Comparison and Evaluation of Two Prediction Models for Speed, Power and Energy Density of Wind in Karaj County, Iran

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Abstract

Prospects of wind energy usage in Iran is promising and by using this type of energy, more saving in petroleum products can be achieved. Due to high populated city of Karaj, this study is conducted for evaluation of wind energy potential as electricity power production source. In this study, using measured wind speed data, at height of 10 meters above the ground surface, from 2004 to 2015, wind energy potential using two methods (Weibull & Rayleigh distribution functions) has been investigated. The highest values of wind speed, power and energy has been seen in 2009. Maximum wind speed in Karaj, reported as 3.08 m/s. annual shape factor and scale factor, regarding Weibull distribution function were 1.78-3.36 and 2.36-3.63, respectively. Mean annual power density value and predicted power density via Weibull and Rayleigh distribution function were 30, 27 and 36 W/m^2 respectively, and corresponding energy density for those quantities were 261.5, 239.2 and 302.49 J/m^2, respectively. After evaluating these factors regarding power density and wind energy, it was concluded that data fitting via Weibull distribution was partly better than Rayleigh distribution function. Coefficient of determination of Rayleigh distribution function was more than the corresponding value in Weibull counterpart, so it suggest that, Rayleigh distribution has more precise results in this regard. The RMSE values of Weibull and Rayleigh were 0.018 and 0.013 and R^2 values of Weibull and Rayleigh were 0.95 and 0.97 in Karaj for years 2004-2015. Also, wind rose charts in Karaj, for 2004-2015, show that the most prevalent wind direction is NW (North-West). Based on the derived results of power density and wind energy, wind energy is not suitable for large-scale wind application in this surveyed area. In this area, wind potential can be used for non-connected grids, such as local usage for battery charging and water pumping.

Keywords: Wind power, Wind energy, Weibull distribution function, Rayleigh distribution function, Karaj

Introduction

The current trend consumption of fossil fuels in world, cause reducing the resources for the next centuries. Also developed and being developed countries have adopted a policy to harness renewable energy and limiting self-dependencies to fossil fuels [Mostafaeipour *et al*., 2014]. Today researchers and most of people are looking for environmentally friendly energy such as wind energy that can be using wind turbines through mechanical power converted to electricity [Karsli *et al*., 2003; Ahmed *et al*., 2008].

Unbalanced growth of supply and demand energy in world caused that the need to development new energy sources be more tangible. In the past 30 years global economic growth was approximately 33 percent, while electricity consumption is grew 36 percent [Qolipour *et al*., 2016]. Efficient development and renewable energies technology and the use of renewable and new energies in the future plays significant role in the sustainable development strategy [Weitemeyer *et al*., 2015; Ozoemena *et al*., 2016]. The oil crisis in 1970, caused increasing fossil fuel prices and in other hand the cost of renewable energy technologies is decreased dramatically [Souheil *et al*., 2005].

One of the major problems designer and users of the renewable energy systems is nature and the weather unpredictable [Souheil *et al*., 2014].

In 2008, a system appointed with 27 GW capacity and this capacity with growth 29% increased to approximately 121 GW. Wind turbine capacity installed worldwide in 2009 was almost equal to 1.8% that this share can be increase to 20% in 2050 [Wiser *et al*., 2011].

The wind energy available in the world is approximately 10 MW and the maximum wind global potential is around 35% available consumable energy in world [Alijani *et al*., 2008].

China, USA, Germany, Spain, India, UK, Italy, France and Canada countries have more than 80% renewable energy resources with the highest wind power capacity. It is shown in Fig. 1 [Alijani *et al*., 2008].

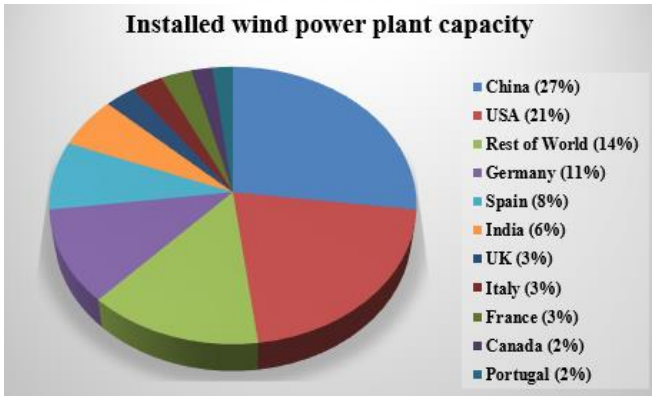

Fig.1 Leading Countries in installed wind power plants capacity as 2012: [Alijani et al., 2008]

The aim of main this study is assessment of potential wind energy in Savojbolagh and Taleghan Counties in Alborz province, Iran. In this study:

- Calculate the monthly and yearly wind speed in different heights.
- Evaluation wind speed data by the Weibull and Rayleigh distributions.
- Calculate wind power density and wind energy density predicted wind speed using the Weibull and Rayleigh distributions and comparison them with real data.
- Draw the wind rose diagram for 2010 to 2015.

Wind energy in Iran

The longitude and latitude of Iran ranged from 44° to 63.99° and 25° to 39.99°, respectively [Mostafaeipour *et al*., 2005]. Iran has a special geographical and climate conditions that caused generated strong flows in some regions [Alamdari *et al*., 2012]. This flows enter to Iran with two ways [Chaparzadeh *et al*., 1999]:

(1) The winds that blow from the Indian and the Atlantic Oceans in winter.

(2) The winds that blow from, north of Asian, Atlantic Ocean and Mediterranean sea in summer [Mirhosseini *et al*., 2011].

