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Investigation of Wind Energy Potential in Zanjan Province, Iran

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Abstract
In the present work, we aim to investigate the possibility of using the wind energy in some regions of the Zanjan Province. The current research work concentrates on computing the wind energy potential and wind power density. Furthermore, some features related to wind for two locations in the Zanjan Province are obtained. The feasibility study of wind energy utilization and computing the wind power density and wind power potential has been widely conducted for the Zanjan Province. First, two locations in the Zanjan Province are considered in order to analyze the data at a reasonable level of the province, and to avoid over-focusing on one area. Thereafter, the statistics about the wind speed are achieved from the Renewable Energy Organization of Iran in ten-minute intervals and include wind speeds at the heights of 30 m, 10 m, and 40 m, and wind directions at the heights of 30 m and 37.5 m. Finally, various wind features are investigated for the given locations in the Zanjan Province. The results obtained demonstrate that the annual wind speeds for Soltanieh and Tarom at a height of 40 m are 4.81 m/s and 3.93 m/s, respectively. The highest values for U_{me} and U_{mp} are calculated; at a height of 40 m, at Soltanie, they are 11.35 m/s and 1.27 m/s, respectively. Also the performance of several wind turbines in the mentioned areas is investigated. Finally, a suitable wind turbine is identified.

Keywords: *Wind turbine, Wind energy potential, Power density, Weibull distribution*.

1. Introduction

Due to the reducing fossil fuel supplies, the renewable energy generation has been recently expanded. Another reason can be mentioned as the fossil fuels' adverse impacts on the environment like greenhouse gas emissions and air pollution. In contrast, the environmental impacts of energy generation from renewable energies including photovoltaics and wind power are insignificant in comparison with the conventional energy sources. In this way, the most effective renewable energy source is wind energy; however, an extremely comprehensive evaluation of wind characteristics in an especial area is required. Large differences in the wind characteristics including the wind direction and wind speed density could be observed in various locations. It is the logic behind the wind data analysis before starting the wind energy projects [1].

An important part of implementing wind turbines can be mentioned as evaluating the wind energy potential in a specific place. This task would be challenging since the speed and direction of wind energy vary with respect to time and space, which might significantly influence the system performance [2]. The potential of wind energy has been evaluated by the recent research works all over the world. Among them, some investigations have focused on Iran since it is considered as a potential location for exploiting the wind energy. The Manjil's project was carried out for a modern wind turbine in Iran for the first time in 1994 [3]. Then in 2003, Iran's capacity for generating the electricity was increased considerably by constructing 60 MW and 25 MW wind power plants in Manjil [4]. Presently in Iran, 15,000 MW is considered as the capacity of wind power production. Furthermore, the wind energy potential assessments have been performed for different areas. As an illustration, the energy potential analysis in Shahryar in the Tehran Province [5], center of Iran [6], Khuzestan Province in Iran [7], Manjil in the Gilan Province [8], Yazd [9], Tehran [10], Northwestern Iranian cities [11], Ardebil [12], Babak city in the Kerman Province [13], Aligodarz in the Lorestan Province

[14], Zarineh in Kurdistan [15], Binalood in Khorasan [16], Zahedan in Sistan and Baluchistan [17] has been performed. Additionally, some studies have been done with concentration on Iran's climate issues like offshore wind turbines' feasibility [18-23]. Also the performance of various distribution functions has been studied by Alavi *et al*. [24] in 5 different locations in the eastern and southeastern Iran. The comparison of Nakagami function's efficiency with seven applied distribution functions has been provided. According to the results obtained, each location has its own efficient function. The parameters influencing the efficiency of distribution functions can be enumerated as the characteristics of wind speed, and the quality and quantity of the recorded wind speed data. The highest performance for Khaf and Chabahar belonged to the Nakagami distribution. Additionally, four conventional distribution functions such as Lognormal, Rayleigh, Weibull, and Gamma using the MOM (method of moments) and MLE (maximum-likelihood estimator) methods have been analyzed by Alavi *et al*. [25] for the Kerman region based on twin groups of statistics: factual statistics and incomplete wind speed statistics. Based on the results obtained, a superior choice in a real-time wind speed data analysis is Lognormal. Nonetheless, Lognormal is not the best option for its incomplete data. Under this condition, the Weibull distribution was considered to be the best option. The actual and truncated wind speed data are two main criteria for analysis whose accuracy are ±0.1 m/s and ±1 m/s, respectively. Moreover, the wind energy potential and cost in different cities in the Sistan and Baluchestan state of Iran have been investigated by Fazelpour *et al*. [26]; the wind power was estimated by the Weibull distribution function. 269.02 w/m^2, 284.97 w/m^2, 138.64 w/m^2, and 144.49 w/m^2 are the annual mean wind power densities in Zahak, Zabol, Mirjavah, and Zahedan, respectively. According to the results obtained, a large-scale wind energy generation can be achieved in Zabol and Zahedan.

