini menganalisis ramalan kelajuan angin untuk taburan Weibull boleh dicapai menggunakan pelbagai kaedah. Menurut kajian terdahulu, kaedah yang disenaraikan terutamanya menyasarkan kawasan dengan kadar halaju sederhana dan tinggi manakala Malaysia pula merupakan sebuah negara tropika dengan angin bertiup yang perlahan sepanjang tahun. Hasilnya, penyelidikan ini bertujuan untuk merangka kaedah yang paling cekap untuk meramalkan kelajuan angin di kawasan berkelajuan rendah. Penyelidik membandingkan kaedah sedia ada seperti Kaedah Momen, Kaedah Empirikal, Kaedah Grafik dan Kaedah Kebarangkalian Maksimum dengan kaedah Grafik Alternatif yang baru dicadangkan. Dapatan menunjukkan bahawa pendekatan baru yang dicadangkan, Kaedah Grafik Alternatif, adalah unggul berdasarkan dapatan kaedah kebagusan penyuaian, Kolmogorov Smirnov dan Chi-Square. Bagi Kolmogorov Smirnov, Kaedah Grafik Alternatif adalah 3.4 % lebih baik daripada kaedah kedua terbaik. Pada masa yang sama, penggunaan Chi-Square sekali lagi berada di kedudukan teratas, dengan perbezaan 61% antara tempat kedua dan ketiga terbaik. Walau bagaimanapun, Kaedah Grafik Alternatif berada di tempat kedua bagi kaedah kebagusan penyuaian Anderson Darling. Namun tetapi prestasi ramalan adalah dengan perbezaan minimum iaitu 0.3%. Penemuan ini membuktikan bahawa Kaedah Grafik Alternatif mampu membuat ramalan yang lebih tepat berbanding kaedah semasa.

Kata kunci: Kelajuan angin, Weibull, histogram, kaedah grafik alternatif, kaedah kebagusan penyuaian

1.0 INTRODUCTION

Wind energy is a virtually limitless renewable energy source [1], [2]. Aside from that, it is one of the most advanced technologies available today [3]–[5]. The increasing interest in constructing wind turbine components, more mature technology, and among the most widely used renewable energy sources all point to technological advances. A region's wind velocity has a significant impact on the performance of this technology. As a result of this link, wind velocity is regarded as one of the most critical variables in wind energy research and development. [6]. Until now, no method has reliably estimated wind speed, and no method has been successful 100% of the time. "The optimal approach is determined by the total observation (n), a fair distribution across the field, the suitability of the customisation method, and the type of data, either time-series or frequency series" [6]. In addition, [7]–[9] provided evidence to support this claim. In Malaysia, however, most research has focused on applying established methods to obtain wind speed prediction parameters [10]–[13]. Finally, some researchers organise the methods used in a particular field based on their personal preferences. As a result, many researchers are unable to achieve reliable estimates of parameters using existing methods. Wind speed prediction methods should be investigated because wind speeds in Malaysia vary significantly from those in other countries. This investigation is significant because Malaysia's nature wind speed is slow.

Deciding on how the distribution will be estimated before progressing further is necessary. [14]. Based on past research, the Weibull distribution was considered for this investigation. [11], [15]–[17]. The findings show that Weibull has been around for a long time. Therefore, it is regarded as a standard in wind research. Furthermore, the International Electrotechnical Commission (IEC) has acknowledged this distribution globally. The most important aspect is that Weibull distribution corresponds to the research site, Mersing. The two most important parameters for Weibull distribution are shape parameter (k) and scale parameter (c) [18]. According to the literature [19]–[21], k is scattered between 1.5 and 3 and c ranges between 1.1 and 1.3 times the wind speed [20]. The following procedure selects the appropriate method after determining the wind speed distribution. According to [22], [23], previous research has generally relied on two methods. The first is a physical prediction method (observation), and the second is statistics to make predictions. Meanwhile, [24] also expressed a similar opinion. Apart from that, he suggested adding another method, namely the computer-based intelligence method.