In 1994, Iran started to use of wind energy to electricity generation. The first windy plant designed in Manjil and Roodbar in 2003. Two wind turbines were installed with 500 kW capacity and with 1.8 million kWh/year total capacity [Saeidi *et al*., 2011].

Materials and methods

Description of regions

Alborz province is located in the northern half of Iran and in the west of Tehran province (capital of Iran). Savojbolagh to centrality of Hashtgerd and Taleghan are the Counties of Alborz province. The weather Alborz province which can be considered as the section indicators of the country that meets environmental management actions, composed from a variety of cold and dry, semi-arid, the Mediterranean and wet [Anonymous., 2016].

Savojbolagh with an area of 2800 km2 and the longitude and altitude ranged from 35.45° to 50.55° earth and 35.45° to 36.5° north is located in the west of Alborz province. Savojbolagh is limited from north to Taleghan, from earth to Karaj (capital of Alborz province), from south to Nazarabad and from west to Abyek counties (Fig. 2). Based on 2012 census results of statistical center of Iran, Savojbolagh population was about 189,305 [Anonymous., 2016 and 2011]. A quarter of this County including mountainous regions and Savojbolagh means cold water fountain.

Taleghan with an area 1325 km2, with the longitude and altitude 80° and 38.5° is located in the north of Savojbolagh County [Anonymous., 2015]. Based on 2012 census results of statistical center of Iran, Taleghan population was about 25,781. This county is limited from north to Mazandaran province, from east to Karaj and from west to Abyek [Anonymous., 2016 and 2011].

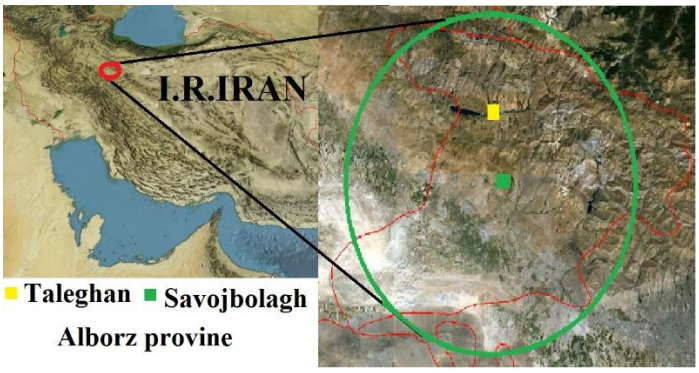

Fig. 2 Map of Iran, Alborz province, Savojbolagh and Taleghan counties [Anonymous., 2015].

The wind speed and direction data for January 1st in 2010 to December 30th in 2015 at height of 10 m were taken from Alborz province meteorological organization. In order to use of different wind turbines, the wind speed for higher than 10 m heights be calculated by Eq 1 [Fazelpour *et al*., 2015; Nawri *et al*., 2014; Karthikeya *et al*., 2016].

$$V_2 = V_1(\frac{Z_2}{Z_1})^{\alpha}$$

(1)

Where α is the surface coefficient, V_2 is the wind speed for the desired height, V_1 is taken the wind speed at 10 m height, Z_2 and Z_1 are the desired height and 10 m height, respectively. The surface coefficient which is dependent on the terrain condition ranged from 0.1 to 0.16. The α parameter value for neutral stable condition is 0.143 and has been used for this study [Ramachandra *et al*., 2005].

To determine the direction of wind turbine establishment, find prevailing wind in the region is important. Drawing diagrams and calculations were performed using Excel.

Wind speed analysis

The mean wind speed (m/s) and standard deviation (σ) of observed data expressed by [Zhou *et al*., 2006; Elliott *et al*., 1987; Chang *et al*., 2007]:

$$V_{avg} = \frac{1}{n}\left[\sum_{i=1}^{n} V_i\right]$$

(2)

$$\sigma = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(V_i - V_{avg}\right)^2}$$

(3)

The optimum wind speed (V_{op}) and the most probable wind speed (V_{mp}) are calculated by [Chang *et al*., 2003; Fazelpour *et al*., 2015; Mirhosseini *et al*., 2013; Nawri *et al*., 2014; Elamouri *et al*., 2007]:

$$V_{op} = C\left(\frac{K+2}{K}\right)^{1/K}$$

(4)

V_{op} is the wind speed that produces the maximum energy.

$$V_{mp} = C\left(\frac{K-1}{K}\right)^{1/K}$$

(5)

Weibull and Rayleigh distribution

In order to estimate the observed wind speed in any region, there are several probability distribution functions (PDFs), which between them Weibull and Rayleigh distributions have more accuracy. To use the Weibull and Rayleigh distribution functions requires to calculate the shape factor (K) and scale factor (C) parameters [Seguro *et al*., 1999]. The

wind speed distribution usually determines the performance of the wind turbine systems [Chang *et al*., 2003].

The Weibull and Rayleigh distributions are presented using Eqs 6 and 7, respectively and the wind speed frequency value calculated by Eq 8 [Morgan *et al*., 2011; Pishgar-Komleh *et al*., 2015; Fazelpour *et al*., 2015].

$$f(V)=\left(\frac{K}{C}\right)\left(\frac{V}{C}\right)^{K-1}\exp\left[-\left(\frac{V}{C}\right)^{K}\right] \qquad (K>0, V>0, C>1)$$

(6)

$$f(V)=\left(\frac{2}{C}\right)\left(\frac{V}{C}\right)^{2-1}\exp\left[-\left(\frac{V}{C}\right)^{2}\right]$$

(7)

The shape factor (K) value for the Weibull distribution is variable and for the Rayleigh distribution is constant (K=2). V is the wind speed (m/s), C is the scale factor (m/s) and $f(V)$ represents the probability of observed wind speed.

