CURRENT SITUATION OF WIND ENERGY IN TURKEY AND ASSESMENT OF YALOVA'S WIND ENERGY POTENTIAL

Cihan GÖKÇÖL[1], Adem UĞURLU[2]

ABSTRACT

According to the wind energy statistics, Turkey has indicated a significant development about wind energy utilization in the last decade. But, it is the fact that Turkey has utilized only 4% of its total technical wind energy potential. Moreover, in order to achieve the wind energy targets in 2023 wind energy exploration activities should be accelerated in every region of Turkey and wind energy utilization in Turkey should be increased. This study aims to determine the wind energy characteristics of a site in Yalova, considering both the statistical formulations in literature and also the one year hourly wind data in time series format which was obtained from the Turkish State Meteorological Service (TSMS) in 2012. To achieve this goal, after having obtained all the wind characteristics of the location such as average wind speed, dominant wind direction, power density values, Weibull parameters (k and c) that act very important role in determining the wind energy profile of any site are calculated by applying one of the widely used methods to the present wind data. Finally, all the findings obtained from the study are discussed in terms of quality and quantity.

Keywords: Turkey, wind energy, Weibull, Wind speed, Wind power

* This paper is prepared based on the study entitled as "Determination of the suitable wind turbine for the location in Yalova, Turkey", that was presented at the 8th Ege Energy Symposium.

[1] Lecturer, kirklareli üniversity, cihan.gokcol@klu.edu.tr
[2] Lecturer, kirklareli üniversity, adem.ugurlu@klu.edu.tr

Introduction

Implementation of the regional wind energy potential and characteristics of a site according to the hourly wind data in time series format has rather importance for being able to make more electricity generation and profit from windy sites. This important operation must be definitely implemented before performing all the required investments on the wind energy generation. Meanwhile wind data must be obtained by installing a wind measurement mast into the considered site and then making measurement for at least one year (Dursun&Gokcol, 2014). It is the fact that the wind data obtained by means of some simulation software programs may be deceptive and can cause failure of investments (significant financial injury to investors). Briefly, determination of wind characteristics of a site shows a significant importance and must be carefully done before establishing a wind power plant.

There have been many studies about determination of regional wind energy potential and characteristics. Kucukali and Dinckal implemented the wind energy resource assessment of Izmit in the West Black Sea Coastal Region of Turkey in this study (Kucukali, S.,& Dinçkal, 2014). Yaniktepe et al. investigated the wind characteristics and wind energy potential in Osmaniye, Turkey (Yaniktepe et al., 2013). Celik reviewed the current energy situation of Turkey and also made a case study for wind energy potential of Çanakkale province (Celik, 2011). Eskin et al. studied the wind energy potential of Gökçeada Island in Turkey (Eskin et al., 2008). Akpınar evaluated the wind energy potentiality at coastal locations along the north eastern coasts of Turkey (Akpinar, 2013). Furthermore, Gokcek et al. investigated the wind characteristics and wind energy potential in Kirklareli, Turkey (Gokcek et al., 2007). Kose performed an evaluation of wind energy potential as a power generation source in Kütahya, Turkey (Köse, 2004). Bilir et al. implemented an investigation on wind energy potential and small scale wind turbine performance at Incek region – Ankara, Turkey (Bilir et al. 2015). Finally, Ilkiliç and Aydın determined the wind power potential and usage in the coastal regions of Turkey (Ilkiliç&Aydın, 2015).

In this study, the wind energy characteristics of a site in Yalova is determined according to the one year hourly wind data in time series format taken from the Turkish State Meteorological Service (TSMS) in 2012 (TSMS, 2012). Firstly, all the wind characteristics (including average wind speed, dominant wind direction, power density and Weibull parameters) are calculated by applying the statistical formulations defined in the section entitled as "Methodology". Weibull parameters (k and c) are calculated using the method of the mean speed-standard deviation. Lastly, all the obtained findings are considered and examined in terms of quality and quantity.

