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Statistical Analysis of Wind Resource Assessment for Different Locations in South-Western Thailand

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ABSTRACT

Weibull parameters have been widely used to evaluate wind energy potential. In this work presents wind resource assessment by statistical analysis with a Weibull distribution model for Krabi, Phuket, and Ranong weather stations in south-western Thailand. Ten-minute intervals include wind speed and wind direction of 10m from four-year records obtained by the Thai meteorological department. Four numerical methods, namely empirical method, graphical method, energy pattern factor method and maximum likelihood method are examined to estimate the Weibull parameters. The Weibull distribution obtained from each method is compared with the observed wind speed distribution by the performance tests using root mean square error, mean percentage error, and chi-square error to select a suitable method for the station area. The results revealed that the maximum likelihood method was the most accurate for Krabi and Phuket stations, and the energy pattern factor method was the most accurate for Ranong station. At a hub height of 80m, the highest mean wind speed and mean wind power density found in Krabi station were 3.25 m/s and 44.84 W/m^2. The most probable wind speed value in three stations had a range from 1.80 to 2.50 m/s. The maximum wind speed carrying maximum energy found in Krabi station was 5.53 m/s. The operating probability of a wind turbine in Krabi station was 49.61%, followed by Phuket station was 46.80%, and Ranong station was 37.84%, respectively. In conclusion, all three stations had wind power potential classified as wind class 1 and can be sorted as follows: Krabi, Phuket, and Ranong stations.

1. Introduction

Population growth, economic progress, and technology advancement result in an increased global demand for energy. Fossil fuel is the main resource utilized for energy. These resources influence the environment and result in climate change. Climate change is one of the leading problems around the world [1]. In present, renewable energy is continuously expanding. Wind energy is a clean and inexhaustible source of renewable energy resource. Wind energy can be used to generate electricity through wind farms and wind turbines. In 2021, the globally installed wind

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capacity already amounted to 850 GW [2]. For Thailand, wind energy is one of the alternatives to electricity generation. The Alternative Energy Development Plan 2018, Thailand has set a target for total wind power generation of 3,000 MW by the end of 2037 [3].

The assessment of wind energy resources is an important step before deciding about a wind turbine station or wind farm [4]. The Weibull distribution function is one of the most widely accepted statistical functions for wind energy assessment [5]. The Weibull distribution function has two adjustable parameters, namely k for shape and c for scale. ‘k’ shape parameter represents the characteristic of the wind wave for a particular wind site and ‘c’ scale factor indicates the potentiality of the wind power that site [6]. There are various methods for determining the k and c parameters. Mahmood *et al.,* [7] used the maximum likelihood method (MLM) to determine Weibull parameters that described the characteristics of wind wave in the Al-Salman site in Iraq. Kaplan [8] presented the power density method for determining Weibull distribution parameters for different location in Turkey. Al Buhairi [9] used the standard deviation method for determining Weibull distribution parameters on Taiz in the southwest of Yemen. In addition, several studies have studied comparative methods for estimating Weibull parameters using statistical analysis. Alsamamra *et al.,* [10] compared five methods for estimating Weibull parameters and used the root mean square error, the mean absolute percentage error, and the chi-square error to compare the accuracy of the five methods. The results showed that the empirical method (EM) and the method of moment (MoM) were the most accurate to approximate wind speed distribution. Azad *et al.,* [11] used three numerical methods consist of the power density method, the least square method, and the modified maximum likelihood method for determining the Weibull parameters for three different sites in Bangladesh. Chang [12] compared six numerical methods estimating the Weibull parameters for three wind farms in Taiwan. Kang *et al.,* [13] compared twelve numerical methods for estimating the Weibull parameters on Maldo Island and Saemangeum Seawall in the Republic of Korea. Many studies revealed that each location around the world had a different suitable method for estimating the Weibull parameters.

Thailand is located near the equator and has low to moderate wind speed [14]. The previous studies for wind energy in Thailand, Ratjiranukool and Ratjiranukool [15] explored wind energy potential for electricity generation in Thailand by regions. The result showed that southern and northeastern Thailand had sufficient wind speed for electricity generation. Niyomtham *et al.,* [16] assessed the wind energy resource in the central region of Thailand for wind power generation. Werapun *et al.,* [17] compared five numerical methods: the empirical method, the energy pattern factor method, the maximum likelihood method, the modified maximum likelihood method, and the graphical method for estimating the Weibull parameters on Phangan Island in Thailand. The south-western part of Thailand is an interesting region to study for wind energy potential. It is located near the Andaman Sea, has a total area of 17,689 km^2, and the topology is coastal mountains and coastal [18]. However, finding a suitable Weibull distribution model using statistical methods to evaluate wind resources in southern-western Thailand is still less.