The shape and scale factors can be calculated by Eqs 8 and 9 [Dabbaghiyan *et al*., 2016; Diuf *et al*., 2013]:

$$K=\left(\frac{\sigma}{V_{avg}}\right)^{-1.086} \qquad (1\le K\le 10)$$

(8)

$$C=\frac{V_{avg}}{\Gamma(1-1/K)}$$

(9)

Where Γ(x) is the gamma function, which is given by [Pishgar-Komleh *et al*., 2015; Yaniktepe et al., 2013]:

$$\Gamma(x)=\int e^{-u}u^{x-1}du$$

(10)

Evaluation of Weibull and Rayleigh distributions

To evaluate the accuracy and to find the performance of Weibull and Rayleigh distributions, the root mean error (RMSE), mean percentage error (MPE), mean absolute percentage error (MAPE) and the Coefficient of determination (R^2) were calculated.

RMSE is difference between predicted values and observed values and has always a positive value and is calculated by [Fazelpour *et al*., 2015]:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}\left(V_{obs} - V_{pre}\right)^2}{N}}$$

(11)

The MPE is mean of all percent of deviations between the predicted values and the observed values. The MPE is represented as:

$$MPE = \frac{1}{N}\sum_{i=1}^{N}\left(\frac{V_{pre} - V_{obs}}{V_{obs}}\right)\times 100$$

(12)

The MAPE shows the average or mean percent of difference between the predicted and observed data. The MAPE calculated by [Najafi *et al*., 2011]:

$$MAPE = \frac{1}{N}\sum_{i=1}^{N}\left|\frac{V_{pre} - V_{obs}}{V_{obs}}\right|\times 100$$

(13)

The coefficient of determination (R^2) is the square of the Pearson correlation coefficient. Whatever R^2 value close to one means that the performance accuracy of Weibull and Rayleigh is good. The R^2 provides a measure of the linear relationship between the predicted and observed values and can be represented as [Kavak Akpinar *et al*., 2004]:

$$R^2 = \frac{\left(\sum_{i=1}^{n}\left(V_{obs} - \overline{V_{abs}}\right)\times\left(X_{pre} - \overline{V_{pre}}\right)\right)^2}{\sum_{i=1}^{n}\left(V_{obs} - V_{obs}\right)^2 \times \sum_{i=1}^{n}\left(V_{pre} - \overline{V_{pre}}\right)^2} \qquad \left(0 \le R^2 \le 1\right)$$

(15) The performance of Weibull and Rayleigh distributions be evaluate where the model with the lowest values RMSE, MPE, MAPE and the highest values R^2 are validated using Eqs 11-15.

Wind power density and wind energy density

Eq 12 shows that wind power increases the flow cubic with speed V that crosses into blades of wind turbines as swept area. The wind power density calculated by Eq 13 [Chang *et al*., 2007]:

$$P(V) = \frac{1}{2}\rho A V_{avg}^3$$

(12)

The wind power per unit of vertical area called the wind power density where V is wind speed (m/s) and ρ is the air density (kg/m^3) (Eq 13) [Fadare *et al*., 2010].

$$\frac{P(V)}{A}=\int_0^{\infty}\frac{1}{2}\rho V^3 f(V)dV=\frac{1}{2}\rho C^3\Gamma\left(\frac{K+3}{K}\right) \quad (13)$$

The mean of wind energy density per unit of area for one specific period of time calculated by Eq 14 [Jianzhou *et al*., 2016]:

$$\frac{E}{A}=\frac{1}{2}\rho C^3\Gamma\left(\frac{K+3}{K}\right)\Delta T \quad (14)$$

Wind rose

The wind rose is a polar diagram that shows relative percentage of time. The drown wind rose diagram to choosing kind of turbine, direction and installing of turbine in the specific site is important [Kamau *et al*., 2010]. In this study, the wind direction drown for 10 m height.

Results and discussion

In this study, wind speed data for Savojbolagh and Taleghan Counties from 2010 to 2015 was measured at 10 m Earth's surface and has been statistically analyzed. The main obtained results are presented in the following:

Monthly and yearly mean wind speeds

Monthly and annual mean wind speed (Eq. 5) as well as standard deviation (Eq.6) for the years 2010 to 2015 are tabulated in Tables 1and 2. To calculate the Shape parameter using Eq.2, scale parameter (Eq.3), most probable wind speed (V_{mp}) (EQ.10) and optimum wind speed (V_{op}) (Eq.11) have to be calculated for 2010 to 2015.

Savojbolgh County

Table. 1 and Fig.3 show the yearly mean wind speeds (V_{avg}) and standard deviations (σ) in Savojbolagh for years 2010 to 2015. The most of the monthly mean wind speeds are between 2 and 4 m/s, while on November and December this value is less than 2 m/s. Results showed higher and lower of mean wind speed in different months belonged to February 2010 and December 2012, respectively (Table 1). As can be seen in Fig. 2,

similar trends are noticed. Also, the monthly standard deviations range between 0.85 and 1.25 m/s.

Table1. Monthly mean wind speeds and standard deviations in Savojbolagh County.

