

Feasibility Study of Wind Energy Potential in Turkey

Case Study of Catalca District in Istanbul

Mohammed Wadi¹, Bedri Kekezoglu², Mustafa Baysal³, Mehmet Rida Tur⁴, Abdulfetah Shobole⁵

^{1,5}Electrical & Electronics Engineering Department, Istanbul Sabahattin Zaim University, Halkalı Mahallesi, Halkalı Caddesi, Halkalı Kampüsü No:2, 34303 Küçükçekmece, Istanbul, Turkey
mohammed.wadi@izu.edu.tr, Abdulfetah.Shobole@izu.edu.tr

^{2,3}Electrical Engineering Department, Yildiz Technical University, Davutpaşa St., 34220 Esenler, Davutpasa, Istanbul, Turkey
bkekez@yildiz.edu.tr, baysal@yildiz.edu.tr,

⁴Electrical Engineering Department, Mardin Artuklu University, Diyarbakır St. Yenişehir Campus, Mardin, Turkey
mridatur@artuklu.edu.tr

Abstract—This paper presents a technical evaluation of the wind potential for the present and the future integration challenges into the Turkey power network. The first part evaluates the feasibility of sites, installments, operation and maintenance. The second part investigates the wind energy integration in the Turkey power network. To determine the potential availability of wind energy in Turkey, feasibility evaluation based on the hourly measured wind speed data for the three years 2008–2010 at 30 m height in Çatalca district is done. These data were obtained from the national meteorology station in Istanbul – the Republic of Turkey are analyzed in order to evaluate the feasibility of wind power potential and to assure supreme assortment of wind turbines installing for the area of interest. Furthermore, the data are extrapolated and analyzed at 60 m and 80 m regarding the variability of the roughness factor. Weibull bi-parameter probability function is used to approximate monthly and annual wind potential and power density based on three calculation methods, namely, the approximated, the graphical and the energy pattern factor methods. The annual mean wind power densities were to be 400.31, 540.08 and 611.02 W/m^2 for 30, 60, and 80 m heights respectively. Simulation results prove that the analyzed area is an appropriate place for constructing large-scale wind farms.

Key words: wind energy, wind speed, wind turbines, feasibility study.

I. INTRODUCTION

Since antiquity, people used windmills to grind grain and to extract ground water. Nowadays, wind is utilized to produce electricity and to provide an alternative source of energy instead of traditional nonrenewable sources, i.e. fossil fuels, which have destructive effects on the environment and the ozone layer (troposphere). Significantly increasing demand of energy and shortage of classical resources have been promoting the governments and the concerned organizations to enhance the quality of the renewable energy and to find alternative solutions such as hydroelectric, wind, solar and biomass energies. Wind is considered as the most increasing technology among the different renewable sources due to its abundance, sustainability and comparatively cost-effectively. The potentiality of wind power is surveyed globally and the installed capacity reached to about 597 GW by 2019 [1]. Before several years, Turkey is one of the countries that has been trying to exploit the wind energy, and this can be noticed by monotonically increasing of installed capacity which reached to 6081 MW by the end of 2016 [2]. Many studies are done in this field; however, these studies are still below the

required level. In [3] a feasibility of wind farms in Izmir was investigated and the study showed that Izmir is feasible for wind farms due to high wind resource capacity and the generating cost which was founded 2.68 US cent/kWh. In [4] wind speed data of Mardin city was analyzed via wavelet functions and the average wind speed was about 3.38 m/s at 10 m height. The study based on two tracks to assess the speed of wind in Mardin, the Weibull function and the continuous Wavelet transform. The two tracks were compared, and the estimation via continuous Wavelet transform was the superior and the closest to measured data. In [5], the wind data in Bahrain were studied for three years based on Weibull probability density function (PDF) and the study proved that the site under consideration is appropriate for small-size turbines at 30 m and for large-size turbines at 60 m. In [6], many techniques were used to assess wind data for Zafarana area in Egypt. The study recommended using the average wind speed and the maximum likelihood techniques in approximating the potentiality of wind. In [7], the paper generally demonstrates the blooming of renewable energy in Europe and especially the wind energy in Sweden. The paper provides an economic evaluation for investing in the field of wind power in Sweden and recommended the Swedish government to simplify the regulations related to investment in this field. In [8], 96 months' wind data for five different areas all over the world were analyzed by using a Weibull function to represent wind data instead of measured data in order to approximate wind potential for small-scale systems. Weibull parameters were approximated monthly based on the gamma function and the error was about 2.79%. In [9], the collected wind data during six years (2004-2009) at Hassi-R'mel in Algeria was analyzed by time-frequency analyses instead of the traditional Fourier analysis due to its capability of following the spectrum diversity with respect to time. Further, both technical and economic studies for Hassi-R'mel site are taken into consideration and the simulation results show that the site is very suitable for generating wind energy. In [10], wind energy potential was analyzed at four zones in two locations in Khorasan in Iran in 2007 at three different height levels every 10 minutes using the Weibull density function. The obtained results show that the four zones have good conditions for power extraction. Also, in [11], in Yazd in Iran, wind speed data for about 13 years at different 11 sites were studied to estimate the potentiality of wind power. The obtained results demonstrated that most of the sites have an annual mean wind speed less than 4.5 m/s , on the contrary the city of Herat has the highest wind potential with annual mean speeds of 5.05 and 6.86 m/s at heights of 10, and 40 m respectively. In [12], adaptive neuro-fuzzy algorithm was used to estimate the wind speed at several heights from 10 to 100m at several locations in the Kingdom of Saudi