As it is clear in Figure 1, an excellent potential for installing wind turbines can be observed in the northwestern and eastern regions. In the GIS map, various colors have been assigned to different power densities for a specific location. According to this figure, a location in red has a superior wind condition. On the other hand, the locations in green have a low-power density [27]. The interpolated wind speed in Zanjan is depicted in Figure 2. As it is clear, all regions in the province, specifically the western areas, have wind energy potentials [28]. Based on the maps [27, 28], the Zanjan Province and cities named Tarom and Soltanie are considered in this study because the Zanjan Province is located in northwest of Iran, and has a favorable wind energy potential.

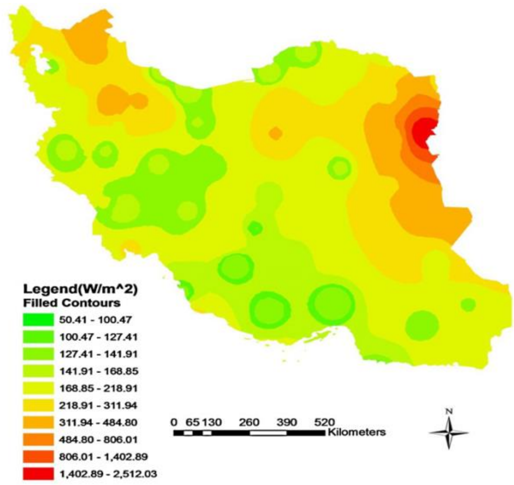

Figure 1: GIS map of power density (measurement data) in 40 m [27].

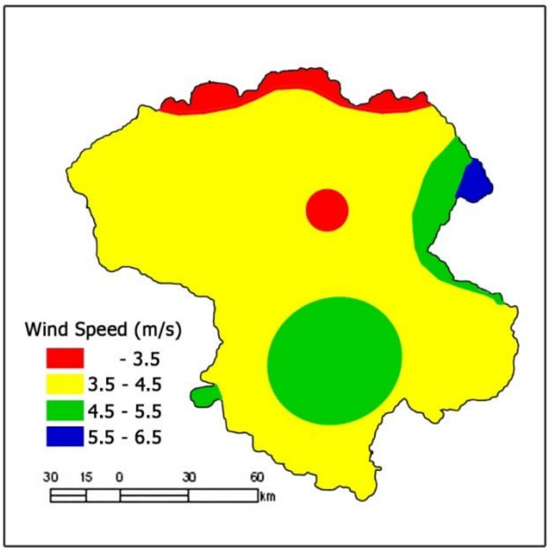

Figure 2. Interpolated wind speed at 40 m above ground level in Zanjan Province [28].

The main purpose of this investigation can be mentioned as finding the wind energy potential and wind power density in specific locations. Furthermore, different wind characteristics are studied for the Zanjan Province. In this work, in addition to different investigations on the wind speed, the wind direction analysis is also investigated. Although there are some good resources of wind power at least for some uses, there is no wind turbine farm in the studied area. For the effective operation of wind turbines, the potential and features of wind energy must be evaluated. Therefore, in the present area, the performance of multiple wind turbines was tested.

2. Introducing Zanjan Province

The Zanjan Province is located in the northwest of Iranian plateau. Its area is around 22,164 km^2, which is 43.1% of the total country. The province has the geographic coordinates of $47^{\circ}10'$ to $50^{\circ}5'$E and $35^{\circ}25'$ to $37^{\circ}10'$ N, with an area of approximately 39,369 km^2. The Zanjan's neighbor provinces in the north are the Gilan and Ardebil Provinces, in the west Azerbaijan, in the south is the Hamadan Province, and southwest and west is Kurdistan, and in the east is Qazvin.

The Zanjan Province now has 8 cities, 16 districts, 46 villages, and 19 towns. Its cities include Zanjan, Tarom, Mahneshan, Khodabandeh, Ijrood, Abhar, Khorramdareh, and Soltanieh [29].

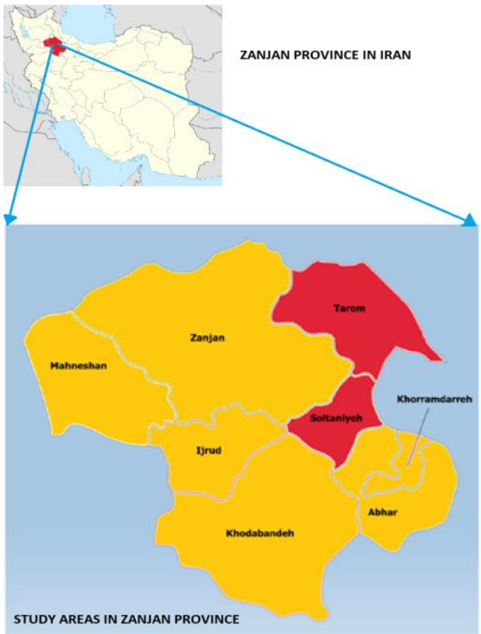

Figure 3. Zanjan Province in Iran and studied areas in the Zanjan Province.