Month	Parameters	2010	2011	2012	2013	2014	2015	Whole year
January	V_{avg}	3.5	1.29	2.30	2.61	2.24	2.69	2.43
	σ	1.06	1.21	1.44	1.75	0.63	1.02	1.18
February	V_{avg}	3.96	3.22	2.62	2.95	2.06	2.79	2.93
	σ	1.21	1.34	1.19	1.10	0.55	0.88	1.04
March	V_{avg}	3.86	2.91	4.24	3.94	3.26	2.96	3.52
	σ	1.44	1.34	1.54	1.28	1.00	0.94	1.25
April	V_{avg}	3.63	3.57	3.58	3.38	3.08	3.49	3.45
	σ	1.27	1.50	0.92	1.19	0.76	0.93	1.09
May	V_{avg}	3.67	3.15	4.44	2.95	2.98	3.54	3.45
	σ	1.05	1.34	1.47	1.21	0.94	0.86	1.15
June	V_{avg}	3.11	2.68	3.04	2.09	3.54	3.10	2.93
	σ	1.16	1.18	1.28	0.97	0.68	0.74	1.00
July	V_{avg}	3.17	3.16	2.32	2.15	3.08	2.49	2.73
	σ	1.29	0.96	0.74	0.86	0.78	0.51	0.85
August	V_{avg}	2.80	1.59	2.60	1.26	2.80	2.46	2.25
	σ	0.97	1.73	0.91	0.70	0.98	0.40	0.95
September	V_{avg}	3.16	2.84	2.08	2.18	2.52	2.63	2.57
	σ	1.06	1.84	1.21	1.03	1.02	0.41	1.09
October	V_{avg}	2.65	1.64	2.50	1.64	2.18	2.22	2.13
	σ	0.92	1.25	1.44	1.01	1.03	0.56	1.03
November	V_{avg}	1.51	1.20	1.49	1.82	1.8	1.86	1.61
	σ	0.93	1.14	1.17	0.94	0.84	0.72	0.95
December	V_{avg}	1.57	0.64	1.07	2.65	1.67	1.71	1.55
	σ	1.29	0.95	1.50	1.59	0.75	0.78	1.14
Yearly	V_{avg}	2.75	2.31	2.69	2.46	2.60	2.66	2.57
	σ	1.13	1.57	1.48	1.30	0.96	0.73	1.19

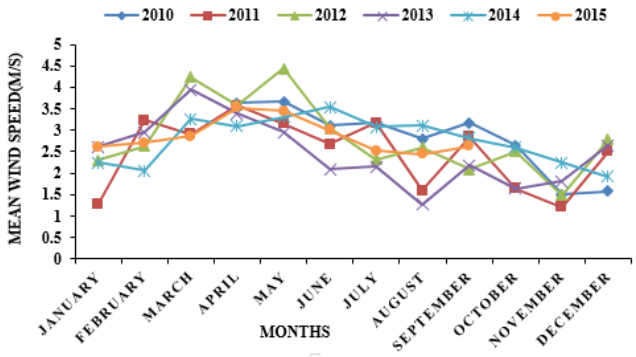

Fig 3. Monthly mean wind speed in Savojbolagh (2010-2015).

Table 2 illustrates that the yearly values of shape parameter (K) ranged from 1.25-4 and an average value of K was 2.45. Also C parameter values varied from 2.26 to 3.76 m/s with an average value of 2.97 m/s. The highest and lowest values of K and C parameters belong to 2015 and 2011, respectively. The highest and lowest values of V_{mp} for 2010 to 2015 were 3.50 and 1.21 m/s with an average value of 2.28 m/s. The values of V_{op} ranged from 3.75 to 4.16 m/s with an average value of 3.97 m/s. The highest and lowest of optimum wind speed belong to 2015 and 2014.

Table2. Parameters and characteristic speeds in Savojbolagh County.

Year	K (-)	C ($m.s^{-1}$)	V_{mp} ($m.s^{-1}$)	V_{op} ($m.s^{-1}$)
2010	2.33	3.16	2.49	4.12
2011	1.25	2.26	1.21	3.92
2012	1.91	2.86	1.95	4.15
2013	2.00	2.66	1.88	3.76
2014	2.95	3.14	2.73	3.75
2015	4.00	3.76	3.50	4.16
Yearly	2.45	2.97	2.28	3.97

Taleghan County

The monthly and yearly V_{avg} and σ parameters calculated and have been shown (Table 3). The wind speed values ranged from 0.27 to 2.84 m/s in Taleghan. The highest and lowest wind speed value belonged to August in 2014 and January in 2010. The maximum and minimum average wind speed value were 2.23 and 1.5 m/s in 2014 and 2011, respectively. The results show the average standard deviation value in 2015 and 2011 with values of 0.87 and 0.56 m/s are the highest and lowest values for all years

(2010-2015) in Taleghan. Bing lower the σ parameter values are due to variation range of the wind speed data in Taleghan for 2010-2015. The highest and lowest wind speed value whole year in the different months belonged to June and January with vales 2.38 and 1.16 m/s, respectively (Table. 3). Fig.4 shows variable trend of the wind speed in Taleghan from 2010 to 2015.

Table3. Monthly mean wind speeds and standard deviations in Taleghan County.

