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Estimation of Weibull distribution parameters for wind energy applications: A case study of Dinar region in Turkey

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Abstract: In this study, the wind energy characteristics of Dinar region were researched. Required wind data was provided by the Dinar Meteorology Station of the Turkish State Meteorology Service. Wind data was recorded hourly between June 2015 and May 2020. The two variable Weibull probability distribution function was used to research wind characteristics of the region. Six different methods were used to calculate shape (k) and scale (c) variables of the probability distribution function. These are moment, graph, Justus empirical, energy trend, energy pattern and maximum likehood estimation methods. The performance of these methods were compared with four different statistical error analysis methods. These are root mean square error (RMSE), coefficient of determination (R^2), chi-square error (X^2) and mean absolute error (MAE). According to the results, maximum likehood estimation and energy trend methods have been the most successful methods in the calculation of Weibull parameters. In addition, this study is an important preliminary study in determining the wind energy characteristic of the region.

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Rüzgar enerji uygulamaları için Weibull dağılım parametrelerinin tahmini: Türkiye'nin Dinar bölgesi için bir çalışma

Anahtar Kelimeler
Rüzgar enerjisi
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Öz: Bu çalışmada, Dinar bölgesinin rüzgar enerji karakteristiğinin incelemesi yapılmıştır. Çalışmada ihtiyaç duyulan rüzgar verisi Meteoroloji Genel Müdürlüğü'nün Dinar Meteoroloji İstasyonu tarafından sağlanmıştır. Rüzgar verileri Haziran 2015 – Mayıs 2020 yılları arasında saatlik olarak kaydedilmiştir.Bölgenin rüzgar karakteristiğinin incelenmesinde iki değişkenli Weibull olasılık dağılım fonksiyonu kullanılmıştır. Olasılık dağılım fonksiyonun şekil (k) ve ölçek(c) değişkenlerinin hesaplanmasında ise altı farklı yöntem kullanılmıştır. Bunlar moment, grafik, Justus empirik, enerji eğilim, enerji pattern ve en yüksek olabilirlik yöntemleridir. Bu yöntemlerin performansları ise dört farklı istatistiksel hata analiz yöntemi ile karşılaştırılmıştır. Bunlar sırasıyla ortalama karekök hatası (RMSE), belirleme katsayısı (R^2), ki-kare hatası (X^2) ve ortalama mutlak hata (MAE)'dır. Elde edilen sonuçlara bakıldığında en yüksek olabilirlik ve enerji eğilim yöntemleri Weibull parametrelerinin hesabında en başarılı yöntemler olmuştur. Ayrıca bu çalışma, bölgenin rüzgar enerji karakteristiğini belirlemede önemli bir ön çalışma niteliği taşımaktadır.

1. Introduction

Renewable energy resources are unending and can be used repeatedly. They do not harm the environment as much as fossil fuels. Because they are found anywhere in nature, they allow to reach energy in rural areas. In addition, the provide independency in energy. There are various types of renewable energy resources such as wind, solar and geothermal.

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Wind energy has been used in ancient times in areas such as milling of grain and sailing of ships. Nowadays, it is used to produce electricity. Because of not burning process, producing electricity from the wind is clean and does not cause pollution. It protects water resources as it does not need cooling water like other energy systems. Since it is found almost everywhere in nature, there is no cost of raw materials. This reduces the energy production cost. If the wind turbines that have expired are removed from their places, the land becomes usable again [1].

Due of advantages of wind energy, investments are increasing day by day. As of 2020, the installed wind power in the world has reached the level of 745 GW. China ranks first in the world with an installed capacity of 228 GW. The USA ranks second with 122 GW and Germany ranks third with 62 GW of installed power [2]. Turkey is one of countries with high wind potential due to its geographical location and climatic conditions. The installed power which was 18,9 MW in 2000, reached 9,3 GW levely by 2021 with government supports [3].

Before making a wind investment in a region, the wind energy characteristics of the region should be examined. According to the results, the energy that can be produced in the region is calculated. Thus, parameters such as tower height, blade length, rotor speed, aerodynamic shape of the wind blades are decided [4]. Various probability distribution methods are used to study the wind energy characteristics. Some of them are lognormal, gamma function, Weibull and Rayleigh distributions. Among the distribution methods, the most preferred method in the literature is the Weibull probability distribution method [4],[5]. The success of the Weibull distribution depends on the success of the parameter estimation [6]. Methods such as moment, graph, empirical, energy trend are used in parameter estimation of the Weibull distribution.

In this study, wind characteristics of Dinar region is researched. Wind data that was recorded hourly at an altitude of 10m between June 2015 and May 2020 was used. Two parameter Weibull distribution was used to obtain wind characteristics in this region. Moment, graph, Justus empirical, energy trend, energy pattern and maximum likelihood methods were used to estimate Weibull distribution parameters. The success of these methods was compared using RMSE, R^2, X^2 and MAE error methods.

