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TÜRKİYE'DE MARDİN VE POLATLI BÖLGELERİNİN RÜZGAR ENERJİSİ GÜÇ POTANSİYELİ

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ÖZET

Rüzgâr enerji potansiyeli ülkemizde yüksek olmasına rağmen rüzgâr enerjisi kullanımı ile elektrik enerjisi üretimi oldukça azdır. Bu yüzden rüzgâr gücüne dayalı olarak yapılan çalışmalardan elde edilen sonuçlar son derece önemli hale gelmiştir. Bu çalışmada Devlet Meteoroloji Genel Müdürlüğü'nden elde edilen verilere göre Türkiye'deki iki bölgenin rüzgâr enerji potansiyeli tahmin edilmiştir. İlk olarak Kolmogorov-Smirnov (K-S) ve Anderson-Darling (A-D) uygunluk testleri ile rüzgâr hızı verileri için uygun dağılım belirlenmiştir. Rüzgâr hızı verileri için Weibull dağılımının en uygun dağılım olduğu saptanmıştır. Literatürde genel olarak kullanılan düzeltilmiş en çok olabilirlik, en küçük kareler ve moment yöntemleri ile Weibull dağılımının parametreleri tahmin edilmiştir. Elde edilen bu parametreler güç yoğunluğu fonksiyonunda yerine koyularak bu iki bölge için güç yoğunluğu hesaplanmıştır. Bu çalışma incelenen bölgelerin rüzgâr enerji potansiyelleri konusunda yaklaşık olarak bilgi vermektedir. Çalışmanın sonucu, Mardin ilinin rüzgâr enerjisi potansiyeli bakımından yatırımcılar için uygun bir bölge olduğunu göstermektedir.

Anahtar Kelimeler: Rüzgâr Enerjisi, Parametre Tahmini, Güç, Weibull Dağılımı

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WIND ENERGY POWER POTENTIAL OF MARDİN AND POLATLI REGIONS IN TURKEY

ABSTRACT

Despite the high wind energy potential in Turkey, electric power generation using wind energy is quite low. Thus, the results obtained from studies on wind power have become extremely important. In this study, the wind power of two regions in Turkey was estimated in accordance with the data obtained from Turkish State Meteorological Service. First, suitable distribution for wind speed data was specified by Anderson-Darling (A-D) and Kolmogorov-Smirnov (K-S) goodness-of-fit tests. The Weibull distribution was determined to be the best fit distribution for wind speed data. The parameters of the Weibull distribution were estimated by the modified maximum likelihood, least squares and moment methods, which are widely used in the literature. The parameters obtained were placed in the power density function and the power density was computed for the two regions. This study provides approximate information about the wind energy potential of the regions examined. The result of the study indicates that with respect to its wind energy potential, Mardin is a suitable region for investors.

Keywords: Wind Energy, Parameter Estimation, Power, Weibull Distribution

1. INTRODUCTION

Energy can be classified under two different headings as renewable energy sources and traditional energy sources. The use of coal, oil, and natural gas increased day by day, in particular coinciding with the rapid industrial developments in the 19^{th} century. The need for new and renewable energy sources has made itself more evident each passing day along with the increasing consumption of natural energy sources (Nayir and Peçen, 2011).

Wind energy is one of the world's most important renewable energy sources (Şahin, Dinçer and Rosen, 2006). With its widespread use, especially between 1990 and 2000, wind has become the most invested-in energy resource (Koçaslan, 2010). The need for electricity is also increasing due to the advancing technology worldwide. Since current fossil fuels used for the generation of electric power are limited, being depleted day by day and will be exhausted one day, electric energy saving efforts are carried out and studies on electric power generation using renewable energy sources continue at a rapid pace (Yıldırım, Gazibey and Güngör, 2012).