The aim of this work is to select a suitable method to estimate Weibull parameters using the statistical methods and evaluate wind resources using the Weibull distribution model for Krabi, Phuket, and Ranong weather observing stations in southern-western Thailand. Four numerical methods, namely the empirical method (EM), the graphical method (GM), the energy pattern factor method (EPF) and the maximum likelihood method (MLM) are examined to estimate the Weibull parameters. The Weibull distribution obtained from these methods is compared with the observed wind speed distribution by the accuracy tests using root mean square error (RMSE), mean percentage error (MPE), and chi-square error (x^2) to select a suitable method for the station area.

2. Methodology
2.1 Wind Data Collection

Thailand has 128 Meteorological Department weather stations classified into six regions. In this study, the wind data of three stations in the southern-western part of Thailand, consisting of Krabi stations, Phuket station and Ranong station, are adopted for statistical analysis with Weibull parameters estimation and assessment of wind energy potential. The wind data including wind speed and wind direction were provided by the Thai Meteorological Department. The collection period of raw wind data was every 10 minutes from 2019 to 2022 (4 years) at 10m above ground level. The geographical coordinates of the selected weather stations are shown in Table 1. The overview procedure of this study is shown in Figure 1 and the wind power class is shown in Table 2.

Table 1
Summarization of study area sites

Station name	Latitude (°)	Longitude (°)	Altitude (m a.s.l)	Zone	Measurement period
Krabi	7.884	98.392	30	47	2019 - 2022
Phuket	8.103	98.975	8	47	2019 - 2022
Ranong	9.955	98.634	39	47	2019 - 2022

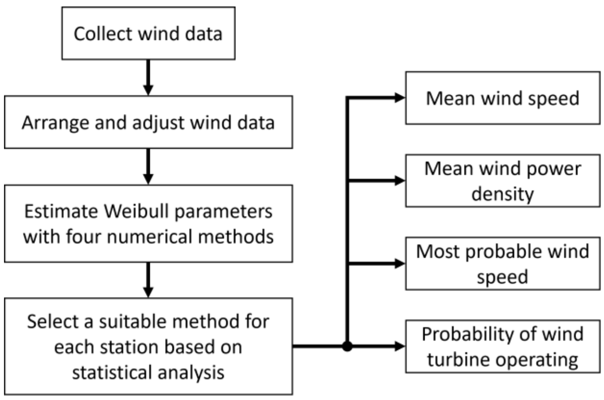

Fig. 1. Overview procedure of the study

Table 2
Wind Power Class at height 10m and 80m [19]

Wind class	At height 10m		At height 80m	
	Density (W/m²)	Speed (m/s)	Density (W/m²)	Speed (m/s)
1	< 100	< 4.4	< 240	< 5.9
2	100 – 150	4.4 – 5.1	240 – 380	5.9 – 6.9
3	150 – 200	5.1 – 5.6	380 – 490	6.9 – 7.5
4	200 – 250	5.6 – 6.0	490 – 620	7.5 – 8.1
5	250 – 300	6.0 – 6.4	620 – 740	8.1 – 8.6
6	300 – 400	6.4 – 7.0	740 – 970	8.6 – 9.4
7	> 400	> 7.0	> 970	> 9.4

2.2 Methods to Estimate Weibull Parameters

The Weibull distribution has been widely used to describe wind speed frequency distribution and to estimate wind energy potential [20]. The Weibull distribution can be divided into probability density function $f(v)$ and cumulative distribution $F(v)$. The Weibull probability density function for fitting the wind speed is shown in Eq. (1) and the cumulative distribution is shown in Eq. (2)

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

$$F(v) = 1 - exp\left[-\left(\frac{v}{c}\right)^{k}\right] \tag{2}$$

where $(v > 0;\ k, c > 0)$, v is wind speed (m/s) and c is a scale parameter and k is a shape parameter.

There are various methods to estimate the Weibull parameters, shape k and scale c, the four different numerical methods were used to estimate the Weibull parameters, which are explained below [21].