Month	Parameters	2010	2011	2012	2013	2014	2015	Whole year
January	V_{avg}	0.98	0.27	1.10	1.43	1.50	1.69	1.16
	σ	0.41	0.35	0.58	0.60	0.44	0.42	0.47
February	V_{avg}	1.15	0.72	1.56	1.23	1.97	1.90	1.42
	σ	0.73	0.48	0.84	0.51	0.61	0.48	0.61
March	V_{avg}	1.56	1.32	2.39	2.13	2.32	2.24	1.99
	σ	0.98	1.00	1.08	1.11	0.71	0.63	0.92
April	V_{avg}	2.03	2.42	2.07	2.18	2.39	2.71	2.30
	σ	0.75	1.16	0.64	0.62	0.39	0.68	0.71
May	V_{avg}	2.63	2.09	2.23	2.06	2.50	2.35	2.31
	σ	0.74	0.78	0.72	0.58	0.50	0.65	0.66
June	V_{avg}	2.33	2.14	2.62	1.94	2.83	2.40	2.38
	σ	0.72	0.78	0.86	0.46	0.49	0.82	0.69
July	V_{avg}	2.07	2.07	2.07	2.29	2.76	2.21	2.24
	σ	0.64	0.81	0.62	0.60	0.54	0.82	0.67
August	V_{avg}	2.46	1.61	1.98	2.04	2.84	2.15	2.18
	σ	0.69	0.59	0.47	0.53	0.75	0.60	0.61
September	V_{avg}	2.36	1.55	2.02	2.19	2.61	2.53	2.21
	σ	0.68	0.52	0.51	0.67	0.50	0.35	0.54
October	V_{avg}	1.70	1.70	1.81	1.78	1.95	1.85	1.80
	σ	0.55	0.66	0.66	0.76	0.43	0.52	0.60
November	V_{avg}	1.32	1.12	1.22	1.10	1.73	1.63	1.35
	σ	0.40	0.69	0.50	0.46	0.47	0.41	0.49
December	V_{avg}	0.80	0.99	1.23	0.90	1.37	1.24	1.09
	σ	0.46	0.54	0.79	0.40	0.314	0.43	0.49
Yearly	V_{avg}	1.78	1.50	1.86	1.78	2.23	2.07	1.90
	σ	0.64	0.87	0.79	0.72	0.67	0.56	0.72

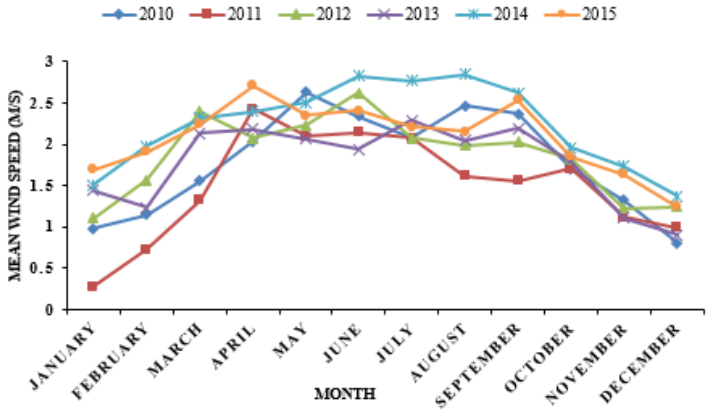

Fig 4. Monthly mean wind speed in Taleghan (2010-2015).

The shape factor (K) value range between 1.81 and 3.71 with average value 2.84. The K values are higher than 2 in Taleghan for 2010-2015, with the exception of 2011. The variations of scale factor values are between 1.56 and 2.85 m/s with average value 2.30 m/s. In 2011, the scale factor value is lower than 2 m/s, while this parameter value for other years is higher than 2 m/s. The highest and lowest V_{mp} and V_{op} parameters values belonged to 2015 and 2011 with average values 1.97 and 2.77 m/s, respectively. The V_{mp} and V_{op} values ranged from 1 to 2.62 m/s and 2.36 to 3.21 m/s.

Table4. Parameters and characteristic speeds in Taleghan County.

Year	K (-)	C ($m.s^{-1}$)	V_{mp} ($m.s^{-1}$)	V_{op} ($m.s^{-1}$)
2010	2.66	2.29	1.92	2.83
2011	1.81	1.56	1.00	2.36
2012	2.53	2.15	1.76	2.71
2013	2.64	2.08	1.74	2.58
2014	3.70	2.84	2.61	3.20
2015	3.71	2.85	2.62	3.21
Yearly	2.84	2.30	1.97	2.77

Evaluation of Weibull and Rayleigh distributions

The result of Comparison of observed and Weibull and Rayleigh wind speed frequencies and evaluation the observed data based two distributions of Weibull and Rayleigh are presented in the following:

Fig.5 shows the results of observed wind speed frequency by two distributions of Weibull and Rayleigh for 2010 to 2015 in Savojbolagh.

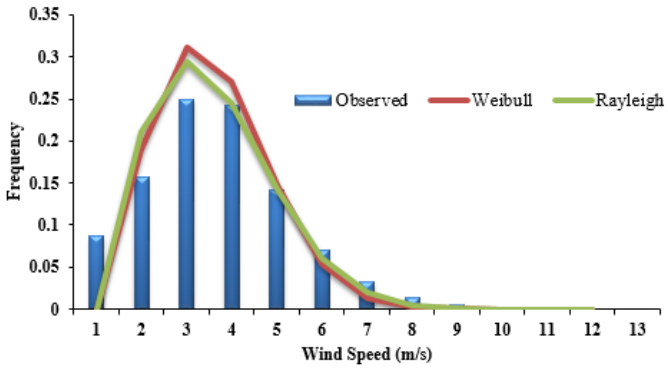

Fig5. Comparison of observed and predicted wind speed frequencies of Savojbolagh.

The results of evaluation observed wind speed for Savojbolagh and Taleghan counties have been shown in Table5. The RMSE. MPE and MAPE values for the Weibull distribution were 0.00012, 54.77% and 84.69% and also for Rayleigh distribution were 0.00039, 57.25% and 81.68% in Savojbolagh. In Table 5 can be seen that The Weibull and Rayleigh have been able estimated the observed wind speed with accuracy 0.941 and 0.936. The R^2 values express that Weibull distribution has estimated the observed wind speed better than Rayleigh distribution. The RMSE, MPE and MAPE values for Weibull were 0.02, 86.61% and 88.81% in Taleghan, while this index for Rayleigh distribution were 0.016, 78.35% and 85.07. To evaluation real data, the R^2 values were higher than 0.96 for Weibull and Rayleigh distributions in Taleghan.

In Fig.6 has been shown the comparison of real data based the Weibull and Rayleigh distributions in Taleghan for 2010-2015.

Table 5. Evaluation of Weibull and Rayleigh distributions in Savojbolagh.