Determining the blowing duration of wind speed in a region is one of the most important parameters for the energy obtained. By determining the frequency distribution of the wind speed in a region, the most suitable wind energy conversion system for the region can be selected. The most economic outcomes can be achieved by determining the appropriate distribution for the region. In recent years, the two-parameter Weibull distribution is a method used to represent the blowing durations of wind speed in many regions of the world. The Weibull distribution is used due to its very good fit to wind distribution, easy determination of the parameters, and its being a two-parameter method (Çetin, 2001). In line with these developments, many researchers in the world and in Turkey have conducted several studies on wind speed and wind energy potential by using different statistical analysis and different techniques.

Chang (2011) compared six numerical methods widely used to estimate Weibull parameters while İslam, et al. (2011) assessed wind energy potentiality in Kudat and Labuan regions of Malaysia in 2006-2008 through the two-parameter Weibull distribution and suggested that these regions were not suitable for large-scale wind energy generation. Another study investigating the best fit distribution for the wind speed data recorded on a daily basis in Islamabad, Pakistan compared six distributions (two parameter Gamma, Rayleigh, Weibull, Lognormal, three parameter Burr and Frechet distributions) and assessed the agreement of the results with other studies in the literature. The aforementioned study also concluded that the Weibull and Rayleigh distributions were inappropriate for the region (Abbas, et al., 2012). Karagali, et al. (2014), on the other hand, analyzed the wind speed data obtained over a period of 10 years from the QuikSCAT satellite for the North and Baltic Seas, and used it demonstrate the applicability of scatterometer observations and data in the mapping of North and Baltic Sea wind sources. The results of this study not only possessed a long-term applicability and usability, but also demonstrated the importance of satellite observations when observing and analyzing larger areas.

As for studies conducted in Turkey, Çelik (2003) statistically analyzed the wind energy potential of Iskenderun according to the hourly time series records of wind speed measured over one year. Yılmaz, et al. (2005) investigated the fitness of the Weibull distribution used without performing statistical analysis in many studies for the five different regions selected from Turkey Wind Energy Potential Atlas (REPA). Sahin, et al. (2005) calculated the wind energy potential of seven regions through the hourly measured wind speed data over a period from 1992 to 2001.

The wind energy potential was investigated in the following studies using the Weibull and Rayleigh distributions and conducted by Akpınar and Akpınar (2005) for the mean hourly time series of wind speed data measured in Elaziğ, Agin, Maden, and Keban regions in 1998-2003; by Kurban, et al. (2007a) for the hourly wind speed data measured in the Iki Eylül Campus of Anadolu University over four months in 2005; and by Gülersoy and Çetin (2010) for the hourly wind speed data in Menemen over a period from 2008 to 2009. The said studies also concluded that the regions examined were suitable for wind energy potential.

In another study, using three goodness-of-fit tests (Kolmogorov-Smirnov, Anderson-Darling ve Chi-Square test) and a graphic method, Yılmaz and Çelik (2008) examined and compared ten distributions in order to find the statistical distribution that best represents the wind speed data of Gelibolu region.

The purpose of this study is to statistically estimate the wind speed distribution for the wind power stations in the regions of Mardin and Polatli(see Figure 1) using the mean hourly wind speed data of the aforementioned stations obtained from the Turkey Wind Energy Potential Atlas (REPA) of the Turkish State Meteorological Service, and to provide potential investors with information about the wind energy potential of these provinces by calculating the energy density with the help of this distribution.

2. METHODS AND MATERIALS

The present study converted the wind speed data measured at a height of 10 meters in Mardin and Polatli regions in 1989-1998, obtained from Turkish State Meteorological Service, to 50 meters and analyzed the wind energy potential of these regions. The suitable statistical distribution for the wind data is presented in this section. The distribution parameters are theoretically shown in Section 2. The results of parameter estimates and power values are explained in Section 3. The locations of Mardin and Polatlı regions on the map are shown in Figure 1.

Figure 1: Mardin and Polatlı Regions in Turkey

2.1. Data Description

In this study, the hourly wind speed data of Mardin and Polatli regions measured in 1989-1998 was obtained. For the two regions with the same highest wind speed recorded, the data measured at a height of 10 meters was converted to 50 meters. Using the blowing durations of wind speed normalized over 1000 hours and divided by the speed ranges, and the midpoints of these speed ranges, parameter estimation and power calculation were performed for the data.