3. Methodology

For estimating the wind energy potential, various numerical approaches could be applied. Among them, the Weibull distribution can be considered as a broadly utilized technique for determining the wind energy potential. Employing the Weibull distribution function is for simplicity and also for the overall accuracy [30]. The main distribution, especially for reliability and maintainability analysis, are done by the Weibull distribution. Also the quality of wind is determined by the Weibull distribution [31]. In this part, initially, the wind speed probability distribution function, and secondly, the equations of power density are provided. Ultimately, the output energy associated with a wind turbine is added, and the crucial parameters are described.

3.1. Governing equations

Long-term meteorological observations have been used to analyze the wind energy potential and its characteristics in a specific location. Prediction of the wind speed probability distribution function is considered as a primary step to determine both the parameters of a wind power potential and the economic cost of a location.

In this investigation, the Weibull distribution function is applied. The Weibull probability density function can be described as follows:

$$\mathbf{P(U)} = \frac{K}{C}\left(\frac{U}{C}\right)^{K-1} \mathbf{exp}\left(\left[-\left(\frac{U}{C}\right)^{K}\right]\right)\left[-\left(\frac{U}{C}\right)^{K}\right] \quad (1)$$

where P(U) represents the probability of wind velocity for the velocity of U, and *K* and *C* indicate the shape parameter (dimensionless) and the scale factor (m/s), respectively. The experimental and analytical approaches for calculating K and C are available. The standard skewness method is one of them and is used as follows [25]:

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

$$K = \left(\frac{\sigma_U}{\bar{U}}\right)^{-1.086} \quad (3)$$

$$\frac{C}{\bar{U}} = \frac{K^{2.6674}}{0.184 + 0.816K^{2.73855}} \quad (4)$$

Here, $\bar{\upsilon}$ and σ_U are the standard skewness and mean wind speed, respectively. Also N expresses the number of data per year.

A further crucial factor in analyzing the wind energy potential is the energy design (scheme, plan) factor used in the aerodynamic design of the turbines, and is expressed as [1]:

$$K_e = \frac{1}{N\bar{U}^3}\sum_{i=1}^{N} U_i^3 = \frac{\overline{U^3}}{\bar{U}^3} = \frac{r(1+\frac{3}{k})}{r^3(1+\frac{1}{k})} \quad (5)$$

The most likely wind speed provides the most iterative wind speed in any area, which can be determined as follows [11, 33]:

$$U_{mp} = C(1-\frac{1}{k})^{1/k} \quad (6)$$

Another crucial characteristic that performs a role in a turbine design is the wind speed, which generates the highest energy per year. This parameter indicates the largest wind energy in a year, and is provided as follows [11, 33]:

$$\mathbf{U_{me}} = \mathbf{C}(\mathbf{1} + \frac{\mathbf{2}}{\mathbf{k}})^{\mathbf{1/k}} \quad (7)$$

The chosen wind turbines must be assessed according to the wind speeds close to the rated speed (at which the maximum energy is generated) for achieving the highest efficiency.

The contingency of wind speed between U_a and U_b is given by the following relation [11]:

$$\mathbf{P}(\mathbf{U_a} \leq \mathbf{U} \leq \mathbf{U_b}) = \int_{\mathbf{U_a}}^{\mathbf{U_b}} \mathbf{p}(\mathbf{U})\mathbf{dU} \quad (8)$$

The cumulative distribution function F(U) that provides the possibility of wind speed identical to or smaller than U, is another substantial parameter in analyzing the wind energy. The cumulative distribution function can be obtained by integrating the probability density function. Thus [11, 33]:

$$\mathbf{F}(\mathbf{U}) = \mathbf{1} - [-\left(\frac{\mathbf{U}}{\mathbf{C}}\right)^{\mathbf{K}}] \quad (9)$$

3.2. Extrapolation of wind speed and surface roughness

In order to determine the energy generated by a wind turbine, the wind speed should be taken into account at the height of the wind turbine hub. In order to do so, the power law model is applied for estimating the wind speeds at that height utilizing wind speed data measured at specified heights. The following relation explains the power-law model [25]:

$$\frac{\mathbf{U_{(Z)}}}{\mathbf{U_{(Z_r)}}} = (\frac{\mathbf{z}}{\mathbf{z_r}})^{\mathbf{a}} \quad (10)$$

where $U_{(Z)}$ expresses the wind speed at the intended height of z, and $U_{(Z_r)}$ indicates the reference wind speed at the reference height z_r. Also a expresses the power of the law.

Another method available to estimate the wind distribution scheme is the Vortman's law:

$$\frac{\mathbf{U_{(Z)}}}{\mathbf{U_{(Z_r)}}} = \frac{\ln(\frac{\mathbf{Z}}{\mathbf{Z_0}})}{\ln(\frac{\mathbf{Z_r}}{\mathbf{Z_0}})} \quad (11)$$

where z_0 is the surface roughness, and is associated with the topography of the region.