2.2.1 Empirical method (EM)

The empirical method is considered a special case of the moment of methods, where k and c parameters can be determined using mean wind speed and standard deviation as follows Eq. (3) and Eq. (4) [22].

$$k = \left(\frac{\sigma}{\overline{v}}\right)^{-1.086} \tag{3}$$

$$c = \left(\frac{\overline{v}}{\Gamma(1+\frac{1}{k})}\right) \tag{4}$$

where, $\overline{v}$ is mean wind speed (m/s), σ is standard variation of observed data (m/s), Γ is gamma function.

2.2.2 Graphical method (GM)

The graphical method is to convert the cumulative function into a linear equation by using the logarithmic function [23]. The cumulative function is shown in Eq. (2) and taking natural logarithms twice gives Eq. (5).

$$ln[-ln\,\{1 - F(v)\}] = -kln(c) + kln(v) \tag{5}$$

where, $F(v)$ is a probability of observing wind speed, v is wind speed (m/s) k is a shape parameter equals the slope of the line, and c is a scale parameter obtained from $-kln(c)$ = the intercept with a y-axis.

2.2.3 Energy pattern factor method (EPFM)

The energy pattern factor method can determine the Weibull parameters following on the ratio of the wind power energy to the third power of the average wind speed values [24]. Eq. (6) presents the energy pattern factor method. Eq. (4) and Eq. (7) present the Weibull parameters estimation.

$$E_{pf} = \left(\frac{\overline{v^3}}{\overline{v}^3}\right) = \frac{\left(\frac{1}{n}\sum_{i=1}^{n} v_i^3\right)}{\left(\frac{1}{n}\sum_{i=1}^{n} v_i\right)^3} \tag{6}$$

$$k = 1 + \left(\frac{3.69}{(E_{pf})^2}\right) \quad (7)$$

Where, E_{pf} is the energy pattern factor, $\overline{v}$ is mean wind speed (m/s).

2.2.4 Maximum likelihood method (MLM)

The maximum likelihood method is a mathematical-based expression known as a likelihood function of wind speed data presented in time-series, it is widely utilized in the literature to estimate the Weibull parameters, Eq. (8) and Eq. (9) present the maximum likelihood method [25].

$$k = \left[\frac{\sum_{i=1}^{n} v_i^k ln\,(v_i)}{\sum_{i=1}^{n} v_i^k} - \frac{\sum_{i=1}^{n} ln(v_i)}{n}\right]^{-1} \quad (8)$$

$$c = \left(\frac{\sum_{i=1}^{n} v_i^k}{n}\right)^{\frac{1}{k}} \quad (9)$$

where, v_i is wind speed measured at the interval i (m/s), i is the measurement interval, n is the number of non-zero values.

2.3 Performance Tests

Three different indicators were used to assess the performance of methods for estimating Weibull parameters. These statistical tools were widely used to compare wind speed data-fitting [10]. The suitable method for estimating Weibull parameters for a study area must have the lowest error ranking among these three statistical tools. Three different indicators show in Eq. (10), Eq. (11) and Eq. (12).

2.3.1 Root mean square error (RMSE)

$$RMSE = \left[\frac{1}{n} \sum_{i=1}^{n}(y_i - x_i)^2\right]^{\frac{1}{2}} \quad (10)$$

where, y_i is the actual wind speed value, x_i is the predicted wind speed value using the Weibull distribution, and n is the number of records in the wind speed data. The result is close to zero, indicating good performance because it has little error [26].

2.3.2 Mean percentage error (MPE)

$$MPE = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{y_i - x_i}{y_i}\right) * 100 \quad (11)$$

where, y_i is the actual wind speed value, x_i is the predicted wind speed value using the Weibull distribution, and n is the number of records in the wind speed data. The result is close to zero, indicating good performance because it has little error [27].

2.3.3 Chi-square error (χ^2)

$$\chi^2 = \sum_{i=1}^{n} \frac{(y_i - x_i)^2}{y_i} \tag{12}$$

where, y_i is the actual wind speed value, x_i is the predicted wind speed value using the Weibull distribution. The chi-square error returns the mean square of the measure value and calculate value for the distributions [10].