Current situation of wind energy in Turkey

Energy is a very important factor indicating both social and also economic development level of countries all around the World. Therefore, for keeping the sustainable economic and social development, all the countries including also Turkey has to meet the increasing energy demand each year. Figure 1 shows the development of the electricity production of Turkey between 2000 and 2014. As clearly seen in this figure, it has been increasing regularly each passing year. It was about 245Tera Watt Hour in 2013 (Suva et al., 2016).

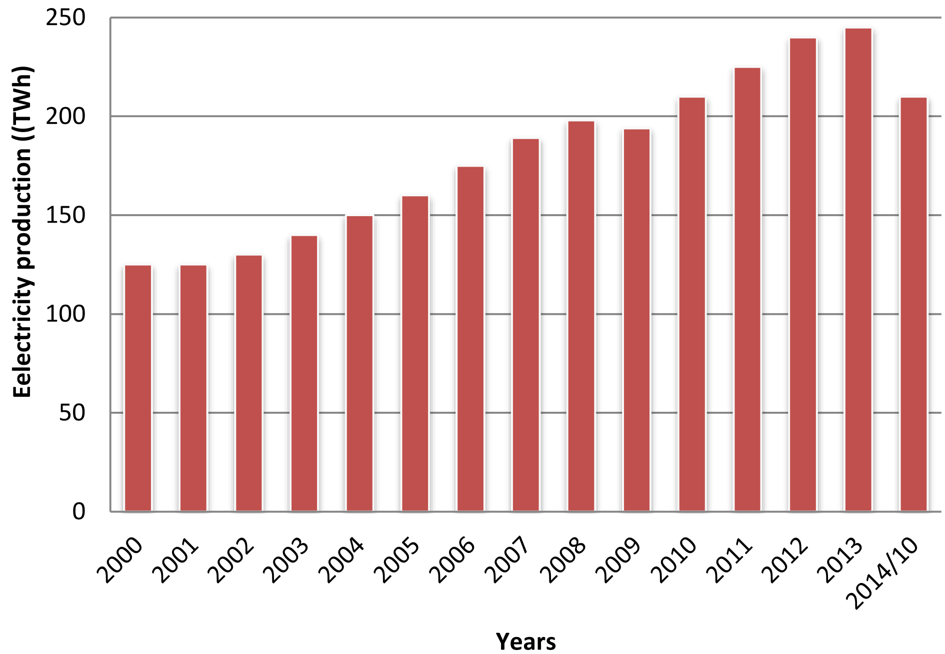

Figure 1: The development of the electricity production of Turkey by years

Since Turkey is not rich of oil and gas reserves, it meets its electricity demand by imports of primary energy resources like oil, gas, coal etc. This situation indicates that Turkey unfortunately has become an energy dependent country. However, nowadays Turkey has explored and utilized its own numerous renewable energy resources like wind, solar, biomass. Especially wind energy has been widely used in Turkey. In Table 1, technical wind energy potentials of European countries are given and it is especially noticed that Turkey has the first place among the European countries regarding the wind energy potential (Suva et al., 2016).

Table 1: Technical wind energy potential of the European countries including Turkey (Suva et al., 2016; MENR, 2015)

Countries	Land potential	Seashore Potential	Technical Potential	
	1000 km^2	km^2	MW	TWh/year
Turkey	781	9,960	88,000	166
England	244	6,840	57,000	114
Spain	505	5,120	43,000	86
France	547	5,080	42,000	85
Norway	324	4,560	38,000	76
İtaly	301	4,160	35,000	69
Greece	132	2,460	22,000	44
Ireland	70	2,680	22,000	44
Sweden	450	2,440	20,000	41
Island	103	2,080	17,000	34
Denmark	43	1,720	14,000	29

Germany	357	1,400	12,000	24
Portugal	92	880	7,000	15
Finland	337	440	4,000	7
Netherland	41	400	3,000	7
Austria	84	200	2,000	3
Belgium	31	280	2,000	5
Swiss	41	80	1,000	1

Although Turkey has a great technical wind energy potential of 88GW, she has utilized only 4% (corresponding to 3512 MW) of the total wind energy potential as of October 2014. Figure 2 shows the development of wind energy utilization in Turkey between 2004- October 2014 (Toklu, 2013).