3.3. Wind power density

Wind power density is a widely utilized scale for predicting the wind resource potential, and calculates the energy available to convert to electricity by means of a wind turbine. The following relation demonstrates the wind power per unit regains P/A or wind power density [32]:

$$\frac{\mathbf{P}}{\mathbf{A}} = \frac{\mathbf{1}}{\mathbf{2}}\boldsymbol{\rho}\mathbf{U^3} \quad (12)$$

Where ρ indicates the air density (1.225 $^{kg}/_{m^3}$) under the standard conditions, which is the atmospheric pressure at sea level and 15 °C. Also U and A are the wind velocity and the surface perpendicular to the wind velocity vector.

The wind power density can be obtained from the following relation by the Weibull probability distribution function [26, 32]:

$$\frac{\mathbf{P}}{\mathbf{A}}\boldsymbol{\rho}\int_{\mathbf{0}}^{\infty}\mathbf{U^3p(U)dU} = \frac{\mathbf{1}}{\mathbf{2}}\boldsymbol{\rho}\mathbf{C^3T}(\mathbf{1} + \frac{\mathbf{3}}{\mathbf{k}}) \quad (13)$$

Also the mean wind power density can be measured by the following relation [25]:

$$\frac{\bar{\mathbf{P}}}{\mathbf{A}} = \frac{\mathbf{1}}{\mathbf{2}}\boldsymbol{\rho}\Delta\mathbf{T}\sum_{\mathbf{i=1}}^{\mathbf{N}}\frac{\mathbf{U_i^3}}{\mathbf{N}} \quad (14)$$

Similarly, the wind energy density can be calculated as follows in the NΔT time interval [32]:

$$\frac{\bar{\mathbf{E}}}{\mathbf{A}} = \frac{\mathbf{1}}{\mathbf{2}}\boldsymbol{\rho}\Delta\mathbf{T}\sum_{\mathbf{i=1}}^{\mathbf{N}}\mathbf{U_i^3} = (\frac{\bar{\mathbf{P}}}{\mathbf{A}})(\mathbf{N}\Delta\mathbf{T}) \quad (15)$$

Where N indicates the time intervals' number with the length of ΔT.

3.4. Wind turbine energy output

Next, the wind turbine energy output is measured, which can be used as a valuable information to choose a wind turbine with the greatest performance in a specific area. In this way, the capacity factor (C_f) should be calculated since it is the most considerable characteristic of the wind turbine power generation [12]. It can be defined as the ratio of the actual output energy (E_{out}) to the maximum rated output energy (E_{rated}). Under the condition of operating a wind turbine during a year at 100% of its rated power [25], the capacity factor can be achieved by the succeeding relation [12, 26]:

$$\mathbf{E_{out}} = \mathbf{C_f E_{rated}} = \mathbf{C_f P_2 T} \quad (17)$$

Or

$$\mathbf{E_{out}} = \sum_{\mathbf{i=1}}^{\mathbf{N}}\mathbf{P_{out}}(\mathbf{U_i})(\Delta\mathbf{T}) \quad (18)$$

In equation (18), P_{out} is given as a function of the wind velocity U_i.

4. Results and Discussion

The wind power potential and the wind features were evaluated in this work. The basis of this work was the data taken from the Renewable Energy Organization of Iran. Wind energy is rather a clean alternative that avoids numerous negative points of conventional sources of energy. The implementation of wind energy for generating power has grown dramatically during the recent years so assessing the characteristics and potential of wind energy to efficiently exploit the wind turbines is essential. At the beginning of this section, the mean wind speeds is presented. Then the wind direction is analyzed. The equations of wind power density and annual wind power are also included in this section. Finally, the wind turbine is selected.

4.1. Mean wind speeds

In the first step of the analysis, as depicted in Table 1, the annual mean wind speeds were obtained at three different heights and for four chosen locations in the province.
Soltanieh has the highest mean wind speed in all three heights.

Table 1. Annual mean wind speed (m/s) at three heights for two sites in Zanjan

Site	Height (m)		
	10	30	40
Soltanie	3.59	4.58	4.81
Tarom	3.17	3.80	3.93

The average monthly wind speed at heights of 10 m, 40 m, and 30 m in places presented in the present work is shown in Figures 4 and 5. According to the data obtained from the SATBA website [29] and analysis of this information utilizing the Windographer software [35], the results for the two cities of Soltanieh and Tarom in the Zanjan Province at the heights of 10 m, 30 m, and 40 m were investigated. Analyzing the monthly mean wind speed diagram for three different heights of 10 m, 30 m, and 40 m at Soltanieh, the wind speed ranges are 2.6-4.8 m/s, 3.3-2.6 m/s, 3.4 m/s, and 6.6 m/s, respectively. Soltanieh also has the lowest wind speeds in January and December and the highest in March.