2.4 Variation of Weibull Parameter with Height

The Weibull parameters value can be adjusted to another hup height by following Eq. (13), Eq. (14) and Eq. (15) [28].

$$k_z = \frac{k_a\left[1 - k_a 0.088\, ln\left(\frac{z_a}{10}\right)\right]}{\left[1 - 0.088\, ln\left(\frac{z}{10}\right)\right]} \tag{13}$$

$$c_z = c_a\left(\frac{z}{z_a}\right)^n \tag{14}$$

$$n = \frac{[0.37 - 0.088\, ln(c_a)]}{\left[1 - 0.088\, ln\left(\frac{z_a}{10}\right)\right]} \tag{15}$$

where, k_z is Weibull shape parameter at height Z, c_z is Weibull scale parameter at height Z (m/s), k_a is Weibull shape parameter at anemometer height c_a is Weibull scale parameter at anemometer height (m/s), n is power law exponent.

2.5 Wind Power Density Base on Weibull Distribution Function (P_W)

The Weibull parameters can be used to determine the wind power density (wind power per unit area) [29]. The calculation of wind power density using the Weibull parameters method is expressed as Eq. (16).

$$P_W = \frac{1}{2}\rho c^3 \Gamma\left(1 + \frac{3}{k}\right) \tag{16}$$

where, ρ is the air density (often adopted as 1.225 kg/m^3), Γ is gamma function, k and c are the Weibull parameters.

2.6 Most Probable Wind Speed (V_{mp}) and Wind Speed Carrying Maximum Energy ($V_{max\,E}$)

V_{mp} represent the most frequently occurring wind speed for the wind speed probability distribution. V_{mp} is expressed in Eq. (17). $V_{\max E}$ represent wind speed carrying maximum energy, which is important for the designed wind speed of a wind turbine [30]. $V_{\max E}$ is expressed in Eq. (18).

$$V_{mp} = c\left(1 - \frac{1}{k}\right)^{\frac{1}{k}} \tag{17}$$

$$V_{max\,E} = c(1 + \frac{2}{k})^{\frac{1}{k}} \tag{18}$$

where, k and c are the Weibull parameters.

2.7 Operating Probability of Wind Turbine (P_{op})

In the wind power industry, wind turbines are used to convert wind energy into electrical energy. In general, wind turbines have two specific characteristics of wind speed: cut-in speed and cut-off speed. The cut-in speed is the minimum wind speed at which the wind turbine will operate to generate power. The cut-off speed is the wind speed when the turbine stops working. The operating probability of wind turbines is an important factor in assessing the cost-effectiveness of installing a wind turbine [28]. (P_{op}) is expressed as Eq. (19).

$$P_{op}(v_1 < v < v_2) = exp\left[-\left(\frac{v_1}{c}\right)^k\right] - \ exp\left[-\left(\frac{v_2}{c}\right)^k\right] \tag{19}$$

where, v_1 and v_2 represent cut-in and cut off wind speed, k and c are the Weibull parameters.

3. Results

3.1 Statistical Analysis

This section describes in detail the Weibull parameters estimation. In this study, the Weibull distribution model was used to assess wind energy potential. The Weibull distribution model had two significant parameters: k and c. The k and c parameters are obtained from four numerical methods: EM, GM, EPFM, and MLM. Appropriate methods for each study area were selected using performance tests to assess accuracy, including RMSE, MPE, and x^2, by comparing the Weibull distribution obtained from each method with the observed wind speed distribution.

Table 3 shows the assessment accuracy of Weibull parameters estimation from different methods for Krabi station by year and the whole year. The results reveal that in 2019, the energy pattern factor method gave the lowest error values for both RMSE, MPE, and χ^2. In 2020, The maximum likelihood method had the most accuracy from the other methods. In 2021 The maximum likelihood method gave the lowest error values for both RMSE, MPE, and χ^2. In 2022 The maximum likelihood method had the most accuracy of the other methods. The whole year shows that the Weibull parameters were k = 1.941 and c =1.9057 m/s for EM, k = 1.2740 and c =1.3183 m/s for GM, k = 1.4917 and c =1.9053 m/s for EPFM, and k = 1.4730 and c = 1.9042 m/s for MLM, which indicated that the maximum likelihood method had the best performance of each method for Krabi station. Figure 2 shows the Weibull frequency distribution according to each method and frequency of measured wind speed for Krabi station for four years (2019 – 2022).