Index	Savojbolagh		Taleghan	
	Weibull	Rayleigh	Weibull	Rayleigh
RMSE	0.00012	0.00039	0.020	0.016
MPE	54.77%	57.25%	86.61%	78.35%
MAPE	84.69%	81.68%	88.81%	85.07%
R^2	0.941	0.936	0.968	0.964

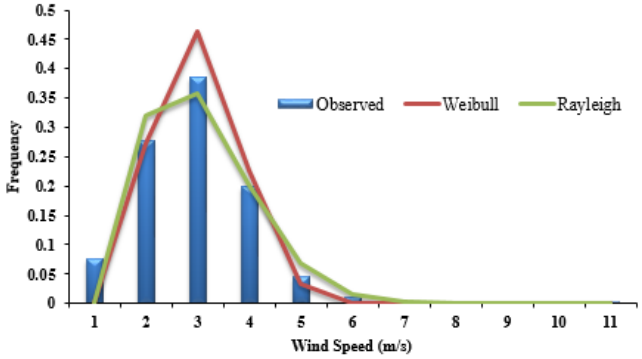

Fig6. Comparison of observed and predicted wind speed frequencies of Taleghan.

Wind power density (PD) and wind energy density (ED)

In Fig 4 and Table 7, the wind power density of any height can be seen. The average wind speed values for height 10 to 50 m, ranged from 2.63 to 3.31 m/s in Savojbolagh and 1.93 to 2.42 m/s in Taleghan. The highest and lowest of PD values were 17 Watt/m^2 in 2014 and 83.41 Watt/m^2 in 2012. In order to use of turbines with large scale (40-50 m heights), the PD parameter was calculated. The PD values for different heights (10-50 m) are 22, 38, 45, 58 and 66 W/m^2 in Savojbolagh, and 8, 18, 21, 23 and 27 W/m^2 in Taleghan for all years (2010-2015). According to results provided in Table 7 and Fig 4 can be seen that Savojbolagh has good wind potential than Taleghan. Calculate wind speed and wind power density to use turbines with different hub height are important. Table 7 and Fig 4 illustrate that by increasing the height, wind power density has increased.

Table 4 shows the monthly wind speeds, wind power density (PD) and wind energy density (ED) parameters in Savojbolagh County. Results illustrated that the highest and lowest of PD and ED parameters value belonged to December and July. Due to the high amount of C parameter, PD and ED parameters have been significant difference in December than other months (listed in Table 4). The maximum and minimum wind power density values are equal to 17719 and 175.15 W/m^2. Also, wind energy density values varied from 130.31 to 13183.42 kWh/m^2.

Table7. Comparison of the wind speed and wind power density at different height (2010-2015).

	Savojbolagh county		Taleghan county	
Height (m)	V_{avg} (m/s)	PD (W/m^2)	V_{avg} (m/s)	PD (W/m^2)

10	2.63	22	1.93	8
20	2.77	38	2.12	18
30	3.08	45	2.25	21
40	3.21	58	2.34	23
50	3.31	66	2.42	27

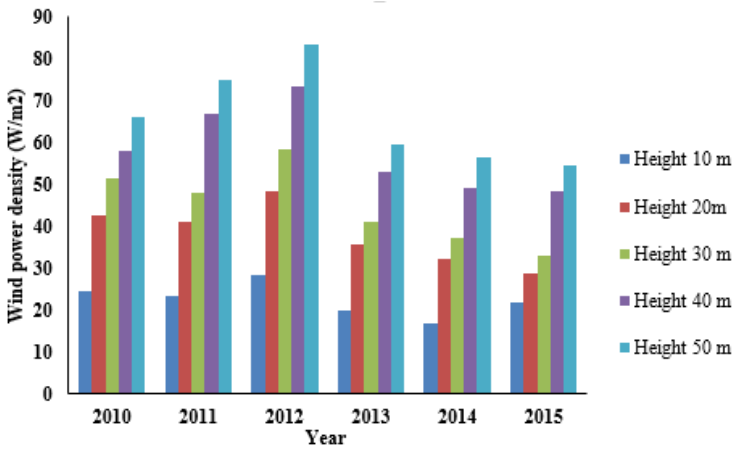

Fig4. Wind power density for difference the height in Savojbolagh.

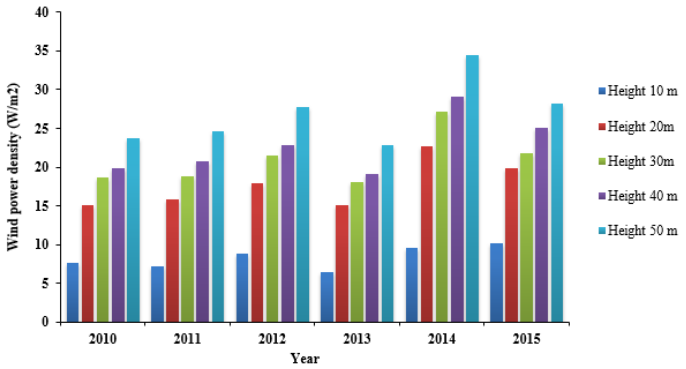

Fig5. Wind power density for difference the height in Taleghan.

Table 8 shows the monthly wind speeds, wins power density (PD) and wind energy density (ED) parameters in Savojbolagh and Taleghan. Results illustrated that the highest and lowest PD and ED parameters value belonged to December and July in savojbolagh. Due to the high amount of C parameter, PD and ED parameters have been significant difference in December than other months in savojbolagh (listed in Table 4). The maximum and minimum wind power density values are 17719 and 175.15 W/m^2. Also, wind energy density values varied from 130.31 to 13183.42 kWh/m^2. The maximum PD and ED parameters belong to March with values 176.22 W/m^2 and

131.11 kW/m^2 and minimum values them were 64.51 W/m^2 and 43.35 kW/m^2 in February.

