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Assessing the wind energy potential locations in province of Semnan in Iran

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ABSTRACT

In this study, the 3-h period measured wind speed data for years 2003–2007 at 10 m, 30 m and 40 m heights for one of the provinces of Iran. Semnan have been statistically analyzed to determine the potential of wind power generation. This paper presents the wind energy potential at five towns in the province – Biarjmand, Damghan, Garmsar, Semnan, and Shahrood. Extrapolation of the 10 m data, using the Power Law, has been used to determine the wind data at heights of 30 m and 40 m. From the primary evaluation and determining mean wind speed and also weibull distribution, it is found that Damghan has better potential for using wind energy in the province. Thus concentrated on Damghan town and its sites – Moalleman, Haddadeh and also Kahak of Garmsar (only had Meteorological stop) using a 10-min time step wind speed and wind direction data for three measured heights. Between these sites, Moalleman is selected for a more accurate and spacious analysis. The objective is to evaluate the most important characteristic of wind energy in the studied site. The statistical attitudes permit us to estimate the mean wind speed, the wind speed distribution function, the mean wind power density and the wind rose in the site at the height of 10 m, 30 m and 40 m. Some local phenomena are also considered in the characterization of the site.

Contents

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1. Introduction

The force of the wind can be very strong, as can be seen after the passage of a hurricane or a typhoon. Historically, people have harnessed this force peacefully, its most important usage probably being the propulsion of ships using sails before the invention of the steam engine and the internal combustion engine. Wind has also been used in windmills to grind grain or to pump water for irrigation or, as in The Netherlands, to prevent the ocean from flooding low-lying land. Vertical-axis windmills were reported in Persia in the 10th century and in China in the 13th century [1]. At the beginning of the 20th century electricity came into use and windmills gradually became wind turbines as the rotor was connected to an electric generator. The first electrical grids consisted of low-voltage DC cables with high losses electricity, therefore had to be generated close to the site of use. On farms, small wind turbines were ideal for this purpose and in Denmark Poul la Cour, who was among the first to connect a windmill to a generator, gave a course for 'agricultural electricians. Gradually, however, diesel engines and steam turbines took over the production of electricity and only during the two world wars, when the supply of fuel was scarce, did wind power flourish again. However, even after the Second World War, the development of more efficient wind turbines was still pursued in several countries such as Germany, the US, France, the UK and Denmark [2].

As already mentioned, a country or region where energy production is based on imported coal or oil will become more self-sufficient by using alternatives such as wind power. Electricity produced from the wind produces no CO_2 emissions and therefore does not contribute to the greenhouse effect. Wind energy is proportionately labour intensive and thus makes many jobs. In solitary areas or areas with a weak grid, wind energy can be used for charging batteries or can be combined with a diesel engine to save fuel whenever wind is available. Moreover, wind turbines can be used for the desalination of water in littoral areas with little fresh water, for instance the Middle East [2].

Wind energy is wild stuff, and very deceitful to handle. Capturing wind energy is like riding an antelope, when we could be using a Volkswagen. Most newcomers to wind energy underestimate the difficulties. Some of the drawbacks of wind energy are also mentioned. Wind turbines create a certain amount of noise when they produce electricity. In modern wind turbines, manufacturers have managed to reduce almost all mechanical noise and are now working hard on reducing aerodynamic noise from the rotating blades. Noise is an important rivalry factor, especially in densely inhabited areas. Some people think that wind turbines are unsightly in the vista, but as bigger and bigger machines gradually replace the older smaller machines, the actual number of wind turbines will be reduced while still increasing capacity. If many turbines are to be erected in a region, it is important to have public approval. This can be achieved by allowing those people living close to the turbines to own a part of the project and thus share the income. Furthermore, noise and visual impact will in the future be less important as more wind turbines will be sited offshore.