Table 3
Assessment accuracy Weibull parameters four methods for Krabi station

Year	Method	Weibull parameters		Performance tests			Ranking
		k	c (m/s)	RMSE	MPE (%)	χ^2	
2019	Empirical	1.5060	1.8948	0.0149	2.6556	0.0616	3
	Graphical	1.2635	1.4191	0.0636	12.9643	0.6165	4
	Energy pattern factor	1.4960	1.8933	0.0142	2.4827	0.0547	1
	Maximum likelihood	1.4977	1.8971	0.0146	2.5561	0.0581	2
2020	Empirical	1.4673	1.8829	0.0165	3.8269	0.1104	2
	Graphical	1.2398	1.3580	0.0739	11.9610	0.7037	4
	Energy pattern factor	1.4719	1.8836	0.0168	3.8934	0.1157	3
	Maximum likelihood	1.4353	1.8779	0.0144	3.3676	0.0777	1
2021	Empirical	1.5902	2.2297	0.0174	4.6527	0.1376	2
	Graphical	1.3229	1.8366	0.0516	9.3488	0.3971	4
	Energy pattern factor	1.5995	2.2310	0.0179	4.8022	0.1494	3
	Maximum likelihood	1.5473	2.2227	0.0150	3.9847	0.0903	1
2022	Empirical	1.4940	1.7606	0.0156	3.0532	0.0722	3
	Graphical	1.2234	1.2397	0.0747	13.9317	0.7824	4
	Energy pattern factor	1.4866	1.7595	0.0151	2.9396	0.0664	2
	Maximum likelihood	1.4803	1.7612	0.0149	2.8753	0.0634	1
Whole	Empirical	1.4941	1.9057	0.0149	3.0525	0.0830	3
	Graphical	1.2740	1.3183	0.0797	13.3542	0.9130	4
	Energy pattern factor	1.4917	1.9053	0.0148	3.0180	0.0808	2
	Maximum likelihood	1.4730	1.9042	0.0136	2.7661	0.0659	1

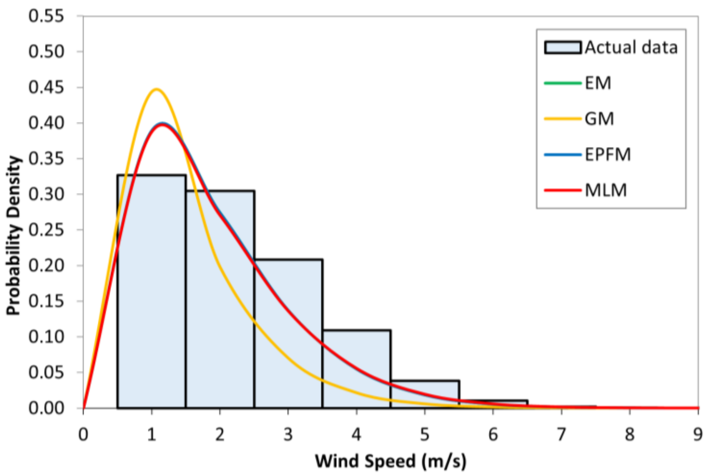

Fig. 2. Weibull distribution generate by 4 methods and measure wind speed as histogram for Krabi station for 4 years

Table 4 shows the assessment accuracy of Weibull parameters estimation from different methods for Phuket station by year and the whole year. The results reveal that from 2019 to 2022, The maximum likelihood method had the lowest values of the root mean square error, the mean percentage error, and the chi-square error, followed by the energy pattern factor method and the empirical method, which had a similar Weibull parameters value, and the graphical method showed the worst performance of the four methods. The whole year shows that the Weibull parameters were k = 1.7102 and c = 1.7679 m/s for EM, k = 1.3706 and c =1.1626 m/s for GM, k = 1.7068 and c =1.7677 m/s for EPFM, k = 1.6720 and c =1.7639 m/s for MLM. Figure 3 shows the Weibull frequency distribution according to each method and frequency of measured wind speed for Phuket station for four years (2019 – 2022).