Table8. Comparison of wind power and wind energy density in Savojbolagh and Taleghan (2010-2015).

Month	Savojbolagh			Taleghan		
	V_{avg} (m/s)	PD (W/m^2)	ED (kWh/m^2)	V_{avg} (m/s)	PD (W/m^2)	ED (kWh/m^2)
Jan	2.14	503.58	374.66	1.04	105.10	78.19
Feb	2.64	250.18	168.12	1.35	64.51	43.35
Mar	3.31	496.72	369.56	1.95	176.22	131.11
Apr	3.38	320.54	230.78	2.31	89.60	64.51
May	3.34	415.90	309.43	2.30	79.68	59.28
Jun	2.84	260.41	187.49	2.37	96.09	69.19
Jul	2.66	175.15	130.31	2.25	81.00	60.26
Aug	2.23	285.60	212.48	2.18	68.15	50.70
Sep	2.54	265.71	191.31	2.19	65.87	47.43
Oct	2.10	311.15	231.49	1.78	47.47	35.32
Nov	1.56	396.40	285.41	1.29	32.45	23.37
Dec	1.52	17719	13183.42	1.05	29.48	21.93

Wind rose

Fig 6 and Fig 7 show the prevailing wind direction in Savojbolagh and Taleghan counties for all years (2010-2015), respectively. The prevailing wind directions are from 247.5° north clockwise to 270° with frequency value 30.03%, 157.5° north clockwise to 180° with frequency value 26% in Savojbolagh and from 225° north clockwise 270° with frequency value 51.11% in Taleghan. The W (west) direction with 16.38% frequency has the highest frequency and the other directions are south with 13.38% frequency, WSW (west-south-west) with 12.65% frequency and SSE (south-south-east) with 12.62% frequency in Savojbolagh (Fig 6). Fig 6 illustrate that the W (west) direction with 20.5% has the highest frequency and other directions are WSW (west-south-west) with 15.78% frequency and SW (south-west) with 14.83% frequency in Taleghan from 2010 to 2015. The 0° north clockwise 270° has the highest wind frequency for two counties Savojbolagh and Taleghan with frequency values 85.66% and 91.24%, respectively.

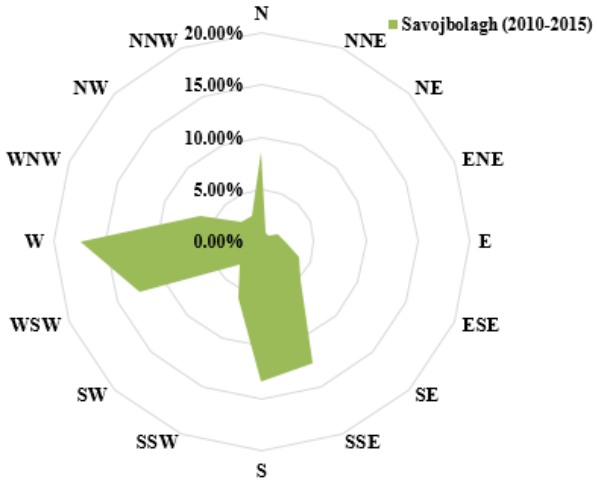

Fig 6. Wind rose diagram of Savojbolagh.

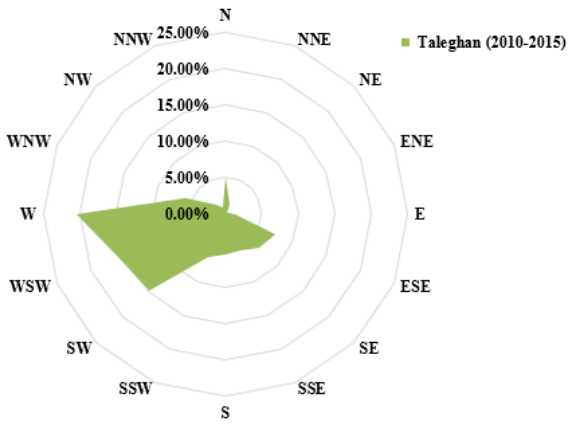

Fig 7. Wind rose diagram of Taleghan.

Conclusion

In this present study, wind speed data were analyzed in Savojbolagh and Taleghan counties for all years 2010-2015. The Shape factor (K (-)) and Scale factor (C (m/s)) as the parameters of Weibull and Rayleigh distributions were calculated. The real power density (PD) and energy density (ED) values with the predicted values by Weibull and Rayleigh distributions for 2010 to 2015 in Savojbolagh and Taleghan Counties were compared. Also, the prevailing wind directions were determined for Savojbolagh and Taleghan using Excel for all years 2004 to 2015. The most important results are as the following:

- The maximum and minimum the mean wind speed belonged to Feb in 2010 and Dec in 2012 in Savojbolagh and for Taleghan belonged to Aug in 2014

and Jan in 2010. The Highest and lowest whole year wind speed value ranged from 1.55 to 3.52 m/s in Savojbolagh and from 0.27 to 2.84 m/s in Taleghan. The highest and lowest standard deviation whole year belonged to March with value 1.25 and July with value 0.85 in Savojbolagh and this parameter belonged to March with value 0.92 and Jan with value 0.47 in Taleghan.