The wind speed at any height is calculated by the following Eq. using the wind speed measured at a certain height (Adekoya and Adewale, 1992).

$$\frac{v_1}{v_2} = \left[\frac{H_1}{H_2}\right]^{k_1}$$

H_1 : The height at which the wind speed is measured (m).
H_2 : The height at which the wind speed is to be calculated (m).
v_1 : The wind speed measured at H_1 height (m/s).
v_2 : The wind speed to be calculated for H_2 height (m/s).
k_1 : Roughness coefficient

The roughness coefficient varies depending on the topography and surface structures of the measuring point's vicinity.

2.2. Fit to Distribution

The goodness of fit tests (K-S and A-D) and standard error values of the mean hourly wind speed data of Mardin and Polatli regions concerning the years 1989-1998 were first calculated by statistical package programs for five distributions (Weibull, Gamma, Lognormal, Loglogistic, and Exponential) and then compared. The goodness of fit results are shown in Table 1, Table 2 and Table 3.

Table 1: Goodness of fit test with Minitab package program

	Mardin			Polatlı		
Distribution	Anderson-Darling test value	Correlation coefficient	Standard error	Anderson-Darling test value	Correlation coefficient	Standard error
Weibull	11.594	0.973	0.0839	35.971	0.925	0.0579
Log-normal	22.571	0.959	0.1147	45.145	0.946	0.0881
Log-logistics	23.117	0.954	0.1119	51.079	0.930	0.0867
Exponential	171.533	*	0.1073	88.476	*	0.0780

Table 2: Goodness of fit test with Easyfit package program

	Mardin				Polatlı			
Distribution	Kolmogorov-Smirnov		Anderson-Darling		Kolmogorov-Smirnov		Anderson-Darling	
	Statistics	Rank	Statistics	Rank	Statistics	Rank	Statistics	Rank
Weibull	0.09906	1	2.8837	3	0.13142	1	9.8135	4
Log-normal	0.10455	2	2.9191	4	0.15018	2	9.2569	3
Log-logistics	0.14987	3	2.1850	2	0.17639	3	6.7052	2
Exponential	0.26499	4	1.9942	1	0.24102	4	6.4116	1

Table 3: Goodness of fit test with Weibull++8 package program

Distribution	Mardin	Polatlı
	Rank	Rank
Weibull	1	2
Log-normal	2	4
Log-logistics	3	3
Exponential	4	1

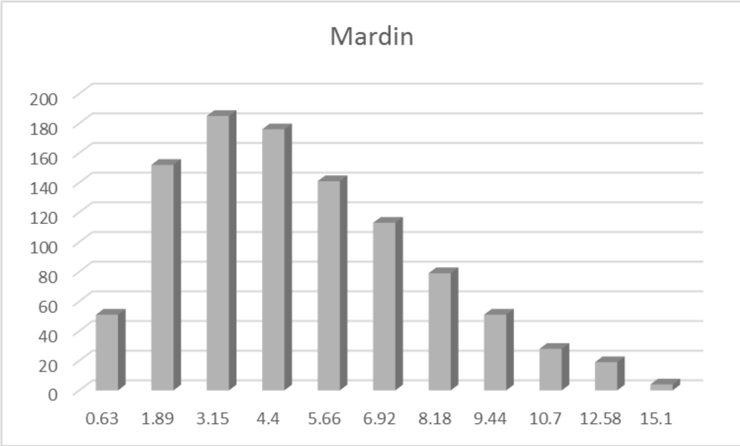

Figure 2: The frequency distribution according to wind speeds for Mardin region.