Table 4
Assessment accuracy Weibull parameter four methods for Phuket station

Year	Method	Weibull parameters		Performance tests			Ranking
		k	c (m/s)	RMSE	MPE (%)	χ^2	
2019	Empirical	1.6938	1.7539	0.0151	4.9662	0.1277	2
	Graphical	1.4125	1.1924	0.1013	17.9688	1.0522	4
	Energy pattern factor	1.6994	1.7543	0.0154	5.0461	0.1335	3
	Maximum likelihood	1.6516	1.7493	0.0127	4.3389	0.0876	1
2020	Empirical	1.6311	1.6230	0.0140	3.9418	0.1026	3
	Graphical	1.2948	1.1036	0.0891	16.0598	0.9373	4
	Energy pattern factor	1.6242	1.6224	0.0136	3.8594	0.0964	2
	Maximum likelihood	1.5989	1.6201	0.0123	3.5584	0.0755	1
2021	Empirical	1.9589	1.9422	0.0117	6.1239	0.1446	3
	Graphical	1.6389	1.7463	0.0350	7.9246	0.1896	4
	Energy pattern factor	1.9583	1.9422	0.0116	6.1151	0.1440	2
	Maximum likelihood	1.9141	1.9372	0.0101	5.3498	0.1060	1
2022	Empirical	1.7278	1.8560	0.0117	4.0494	0.0887	3
	Graphical	1.3758	1.4382	0.0647	12.9292	0.6211	4
	Energy pattern factor	1.7174	1.8553	0.0112	3.9204	0.0804	2
	Maximum likelihood	1.6955	1.8530	0.0101	3.6229	0.0641	1
Whole	Empirical	1.7102	1.7679	0.0123	3.9490	0.1119	3
	Graphical	1.3706	1.1626	0.0994	17.7717	1.2622	4
	Energy pattern factor	1.7068	1.7677	0.0121	3.9110	0.1088	2
	Maximum likelihood	1.6720	1.7639	0.0104	3.4920	0.0787	1

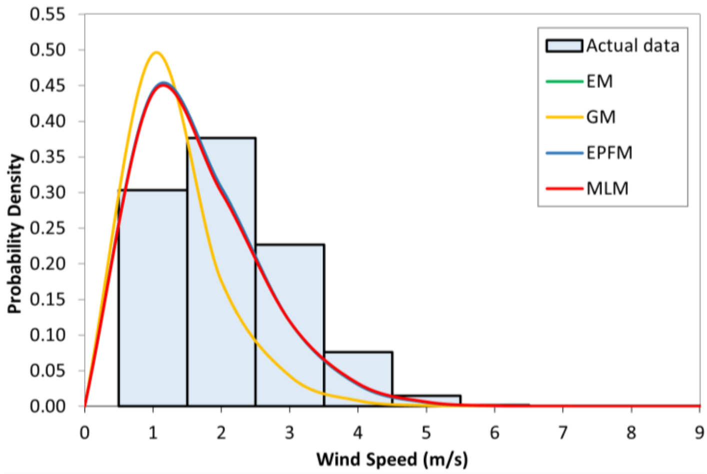

Fig. 3. Weibull distribution generate by 4 methods and measure wind speed as histogram for Phuket station for 4 years

Table 5 shows the assessment accuracy of Weibull parameters estimation from different methods for Ranong station by year and the whole year. The results reveal that in 2019, the maximum likelihood method gave the lowest error values for both RMSE, MPE, and χ^2. In 2020 – 2022, the energy pattern factor method gave the lowest error values for both RMSE, MPE, and χ^2. The whole year shows that the Weibull parameters k = 1.4020 and c =1.5286 m/s for EM, k = 1.1399 and c = 0.9855 m/s for GM, k = 1.3944 and c =1.5286 m/s for EPFM, k = 1.4139 and c =1.5355 m/s for MLM, which indicated that the energy pattern factor method had the best performance of each method for Ranong station. Figure 4 shows the Weibull frequency distribution according to each method and frequency of measured wind speed for Ranong station for four years (2019 – 2022).