The scope of this study is solely limited to statistical analysis methods and procedures. The statistical process of obtaining parameters is an essential and critical component of a wind speed assessment [24], [25]. In the meantime, the parameter is a numerical value that able to be used to obtain information about a specific wind speed. Therefore, it is critical to use the most suitable method for obtaining the appropriate parameters [26]. These precise parameters can also be used to estimate wind speed accurately. As a result, there is a need for method optimisation to get the best value of parameters for wind speed. The impact will lead to the reliability of the method, produce good information and at the same time will minimise the effect resulting from wind source uncertainty [24], [27], [28]. Consequently, this research focuses on optimising the approach to obtain Weibull variables in Malaysia, emphasising low wind speeds. This emphasis is placed on the fact that all existing methods apply in locations with medium and high wind speeds.

1.1 Distribution and Methods

The Weibull distribution has been used as a standard in wind studies [9], [29], [30]. Consequently, the statistical methods used to obtain parameter values from the Weibull distribution are the sole focus of this study. Procedures for determining parameter values for distribution, also known as parameter estimation procedures, are included in statistical prediction methods. Earlier researchers used more than ten statistical methods based on previous studies to determine parameter values while calculating wind power density. The methods are chosen following the findings of the conducted literature review. The selected method consisted of the Moment of Method (MOM), Empirical Method (EM), Graphical Method (GM), and Maximum Likelihood Method (MLM).

Table 1 shows the types of methods matched to the wind speed types. Four different techniques represent three wind speed types: fast, medium and slow. According to [12], slow winds are lower than

3.5 m/s, fair winds are between 3.5-8.5 m/s and high winds are more than 8.5m/s. As shown in Table 1, the current methods are well suited for forecasting in regions with high and medium winds, except for one technique, GM. This method works well in places with low wind speeds, but it is one of the worst choices for most studies. [31]. The following descriptions are the advantages and disadvantages of each existing method.

Table 1 Types of methods matched types of wind speed

Method	Type of wind speed	Sources
MLM	Medium, fast	[21], [31], [32]
MOM	Medium, fast	[23], [28], [33]
EM	Medium	[12], [34], [35]
GM	Slow	[17], [29], [36]

1.2 Maximum Likelihood Method (MLM)

Most researchers typically prefer the Maximum Likelihood Method (MLM) as a type of statistical analysis. A review of the literature revealed that this was the most commonly used method. Based on its widespread use and popularity, it is reasonable to conclude that the MLM method has several advantages. One of its advantages is the ability to predict parameter values accurately [37], [38]. Iterative processes are one of the factors that contribute to the accuracy of the findings. This method is also dear to the hearts of software developers. "EasyFit" is one piece of software that employs predefined functions for MLM methods. However, there is no denying that this MLM strategy has some flaws. The method's disadvantages include requiring numerous iterations and ensuring that the data's zero value is removed first [30]. On the other hand, the iteration used can provide a minimal error value [21].

1.3 Empirical Method (EM)

The Empirical method (EM) can be utilised to retrieve the two Weibull parameters using descriptive values such as averages and standard deviations rather than numerical values. Hence, in some circles, it is also referred to as the "Standard Deviation Method (SDM)" [39]. This name comes from the term used to describe it: standard deviation. Without a doubt, Empirical Methods are the most straightforward. It is worth noting that the term "easy" refers to the fact that researchers only need two descriptive data values: the mean and standard deviation. However, this method has the disadvantage of predicting low-speed wind data and having no data, as in Malaysia. This disadvantage stems from the standard deviation being easily skewed when using data with a null value.

1.4 Moment of Method (MOM)

Before MLM, the Moment of Method (MOM) was invented and used. As a result, it has often been associated with a different approach to MLM. The forecast's precision is considered in this relationship, which is nearly identical to the MLM approach. This method, like EM, relied on two descriptive data values: the average and standard deviation, both of which were calculated. As a result, the shortcomings of this method are the same as those of the EM method, which, as previously stated, is based on easily biased descriptive values.