Arabia and the mean found absolute error between estimated and measured wind data was 3%.

In this study, in Istanbul, Catalca (Latitude:41.14 N° and Longitude: 28.46 E°) was selected because it could be considered as one of the most viable sites due to high potential of wind capacity. In addition, in order to study the wind power availability in a specific site, wind speed measurements for sufficient period should be recorded. In Catalca, three years 2008-2010 wind speed data obtained from the national meteorology station in Istanbul – Republic of Turkey are analyzed to evaluate the feasibility of the wind potentiality based on three methods, the approximated, the graphical and the energy pattern factor. However, there have been a lot of challenges to integrate wind energy into Turkey power network such as high capital cost, high operational and maintenance (O&M) costs and network durability and reliability.

II. WIND DATA AND ATLAS OF TURKEY

The main advantages of renewable energy that are sustainable, unpolluted, omnipresent, and zero-fuel costs in contrast to fossil fuels. However, the main drawbacks are its variability (unpredictability and inconsistency), difficult to generate large quantity, large tracts of land required and extremely large capital cost needed. Many years ago, exploitation of renewable energy sources in Turkey has been started, but it is still in its initial junctures of development. Despite the theoretical potential energy of wind in Turkey is assessed to be about 90000 MW and the annual energy up to 166 TWh, the total amount of installed wind energy is about 14% [14]. Figure 1 shows a Potential wind energy map of Turkey. This study is one of important studies which highlights wind potential in Istanbul-experiencing a rapid construction and economic boom- therefore, there is an extraordinary demand for energy. This article based on the hourly wind data obtained from the national metrology station at Catalca

for three years (2008-2010) at height 30m as shown in Table 1, and the data were statistically analyzed.

III. WEIBULL PROBABILITY DENSITY FUNCTION

Weibull bi-parameter and Rayleigh PDFs are the most widely used functions to describe wind speed measurements due to their easy calculations of their parameters.

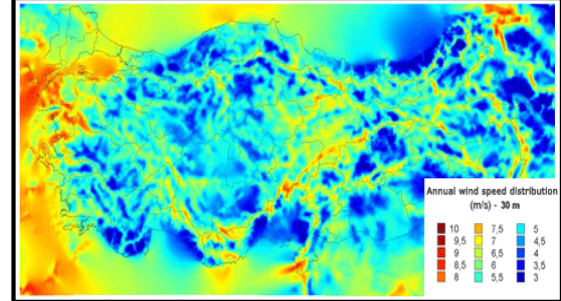


Fig. 1. Potential wind energy map of Turkey [2]

Two-parameter Weibull function depends on two factors, namely, scale and shape parameters while Rayleigh function depends only on one parameter. Weibull function gives more accurate and superior results than Rayleigh; whereas, Rayleigh parameter calculations are simpler. The PDF of a Weibull bi-parameter function is given by [15]:

$$f(v) = \frac{k}{c} \cdot \left(\frac{v}{c}\right)^{k-1} \cdot e^{-\left(\frac{v}{c}\right)^k} \quad (1)$$

where; k is the shape factor, c is the scale factor, and v is the wind speed. While, the CDF is given by [15]:

$$F(v) = 1 - e^{-\left(\frac{v}{c}\right)^k} \quad (2)$$

Table 1. Wind speed frequencies for the height of 30 m for years 2008-2010 in hours Catalca province