Table 5
Assessment accuracy Weibull parameter four methods for Ranong station

Year	Method	Weibull parameters		Performance tests			Ranking
		k	c (m/s)	RMSE	MPE (%)	χ^2	
2019	Empirical	1.4026	1.5943	0.0175	3.3442	0.0855	2
	Graphical	1.1533	1.0322	0.0879	15.0033	0.9018	4
	Energy pattern factor	1.4074	1.5951	0.0179	3.4194	0.0901	3
	Maximum likelihood	1.3886	1.5944	0.0166	3.1452	0.0747	1
2020	Empirical	1.3908	1.4646	0.0195	1.9701	0.0636	2
	Graphical	1.1504	1.0835	0.0533	11.8419	0.4706	4
	Energy pattern factor	1.3763	1.4621	0.0187	1.9736	0.0577	1
	Maximum likelihood	1.4197	1.4755	0.0220	2.1962	0.0837	3
2021	Empirical	1.4520	1.5669	0.0175	2.1419	0.0545	2
	Graphical	1.1967	1.0397	0.0840	18.2373	0.8770	4
	Energy pattern factor	1.4356	1.5644	0.0164	1.9105	0.0465	1
	Maximum likelihood	1.4652	1.5739	0.0190	2.4723	0.0660	3
2022	Empirical	1.3874	1.4966	0.0184	1.9364	0.0607	2
	Graphical	1.1252	1.0491	0.0643	13.5101	0.6272	4
	Energy pattern factor	1.3782	1.4950	0.0178	1.8262	0.0560	1
	Maximum likelihood	1.4085	1.5058	0.0204	2.2989	0.0774	3
Whole	Empirical	1.4020	1.5286	0.0169	2.0515	0.0603	2
	Graphical	1.1399	0.9855	0.0792	14.8207	0.9073	4
	Energy pattern factor	1.3944	1.5286	0.0164	1.9328	0.0558	1
	Maximum likelihood	1.4139	1.5355	0.0182	2.2927	0.0718	3

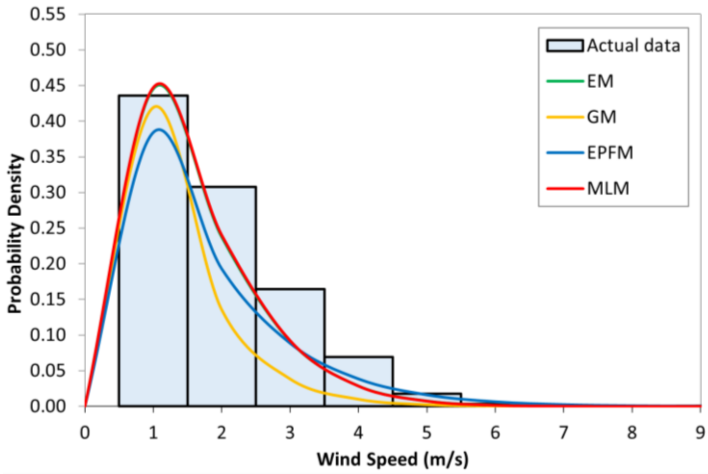

Fig. 4. Weibull distribution generate by 4 methods and measure wind speed as histogram for Ranong station for 4 years

Table 6 shows summarization of suitable method for estimating Weibull parameters. The maximum likelihood method was suitable for Krabi and Phuket station. The energy pattern factor method was suitable for Ranong station. The calculation about Weibull shape parameter k varied from 1.40 to 1.70 and the range of Weibull scale parameter c was 1.50 to 2.00 m/s. The scale parameter c is highly consistent with the mean wind speed. The maximum scale parameter c was found in Krabi station, and the lowest scale parameter c was found in Ranong station. Figure 5 shows a comparison of the Weibull distribution model for Krabi, Phuket and Ranong station for four years (2019 – 2022).

Table 6
Summarization of suitable method for estimating the Weibull parameters of 10m

Station	Method estimates Weibull parameters	Weibull parameter	
		k	c (m/s)
Krabi	Maximum likelihood	1.4730	1.9042
Phuket	Maximum likelihood	1.6720	1.7639
Ranong	Energy pattern factor	1.3944	1.5273

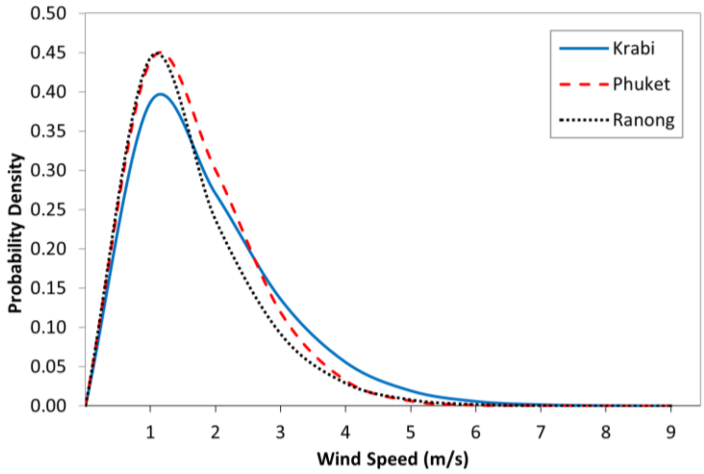

Fig. 5. Weibull distribution model for three stations of 10m

3.2 Evaluate of Wind Resource

This section describes in detail the assessment of wind potential by the Weibull model. The standard wind turbine installed hub height is in the range of 80 to 100 meters [31,32]. In this study, a reference hup height of 80m was used to assess the wind energy potential.