1.5 Graphical Method (GM)

The graphical approach is the most commonly used among researchers. It is also known as the Least Square Method (LSM) [40], [41]. Before using the Graphical Method, the data must be converted from a time series form to a frequency data form. The following stages must be followed precisely in order to obtain the cumulative distribution function, $F(v)$ which would be needed to access a straight line [37]. As a result, data from calm or zero wind periods should be excluded [10], [29]. Regression can be used to determine the best line. Despite this, using a computer and performing linear regression analysis has made the task easier to complete.

This method does not necessitate the application of advanced skills. Furthermore, this Graphical Method (GM) was the primary method for calculating Weibull parameters. In addition, this method has the same factors as the MLM method, removing zero values first before starting the analysis. Consequently, it has become one of the most inappropriate methods for most studies [42]–[44].

The following Table 2 is the formula for the Moment of Method (MOM), the Empirical Method (EM), the Maximum Likelihood Method (MLM) and the Graphical Method (GM). The formula is used to obtain the shape parameter (k) and scale parameter (c) values for the Weibull distribution. As can be seen, the calculation to determine the value of k differs between methods. This difference will result in a different value of k, which will affect the calculation of c, whereas two methods use different formulas and two methods that use the same formula, EM and MOM, for determining the value of parameter c. This formula difference will lead to different parameter values.

Table 2 The formula for MLM, MOM, EM and GM

Method	Formula	Sources
MLM	$k=\left(\frac{\sum_{i=1}^{n} {v_i}^k \ln v_i}{\sum_{i=1}^{n} {v_i}^k}-\frac{\sum_{i=1}^{n}\ln v_i}{n}\right)^{-1}$ $c=\left(\frac{1}{n}\sum_{i=1}^{n} {v_i}^k\right)^{\frac{1}{k}}$	[37]

Method	Formula	Sources
EM	$k = \left(\frac{\sigma}{\bar{v}}\right)^{-1.086}$ $c = \frac{\bar{v}}{\gamma\left(1+\frac{1}{k}\right)}$	[45]
MOM	$k = \left(\frac{0.9874}{\frac{\sigma}{\bar{v}}}\right)^{1.0983}$ $c = \frac{\bar{v}}{\gamma\left(1+\frac{1}{k}\right)}$	[46]
GM	k = the slope of straight line y-intercept $= -k\ \ln c$ $-\ln\{1-(F(v)\} = k\ln v - k\ln c$	[21]

where k is the Weibull shape parameter, c is the Weibull scale parameter, v_i are the wind speed at term i and n is the total number of data, σ is the standard deviation, $\bar{v}$ the average wind speed, γ is the Gamma function and $F(v)$ is the cumulative distribution function [47].

2.0 METHODOLOGY

2.1 Site Description and Data Collection

The daily data for 2009 are analysed, compared, and determined to be the best method. The data used is time series data, collected over one year. It comprises 365 data points (from January to December 2009) and meters per second (m/s) units of measurement. It was determined that Mersing would be a good study location based on the findings of previous studies [10], [48], [49]. As a result of this consideration, the city of Mersing in the state of Johor (in the southern region of Peninsular Malaysia) was chosen as a potential site for a potential initial pilot project.

The location itself, which is higher than other places in Malaysia, is one of the factors, and it is situated 43.6 metres above mean sea level [12]. In addition, the area, which is situated opposite the South China Sea, experiences a great deal of wind throughout the year. Thus, Mersing is affected by both the sea breeze, the land breeze, and the monsoon seasons [50]. In addition, Mersing was chosen based on 100 per cent of the sources that can be used for analysis purposes. This research makes use of average wind speed data daily.

The data used was classified as a secondary source, and this is because the data collection process has been streamlined and can only be applied for its use through The Malaysia Meteorology Department (MMD) in Petaling Jaya. The data was then analysed using the Easy fit and R software packages. R software is free and open-source, and it does offer several benefits, such as the ability for anyone to add applications that they believe are necessary for their academic pursuits.