Bins	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Month	Frequency in Hours																				
January	28	0	11	58	90	89	69	71	80	45	56	37	40	24	8	9	6	4	1	0	4
February	0	2	32	57	53	81	58	85	79	58	55	35	31	19	18	15	19	16	9	2	5
March	0	4	26	54	78	104	110	74	68	51	31	31	29	29	18	11	6	5	1	0	0
April	0	3	27	52	75	102	112	101	65	36	25	40	30	25	19	10	6	2	0	0	0
May	1	6	37	49	100	125	103	118	65	41	28	12	15	12	5	2	3	1	3	2	0
June	0	9	44	63	142	143	112	77	54	37	20	9	11	6	2	0	1	0	0	0	0
July	0	3	9	27	75	92	86	78	79	61	61	30	29	42	33	10	10	2	3	0	0
August	0	6	31	45	62	88	84	95	81	81	47	34	23	22	9	9	6	3	2	2	0
September	0	10	40	92	89	87	64	71	46	42	14	17	23	127	25	18	20	10	9	8	10
October	0	6	8	19	34	54	51	66	85	50	76	61	50	44	39	30	13	12	7	5	8
November	0	3	12	24	60	102	99	103	111	75	62	29	30	12	6	1	1	0	0	0	0
December	0	4	27	69	98	99	85	77	84	32	40	27	33	19	7	11	7	6	1	0	4
Total	29	56	304	609	956	1166	1033	1016	897	609	515	362	344	271	189	126	98	61	36	19	31

Many methods are used for determining the Weibull parameters, shape factor (k) and scale factor (c) [16]. This paper uses three methods, the approximated, the graphical [3-6] and the energy pattern factor methods [17, 18].

IV. ANALYSIS OF WIND REGIME

Wind energy generation mainly depends on the velocity of wind due to the cubic expression between them. Unfortunately, wind speed, magnitude and direction vary stochastically with time. Hence, real characterization of wind regime is important for both the developer and the designer. Wind speed average is a prefatory indication of the appropriateness of sites' potential. Sites with mean wind speed

at a minimum of 7 m/s are considered as suitable location for wind energy generation [20]. Table 2 provides the annual mean wind speed values at the different heights on Catalca site and it can be noticed that the values are a good indication of wind potential when compared with speed values in [11]. It can be noticed from Tables 3-5 that the lowest mean speed values were in June, 5.18 m/s, 5.71 m/s and 5.95 m/s, while the highest values were in October, 9.20 m/s, 10.15 m/s and 10.58 m/s for 30 m, 60 m and 80 m heights respectively.

Table 2. Average wind speeds annual data at Catalca

Height	30 m	60 m	80 m
Annual Average Speed m/s	6.91	7.65	7.97

V. ESTIMATION OF WIND POWER DENSITY

Wind power density (P_D) is an important marker of the availability of wind power and the energy density (E_D) is the availability of wind power for a unit rotor area and time. Per unit area, the total energy spectra (E_s) can be computed as in [16]. One of the factors that mainly contribute to have the maximum energy is when wind velocity is at its highest level.

Tables 3-5 show the average of power density and the maximum value was found in October, 796, 1072 and 1212 W/m^2 , while the annual average power density was computed to be 400.31, 540.08 and 611.02 W/m^2 for heights 30 m, 60 m and 80 respectively. The average power densities of this site show the suitability of the understudied area for wind power generation when comparing the results with the criteria in [10]. Figures 2–4 show the real PDF, and Weibull PDF based on approximated, graphical and energy pattern factor methods for the heights 30, 60, and 80 m. Based on these PDFs the mean wind speed and their corresponding power can be predicted.

It can be noticed from Fig. 5 that the approximated approach is the closest pattern of collecting data on 30m height; the graphical approach provides the optimal approximation at 60 m height, while the EPF approach is the best at 80 m height. This indicates that the methods which have been used in wind potential estimation vary in accuracy according to data under process and we cannot say that one is the best at all times [19-23].

VI. ESTIMATION OF CAPACITY FACTOR

CF is described by the ratio of the real output power to the nominal power produced by the wind turbine generator [16]. CF is one of the important factors that indicates the maximum efficiency of turbine to benefit from the energy available in the wind spectra and its values locates between 0.25 and 0.40 [24 -31].