By 2050 the demand for energy could double or even triple as the global population grows and developing countries expand their economies. We must explore all aspects of energy production and consumption, including energy efficiency, clean energy, the global carbon cycle, carbon sources, and sinks and biomass, as well as their relationship to climate and natural resource issues. Knowledge of energy has allowed humans to flourish in numbers inconceivable to our ancestors.

All alternative energy technologies are not equal; they have various risks and drawbacks. When evaluating our energy options, we must consider all aspects, including performance against known criteria, basic economics and benefits, efficiency, processing and utilization requirements, infrastructure requirements, subsidies and credits, and waste and the ecosystem, as well as unintended consequences such as impacts on natural resources and the environment. Additionally, we must include the overall changes and the emerging energy picture based on current and future efforts to modify fossil fuels and evaluate the energy return for the investment of funds and other natural resources such as water.

The advantages of renewable energy are that it is sustainable (nondepletable), ubiquitous (found everywhere across the world in contrast to fossil fuels and minerals), and essentially non-polluting. The disadvantages of renewable energy are low density and variability, which results in higher initial cost because of the need for large capture area and storage or backup power.

1.1. World wind energy report 2009 http://www.wwindea.org/home/index.php?option=com_content&task=view&id=266&Itemid=43

It is shown in Fig. 1 that worldwide capacity reached 159′213 MW, out of which 38′312 MW were added in 2009. Wind power showed a growth rate of 31.7%, the highest rate since 2001. The trend continued that wind capacity doubles every 3 years. All wind turbines installed by the end of 2009 worldwide are generating 340 TWh per annum, equivalent to the total electricity demand of Italy, the 7th largest economy of the world, and equaling 2% of global electricity consumption. The wind sector in 2009 had a turnover of 50 billion €. The wind sector employed 550′000 persons worldwide. In the year 2012, the wind industry is expected for the first time to offer 1 million jobs. China continued its role as the locomotive of the international wind industry and added 13′800 MW within 1 year – as the biggest market for new turbines – more than doubling the installations for the 4th year in a row. The USA maintained its number one position in terms of total installed capacity and China became number two in total capacity, only slightly http://www.wwindea.org/home/index2.php?option=com_jce&task=popup ahead of Germany, both of them with around 26′000 MW of wind capacity installed. Asia accounted for the largest share of new installations (40.4%), followed by North America (28.4%) and Europe fell back to the third place (27.3%). Latin America showed encouraging growth and more than doubled its installations, mainly due to Brazil and Mexico. A total wind capacity of 200′000 MW will be exceeded within the year 2010. Based on accelerated development and further improved policies, WWEA increases its predictions and sees a global capacity of 1′900′000 MW as possible by the year 2020 [3].

Fig. 1. Development of World Wind Energy.

1.2. Wind power in Iran

It is known that the supplies of fossil fuels are limited and their utilization as energy sources cause environmental degradation due to incomplete combustion when used as energy source, in addition to this as the world population increases the demand for energy sources increases, therefore the issue of a gradual replacement of fossil fuels with renewable energy sources is of major consideration for most countries: studies and evaluations regarding the wind potential estimation in Iran illustrates that in 26 sections of the country (including more than 45 suitable sites) the nominal capacity of the sites, considering a general efficiency of 33% is approximately 6500 MW, however, it is noteworthy that the nominal capacity of all power plants of the country is already 3400 [4]. The feasibility of manufacturing wind turbines is investigated in this article. Utilization of renewable energy sources in Iran began a decade ago and it is still in its initial stages of development.

Condition of Iran's geographical is such that its low air pressures produce strong air flows over it in general during the summer and winter months in comparison with high pressures in the north and northwestern areas. It is the difference in the air pressure between the atmosphere over Iran, central Asia as well as the Atlantic Ocean during the winter months that causes cold winds from north and humid air flows from the Atlantic and Mediterranean from west. Since these systems of air maldes collide with the humid air from the Mediterranean, it produces snow over the country. Iran is also influenced by winds from the Atlantic Ocean on the northwest and by the winds from the Indian Ocean from the southeast during the summer; of the well-known winds from the east are the 120 day winds of Sistan and lavas wind: other local winds in the country include the north winds on the Persian golf and Khoch bad winds in the Gorgan plain, deez wind between Mashad and Nayshabour and Sham winds in Khuzestan [5].