Furthermore, the researchers were able to distribute their applications. This sharing can be accomplished by uploading proven effective coding. The coding will then be packaged and managed to make available for download by others [51]. Each piece of wind speed data will be subjected to a preliminary screening process. This procedure is a requirement for any research project. The purpose of this procedure is to ensure that the findings of the investigation are valid and consistent. The next step in the process is to identify and analyse the descriptive parameters. This analysis is critical because it can provide an initial picture of data representing the entire group. Additionally, it could be used to evaluate the generating capacity of a location.

2.2 The Goodness of Fit

For this study, Goodness of fit is a type of statistical instrument used to determine the position of a method. The role of technique can be classified hierarchically from best to worst and vice versa. Among the GOFs used for this study were Chi-Squared (χ^2), Kolmogorov-Smirnov (KS) and Anderson-Darling (AD).

2.3 The Novel Propose Method – Alternative Graphical Method (AGM)

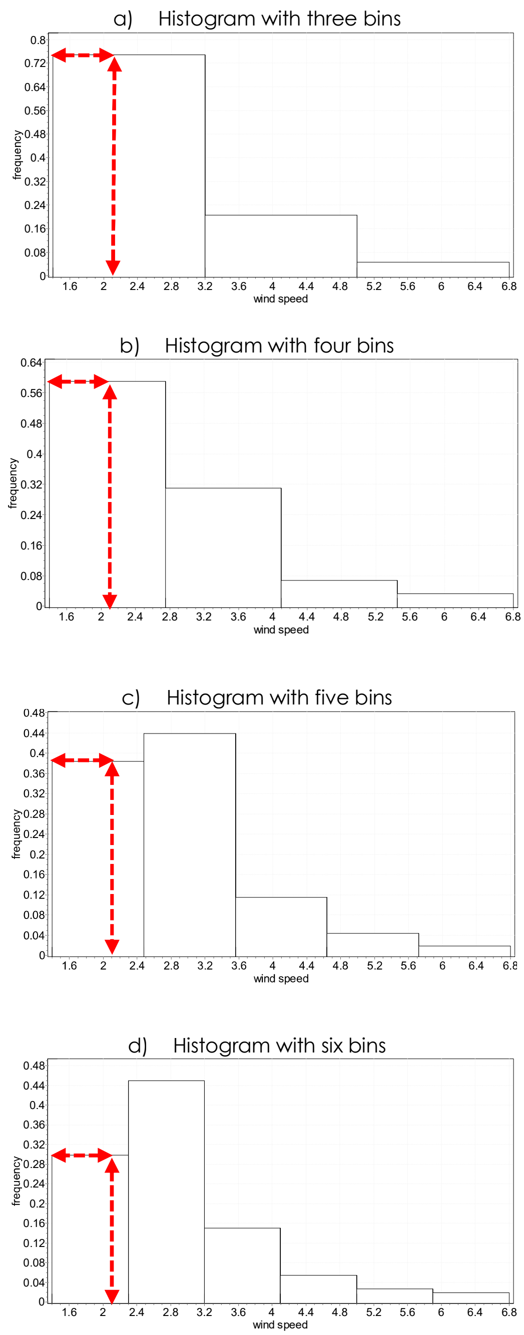
The need to obtain methods for modelling wind speeds is vital [52] and must be developed. A new method for forecasting wind velocity at the Weibull distribution area was proposed and tested in this study. According to the descriptive analysis, the wind speed at the site is low, with a mean daily wind velocity of significantly below 3.5 m/s [53], [54]. As a result, this proposed method is a viable option in areas with low wind speeds. Furthermore, this new method is based on the shortcomings of other approaches that do not account for zero or calm wind speed. This method's main advantage is that it uses all raw data without discarding any external or partial placement values, which is a significant advantage. As a result, the AGM is unaffected by the bias value.

AGM approach has discovered a novel way to calculate shape parameter (k). AGM introduced the value of k through the histogram. The histogram can compute the value of the shape parameter (k) by adding all the value probability (red dot at y-axis) (Figure 1), while the scale parameter (c) can be assessed using formula 1.

$$c = \frac{\bar{v}}{\gamma\left(1+\frac{1}{k}\right)} \tag{1}$$

where k is the Weibull shape parameter, c is the Weibull scale parameter, $\bar{v}$ is the average wind speed and γ is the Gamma function [45], [46].