Table 3. Comparison between Weibull parameters calculated using different methods for years 2008-2010 at Catalca at a height of 30 m

Methods	Mean Wind Speed, V_m m/s	Standard Deviation, σ	Weibull Approximated k	Weibull Approximated c	Weibull Graphical, k	Weibull Graphical, c	Weibull Pattern, k	Energy	Weibull Pattern, c	Energy
Month										
January	6.74	3.60	1.97	7.60	1.96	7.60	2.17			7.57
February	7.61	4.08	1.96	8.58	1.92	8.57	2.14			8.54
March	6.70	3.37	2.11	7.57	2.06	7.57	2.27			7.53
April	6.62	3.24	2.17	7.48	2.12	7.48	2.33			7.44
May	5.90	2.94	2.13	6.66	1.99	6.65	2.21			6.63
June	5.18	2.38	2.33	5.84	2.25	5.85	2.44			5.82
July	7.50	3.39	2.36	8.45	2.33	8.45	2.50			8.41
August	6.84	3.25	2.24	7.72	2.20	7.72	2.40			7.68
September	7.28	5.06	1.48	8.06	1.1	7.56	1.55			8.18
October	9.20	4.17	2.36	10.37	2.30	10.38	2.49			10.32
November	6.79	2.55	2.89	7.62	2.82	7.63	2.85			7.63
December	6.51	3.46	1.98	7.35	1.91	7.34	2.12			7.32
Total	6.91	3.65	1.99	7.79	1.97	7.85	2.14			7.76

Table 4. Comparison between Weibull parameters calculated using different methods for years 2008- 2010 at Catalca at a height of 60 m

Methods	Mean Wind Speed, V_m m/s	Standard Deviation, σ	Weibull Approximated k	Weibull Approximated c	Weibull Graphical, k	Weibull Graphical, c	Weibull Pattern, k	Energy	Weibull Pattern, c	Energy
Month										
January	7.67	3.41	2.42	8.66	2.11	8.67	2.32			8.62
February	8.42	4.10	2.19	9.51	1.88	9.48	2.14			9.46
March	7.41	3.37	2.35	8.35	2.06	8.36	2.27			8.34
April	7.31	3.25	2.41	8.24	2.12	8.25	2.33			8.22
May	6.51	2.93	2.38	7.35	1.99	7.35	2.21			7.32
June	5.71	2.38	2.58	6.43	2.25	6.45	2.44			6.43
July	8.27	3.36	2.66	9.30	2.33	9.33	2.50			9.31
August	7.56	3.46	2.33	8.53	2.21	8.54	2.40			8.49
September	8.03	4.93	1.70	9.00	1.23	8.60	1.55			9.04
October	10.15	4.17	2.62	11.43	2.24	11.46	2.50			11.41
November	7.50	2.52	3.26	8.36	2.87	8.41	2.85			8.43
December	7.20	3.47	2.21	8.12	1.91	8.11	2.12			8.08
Total	7.65	4.01	2.01	8.63	1.92	8.62	2.15			8.60

Table 5. Comparison between Weibull parameters calculated using different methods for years 2008- 2010 at Catalca at a height of 80 m

Methods	Mean Wind Speed, V_m m/s	Standard Deviatio, σ	Weibull Approximated k	Weibull Approximated c	Weibull Graphical, k	Weibull Graphical, c	Weibull Energy Pattern, k	Weibull Energy Pattern, c
Month								
January	8.00	3.41	2.53	9.01	2.11	9.03	2.32	8.98
February	8.77	4.10	2.29	9.90	1.85	9.87	2.14	9.86
March	7.72	3.37	2.46	8.70	2.05	8.71	2.27	8.66
April	7.61	3.25	2.52	8.58	2.11	8.60	2.33	8.56
May	6.78	2.94	2.49	7.65	1.98	7.66	2.21	7.63
June	5.95	2.39	2.70	6.70	2.25	6.72	2.44	6.70
July	8.62	3.36	2.78	9.68	2.32	9.72	2.50	9.68
August	7.88	3.46	2.44	8.88	2.21	8.90	2.40	8.84
September	8.37	4.93	1.77	9.41	1.29	9.05	1.55	9.42
October	10.58	4.17	2.75	11.89	2.16	11.95	2.50	11.88
November	7.81	2.52	3.42	8.70	2.87	8.76	2.85	8.78
December	7.50	3.48	2.31	8.46	1.90	8.45	2.12	8.42
Total	7.97	4.18	2.01	8.99	1.91	8.98	2.01	8.99