2. Weibull Distribution

Weibull distribution was discovered in 1939 by the Waloddi Weibull. It is a function of three variables. These are shape (k), scale (c) and location (a) parameters. Wind speed is measured by an anemometer mounted on a pole. Since the measuring point does not change, two parameter Weibull distribution is used in wind applications [7]. Two parameter Weibull probability distribution function is given in Equation (1).

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

Cumulative distribution function is given Equation (2).

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

Mean wind speed of the Weibull distribution is expressed by Equation (3) [6],[8].

$$V_m = c\Gamma\left(1 + \frac{1}{k}\right) \quad (3)$$

Here, V_m is the mean wind speed, c is the scale parameter, k is the shape parameter and Γ is the Gamma function.

According to the Weibull probability density graph, the peak represents the most probable wind speed. Equation (4) is used to calculate it [6].

$$V_{mp} = c\left(\frac{k-1}{k}\right)^{\frac{1}{k}} \quad (4)$$

Equation (5) is used to calculate the highest velocity value of the Weibull distribution [6].

$$V_{max} = c\left(\frac{k+2}{k}\right)^{\frac{1}{k}} \quad (5)$$

Equation (6) is used in the power calculation of Weibull distribution [8].

$$P = \frac{1}{2}\rho c^3 \Gamma\left(1 + \frac{3}{k}\right) \quad (6)$$

Here, ρ is air density value of the region.

Hourly wind speed data recorded in the Dinar region between 2015 and 2020 is given in Figure 1. According to the figure, it is seen that the average wind speed value of the region is around 2 m/s. The highest speed value was found to be around 16 m/s.

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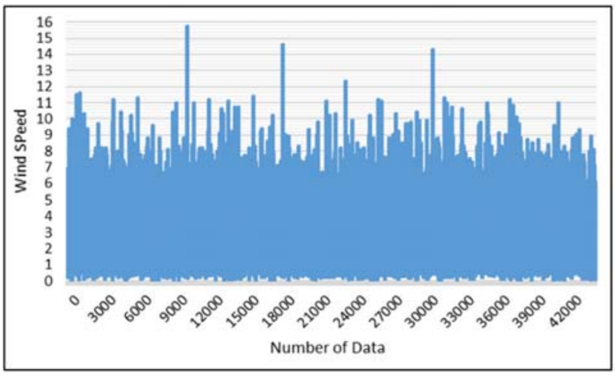

Figure 1. Wind speed data of Dinar region between July 2015 and May 2020

In Table 1, frequency and probability densities of wind speed data are given. Wind speed groups are given in the second column and the average of each wind speed group is given the third column. Blow count for each velocity group is given in the fourth column. The probability density is given in the fifth column while the cumulative distribution is given in the last column.

Table 1. Frequency and probability densities of wind data for Dinar region

i	v_i(m/s)	v_{im}(m/s)	f_i	f (V)	F (V)
1	0-1	0,5	6837	0,161448	0,161448
2	1-2	1,5	15009	0,351236	0,512684
3	2-3	2,5	8700	0,203594	0,716278
4	3-4	3,5	5767	0,134957	0,851236
5	4-5	4,5	3323	0,077764	0,928999
6	5-6	5,5	1721	0,040274	0,969274
7	6-7	6,5	814	0,019049	0,988323
8	7-8	7,5	296	0,006927	0,995249
9	8-9	8,5	108	0,002527	0,997777
10	9-10	9,5	49	0,001147	0,998924
11	10-11	10,5	24	0,000562	0,999485
12	11-12	11,5	18	0,000421	0,999906
13	12-13	12,5	1	0,000023	0,999930
14	13-14	13,5	0	0,000000	0,999930
15	14-15	14,5	2	0,000047	0,999977
16	15-16	15,5	1	0,000023	1,000000

3. Parameter Calculation Methods

Various numerical methods have been used in the parameter calculation of the Weibull distribution until today. Some of these are moment, graph, Justus empirical, energy trend, energy pattern and maximum likelihood methods.

3.1. Moment method

Before calculating parameter in the moment method, standard deviation (σ) and mean (V_m) of the distribution must be calculated [6]. Equations (7) and (8) are used for this.

$$\sigma = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(v_i - V_m)} \quad (7)$$

$$V_m = \frac{1}{n}\sum_{i=1}^{n} v_i \quad (8)$$

Then, shape parameter can be calculated with Equation (9).

$$k = \left(\frac{0{,}9874}{\frac{\sigma}{V_m}}\right)^{1{,}0983} \quad (9)$$

After calculating shape parameter, scale parameter is calculated with Equation (10).

$$c = \frac{V_m}{\Gamma\left(1+\frac{1}{k}\right)} \quad (10)$$

3.2. Graph method

One of the methods used in calculation of Weibull parameters is graph method. In this method, parameters are found by drawing graphs instead of making calculations. Equation (11) is obtained by taking the logarithm of both sides of the function specified in Equation (2) twice [9].

$$\ln\left[-\ln[1-F(v)]\right] = k\ln v - k\ln c \quad (11)$$

The graph of the expression in Equation (11) with respect to lnx shows the line in space. In this case, shape parameter is the slope of this line. This expression is explained more clearly in Equations (12) and (13).

$$\mathrm{x} = \ln v \quad (12)$$

$$\mathrm{y} = \ln\left[-\ln[1-F(v)]\right] \quad (13)$$

Then, shape and scale parameters are calculated by applying the least squares method.