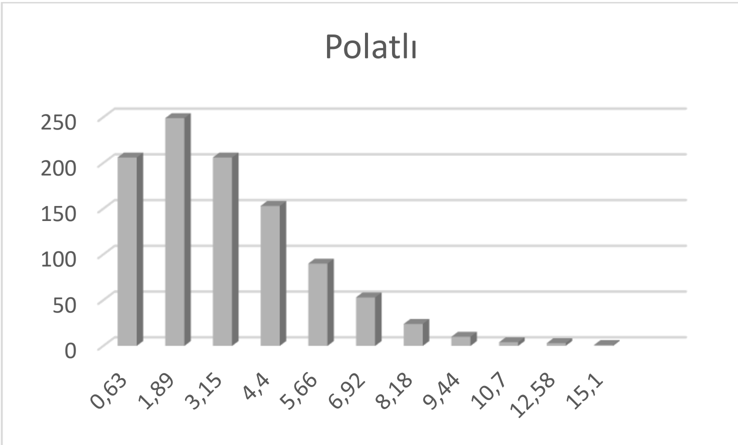

Figure 3: The frequency distribution according to wind speeds for Polatlı region.

The Weibull distribution was accepted as the best-fit statistical distribution at a significance level of 1% as a result of the comparison made by applying K-S and A-D goodness of fit tests to the hourly wind speed values of the regions of Mardin and Polatli with the help of statistical package programs (Minitab, EasyFit and Weibull++8).

3. METHODOLOGY

3.1. Weibull Distribution and Parameter Estimation Methods

To determine the wind potential of a particular area, wind speed distribution measurement or frequency distribution, if available, are used. If wind speed measurement or frequency distribution is not available, wind speed distribution can be represented by other distribution functions. The Weibull distribution is one of them (Gülersoy and Çetin, 2010). The probability density function (pdf) of the two-parameter Weibull distribution is as Eq. (1):

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

$f(v)$ is the probability density of v wind speed, k is the dimensionless shape parameter, and c is the scale (m/s) parameter. The cumulative density function (cdf) of the two-parameter Weibull distribution is represented as Eq. (2) (Akdağ and Güler, 2008):

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

If the shape parameter $k = 2$, this distribution is known as Rayleigh distribution (Akpınar and Akpınar, 2005). Statistical parameter estimation methods commonly used in practices will be detailed in the following section.

3.1.1. Moment Method

For the moment method, the scale and shape parameters can be estimated using Eq. (3) and Eq. (4) when the mean wind speed $\left(\overline{V}\right)$ and standard deviation $\left(\sigma\right)$ are available.

$$\hat{k} = \left(\frac{\sigma}{\overline{V}}\right)^{-1,086} \quad 1 \le k \le 10 \tag{3}$$

$$\hat{c} = \frac{\overline{V}}{\Gamma(1+\frac{1}{\hat{k}})} \tag{4}$$

Since k shape parameter and c scale parameter are related to $\overline{V}$ and σ, Eq.(5) and Eq.(6) can be written as:

$$\overline{V} = \hat{c}\Gamma(1+\frac{1}{\hat{k}}) \tag{5}$$

$$\left(\frac{\sigma}{\overline{V}}\right)^2 = \left[\frac{\Gamma(1+\frac{2}{\hat{k}})}{\Gamma(1+\frac{1}{\hat{k}})^2}\right] - 1 \tag{6}$$

The gamma function is as Eq.(7):

$$\Gamma(x) = \int_0^\infty e^{-u} u^{x-1} du \tag{7}$$

The mean and standard deviation of wind speed can be respectively calculated by Eq.(8) and Eq.(9) (Kurban, Hocaoğlu and Kantar, 2007a; Islam, Saidur and Rahim, 2011; Yıldırım, Gazibey and Güngör, 2012):

$$\overline{V} = \left(\frac{1}{n}\sum_{i=1}^{n} v_i\right) \tag{8}$$

$$\sigma = \left[\frac{1}{n-1}\sum_{i=1}^{n}(v_i - \overline{V})\right]^{0,5} \tag{9}$$