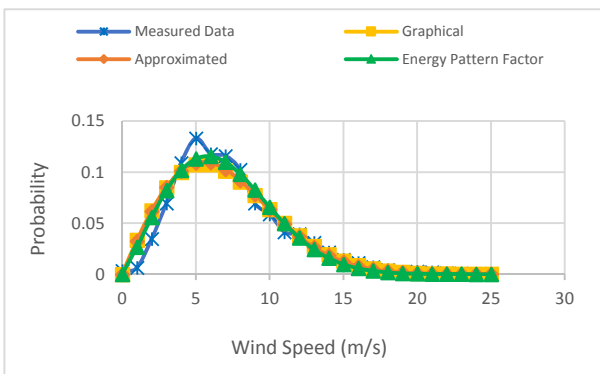


Fig 2. PDFs of wind speeds at 30 m height

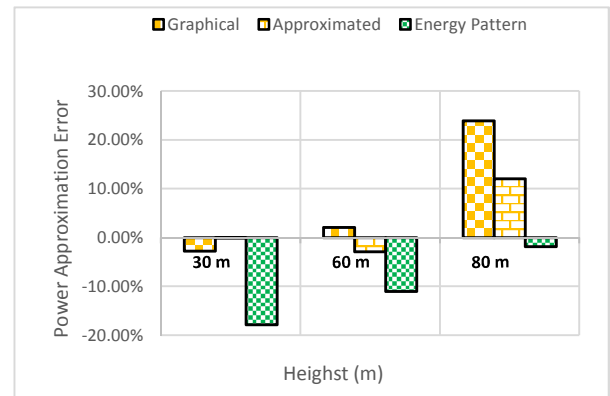


Fig. 5. PDFs approximation error at 30, 60 and 80 m heights

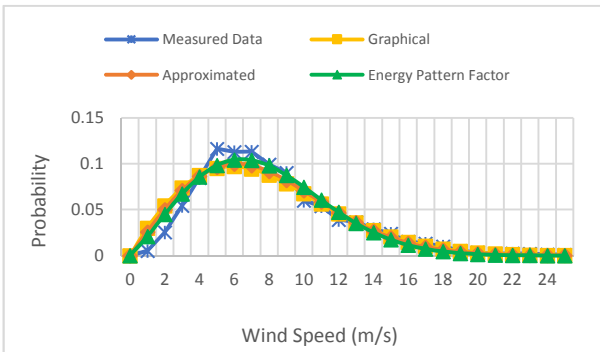


Fig. 3. PDFs of wind speeds at 60 m height

Table 6. Wind turbines data for 60 m and 80 m heights

Turbine No	Rated Power kW	Cut-in Velocity V_{in} , m/s	Cut-out Velocity V_{out} , m/s
I	600	4	25
II	750	4	25
III	1000	5	25
IV	1300	5	25
V	1800	5	25
VI	2000	5	25

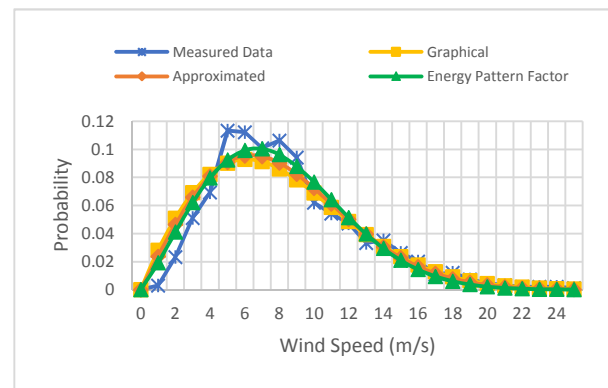


Fig. 4. PDFs of wind speed at 80 m height

In this paper, six different wind turbines are used for measuring CF for 60 m and 80 m heights as illustrated in Table 6. Figures 6 and 7 explain the monthly variation in CF corresponding to 60 m and 80 m heights, while Figure 8 explains both of annual variation in CF that was calculated for wind turbines in Table 6 corresponding to 60 m and 80 m heights. By anatomizing Figures 6 and 7, it can be seen that #V has the maximum monthly CF in October, 63% and 65%, while the minimum monthly CF was in June for turbine #II, 16% and 18% at 60 m and 80 m respectively. Similarly, by examining Fig. 8, it exhibits that turbine #V has the maximum annual CF, 41% and 44%, while the minimum annual CF was for turbine #II, 32% and 35% at 60 m and 80 m respectively.