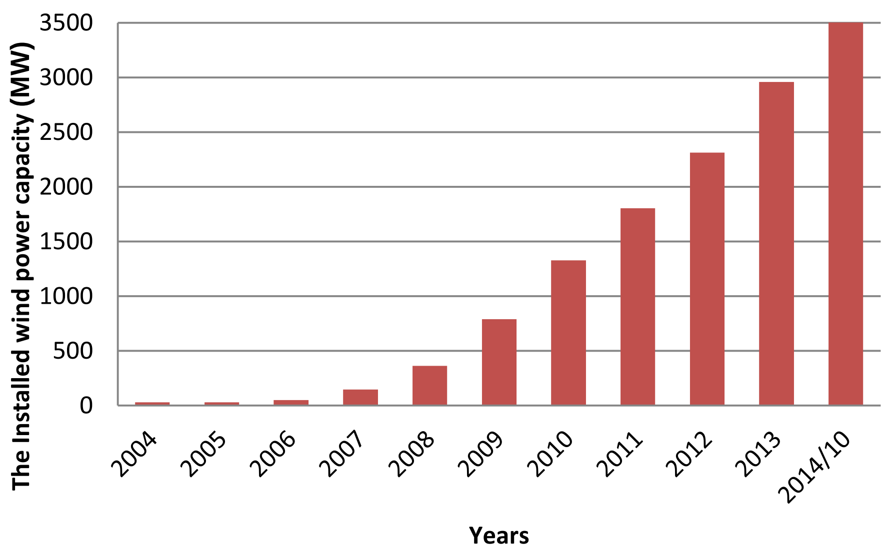

Figure 2: The development of wind energy utilization in Turkey by years [11, 13]

According to Figure 2, it can be easily expressed that a dramatically increase in the installed wind power capacity of Turkey has been experienced in the last decade (from 20 MW in 2005 to 3512 MW in 2014). But, this significant development about wind energy utilization in Turkey is fairly small considering its great wind energy potential (Suva et al., 2016; Toklu, 2013).

Although Turkey whose electric energy demand is continuously increasing each year (indicated in Figure 1) has a great amount of wind energy potential (indicated in Table 1), unfortunately there has been no sufficient development of the wind energy utilization in Turkey. Therefore, it seems fairly difficult for Turkey to achieve the tough wind energy targets in 2023 that will be the 100th anniversary of the Turkish Republic. Meanwhile, the total amount of wind energy utilization in Turkey in 2023 is foreseen to become 20,000 MW while it was about 3500MW as of October 2014 (Suva et al., 2016). Due to all the facts about the wind energy in Turkey as well as the increasing electricity demand of Turkey, every wind in any site in Turkey, that may provide feasible electricity supply, should be absolutely evaluated by establishing small or large wind power plants. In this context, the first and necessary step is both to make much more wind energy exploration in every part of Turkey and also to determine the wind energy characterization of the wind sites.

Methodology

While determining both the wind energy potential of the region and also its economical suitability, first of all, it is required to estimate the wind speed probability distribution function. There are some probability functions in literature like Weibull, Rayleigh, Gamma distributions. In this study, Weibull distribution function is utilized to describe the wind speed frequency distribution because of its following properties: more simple applicability and better accuracy. The Weibull probability density function is given in the following equation (Suva et al., 2016).

$$p(u) = \left(\frac{k}{c}\right)\left(\frac{U}{c}\right)^{k-1} \exp\left[-\left(\frac{U}{c}\right)^{k}\right] \qquad [1]$$

Where, $p(u)$ denotes the wind speed probability, U represents speed, k is a shape parameter (dimensionless) and c is scale factor (m/s).

There are various analytical and empirical methods in literature which are used for obtaining k and c. In this study, the mean speed-standard deviation method is utilized to determine the Weibull parameters. The governing equations of this method are given in the following equations (Dursun&Gokcol, 2012).

$$\sigma_U = \sqrt{\frac{\sum_{i=1}^{N}(U-\bar{U})^2}{N-1}} \qquad [2]$$

$$k = \left(\frac{\sigma_U}{\bar{U}}\right)^{-1.086} \qquad [3]$$

$$\frac{c}{\bar{U}} = \frac{k^{2.6674}}{0.184+0.816k^{2.73855}} \qquad [4]$$

Where, σ_U and U denote the standard deviation and mean wind speed, respectively, and N is the number of data.