The potential energy of wind is estimated to be about 6500 MW in Iran. As a matter of fact this level of energy is considered to be of medium level among different countries. At the present time most developed countries, which have wind energy potential similar to those in Iran are taking advantage of this power at an accelerating rate. Presently more than 23 billion kWh of cheap, clean and development sources electricity are being produced annually across the world. Germany, for example, produced some 4400 MW of electricity with wind. While Iran with a similar level of available wind power produces only 10 MW. The related figure for India, neighboring country, is 1000 MW [6].

Iran's first experience in installing and using modern wind turbines dates back to 1994. Two sets of 500 kW Nordtank wind turbines were installed in Manjil and Roodbar. They produced more than 1.8 million kWh per year. These two sites are in the north of Iran, 250 km from Tehran, the capital of Iran. The average wind speed is 15 m/s for 3700 h/year in Roodbar, and 13 m/s for 3400 h/year in Manjil. After this successful experience, in 1996 the contract for 27 wind turbines was signed and they were installed by 1999 in Manjil, Roodbar and Harzevil. Harzevil is the third wind farm site near to Manjil. Manjil is about 800 m above sea level and Harzevil is about 500 m higher there are 21 installed wind turbines in Manjil, 1 × 500 KW, 5 × 550 KW and 15 × 300 KW [7].

When mean wind speed is in the range of 5–25, technical usage of wind power would be possible. Producible potential of wind power in the world is estimated about 110 Ej (each Ej equals to 1018 J), 40 MW of which is the capacity installed by the end of 2003 (1382-solar calendar) all over the world.

In 2006, Iran generated 47 MW of electricity from wind power (ranked 30th in the world). This was a 47% increase over 32 MW in 2005. Total wind generation in 2004 was 25 MW out of 33,000 MW total electrical generation capacity for the country. In 2008, Iran's wind power plants in Manjil (in Gilan province) and Binaloud (in Khorasan Razavi province) produce 82 MW of electricity per year. By 2009, Iran had wind power installed capacity of 91 MW [8].

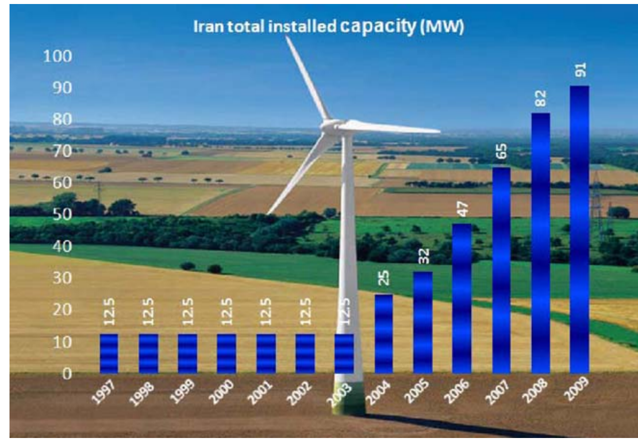

Fig. 2. Growth of Wind Energy in Iran.

Assessment of wind energy potential in Iran has been done for some areas such as Manjil in Gilan province [9], Yazd [10] and Tehran [11] provinces. There are also studies about feasibility of offshore wind turbine installation in Iran and comparison with the world [12], future of renewable energies in Iran [13] and renewable energy issues in Middle East compared with Iran [14]; and the present study shows feasibility of wind energy potential in another suitable province. Recent discussions were exposed in Fig. 2.