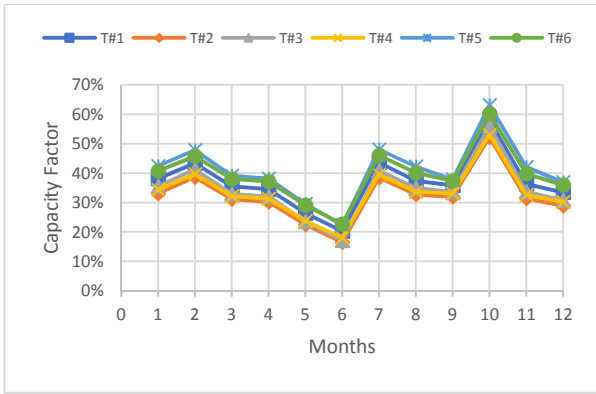


Fig. 6. CF variation on monthly basis at 60m height for wind turbines of Table 6

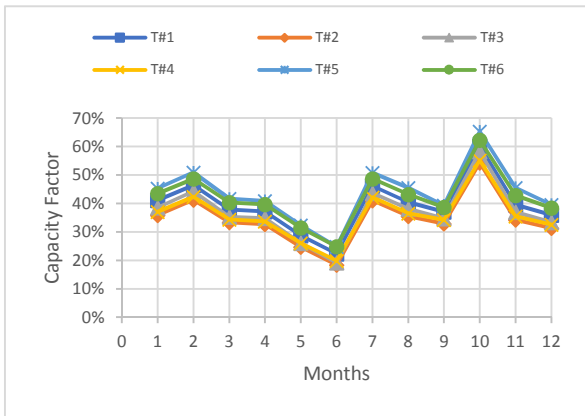


Fig. 7. CF variation on monthly basis at 80m height for wind turbines of Table 6

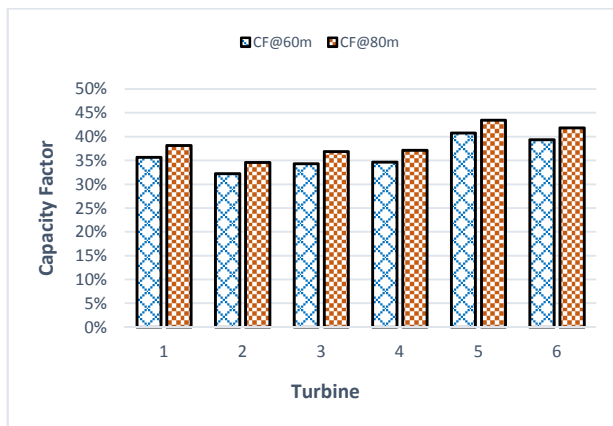


Fig. 8. Annual CF variance at 60 and 80 m heights for wind turbines of Table 6

VII. CONCLUSION

This paper presents a technical evaluation of the wind potential for the present and the future integration challenges into the Turkey power network. The first part evaluates the feasibility of sites, installments, operation and maintenance. The second part investigates the wind energy integration in the Turkey power network. Also, the paper introduces a technical survey of Catalca site in Istanbul, Republic of Turkey. Wind speed and power potential at 30, 60 and 80 m heights that collected during the three years 2008-2010 are statistically analyzed. The lowest mean speed values were in June, 5.18, 5.71 and 5.95 m/s while the highest values were in October, 9.20, 10.15 and 10.58 m/s for 30, 60 and 80 m heights

respectively. Wind potential is modeled via bi-parameter Weibull PDF based on the graphical, the approximated and the energy pattern factor methods. It was found that graphical approach is the most accurate at 60 m height and the approximated approach is the most accurate at 30 m, while the Energy pattern factor is the most accurate at 80 m. In addition, monthly and annually capacity factor was approximated for six different commercial wind turbines and it was found that turbine #V with monthly capacity factor 63% and 65%, and annual capacity factor 41% and 44% at 60 m and 80 m respectively is the suitable turbine. Finally, the most difficult challenges and their necessary solutions are presented.

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