Other important factors in the determination of the wind energy characteristics of a site are average wind speed, average power density, dominant wind direction, wind speeds at different heights (power law model). These parameters are calculated by using the following equations related to the interested parameter.

Average wind speed of a location can be usually calculated by using the following equation (Dursun&Gokcol, 2012).

$$V_m = \frac{\sum_i^n f_i V_i}{\sum f} \qquad [5]$$

The following equation called as “Power law formulation” is used to determine the wind speed values for different heights considering the wind speed data measured at 10m (Suva et al., 2016; Dursun&Gokcol, 2012).

$$\frac{V}{V_0} = \left(\frac{h}{h_0}\right)^{\propto} \qquad [6]$$

Where, alpha is power law exponent and its value is considered as 0,14 in the study.

h: the reference height (10m), m

ho: the desired height, m

V: wind speed value calculated at the desired height, m/s

Vo: wind speed value at the referenced height (10m), m/s

Average power density is calculated by means the following equation taking all the available wind speed data into consideration (Dursun&Gokcol, 2012).

$$P = \frac{1}{2}\rho V^3 \qquad [7]$$

Regional description of Yalova

Yalova is a small city in the Marmara region and its population is 121,479 and it has a fairly small surface area of 847 km2. It has a border to the west of the Marmara Sea. Yalova has the latitude of 40.65502 N and the longitude of 29.27693 E. Besides, it used to be a town of Istanbul. Figure 3 indicates the map of Yalova province (Wikipedia, 2016).

Figure 3: Map of Yalova, Turkey[15]

Wind characteristics of the site in Yalova

After classifying the one-year wind data in time series format, that was taken from TSMS in 2012, cumulative frequency distribution of the location was determined. Figure 4 gives the cumulative frequency distribution of the site in Yalova (Suva et al., 2016). It indicates that average wind speed and power density of the location are at fairly low level.

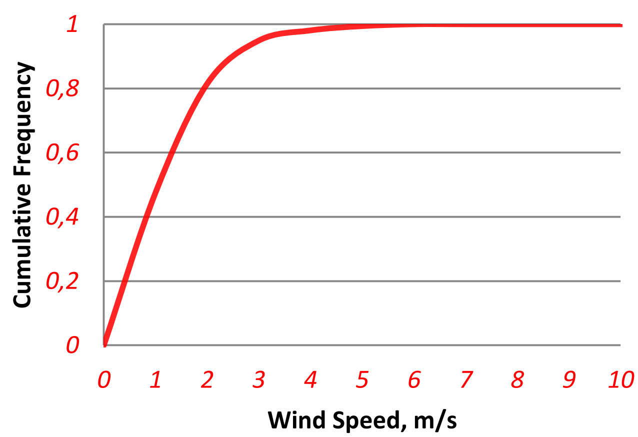

Figure 4: Cumulative frequency versus wind speed graph

One of the important parameters is the dominant wind direction, too. Figure 5 shows the frequency distribution (%) of the wind direction. It indicates that the dominant wind direction is SSE (Suva et al., 2016).

However, all the findings obtained from this study states that the dominant wind direction is NW because the highest power density value is obtained in this direction. Otherwise, the wind direction SSE has the third place in terms of wind power density value. Figure 6 shows the relationship between wind direction and wind power density. The dominant wind direction NW generates the highest annual (yearly) wind power of 6500 MW/m2.