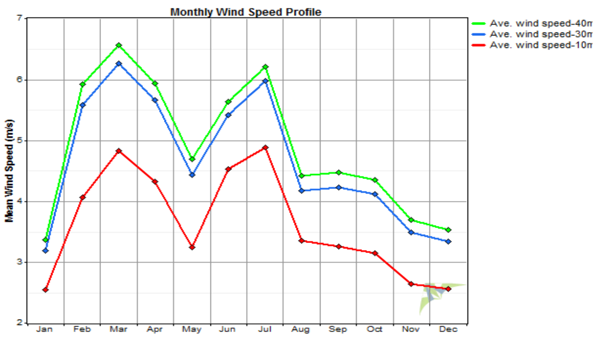

Figure 4. Monthly mean wind speeds for three heights at Soltanieh.

Analyzing the monthly mean wind speed diagram for 3 different heights of 10 m, 30 m, and 40 m at Tarom, the wind speed ranges are estimated at about 1.9-4.7 m/s, 2.5-3.5 m/s, and 2.6-3.5 m/s, respectively. The lowest wind speed is experienced in November and the highest in January.

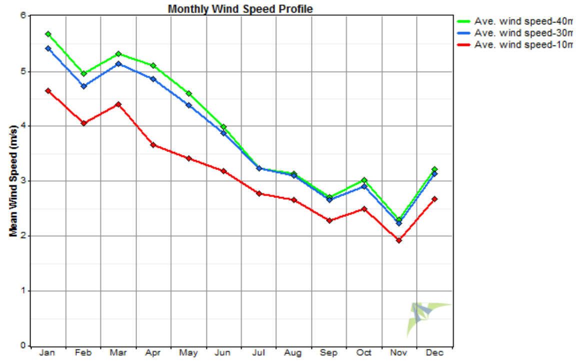

Figure 5. Monthly mean wind speeds for three heights at Tarom

Figures 6 and 7 demonstrate the diurnal mean wind speeds. As it can be seen, Soltanieh's hourly wind speed is more monotonous than Tarom. The maximum hourly mean wind speed for Soltanieh can be seen at 15 to 17 p.m., and is 2.7 m/s at a height of 40 m. However, the least hourly mean wind speed is 9.2 m/s, which occurs at 7 a.m. on a fairly regular basis. At Tarom from 11 a.m. to 15 p.m., the wind speed is higher, and is equivalent to 5.5 m/s.

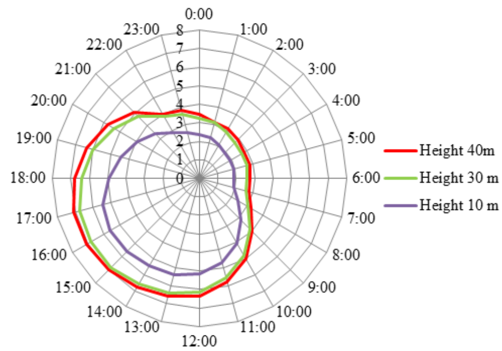

Figure 6. Hourly distribution of annual mean wind speeds (m/s) for three heights at Soltanie

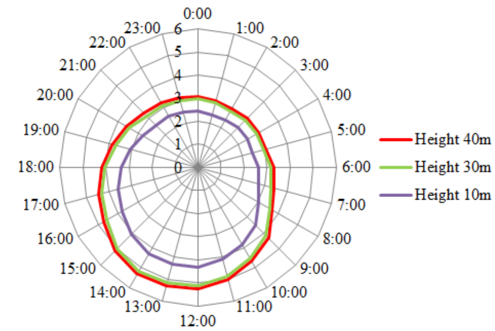

Figure 7. Hourly distribution of annual mean wind speeds (m/s) for three heights at Tarom

4.2. Wind speed broadcast

Table 2 lists the yearly parameters of the Weibull distribution function (c, k) for the three heights at two chosen locations within the Zanjan Province.

Table 2. Annual Weibull parameters k (dimensionless) and c (m/s) for four sites in Zanjan province.

Height				Site
40 m	30 m	10 m		
1.215	1.225	1.111	k	Soltanie
5.104	4.868	3.709	c	
1.146	1.143	1.142	k	Tarom
4.161	4.016	3.347	c	

Figures 8 and 9 show the Weibull distribution and wind related data at 40 m height for the two locations. The chart demonstrates which Weibull distribution perfectly conforms to the experimental data.

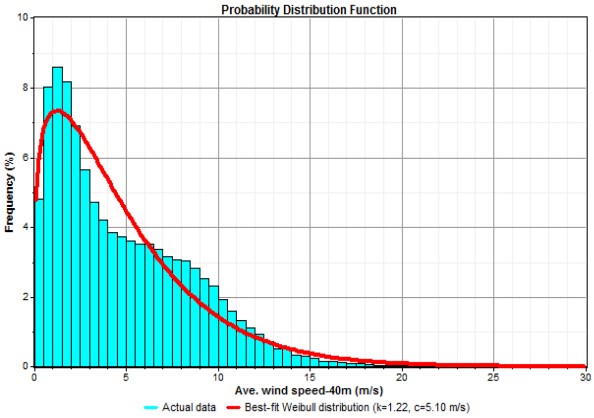

Figure 8. Wind speed distribution for Soltanie at 40 m.