3.3. Justus empirical method

While calculating parameters with this method, the standart deviation and average wind speed should be calculated. Then Equations (14) and (15) are used to calculate shape and scale parameters [10].

$$k = \left(\frac{\sigma}{V_m}\right)^{-1{,}086} \tag{14}$$

$$c = \frac{V_m}{\Gamma\left(1 + \frac{1}{k}\right)} \tag{15}$$

3.4. Energy trend method

First of all, the energy pattern factor is calculated using Equation (16) [9].

$$E_{PF} = \frac{\frac{1}{n}\sum_{i=1}^{n} v_i^3}{\left(\frac{1}{n}\sum_{i=1}^{n} v_i\right)^3} \tag{16}$$

After calculating energy pattern factor, shape and scale parameters are calculated using Equations (17) and (18).

$$k = 3{,}9557 E_{PF}^{-0{,}898} \tag{17}$$

$$c = \left(\frac{1}{n}\sum_{i=1}^{n} v_i^k\right)^{1/k} \tag{18}$$

3.5. Energy pattern method

In this method, average wind speed and energy pattern factor are need [7]. Then, shape and scale parameters are calculated with the help of Equations (19) and (20).

$$k = 1 + \frac{3.69}{E_{PF}^2} \tag{19}$$

$$c = \frac{V_m}{\Gamma\left(1 + \frac{1}{k}\right)} \tag{20}$$

3.6. Maximum likelihood estimation method

When calculating with this method, iteration is required in the parameter calculation of Weibull distribution [11]. Shape and scale parameters are calculated by Equations (21) and (22).

$$k = \left(\frac{\sum_{i=1}^{n} v_i^k ln(v_i)}{\sum_{i=1}^{n} v_i^k} - \frac{\sum_{i=1}^{n} ln(v_i)}{n}\right)^{-1} \tag{21}$$

$$c = \left(\frac{1}{n}\sum_{i=1}^{n} v_i^k\right)^{1/k} \tag{22}$$

4. Statistical Error Analysis Methods

4.1. Root mean square error (RMSE) method

This method expresses the difference between the predicted results and the actual data as an absolute number. The result obtained is positive because of the absolute value [12]. It is expressed by Equation (23).

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(y_i - x_i)^2}{N}} \tag{23}$$

Here, x is the measured wind speed, y is the calculated wind speed and N is the number of occurrences.

4.2. Coefficient of determination (R^2) method

This method shows the linear relationship between the measured and calculated data [12]. It is expressed by Equation (24).

$$R^2 = \frac{\sum_{i=1}^{N}(x_i - z_i)^2 - \sum_{i=1}^{N}(x_i - y_i)^2}{\sum_{i=1}^{N}(x_i - z_i)^2} \tag{24}$$

z is the mean wind speed.

4.3. Chi-square error (X^2) method

This method is based on whether the difference between the measured frequency and the calculated frequency is significant [12]. The mathematical expression of the method is expressed by Equation (25).

$$X^2 = \sum_{i=1}^{N} \frac{(x_i - y_i)^2}{y_i} \tag{25}$$

4.4. Mean absolute error (MAE) method

It is based on the arithmetic mean between the measured and calculated data [12]. It is expressed by Equation (26).

$$\text{MAE} = \frac{\sum_{i=1}^{N}|y_i - x_i|}{N} \tag{26}$$

5. Analysis Results

The comparison of the shape and scale parameters calculated by six different methods is given in Table 2. According to the calculation results, the value of k parameter was found between 1,4093 and 2,1619. The value of c parameter was found between 2,1232 and 3,2098. According to Table 2, the value of k parameter for all methods increased in summer months, while its value decreased in winter months.

When the performance analysis results are examined, successful and unsuccessful methods have varied according to months. When all methods were compared, it was seen that maximum likelihood method was the most successful method. This method was followed by the energy trend method. Moment and energy pattern methods were the most unsuccessful.

Table 2. Comparison of the results calculated by six different methods.