3.1.2. Modified Maximum Likelihood Method

If the wind speed is in the form of frequency distribution, modified maximum likelihood method is one of the most suitable methods to estimate parameters. The parameters of the two-parameter Weibull distribution can be estimated by modified maximum likelihood method using Eq.(10) and Eq.(11):

$$\hat{k} = \left[\frac{\sum_{i=1}^{n} v_i^{\,k} \ln(v_i) f(v_i)}{\sum_{i=1}^{n} v_i^{\,k} f(v_i)} - \frac{\sum_{i=1}^{n} \ln(v_i) f(v_i)}{f(v \geq 0)} \right]^{-1} \tag{10}$$

$$\hat{c} = \left(\frac{1}{f(v \geq 0)} \sum_{i=1}^{n} v_i^{\,k} f(v_i) \right)^{1/\hat{k}} \tag{11}$$

v_i represents the wind speed at line i, n is the number of lines, $f(v_i)$ represents the wind speed proportional frequency changing at line i, and $f(v \geq 0)$ represents the probability of wind speeds greater than or equal to zero (Chang, 2011).

3.1.3. Method of Least Squares

The method of least squares is one of the methods commonly used in the parameter estimation. Although the method of least squares gives quite good solutions in larger sample sizes, it fails to satisfy in small sample sizes when compared with other methods. For the two-parameter Weibull distribution, where $i = 1,2, \ldots, n$ the cumulative distribution function can be written as:

$$F(v_i) = 1 - \exp\left(-\frac{v_i^{\,k}}{c^k} \right) \tag{12}$$

Using Eq.(12), if the natural logarithm of the following Eq.(12) and Eq.(14) is taken,

$$1 - F(v_i) = \exp\left(-\frac{v_i^{\,k}}{c^k} \right) \tag{13}$$

$$[1 - F(v_i)]^{-1} = \exp\left(\frac{v_i^{k}}{c^k} \right) \tag{14}$$

and if the natural logarithm of Eq.(15) is retaken,

$$-ln\left[1 - F(v_i)\right] = \frac{v_i^{\,k}}{c^k} \tag{15}$$

It gives the following elution:

$$ln\left[-ln\left[1 - F(v_i)\right]\right] = -k \ln c + k \ln v_i \tag{16}$$

It is safe to say that there is a linear relationship between $ln\left[-ln\left[1-F\left(v_i\right)\right]\right]$ and $\ln v_i$ (Ülgen and Hepbaşlı, 2002). Then, the parameters of the two-parameter Weibull distribution are estimated by minimizing Eq.(17):

$$\sum_{i=1}^{n}\left\{ln\left[-ln\left[1-F\left(v_i\right)\right]\right]-n\left[-ln\left[1-E\left(F\left(v_i\right)\right)\right]\right]\right\}^2 \tag{17}$$

In other words, k and c parameters are estimated by Eq.(18) and Eq.(19) (Erişoğlu, 2003):

$$\hat{k}=\frac{n\sum_{i=1}^{n}\ln v_i \ln\left[-\ln\left\{1-F\left(v_i\right)\right\}\right]-\sum_{i=1}^{n}\ln v_i\sum_{i=1}^{n}\ln\left[-\ln\left\{1-F\left(v_i\right)\right\}\right]}{n\sum_{i=1}^{n}\ln v_i^2-\left[\sum_{i=1}^{n}\ln v_i\right]^2} \tag{18}$$

$$\hat{c}=\exp\left[\frac{\hat{k}\sum_{i=1}^{n}\ln v_i-\sum_{i=1}^{n}\ln\left[-\ln\left\{1-F\left(v_i\right)\right\}\right]}{n\hat{k}}\right] \tag{19}$$

3.2.Calculation Power

In wind energy generation, it is quite important to know the current wind conditions of a specific region to convert wind energy into electricity by using wind turbines. A method that will be useful for researchers while evaluating wind energy resources is the estimation of wind power density in the region of interest (Saenko, 2008). For the region, the wind energy potential of which is assessed, the mean wind speed is calculated as:

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

the most frequently observed wind speed:

$$v_{\text{mod}}=c\left(\frac{k-1}{k}\right)^{\frac{1}{k}} \tag{21}$$

the wind speed carrying maximum energy:

$$v_{\max E}=c\left(\frac{k+2}{k}\right)^{\frac{1}{k}} \tag{22}$$

and the mean power density for the Weibull distribution:

$$P_{W/\rho A}=\frac{1}{2}c^3\Gamma\left(\frac{k+3}{k}\right) \tag{23}$$

A (m^2) represent the sweep area, and ρ (kg/m^3) is the air density calculated based on the location, pressure and temperature of the region (Kurban, Kantar and Hocaoğlu, 2007b).

4. RESULT

4.1.Parameter Estimation

For the Weibull distribution parameters of the wind speeds converted to 50 meters by using the hourly wind speed data, parameter estimation was made based on the modified maximum likelihood, least squares and moment methods. Table 4 shows the estimated parameter values.

Table 4: Parameter estimation based on the parameter estimation methods

Regions	Parameters	Moment Method	Modified Maximum Likelihood Method	Method of Least Squares
Mardin	***k***	1.872	1.852	1.860
	c	5.619	5.667	5.620
Polatlı	***k***	1.485	1.482	1.480
	c	3.528	3.527	3.530

Error analysis are required to determine which shape and scale parameters obtained using the modified maximum likelihood, least squares and moment methods are better fit for the actual data. The three methods studied in the present research were analyzed by R-squared (R^2) and Root Mean Square Error (RMSE) error analyses. The R^2 and RMSE error analyses are calculated by using Eq.(24) and Eq.(25), respectively.

$$R^2 = 1 - \frac{\sum_{i=1}^{n}\left(y_i - x_i\right)^2}{\sum_{i=1}^{n}\left(y_i - \bar{y}\right)^2} \tag{24}$$

$$RMSE = \left[\frac{1}{n}\sum_{i=1}^{n}\left(y_i - x_i\right)^2\right]^{0,5} \tag{25}$$

Here, n represents the number of observations, y_i represent the actual values in line i., while x_i represent the values determined by the Weibull distribution. The distribution function where R^2 value is close to 1 and RMSE value is small is regarded as the best distribution function (Akpınar, 2006; Akdağ and Güler, 2008).

Table 5 indicates that the R^2 value of the method of LS for both regions is the highest, while the RMSE value is the lowest. With $k = 1.86$, $c = 5.62$ for Mardin and $k = 1.48$, $c = 3.53$ for Polatli, the method of LS was determined to estimate the Weibull distribution parameters. The wind speed carrying maximum wind energy, the mean wind speed and the most probable wind speed were estimated with the parameters obtained from the method of LS. Table 6 shows the results of the estimation.

Table 5: Error Analysis

		Moment Method	Modified Maximum Likelihood Method	Method of Least Squares
Mardin	R^2	0.990827	0.990256	0.991259
	RMSE	0.005982	0.006166	0.005840
Polatlı	R^2	0.995771	0.995979	0.996133
	RMSE	0.005926	0.005779	0.005667

Table 6: Calculation of Power Based On the Method of Least Squares

	V_{ort}	V_{mod}	$V_{\max E}$	$P_w/\rho A$
Mardin	4.99	3.71	8.32	128.13
Polatlı	3.19	1.65	6.29	45.1026

As a result of these estimations, for Mardin, the mean wind speed was $4.99\ m/s$, the most frequently observed wind speed was $3.71\ m/s$, and the wind speed carrying maximum wind energy was $8.32\ m/s$. For Polatli, the mean wind speed was $3.19\ m/s$, the most frequently observed wind speed was $1.65\ m/s$, and the wind speed carrying maximum wind energy was $6.29\ m/s$. Mardin had the highest value of power density. Figure 4 and Figure 5 show the graphs of the actual distribution and Weibull (1,86;5,62) distribution representing the wind speeds for Mardin and Polatlı region.