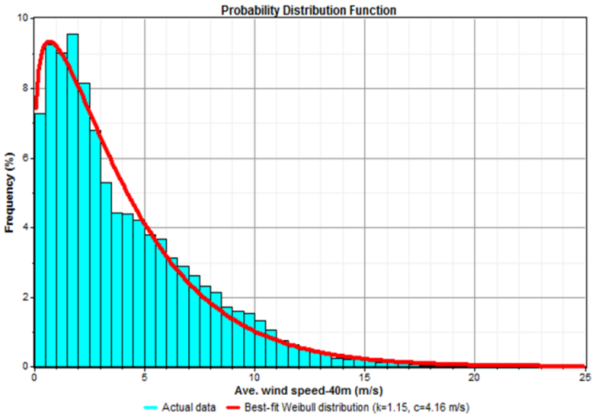

Figure 9. Wind speed distribution for Tarom at 40 m.

Table 3 presents the calculated values of U_{me}-U_{mp} for three heights in the two evaluated locations. It was observed that the wind speeds that generated most energy during the year were U_{me} and U_{mp}; the most likely wind speeds for Soltanieh were higher than the values calculated for Tarom. Thus these results show that Soltanieh suggests a larger potential for generating power by means of wind turbines.

Table 3. Value of Ume & Ump at three heights for two sites considered.

Site	Ume (m/s)			Ump (m/s)		
	10 m	30 m	40 m	10 m	30 m	40 m
Soltani	9.37	10.66	11.35	0.46	1.26	1.27
Tarom	8.05	9.68	10	0.56	0.68	0.7

The cumulative wind speed distribution for each location at three different altitudes is shown in Figures 10 and 11. These images illustrate the probability of the wind speeds larger than a specified speed. In all the four investigated locations, the contingency of a wind speed at 40 m height is greater than the others. As mentioned earlier, this happens because as height increases, the wind speed increases as well. Comparing the cumulative distribution patterns for various locations indicates that Soltanieh is mostly exposed to windy conditions. As shown in Figure 9, the possibility of wind speeds higher than 2.5 m/s for Soltanieh at heights of 10 m, 30 m, and 40 m are 50.6%, 60.2%, and 62.3%, respectively. Table 4 provides the possibility (contingency) of wind speeds greater 2.5 m⁄s for different locations in Zanjan. As it is evident, the wind speed at 40 m height is above 2.5 m/s for over 50 year (56%).

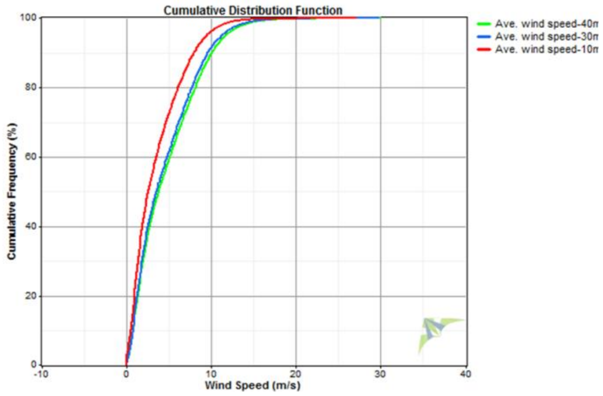

Figure 10. Cumulative density of wind speed at three heights for Soltanie.

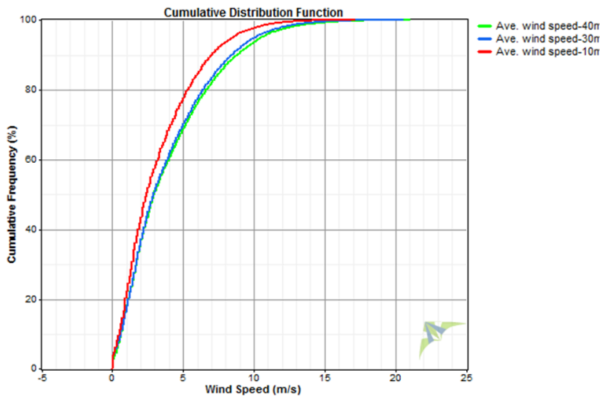

Figure 11. Cumulative density of wind speed at three heights for Tarom.

Table 4. Probability of wind speed P(U>2.5 m/s) and annual direction at several heights for the two sites considered.