Months	Parameter Calculation Methods	Weibull Parameters		Statistical Analysis Methods			
		k	c	RMSE	R^2	X^2	MAE
January	Justus Empirical	1,5209	3,1509	**0,0141**	**0,999974756**	**1,9878e-04**	0,0058
	Moment	1,5070	3,1475	0,0142	0,999974559	2,0033e-04	0,0059
	Graph	1,7074	3,1202	0,0165	0,999965440	2,7214e-04	0,0066
	Energy Pattern	1,4995	3,1456	0,0142	0,999974393	2,0164e-04	0,0059
	Energy Trend	1,6116	3,2098	0,0147	0,999972490	2,1662e-04	**0,0057**
	Maximum Likelihood	1,5516	3,1743	**0,0141**	0,999974735	1,9894e-04	**0,0057**
February	Justus Empirical	1,4578	2,9783	**0,0125**	**0,999977873**	**1,5713e-04**	0,0053
	Moment	1,4438	2,9743	0,0126	0,999977628	1,5887e-04	0,0053
	Graph	1,6478	2,9502	0,0154	0,999966444	2,3830e-04	0,0063
	Energy Pattern	1,4384	2,9727	0,0126	0,999977487	1,5987e-04	0,0053
	Energy Trend	1,5199	3,0198	0,0128	0,999976869	1,6427e-04	**0,0051**
	Maximum Likelihood	1,4925	3,0032	0,0126	0,999977785	1,5776e-04	0,0052
March	Justus Empirical	1,4886	2,7720	0,0149	0,999963627	2,2216e-04	**0,0054**
	Moment	1,4746	2,7687	0,0153	0,999961893	2,3275e-04	**0,0054**
	Graph	1,7243	2,7479	0,0143	0,999966671	2,0357e-04	0,0061
	Energy Pattern	1,4536	2,7634	0,0158	0,999958872	2,5121e-04	**0,0054**
	Energy Trend	1,5433	2,8026	**0,0139**	**0,999968289**	**1,9369e-04**	0,0055
	Maximum Likelihood	1,5356	2,7984	0,0140	0,999967857	1,9632e-04	0,0055
April	Justus Empirical	1,6204	2,5104	0,0231	0,999890837	5,3574e-04	0,0080
	Moment	1,6068	2,5085	0,0236	0,999886882	5,5515e-04	0,0080
	Graph	1,9769	2,4868	**0,0195**	**0,999922503**	**3,8033e-04**	**0,0079**
	Energy Pattern	1,5399	2,4979	0,0259	0,999863737	6,6874e-04	0,0080
	Energy Trend	1,6690	2,5290	0,0219	0,999902462	4,7869e-04	0,0080
	Maximum Likelihood	1,6835	2,5352	0,0216	0,999905162	4,6544e-04	0,0080
May	Justus Empirical	1,7037	2,1451	0,0192	0,999895493	3,6994e-04	0,0066
	Moment	1,6903	2,1440	0,0197	0,999890244	3,8852e-04	0,0067
	Graph	2,0651	2,1232	**0,0156**	**0,999931545**	**2,4232e-04**	**0,0051**
	Energy Pattern	1,5928	2,1336	0,0237	0,999841699	5,6036e-04	0,0071
	Energy Trend	1,7404	2,1565	0,0180	0,999908308	3,2458e-04	0,0065
	Maximum Likelihood	1,7566	2,1619	0,0176	0,999912980	3,0804e-04	0,0064
June	Justus Empirical	1,7775	2,3223	0,0116	0,999967491	1,3447e-04	0,0042
	Moment	1,7643	2,3214	0,0120	0,999965299	1,4354e-04	0,0042
	Graph	2,1098	2,3002	0,0138	0,999953977	1,9038e-04	0,0045
	Energy Pattern	1,6821	2,3144	0,0150	0,999945855	2,2398e-04	0,0047
	Energy Trend	1,8536	2,3491	**0,0100**	**0,999975621**	**1,0085e-04**	**0,0037**
	Maximum Likelihood	1,8201	2,3380	0,0105	0,999973235	1,1071e-04	0,0039

Table 2. Comparison of the results calculated by six different methods (Cont.).