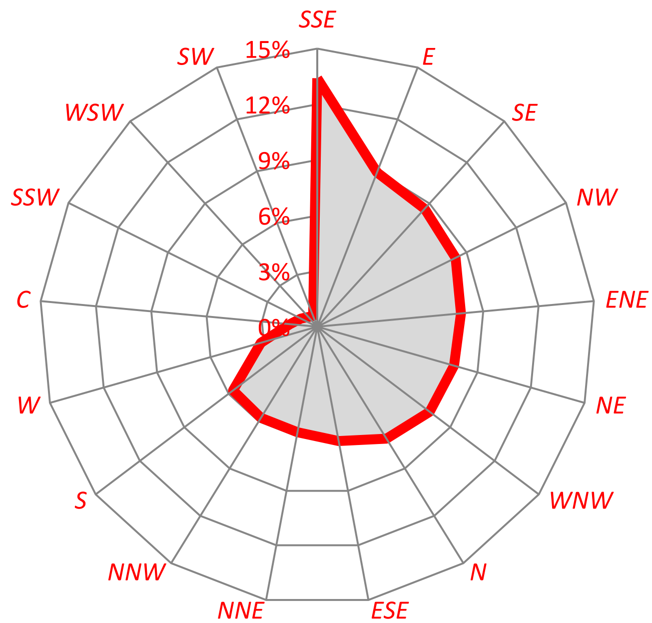

Figure 5: The frequency distribution of the wind direction

As a result of the calculation made by means of equation 5, average wind speed of the location is obtained as 1.3 m/s (Suva et al., 2016).

Furthermore, wind speed values at different heights are calculated using the equation (6), variation of average wind speed values is shown in Figure 7.