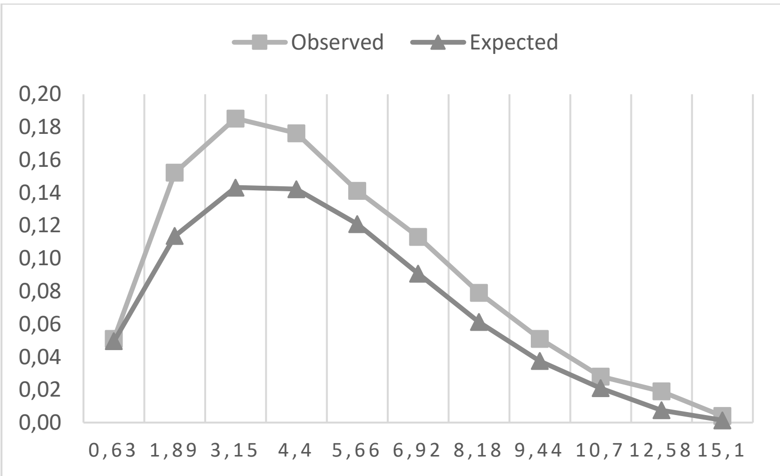

Figure 4: The graph of the actual distribution and Weibull (1,86;5,62) distribution representing the wind speeds of Mardin region.

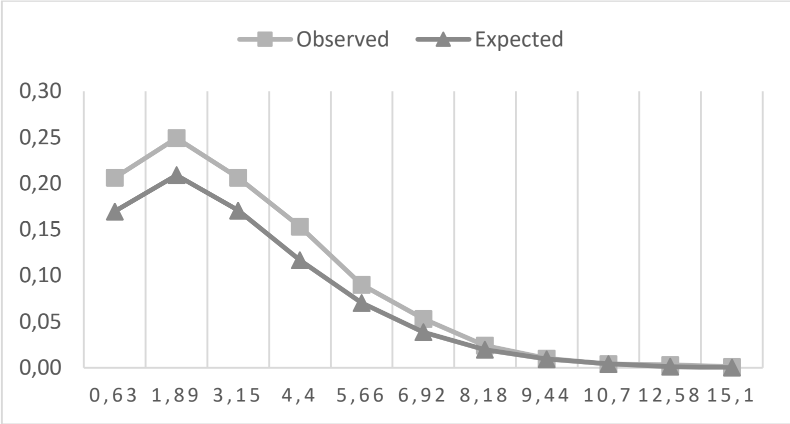

Figure 5: The graph of the actual distribution and Weibull (1,86;5,62) distribution representing the wind speeds of Polatlı region.

Converting the data recorded at a height of 10 meters at Mardin and Polatli in 1989-1998, obtained from Turkish State Meteorological Service, to 50 meters, the present study first specified the suitable statistical distribution for the regions. The Weibull distribution was found to be the best fit distribution for both regions with the help of statistical package programs (Easyfit, Minitab and Weibull++8). Parameter estimation was performed based on the moment method, method of least squares, and modified maximum likelihood method. In order to determine which of the parameters, estimated by using these three methods, were a better fit for the actual data, error analyses were performed for R^2 and RMSE, and the least squares method was ultimately determined as the most suitable method for estimating the Weibull distribution parameters. The wind speed carrying maximum wind energy, the mean wind speed, the most probable wind speed and the power density were estimated with the parameters obtained from the method of LS. The power density of Mardin and Polatli were calculated as $128.13\ W/m^2$ and $45.1026\ W/m^2$, respectively. The power density of Mardin is relatively high when compared with Polatli.

5. CONCLUSION

The smoothness value of the region, where the wind speed is to be measured, also plays an important role in energy estimation. Considering that there will be little or no smoothness in the area where a station is to be built, measurement values and energy estimations may also change. This study provides approximate information about the goodness-of-fit of wind speed data of Mardin and Polatli to the Weibull distribution and the wind energy potential of these regions. The result of the study indicates that with respect to its wind energy potential, Mardin is an extremely suitable region for investors.

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