1.3. Semnan

Semnan province is 95,815 km^2. The province with 5.6% of the whole area of Iran is the sixth big province in the country. Semnan is located between N34°40′–N37°10′ latitude and E51°59′–E57°4′ longitude. It is in the north-east of the central plateau of Iran, and its capital is Semnan. Townships of the province include Semnan, Damghan, Shahrood, Garmsar and mahdi-shahr that has been recognized as township recently. Semnan province stretches along the Alborz mountain range and borders to Dasht-e Kavir desert in its southern parts. Neighboring with mountain and desert, the province faces the high and low pressure centers, which finally cause the creation of local winds and also dominant western (Desert) winds. The province is divided into two parts: a mountainous region, and the plains at the foot of the mountains. The former offers a scope for recreational activities as well as being a source for minerals, whereas the latter encompasses some ancient cities of Iran as one of the capitals of the *Parthian Empire* was located here. This state had good development in Sasani era. Semnan can be divided into 16 sectors from the old days of Avesta. During the *Median* (Medes) and *Achaemenid* periods, it accounted for being one of the largest satrapies (provinces) of the empire During the Islamic era, Semnan was part of the historical region of *Gomess* or *Komesh*, and The Silk Road paved its way from the midst of this region. Needless to say, the province was witness to numerous wars. The Cultural Historical Heritage Organization of Iran lists 470 sites of historical and cultural heritage such as palaces, forts, castles, caravanserais, water reservoirs (abanbar), and wind-wards (badgir), in Semnan. In addition to these, there are various religious and sacred places as well [15].

The province of Semnan is bordered from east by the province of Khorasan razavi, from north, Northern Khorasan, Mazandaran and Golestan provinces, from south, Yazd and Esfahan provinces, west, Tehran and Qom provinces. The center of province, Semnan is located at 228 km from Tehran and the distance from international waters of Persian gulf and Caspian sea in turn is 1600 and 200 km. This province includes five townships, 13 districts, 18 cities and 29 villages. According to the latest statistics in 2001, the population of the province are estimated to be 558,000 that 73.5% were in urban area and 26.5% were rural dwellers [16]. In general, the dominant prevailing wind in the area is blowing from the northwest to the southeast and is called Tooraneh. Also other winds in the province called Shahriari, Kavir and Khorasan winds, blow from west, south and east to west in different seasons of the year, respectively [17].

1.4. Towns

Garmsar is located in the west of the province. It is limited from north to Firooz Kooh and Damavand, from east to Semnan, from west to Varamin and Qom and from south to the desert of Esfahan province. In Garmsar, the dominant prevailing winds flow from northwest to the southeast, Shahriari wind from west and southwest, Semnan wind from east and northeast and Kavir wind in the warm seasons of the year from south to the north.

Shahrood is located in a far reaching and green space encompassing Shahrood, Bastam, Kalateh khij, Mojen and Mayami cities. The distance between Shahrood and Tehran is 400 km. Shahrood lies east of Semnan province. In Shahrood, dominant wind directions are also from northeast to the southwest. The famous wind in this area is Damghan or North wind which blows from north and northwest to east and north to south in spring and summer, respectively.

Semnan is a city with a population estimated at 119,778 inhabitants. It has been built in from north towards southern part in a vast field with heavy slope and includes the cities of Semnan, Sorkheh, etc. Semnan is situated at 1138 m above sea level. The city of Semnan is limited in west by Garmasar and in east by Damghan city, from north to Mazandaran province and Firooz kooh. From south by Kavir desert. This city is located on route of Tehran to Khorasan razavi province with both of them being on the road and railway network. Mahdi shahr is a new township located north of Semnan city and is closed to it.

Damghan has the best conditions to install wind turbine compared to others in the province mentioned. Damghan with the area of 12,110.312 km^2 is located at the northern latitude of 34°45′–36°58′ and the eastern longitude of 53°15′–55°20′. It is also 1170 m above the sea level. This township stretches along Alborz mountain, Shahrood township, Kavir desert, Semnan town from north, east, south and west, respectively. The distance of Damghan from Tehran is about 335 km and is located in the center of the province. Also Biarjmand is a parish of shahrood located in the most eastern point of Semnan province between mentioned regions [16].