Figure 6 plots the Weibull distribution model for three stations of 80m. Table 7 shows adjusting the parameters k and c to the hub height of 80m and assessing wind energy potential. The Weibull parameters k value was 1.8029, 2.0465, and 1.7067, and the parameter c value were 3.6533 m/s, 3.4317 m/s, and 3.0508 m/s for Krabi, Phuket, and Ranong stations, respectively. The mean wind speed was 3.25 m/s for Krabi, 3.04 m/s for Phuket, and 2.72 m/s for Ranong station. The mean power density was 44.84 W/m^2 for Krabi, 32.13 W/m^2 for Phuket, and 28.15 W/m^2 for Ranong station. The wind speed carrying maximum energy found in Krabi station was 5.53 m/s. In terms of the most probable wind speed, all three stations had a range from 1.80 to 2.50 m/s, which is in the range of low wind speed. In this study, the selected cut-in speed is 3 m/s, which is generally the minimum wind speed for wind turbine working, while the selected cut-out speed is constant at 25 m/s. The operating probability of a wind turbine at Krabi station was 49.61%, followed by Phuket station was 46.80%, and Ranong station was 37.84%, respectively.

Table 7
Wind resource assessment from the Weibull distribution model of 80m

Station	Weibull parameters		$\overline{v}$ (m/s)	P_W (W/m^2)	$V_{\max E}$ (m/s)	V_{mp} (m/s)	P_{op} (3 < v < 25) (%)
	k	c (m/s)					
Krabi	1.8029	3.6533	3.2486	44.8403	5.5269	2.3325	49.6068
Phuket	2.0465	3.4317	3.0402	32.1349	4.7883	2.4727	46.7909
Ranong	1.7067	3.0508	2.7213	28.1521	4.8059	1.8199	37.8423

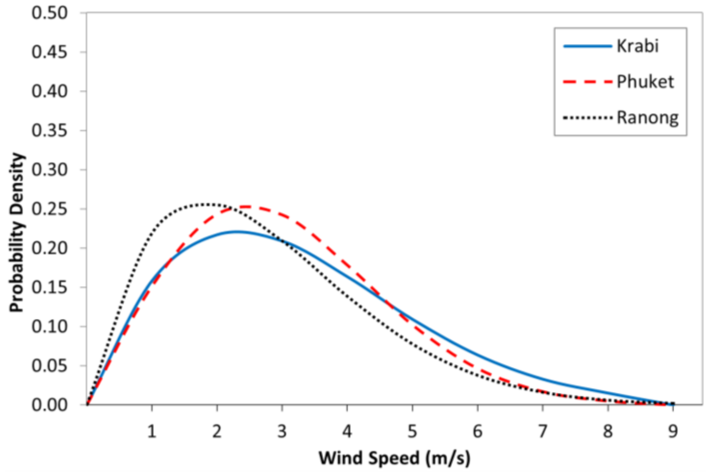

Fig. 6. Weibull distribution model for three stations of 80m

4. Conclusions

This study presents an estimation of Weibull parameters using statistical methods and evaluates wind resources using the Weibull distribution model for Krabi, Phuket, and Ranong stations in southern-western Thailand. The main outcome presented as follows:

The maximum likelihood method was the most accurate for determining Weibull parameters for Krabi and Phuket stations. The energy pattern factor method was the most accurate for determining Weibull parameters for Ranong station. The graphical method was the worst performance.

At a hub height of 80m, the maximum mean wind speed and the maximum wind power density were found in Krabi station, which are 3.25 m/s and 44.84 W/m^2. The wind speed carrying maximum energy found in Krabi station was 5.53 m/s. The most operating probability of a wind turbine found at Krabi station was 49.61%. All three stations had wind power potential classified as wind class 1 and can be sorted as follows: Krabi, Phuket, and Ranong stations.

This study does not include wind turbine installation simulations and economic calculations for a better assessment and exploitation of the wind energy potential in Thailand. More studies are still needed in the future, such as using another statistic function besides the Weibull function to evaluate the wind speed profile and using numerical simulation by computational fluid dynamics (CFD) to determine the spatial distributions of wind speeds over a weather observing station, which can offer valuable information for wind turbine installation.

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