- The shape factor (K (dimensionless)) values ranged from 1.25 to 4 with average yearly value 2.45 in Savojbolagh and from 1.88 to 3.71 with average yearly value 2.84 in Taleghan. The maximum and minimum scale factor (C) value were 3.76 and 2.25 in Savojbolagh, Also were 2.85 and 1.56 m/s in Taleghan. The highest and lowest K and C parameters values belonged to 2015 and 2011 for two counties.
- The variations value of the V_{mp} are between 1.21 and 3.50 m/s with average yearly value 2.28 m/s and the V_{op} value ranged between 3.75 to 4.16 m/s with average yearly value 3.97 m/s in Savojbolagh. The V_{mp} and V_{op} values ranged from 1.00 to 2.62 m/s with average yearly value 1.97 m/s and from 2.36 to 3.21 m/s with average yearly value 2.77 m/s in Taleghan. The highest and lowest V_{mp} value belonged to 2015 and 2011, also for V_{op} are belonged to 2015 and 2011 in Savojbolgh. The maximum and minimum V_{mp} and V_{op} values were observed in 2015 and 2011 in Taleghan. Therefor mean wind speed values in Savojbolagh are higher than Taleghan for 2010-2015.
- Results of evaluation observed data with Weibull and Rayleigh distributions show that the Weibull estimated real data well, and the accuracy of distribution functions were higher in Taleghan than Savojbolagh for all years 2010-2015.
- Results of calculation the wind speed and power density illustrated that wind speed and power density values in Savojbolagh were the more of Taleghan. In order to installation of wind turbines order to power generation Savojbolagh has more potential than Taleghan. The highest and lowest wind power density value at different heights belonged to 2012 and 2015 in Savojbolagh and the maximum and minimum PD value at different heights

belonged to 2014 and 2013 in Taleghan. The highest and lowest PD and ED values belonged to December and July in Savojbolagh and there parameters values belonged to March and December in Taleghan.

- The west, south and south-south-east (SSE) were the prevailing wind directions in Savojbolagh. Also the prevailing wind in Taleghan was in west direction for all years (2010-2015).

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بررسی و ارزیابی پتانسیل انرژی باد در شهرستان‌های ساوجبلاغ و طالقان، استان البرز، ایران

چکیده

مطالعه امکان‌سنجی، اولین گام برای احداث مزرعه بادی است که هدف نهایی آن، ارزیابی امکان‌سنجی احداث یک نیروگاه توان بادی از لحاظ فنی و اقتصادی در یک مکان مشخص و استفاده از توربین‌های مشخص می‌باشد. در این مطالعه، داده‌های سرعت باد تجزیه و تحلیل و توسط دو مدل (توزیع ویبول و ریلی) در شهرستان ساوجبلاغ و طالقان برای سال‌های ۲۰۱۵-۲۰۱۰ ارزیابی شد. بیش‌ترین و کم‌ترین میانگین سرعت باد مربوط به ماه‌های مارس با مقدار ۳/۲۵ متربرثانیه و دسامبر با مقدار ۱/۰۵ متربرثانیه در ساوجبلاغ و ماه‌های ژوئن با مقدار ۲/۳۸ متربرثانیه و دسامبر با مقدار ۱/۰۹ متربرثانیه در طالقان بود. مقدار میانگین سالیانه انحراف معیار برابر ۱/۱۹ و ۰/۷۲ متربرثانیه در ساوجبلاغ و طالقان به ترتیب مشاهده شد. بالاترین و پایین‌ترین مقدار میانگین سالیانه فاکتور ضریب شکل (K (بدون بعد)) در ساوجبلاغ برابر ۴ و ۱/۲۵ و در طالقان برابر ۳/۷۱ و ۱/۸۱ بود. مقدار میانگین فاکتور مقیاس (C) در محدوده ۲/۲۶ تا ۳/۷۶ متربرثانیه و ۱/۵۶ تا ۲/۸۵ متربرثانیه در ساوجبلاغ و طالقان قرار داشت. مقدار RMSE توزیع ویبول و ریلی برابر ۰/۰۰۰۱۲ و ۰/۰۰۰۳۹ در ساوجبلاغ و ۰/۰۲۰ و ۰/۰۱۶ در طالقان مشاهده شد و هم‌چنین مقدار ضریب تعیین (R^2) ویبول و ریلی برابر ۰/۹۴۱ و ۰/۹۳۱ در ساوجبلاغ و ۰/۹۶۸ و ۰/۹۶۴ در طالقان بود. مقدار چگالی توان باد از ۲۲ تا ۶۶ وات‌برمترمربع در ساوجبلاغ و ۸ تا ۲۷ وات‌برمترمربع برای ارتفاع‌های ۱۰ تا ۵۰ متری متغیر بود. بالاترین و پایین-ترین مقدار چگالی توان باد مربوط به ماه‌های دسامبر با مقدار ۱۷۷۱۹ وات‌برمترمربع و جولای با مقدار ۱۷۵/۱۵ وات‌برمترمربع در ساوجبلاغ و ماه‌های مارس با مقدار ۱۷۶/۲۲ وات‌برمترمربع و دسامبر با مقدار ۲۹/۲۸ در طالقان می‌باشد. بیش‌ترین و کم‌ترین مقدار چگالی انرژی باد مربوط به ماه‌های دسامبر و جولای با مقادیر ۱۳۱۸۳/۴۲ و ۱۳۰/۳۱ کیلووات‌ساعت‌برمترمربع در ساوجبلاغ و ماه‌های مارس و دسامبر با مقادیر ۱۳۱/۱۱ و ۲۱/۹۳ کیلووات‌ساعت‌برمترمربع در طالقان مشاهده شد. W، SSW و WSW در ساوجبلاغ و W و SW در طالقان، جهت‌های باد غالب برای سال‌های ۲۰۱۵-۲۰۱۰ بودند.

کلمات کلیدی: انرژی باد، توان باد، توزیع ریلی، توزیع ویبول، ساوجبلاغ، طالقان