Months	Parameter Calculation Methods	Weibull Parameters		Statistical Analysis Methods			
		k	c	RMSE	R^2	X^2	MAE
July	Justus Empirical	1,9445	2,9595	**0,0088**	0,999988434	7,7643e-05	0,0036
	Moment	1,9321	2,9590	0,0089	0,999988296	7,8569e-05	0,0036
	Graph	2,1209	2,9349	0,0111	0,999981746	1,2254e-04	0,0038
	Energy Pattern	1,9197	2,9584	0,0089	0,999988073	8,0067e-05	0,0036
	Energy Trend	2,1199	3,0258	0,0111	0,999981608	1,2347e-04	0,0040
	Maximum Likelihood	1,9583	2,9708	**0,0088**	**0,999988590**	**7,6594e-05**	**0,0035**
August	Justus Empirical	1,9864	2,8073	0,0057	0,999994624	3,2395e-05	0,0025
	Moment	1,9742	2,8069	0,0058	0,999994467	3,3346e-05	**0,0024**
	Graph	2,1404	2,7851	0,0080	0,999989304	6,4464e-05	0,0033
	Energy Pattern	1,9609	2,8065	0,0059	0,999994190	3,5014e-05	**0,0024**
	Energy Trend	2,1619	2,8679	0,0089	0,999986766	7,9756e-05	0,0037
	Maximum Likelihood	1,9931	2,8156	**0,0056**	**0,999994740**	**3,1701e-05**	0,0025
September	Justus Empirical	1,6277	2,2802	0,0199	0,999901850	3,9603e-04	0,0072
	Moment	1,6141	2,2786	0,0204	0,999897145	4,1501e-04	0,0073
	Graph	2,0006	2,2581	**0,0161**	**0,999935896**	**2,5865e-04**	**0,0063**
	Energy Pattern	1,5585	2,2709	0,0225	0,999874757	5,0534e-04	0,0075
	Energy Trend	1,6946	2,3046	0,0180	0,999919809	3,2356e-04	0,0070
	Maximum Likelihood	1,6935	2,3042	0,0180	0,999919593	3,2443e-04	0,0070
October	Justus Empirical	1,6038	2,2569	0,0231	0,999865601	5,3250e-04	0,0083
	Moment	1,5901	2,2551	0,0234	0,999861400	5,4915e-04	0,0083
	Graph	1,9708	2,2389	0,0220	0,999877864	4,8392e-04	**0,0074**
	Energy Pattern	1,5426	2,2482	0,0248	0,999844215	6,1724e-04	0,0084
	Energy Trend	1,6726	2,2826	**0,0217**	0,999881127	4,7099e-04	0,0081
	Maximum Likelihood	1,6735	2,2829	**0,0217**	**0,999881254**	**4,7048e-04**	0,0081
November	Justus Empirical	1,5460	2,2885	0,0207	0,999895983	4,2701e-04	0,0083
	Moment	1,5321	2,2863	0,0209	0,999893236	4,3829e-04	0,0084
	Graph	1,8774	2,2757	0,0221	0,999881165	4,8784e-04	**0,0080**
	Energy Pattern	1,5083	2,2822	0,0215	0,999887742	4,6084e-04	0,0085
	Energy Trend	1,6244	2,3213	**0,0198**	**0,999904756**	**3,9099e-04**	**0,0080**
	Maximum Likelihood	1,6161	2,3178	**0,0198**	0,999904427	3,9234e-04	0,0081
December	Justus Empirical	1,4459	2,8094	0,0188	0,999944207	3,5289e-04	0,0071
	Moment	1,4319	2,8055	0,0191	0,999942504	3,6366e-04	0,0071
	Graph	1,7358	2,7944	0,0196	0,999939154	3,8485e-04	0,0078
	Energy Pattern	1,4093	2,7989	0,0196	0,999939291	3,8398e-04	0,0072
	Energy Trend	1,4737	2,8243	0,0183	0,999946974	3,3539e-04	0,0070
	Maximum Likelihood	1,5134	2,8474	**0,0179**	**0,999949257**	**3,2095e-04**	**0,0069**
June 2015 -May 2020	Justus Empirical	1,5678	2,5999	0,0169	0,999946369	2,8430e-04	0,0059
	Moment	1,5540	2,5975	0,0172	0,999943996	2,9688e-04	**0,0058**
	Graph	1,8790	2,5756	0,0165	0,999948804	2,7139e-04	0,0066
	Energy Pattern	1,5072	2,5886	0,0187	0,999934154	3,4906e-04	**0,0058**
	Energy Trend	1,6228	2,6247	**0,0157**	0,999953360	2,4724e-04	0,0059
	Maximum Likelihood	1,6265	2,6265	**0,0157**	**0,999953678**	**2,4556e-04**	0,0059

The average speed, the wind speed with the highest probability of blowing, the highest wind speed and power values of Weibull distribution are calculated and shown in Table 3. According to the statistical error analysis results, the most successful method is the maximum likelihood method. In the calculation of the parameters given in Table 3, k and c parameters calculated with the maximum likelihood method were used. Air density was needed to calculate the area's wind power. Air density value is inversely proportional to temperature. Therefore, as the temperature increases, the air density and power density values decreases. In this study, this change was neglected and the air density value was accepted as 1,04 kg/m^3 for the Dinar region. When Table 3 is examined in general, it is seen that the values increase in the winter period and decrease in the spring periods. While the power density reaches its highest value in January, it reaches its lowest value in May.

Table 3. Wind speed and power values of Dinar region

Months	V_m(m/s)	V_{mp}(m/s)	V_{maxE}(m/s)	P(W/m^2)
January	2,8546	1,6299	5,4130	31,3116
February	2,7128	1,4288	5,3085	28,4330
March	2,5194	1,4094	4,8169	21,8457
April	2,2636	1,4841	4,0365	13,9927
May	1,9250	1,3384	3,3325	8,1672
June	2,0781	1,5088	3,5136	9,8568
July	2,6340	2,0624	4,2554	18,5405
August	2,4954	1,9851	3,9901	15,4861
September	2,0565	1,3601	3,6517	10,4143
October	2,0392	1,3252	3,6519	10,3083
November	2,0762	1,2762	3,8151	11,3890
December	2,5678	1,3939	4,9675	23,6216
June 2015 -May 2020	2,3514	1,4610	4,3001	16,4039

As a result, k and c values were calculated for each method. Weibull probability density and cumulative distribution calculations were made using equations 1 and 2. The graphs obtained as a result of these calculations are given on monthly and 5 years basis. The "data" given in the graph refers to the measured wind data. "emp" refers to the Justus empirical method, "mom" refers to the moment method, "grf" refers to the graph method, "epf" refers to the energy pattern method, "enj" refers to the energy trend method and "mle" refers to the maximum likelihood estimation method.