A different number of bins is depicted in Figure 1 for each histogram (from the smallest to the most significant, according to relationship $1 + 3.3 \log n$). Sturge's law governs the behaviour of the logarithmic function. Immediately after generating the histogram, the mode value is investigated in greater detail. It is estimated that the mode value is 2.1 meters per second, based on data from 2009. Afterwards, the probability of a mode value occurring in a particular bin must be calculated for each histogram. Therefore, the total sum of all possible probabilities equals the value of k in the given situation.



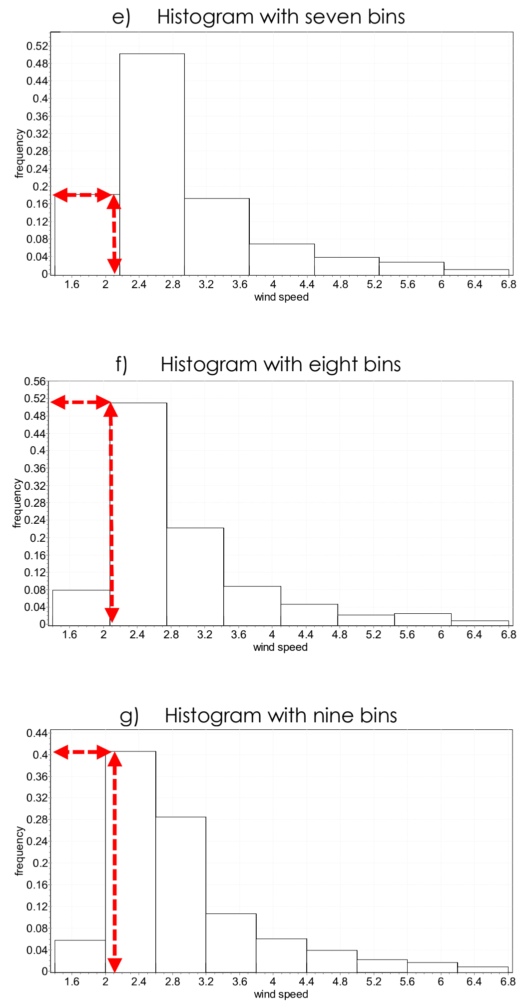


Figure 1 Histogram according to the number of bins (a-g).

3.0 RESULTS AND DISCUSSION

The informative values of wind velocity in Mersing, which are based on observations, are shown in Table 3. One of the preliminary findings was a minimum speed of 1.4 meters per second. Meanwhile, the mean wind velocity in Mersing was 2.88 m/s. In comparison, the maximum velocity for this location is 6.8 m/s. Following this descriptive value, it is possible to draw the first conclusion that the wind speed in Mersing is ideal. In addition, the suitability of this location also can be determined by the fact that more than half data collected exceeds the 2.5 m/s input separator value for most wind turbines, indicating that the location is appropriate [55]. The median value at the location was taken into account to arrive at this 50% percentage estimate. The input separator value is the absolute minimum required for the wind turbine to function correctly. Furthermore, the average wind speed (2.88 m/s), more significant than the minimum value of the wind turbine cut in, demonstrates the suitability for generating electricity.

Table 3 The descriptive value of wind speed in Mersing

Descriptive value	Wind speed (m/s)
Minimum	1.40
Mode	2.10
First Quartile	2.30
Median	2.60
Average	2.88
Third Quartile	3.20
Maximum	6.80

Table 4 summarises the probability of mode value. According to the Table 4, the mode probability values for each different histogram are 0.75, 0.59, 0.385, 0.30, 0.18, 0.51, and 0.409, with 0.75 being the highest and 0.59 being the lowest. This newly proposed method, AGM, was created using facts as a foundation. The value of k represents the maximum point of the Weibull probability density function (pdf) [56]. Since mode represents the highest probability value in each histogram, the sum of all mode probability values is used to calculate the parameter k. As a result, the AGM produces a value of 3.124 for the shape parameter (k), whereas the formula 1.1 produces a value of 3.2241 for the scale parameter (c).