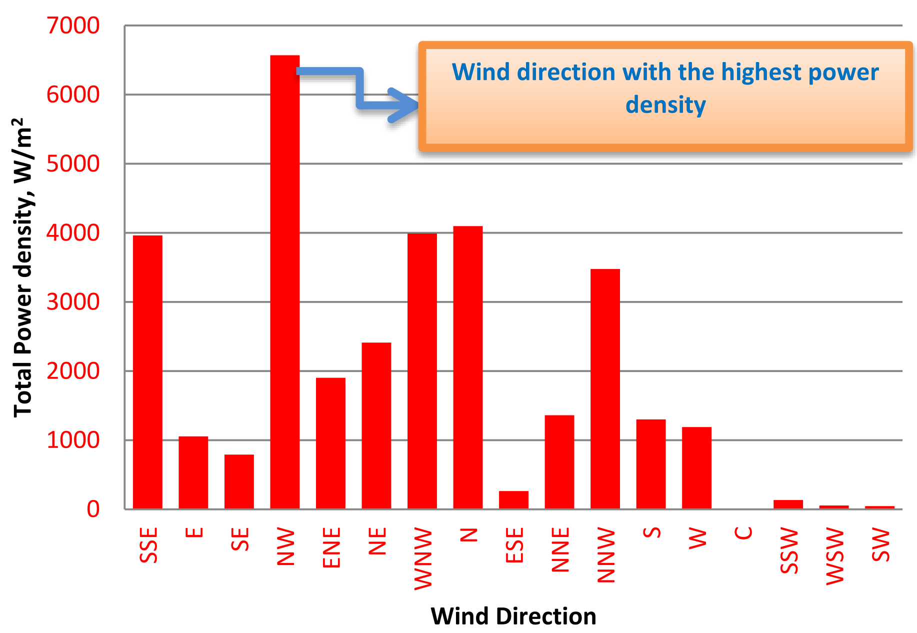

Figure 6: The relationship between wind direction and wind power density

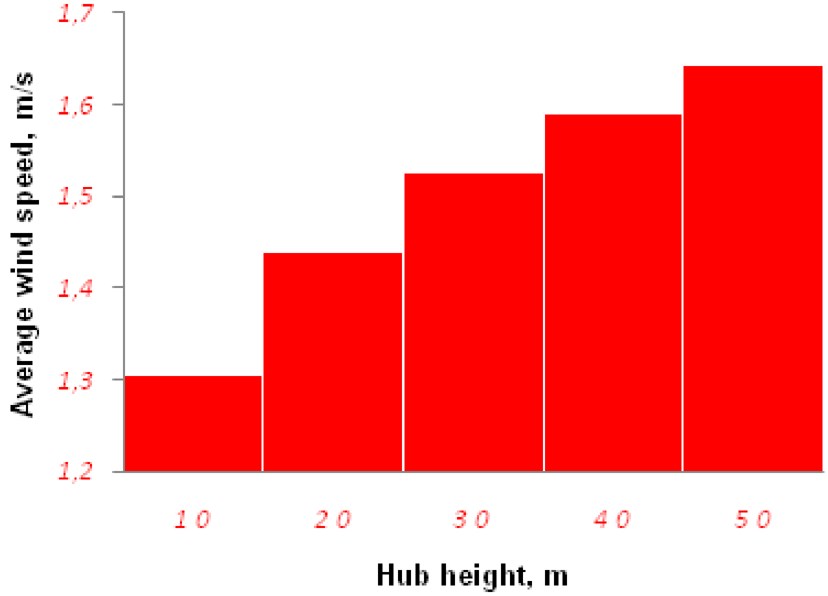

Figure 7: Variation of wind speed with different hub heights

As clearly seen in Figure 8, power generated in this location is too small to generate electricity in order to meet electricity demand of a town. It can only meet the electricity demand of a small house.

Furthermore, using mean speed-standard deviation method including the equations (2-4), Weibull parameters was calculated. k and c are calculated as 1,56 and 1,45 m/s, respectively (Suva et al., 2016). Figure 9 shows the Weibull frequency distribution obtained using the calculated Weibull parameters.