We have studied the feasibility of using the wind in the different areas of Semnan province and compared it with the other acceptable sources by analyzing the speed of the winds and its potentials in period of 5 years. The studies indicated that Moalleman zone in Damghan is the best. This zone is situated about 36 km. Moalleman area is located at the northern latitude of 35°13′ and the eastern longitude of 54°34′. It is in south of Damghan with the distance of 128 km, and north of Kavir desert. It is surrounded by Dozina, Anarou, Tabarkooh and Dogoush mountains from north, Bidestan village from east, Kalate rashm village from west and Chalekavir area from south [15]. In Fig. 3 map of Semnan province with its different regions delineated, the name of regions has been brought, too (Table 1).

The location of meteorological sites for all studied zones are in Tables 2 and 3.

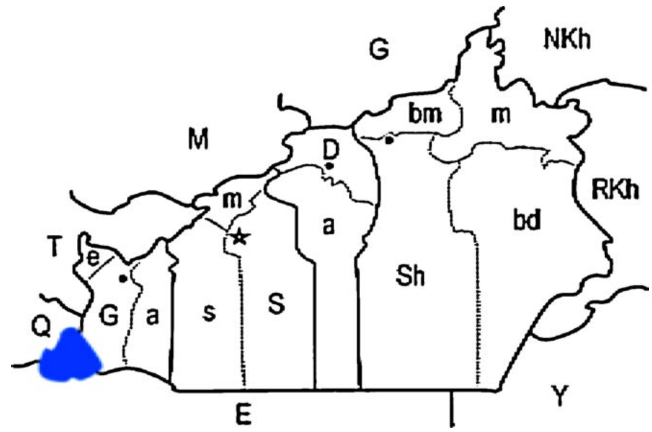

Fig. 3. Map of Semnan province.

Table 1
Guide of Semnan map.

Township	Map key	Area	Center
Damghan	D	Central	Damghan
	a	Amir Abad	
Garmsar	G	Central	Garmsar
	a	Aradan	
	e	Eyvanakey	
Semnan	S	Central	Semnan
	m	Mahdishahr	
	s	Sorkheh	
Shahrood	Sh	Central	Shahrood
	bd	Biarjmand	
	bm	Bastam	
	m	Mayami	

Neighbor provinces: E, Esfahan; G, Golestan; M, Mazandaran; NKh, North Khorasan; Q, Qom; RKh, Razavi Khorasan; T, Tehran; Y, Yazd.

Table 2
Geological location of meteorological sites for Semnan areas [17].

Site	Latitude	Longitude
Biarjmand	36°03′	55°50′
Damghan	36°09′	54°19′
Garmsar	35°12′	52°16′
Semnan	35°35′	53°33′
Shahrood	36°25′	54°57′

Table 3
Geological location of meteorological sites for Damghan and Garmsar sites [18].

Site	Latitude	Longitude
Moalleman	34°87′	54°57′
Haddadeh	36°25′	54°73′
Kahak of Garmsar	35°12′	52°32′

2. Analysis of wind data

Data used in the study was in two parts:

1. Three-hour period measured wind speed data for years 2003–2007 at 10 m for Biarjmand, Damghan, Garmsar, Semnan, and Shahrood. And data for 30 m and 40 m is determined from extrapolation of the 10 m data [19]. It was found that Damghan is in a better level for utilizing the wind energy [20].
2. Data collected over a period of 1 year, from 1/1/2007 to 12/31/2007 in the time interval of 10 min for sites corresponded to Moalleman and Haddadeh villages of Damghan, as well as Kahak

village of Garmsar. The meteorological masts with 40 m height were installed in suitable coordinates by power ministry. The datalogger used has three sensors of velocity at 10 m, 30 m and 40 m heights and also two sensors of direction at 30 m and 37.5 m. Without any extrapolation [4].