Table 4 Probability value according to the number of the bins

Number of bins	Probability Value
Three bins	0.750
Four bins	0.590
Five bins	0.385
Six bins	0.300
Seven bins	0.180
Eight bins	0.510
Nine bins	0.409

3.1 Parameters Value Comparison

Next, once the parameter values have been determined and recorded, further comparative analysis of pdf Weibull distribution will be conducted. This study examines the performance of the various methods used with the AGM method. Aside from that, this study seeks to optimise Weibull distribution parameters while improving wind speed prediction accuracy.

Table 5 illustrates the parameter values for the Weibull distribution. These parameters are determined using five distinct techniques. Table 2 summarises the most significant differences and includes the formula for calculating k and c. When the shape parameter (k) is increased, it creates the appearance of a stable (constant) wind speed in an area and the shape parameter's value has no unit [19]. The MLM method produces the highest value for k, 4.0944, followed by the MOM and EM methods, which produce nearly identical values of 3.4287 and 3.4286, respectively. MOM and EM methods produce identical results in three decimal places. The AGM method is ranked fourth with a value of 3.1240, and the GM method is ranked last with 3.0970.

Nonetheless, while the scale parameter (c) provides information about appropriate wind potential, this information is due to the scale parameter (c) in combination with the average wind speed's descriptive value. Wind velocity is commonly measured in meters per second (m/s), widely used in the industry. The larger the scale parameter value (c), the more it describes the tremendous expected wind potential in the surrounding area. As shown in Table 5, the AGM method yields the maximum possible value of c, 3.2241. Next, the MOM and EM methods are tied for second place with a score of 3.2093 due to no difference between the two methods up to four decimal places. The MLM technique and the lowest Graphical Method, with 3.1702 and 2.8509 points, respectively, round out the top five techniques.

Table 5 Comparison of parameters between MLM, MOM, EM, GM and AGM

Parameter	Method				
	MLM	MOM	EM	GM	AGM
k	4.0944	3.4287	3.4286	3.0970	3.1240
c	3.1702	3.2093	3.2093	2.8509	3.2241

The parameter values obtained through various approaches were combined to create Figure 2. The diagram depicts a histogram, and the probability density function for 2009 for the MLM, MOM, EM, PDM, GM, and AGM methods is plotted on the graph. The histogram represents the frequency with which actual wind speed data is gathered. There are a lot of statistically significant values in this histogram. Figure 2 also makes determining the lowest and the highest data values simple. The minimum data rate is 1.4 m/s together with the maximum data rate is 6.8 m/s. Aside from that, the most common wind speed data (mode) can be identified. At the same time, the wind speed mode ranges from 2.0 to 2.6 meters per second. This value is very close to the cut-in speed of some wind turbines, which is 2.5 metres per second [57]. This range is encouraging; this location can also generate electricity via wind energy.

The plot represents a wind speed forecast using a probability density function (pdf). This study is solely focused on the pdf of Weibull distribution. Five approaches to identifying the parameter value will yield the best results pdf. MLM, MOM, EM, GM, and AGM are a few methods used. The fact that Figure 2 only contains four probability density function plots is a significant limitation. This plot is because the parameter values for the Method of Moment (MOM) and the empirical method (EM) are nearly identical, preventing generating plots. This value is indistinguishable from the previous one up to four decimal places. As a result, the plots of the probability density functions for MOM and EM are identical.

Based on Figure 2, the best method is chosen based on the predicted results based on the experimental data. In some cases, the best predictions can produce graphs that look similar to the actual data [23]. Finally, as shown in Figure 2, it is difficult to determine which method best suits this discovery. The method used appears to be capable of yielding predictions that are nearly identical to one another. As a result, the most effective method must be determined scientifically and systematically [23]. The Goodness of Fit (GOF) is a statistical instrument to evaluate the best method.