Figure 2 shows the Weibull probability density and cumulative distribution graphs for January. According to the Figure 2, the wind speed frequency is around 3 m/s. It is observed that the cumulative distribution graph approached 1 around 9 m/s.

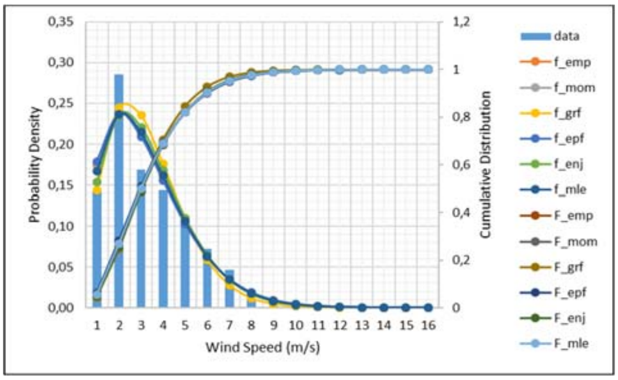

Figure 2. Weibull probability distribution and cumulative graphs for January

Figure 3 shows the Weibull probability density and cumulative distribution graphs for February. According to the Figure 3, the wind speed frequency is around 2 m/s. It is observed that the cumulative distribution graph approached 1 around 8 m/s.

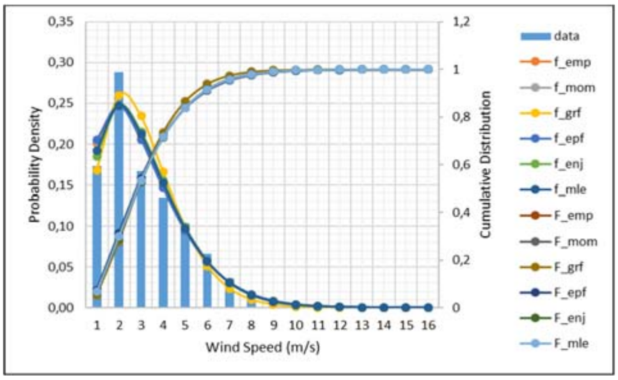

Figure 3. Weibull probability distribution and cumulative graphs for February

Figure 4 shows the Weibull probability density and cumulative distribution graphs for March. According to the Figure 4, the wind speed frequency is around 2 m/s. It is observed that the cumulative distribution graph approached 1 around 8 m/s.

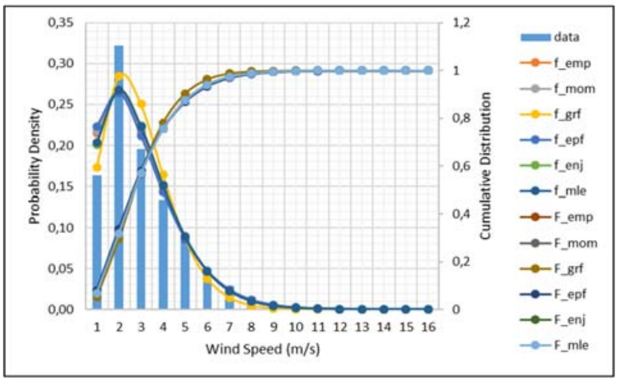

Figure 4. Weibull probability distribution and cumulative graphs for March

Figure 5 shows the Weibull probability density and cumulative distribution graphs for April. According to the Figure 5, the wind speed frequency is around 2 m/s. It is observed that the cumulative distribution graph approached 1 around 6 m/s.

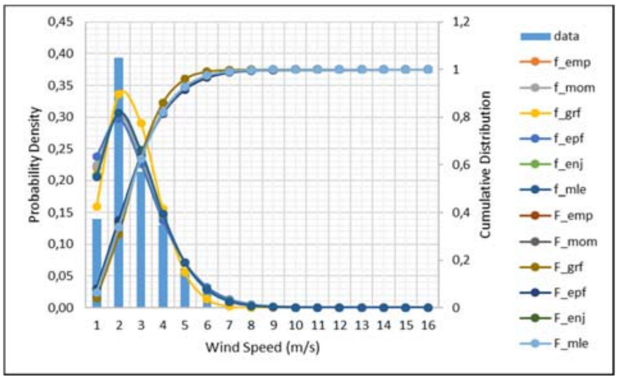

Figure 5. Weibull probability distribution and cumulative graphs for April

Figure 6 shows the Weibull probability density and cumulative distribution graphs for May. According to the Figure 6, the wind speed frequency is around 1 m/s. It is observed that the cumulative distribution graph approached 1 around 5 m/s.