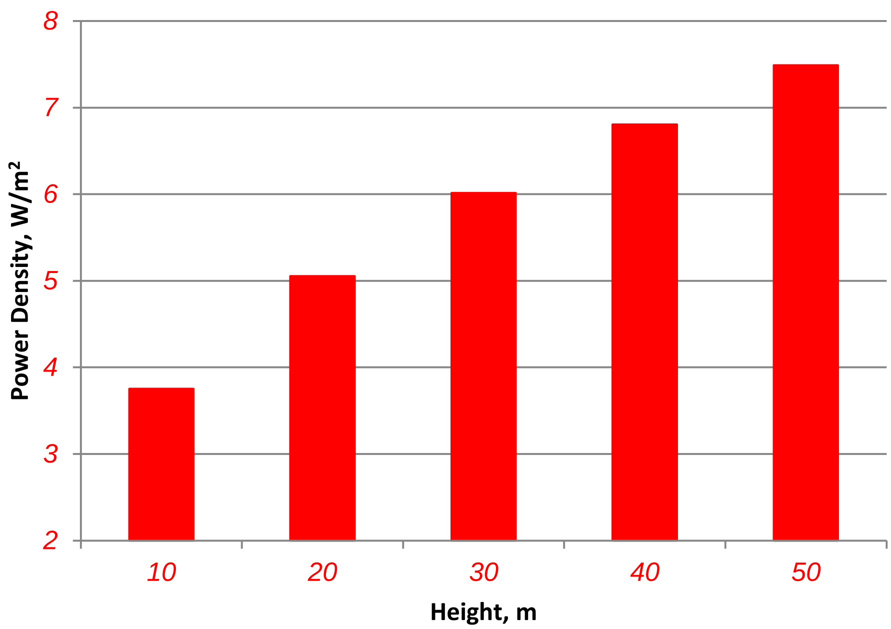

Figure 8: Variation of the power generated at the different heights

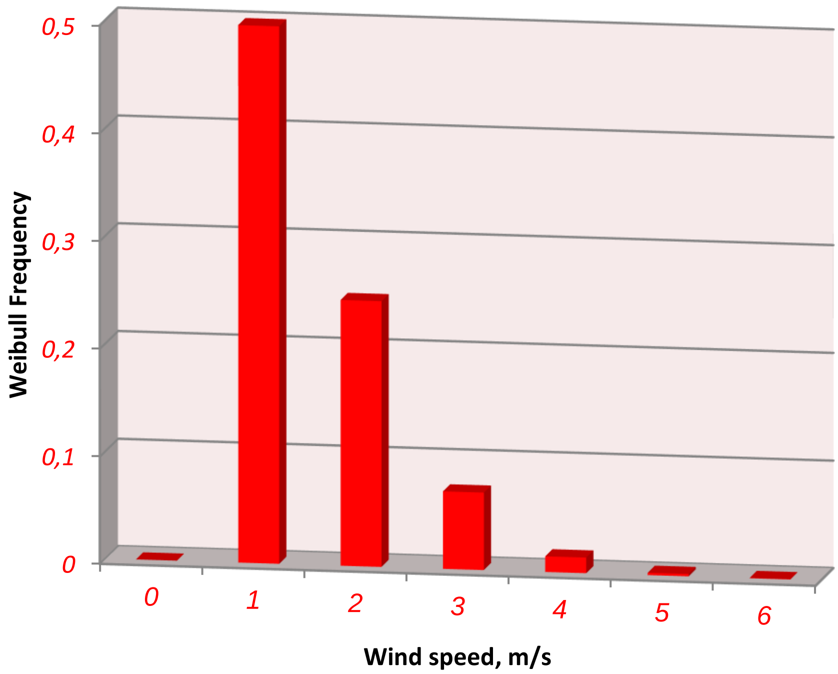

Figure 9: Weibull frequency distribution

Considering Table 2 including power curve values (producible power values versus wind speed) of some wind turbines, it is the fact that all the wind turbines does not generate any electricity power because they start to operate at wind speed values greater than or equal to 3m/s. Furthermore, from the Weibull frequency distribution graph, only 10% of the total wind data has wind speeds that are greater than or equal to 3m/s. Therefore, it is necessary to select the wind turbines than can generate electricity at even lower wind speeds than 3m/s. The best option to evaluate such poor windy sites is to utilize non-conventional wind turbines such as Savounious and American type wind turbines. Moreover, they have less efficiency values compared to conventional ones, but they can even harvest a little bit of kinetic energy inside wind.

Table 2: Power curves of some three-bladed wind turbines (Gokcol et al., 2008)

Wind speed, m/s	Proven 0.6 kW	ACSA LMW 1 kW	Proven 2.5 kW	Proven 6 kW
1	0	0	0	0
2	0	0	0	0
3	30	0	100	200
4	65	48	200	500
5	120	128	380	1,000
6	180	233	550	1,520
7	245	356	780	2,120
8	355	485	1,150	3,000
9	470	611	1,450	4,000
10	600	726	1,800	5,000
11	600	820	2,200	5,930
12	600	888	2,450	6,000
13	600	1,000	2,500	6,000

In the first step known as "determination of the regional wind characteristics", main factors such as average wind speed, power density, dominant wind direction and Weibull parameters clearly proves if this site has sufficient wind energy potential or not. As mentioned before, wind power density and average wind speed of the site are too low. In a word, all the obtained results from this study underlines that this site is not convenient to establish the big wind energy projects including large scaled three-bladed wind turbines. Additionally, wind energy potential of this site can be evaluated to meet the energy demand of only one or two houses with aforementioned special wind turbines.

Conclusion

Turkey has significant wind energy potential and the technical wind energy potential of Turkey is the greatest among the European countries. Recently the wind energy utilization in Turkey has increased remarkably but insufficiently. To achieve the wind energy targets, Turkey must not allow wind to blow in vain (without electricity generation from wind) and must efficiently (economically) utilize its all the wind energy potential. Furthermore, the following wind characteristics for the location were obtained in this study.

- Average wind speed of the location is obtained as 1.30m/s considering the wind data measured at 10m height.
- Dominant wind direction is determined as NW regarding wind power generating capacity.
- According to the frequency distribution (%) of the wind direction, the dominant wind direction is SSE.
- Its power density value is about 3.6 W/m^2.
- By using the mean speed-standard deviation method, Weibull parameters, k and c are calculated as 1,56 and 1,45 m/s, respectively.
- The considered wind turbines in this study can not be efficiently used to generate electricity because those wind turbines start to operate at the wind speeds more than or equal to 3m/s and also only 10% of the total wind data has wind speeds that are greater than or equal to 3m/s.
- This site in Yalova is not sufficient for big wind energy projects because of its low wind power density.
- It can be only assessed for a small house in a remote place by using Savonius and American type wind generators.

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