Site	Height (m)			Annual direction (deg.)	
	10	30	40	30	37.5
Soltanie	50.6	60.2	62.3	180.1	179.4
Tarom	52.2	54.7	55.3	149	167

4.3. Wind direction analysis

Determining the wind direction distribution and wind speed frequency in a specific direction is another considerable step in evaluating the wind energy, and undeniably affects finding the optimum location for establishment of a wind farm [10]. The geographical aspects and atmospheric circulations tremendously affect the wind direction, and may lead to instability in the wind direction. The monthly mean wind direction in Figure 12 is presented for a height of 30 m.

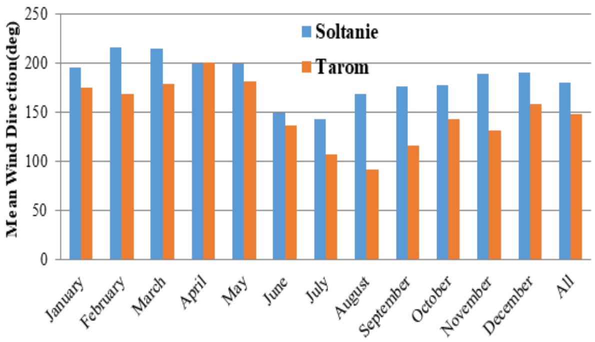

Figure 12. Monthly mean wind direction at height of 30 m for four sites.

A circular chart that demonstrates the speed and frequency of wind farm from all directions in a location using a central coordinate system is called a wind rose. This diagram has volatile applications; feasibility assessment (location, wind density, and wind power) is one of its applications. The wind rose diagram is very valuable for a simultaneous exhibition of the data associated with the frequency of wind speed and wind direction [23, 34]. These diagrams include 16 sections, each covering an arc of 22.5˚. According to the frequency of wind speed (%) and the wind direction data at various speeds, the polar chart gives information about the outcomes by the Windograoher software. [35]. By analyzing the wind rose diagrams for Soltanieh and Tarom regarding the 3 different heights, it can be concluded that the most possible wind direction for these cities occurs at 180 and 45 degrees, respectively (Figures 13 and 14).

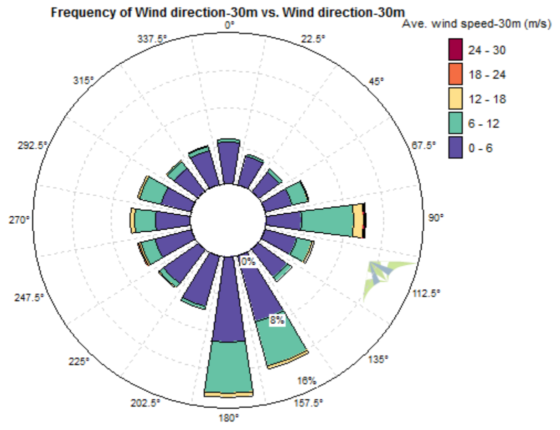

Figure 13. Wind rose diagram for Soltanie.

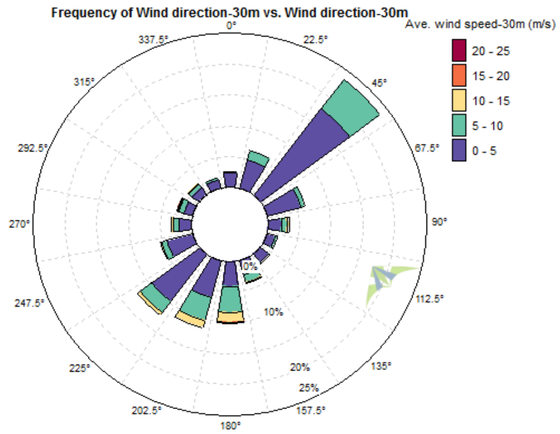

Figure 14. Wind rose diagram for Tarom.

4.4. Wind power density and annual wind power

The annual power density was estimated utilizing the calculated data (Equation 14) and the Weibull distribution output data (Equation 13). Figures 15 and 16, a comparison between the results obtained, show that there are some negligible discrepancies between the Weibull distribution and the measured data. The calculated data and the prediction of the power density are described by the Weibull distribution function. Also it indicates that the highest power density happens in Soltanieh. Based on the range specified above and the results shown in Figures 15 and 16, Soltanieh is recognized as the optimum location for installing wind turbines.

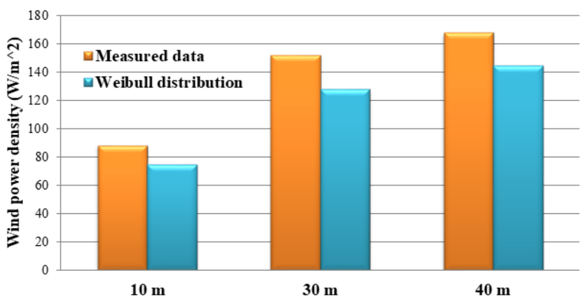

Figure 15. Annual wind power density at height of 10 m, 30 m and 40 m for Soltanie.