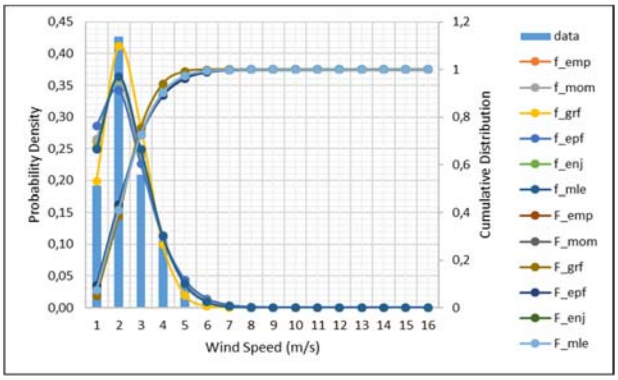

Figure 6. Weibull probability distribution and cumulative graphs for May

Figure 7 shows the Weibull probability density and cumulative distribution graphs for June. According to the Figure 7, the wind speed frequency is around 2 m/s. It is observed that the cumulative distribution graph approached 1 around 5 m/s.

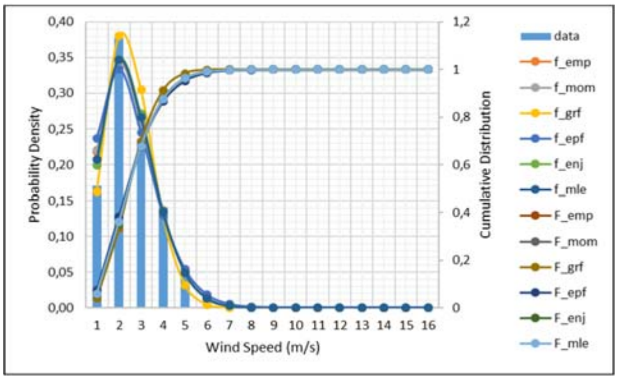

Figure 7. Weibull probability distribution and cumulative graphs for June

Figure 8 shows the Weibull probability density and cumulative distribution graphs for July. According to the Figure 8, the wind speed frequency is around 3 m/s. It is observed that the cumulative distribution graph approached 1 around 7 m/s.

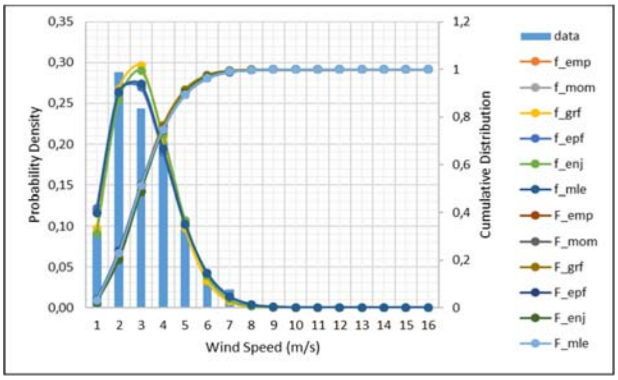

Figure 8. Weibull probability distribution and cumulative graphs for July

Figure 9 shows the Weibull probability density and cumulative distribution graphs for August. According to the Figure 9, the wind speed frequency is around 2 m/s. It is observed that the cumulative distribution graph approached 1 around 6 m/s.

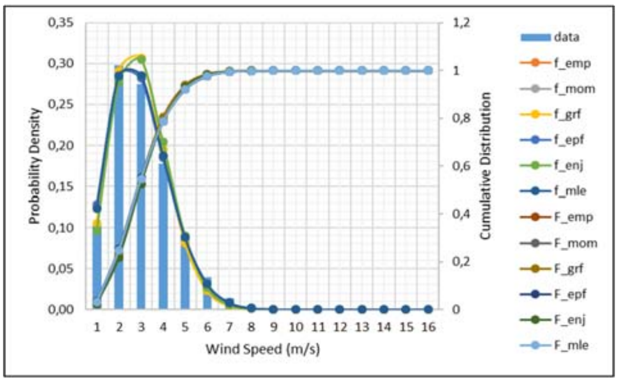

Figure 9. Weibull probability distribution and cumulative graphs for August

Figure 10 shows the Weibull probability density and cumulative distribution graphs for September. According to the Figure 10, the wind speed frequency is around 2 m/s. It is observed that the cumulative distribution graph approached 1 around 6 m/s.

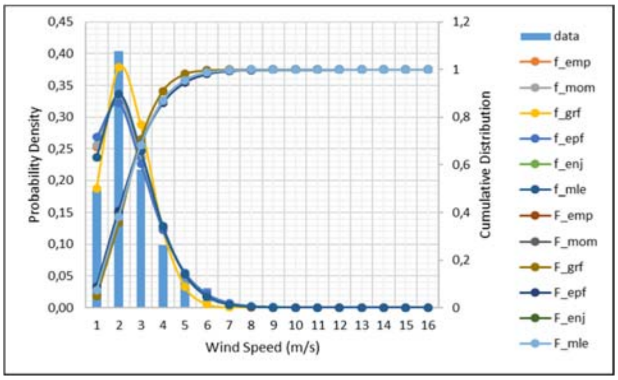

Figure 10. Weibull probability distribution and cumulative graphs for September

Figure 11 shows the Weibull probability density and cumulative distribution graphs for October. According to the Figure 11, the wind speed frequency is around 2 m/s. It is observed that the cumulative distribution graph approached 1 around 5 m/s.