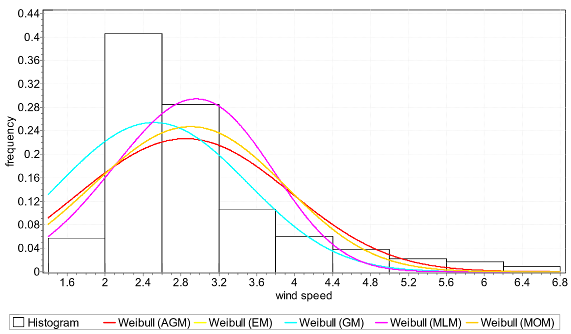


Figure 2 The histogram and pdf of wind speed

3.2 Goodness of Fit

Table 6 shows the adaptive Goodness of Fit (GOF) results among the various techniques used. The results for Goodness of fit are selected based on the lowest value method. By obtaining the lowest possible value of 0.1698 in Table 6, KS has demonstrated that the Alternative Graphical Method is the most effective technique. Meanwhile, EM and MOM methods share the second position, with only a 0.006 difference in value. This sharing occurs because the parameters are the same for both parties. The MLM method yielded a value of 0.1846, while the GM method was the most inaccurate, yielding a value of 0.2422. Due to this enormous value, it can be concluded that the GM method has a significantly higher prediction error in the middle part of the graph curve than the other methods.

However, the results are different when the AD is adjusted for Goodness of Fit. Due to AD focus on the edges of the pdf graph curve, the outcomes have a significant distinction. According to the findings of the analysis, MOM and EM are the most effective methods. This method and the other can be considered equivalent because the result is nearly identical, 18.305. Second place goes to the AGM method, which received a score of 18.667, and third place goes to the MLM technique, which received a score of 22.025. The GM method took up the final position with a value of 28.484. It demonstrates numerous errors in making predictions on both sides of the graph curve using the GM method on both sides of the graph curve. As a result of this discovery, no single method of predicting wind speed is more efficient. As a consequence of this factor, there is a requirement to use another GOF, which is Chi-Square (χ^2) It is also consistent with literature findings, making it a good choice [47].

The AGM method is the most appropriate finding for χ^2 (Table 6). This finding is since the calculation provided the lowest possible value of 191.59. Next, the EM is the second-best method with a score of 307.79, while the MOM and GM methods are in third and fourth place, respectively, with scores of 307.86 and 871.75. It is important to note that a low value indicates a minor difference between the data collected and the predictions. However, there are instances in which the value of χ^2can reach thousands. Taking the MLM method as an example, its value was 6622.3, ranking it last. These figures demonstrate a statistically significant difference between the forecasted data and the gathered data in this study. In conclusion, based on the most recent GOF result, the AGM is the most effective method.

Table 6 Comparative analysis of the method based on Goodness of Fit (GOF)

GOF	Method				
	MLM	MOM	EM	GM	AGM
KS	0.1846	0.1756	0.1756	0.2422	0.1698
AD	22.025	18.305	18.305	28.484	18.667
χ^2	6622.3	307.86	307.79	871.75	191.59

4.0 CONCLUSION

This research is concerned with selecting the most effective method for predicting low wind speeds. The comparison is between existing methods (MOM, EM, MLM, GM), and the Alternative Graphical Method (AGM) has recently been proposed. The ability to produce good results is based on three Goodness of Fit measures, namely Chi-Square (χ^2), Kolmogorov Smirnov (KS), and Anderson Darling (AD). Based on the results, it can be concluded that the AGM is comparable to methods previously employed by researchers. It has a high degree of accuracy in predicting wind speed. This strong performance can be seen in the findings of the KS and χ^2 is at the top of the list. For example, KS is 3.4 per cent better than the EM and MOM methods. However for χ^2, There is a 61 per % third best places, EM and MOM, respectively. In terms of the use of AD, it is ranked second. However, this time the performance of AGM is only 1.9% behind the first rank. These findings indicate that AGM could be used as one of the methods for predicting wind speed, especially at relatively low wind speeds. Finally, to fully realise this potential, the AGM method must be tested and validated using as much data as possible in the coming years.

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