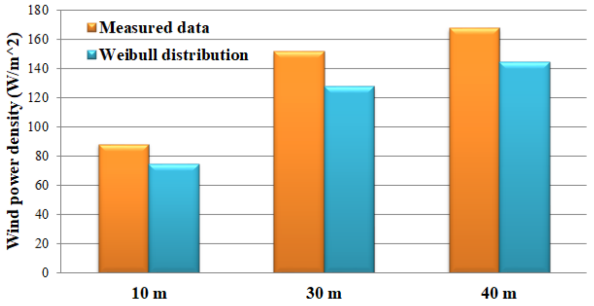

Figure 16. Annual wind power density at height of 10 m, 30 m and 40 m for Tarom.

4.5. Wind turbine selection

Four turbines were selected to evaluate their performances in the Zanjan Province.

Table 6 provides the technical specifications of the chosen turbines. Figure 17 shows the power curves of the wind turbines.

Table 6. Technical specification of selected wind turbines.

Wind turbine model	Lagerwey FB18	Aeronautica 29-225	EWT DW54-500	EWT DW54-900
Rated power (kW)	80	15	10	14
Rated speed (m/s)	14	15	10	14
Cut-in speed (m/s)	2	3	2	2
Cut-out speed (m/s)	25	23	25	25
Rotor diameter (m)	18	29	54	54

The annual capacity factor of the wind turbine and also the annual energy output of the wind turbine can be obtained by the Weibull probability distribution function and also the Windographer software [35].

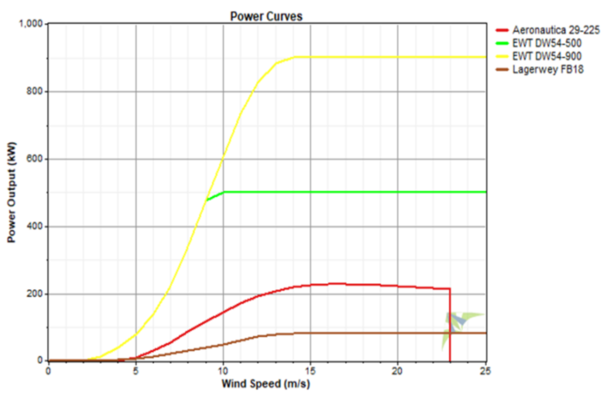

Figure 17. Power curves of considered wind turbines [35].

Various parameters such as wake effect and frost were taken into account in order to measure the production losses due to the wind turbines being out-of-service. Table 7 shows the annual capacity factor and energy output of the considered wind turbines for the selected locations in the Zanjan Province at 40 m height. As shown in Table 7, based on the capacity factor, EWT DW54-500 with a nominal output of 500 kW had the highest efficiency in both locations; the capacity factor is the most influential parameter in the evaluation performance of the wind turbine that directly affects the power generation cost. [39]. Thus the EWT DW54-500 turbine is a cost-effective choice. According to Table 7, the least potential and the most capacity factor exist in Tarom and Soltanieh, respectively, which are appropriate for wind turbine installation. Though EWT DW54-500 has the largest capacity factor, EWT DW54-900 offers the best chance with respect to the annual power generation. As an illustration, at Soltanieh and at a height of 40 m, the EWT DW54-900 turbine generates approximately 1433.58 mwh of power, while this number is only about 1133.6 mwh for the EWT DW54-500 turbine. EWT DW54-900 would be the best alternative according to the annual energy output. However, as concluded, the capacity factor is lower than the EWT DW54-500 turbine evaluated in the present work. Thus utilizing the EWT DW54-900 turbine is not reasonable.

Table 7. Annual output energy and capacity factor for four wind tourbines at height of 40m.

Wind turbine model	Soltanie		Tarom	
	C_F	Eout (MWh)	C_F	Eout (MWh)
Lagerwey FB18	17.6	122.99	12.2	85.31
Aeronautica 29-225	16.5	325	11.3	221.998
EWT DW54-500	25.9	1133.6	18.8	822.55
EWT DW54-900	18.2	1433.58	12.7	1000.187

5. Conclusions

In this work, the wind energy potential for two areas in the Zanjan Province in Iran was evaluated. A comprehensive analysis was conducted on the wind speed data measured at heights of 10 m, 30 m, and 40 m. The Weibull probability distribution function was utilized for computing the wind power density and output energy of the considered regions. The results obtained show that Soltanieh has a much better annual power density for the application of wind turbine technology. Therefore, Soltanieh was taken as the optimum location for wind energy development in Zanjan. Also given the capacity factor, the wind turbine EWT DW54-500 is the best selection. However, the EWT DW54-900 turbine produces the highest amount of power in all locations. As a result, the EWT DW54-500 turbine is an economically ideal choice. Altogether, the outcomes indicate that the wind energy is a hopeful alternative for increasing the national electricity production, and can be regarded as a sustainable source of power production in the area in the 21st century.

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