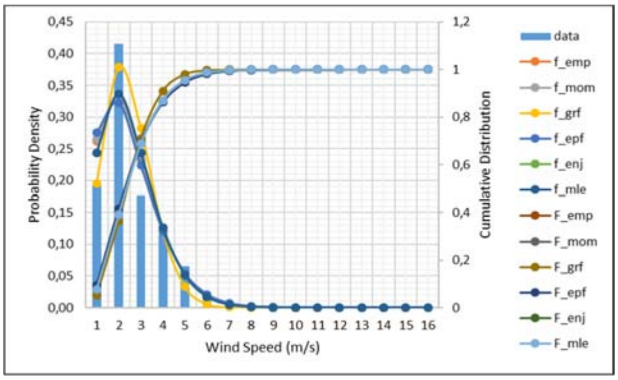

Figure 11. Weibull probability distribution and cumulative graphs for October

Figure 12 shows the Weibull probability density and cumulative distribution graphs for November. According to the Figure 12, the wind speed frequency is around 2 m/s. It is observed that the cumulative distribution graph approached 1 around 6 m/s.

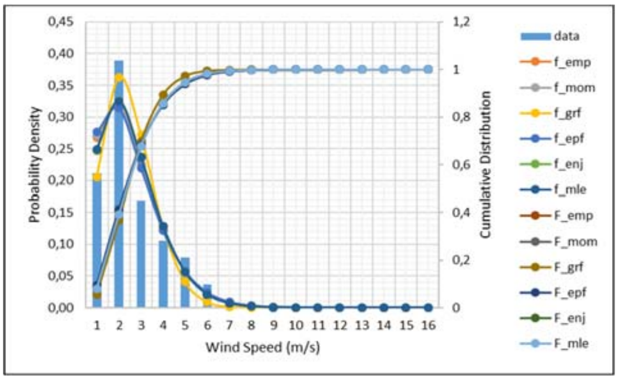

Figure 12. Weibull probability distribution and cumulative graphs for November

Figure 13 shows the Weibull probability density and cumulative distribution graphs for December. According to the Figure 13, the wind speed frequency is around 2 m/s. It is observed that the cumulative distribution graph approached 1 around 8 m/s.

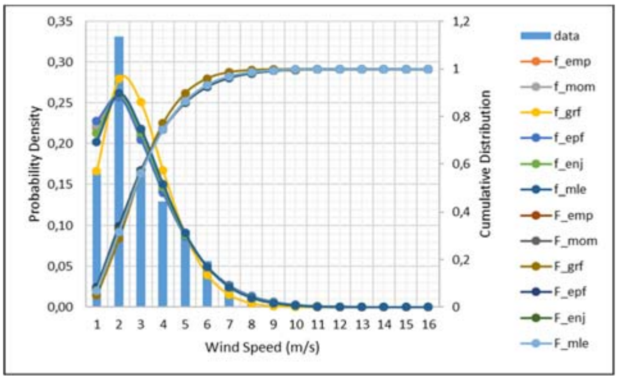

Figure 13. Weibull probability distribution and cumulative graphs for December

Figure 14 shows the Weibull probability density and cumulative distribution graphs from June 2015 to May 2020. According to the Figure 14, the wind speed frequency is around 2 m/s. It is observed that the cumulative distribution graph approached 1 around 7 m/s.

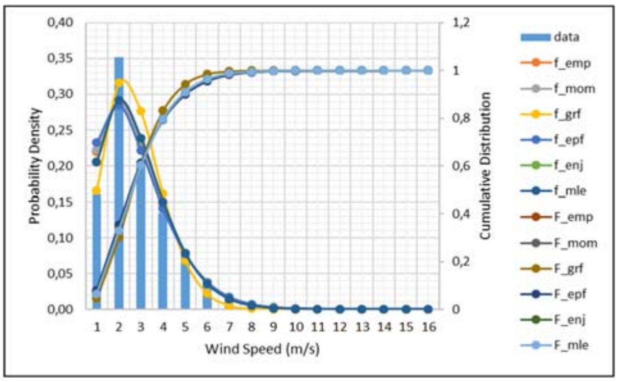

Figure 14. Weibull probability distribution and cumulative graphs from June 2015 to May 2020

6. Conclusion

One of the methods used to analyze the wind characteristics of a region is the Weibull distribution. The most important factor affecting the Weibull distribution is the correct estimation of shape and scale parameters. In this study, shape and scale parameters of Weibull dstribution parameters were calculated using six different parameter calculation methods. These are Justus empirical, moment, graph, energy pattern, energy trend and maximum likelihood estimation methods. In the study, the wind data of the Dinar region recorded hourly between June 2015 and May 2020 were used. According to the calculation results, the lowest value of the shape parameter was calculated as 1,4093, while the highest value was calculated as 2,1619. The lowest scale parameter was calculated as 2,1232, while the highest was calculated as 3,2098. In addition, the performance analysis of the parameter calculation methods was compared with the RMSE, R^2, X^2 and MAE methods. According to the comparison results, maximum likelihood estimation method was found the most successful method. The energy trend method was the second method. Moment and energy pattern methods have been unsuccessful.

Acknowledgment

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