2.1. Average wind speed

In the first phase of study, as shown in Table 4, for five different areas in the province, the 5-year average wind speed at three heights was determined. It is observed that Damghan has a better situation at this respect. Therefore in the following, annual mean wind speed in the time interval of 10 min for three different sites – Moalleman, Haddadeh and Kahak zones are examined (Table 5).

It is observed that Moalleman has the highest mean wind speed in the province. Fig. 4 shows the monthly mean wind speed for 10 m, 30 m and 40 m of Moalleman.

It is commented that the monthly mean wind speed are between 3.03–7.75 m/s, 3.7–8.97 m/s and 3.94–9.53 m/s, respectively. The maximum and minimum wind speeds occur in July and December, respectively.

The annual mean wind speed per half hour is demonstrated in Fig. 5. This figure shows hours of day that have a suitable wind speed in all over the year 2007. Best wind speeds almost occur at 10 pm in the year.

2.2. Wind speed distribution

Statistical analysis can be used to determine the wind energy potential of a given site and estimate the wind energy output at this site. To describe the Statistical distribution of wind speed, various probability functions can be suitable for wind regimes.

Table 4
Five year mean wind speed at three heights for five areas in the province (m/s).

Site	10 m	30 m	40 m
Biarjmand	3.06	4.13	4.47
Damghan	3.90	5.14	5.52
Garmsar	2.60	3.56	3.87
Semnan	2.73	3.73	4.04
Shahrood	1.77	2.52	2.76

Table 5
Annual mean wind speed at three heights for sites in Damghan and Garmsar (m/s).

Site	10 m	30 m	40 m
Moalleman	4.93	5.82	6.17
Haddadeh	4.67	5.47	5.86
Kahak	3.61	4.56	4.88

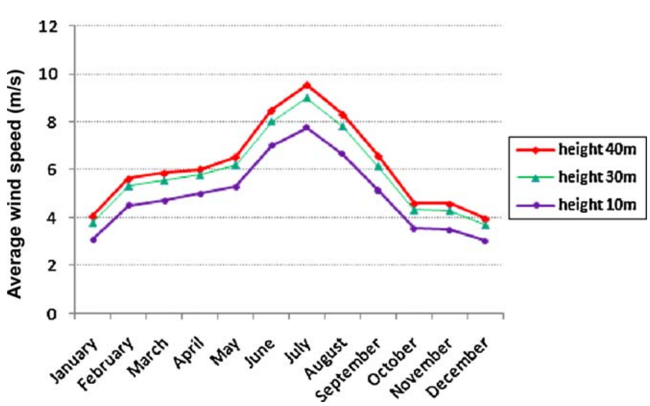

Fig. 4. Monthly mean wind speed for three heights of Moalleman.

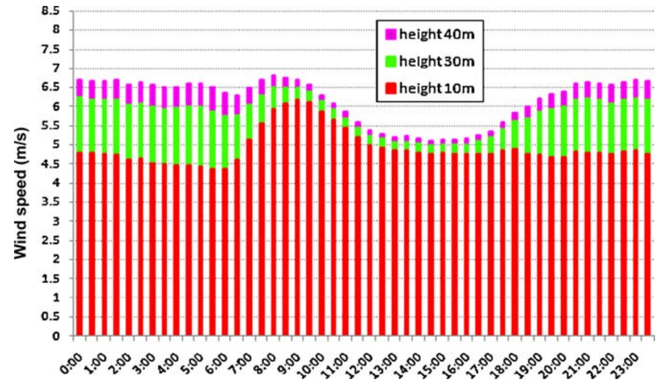

Fig. 5. Mean wind speed at different hours of the year-Moalleman.

According to Gumbel [21], Weibull distribution is the best one, with an acceptable accuracy level. This function has the advantage of making it possible to quickly determine the average of annual production of a given wind turbine. The Weibull probability density function is given by [22]:

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

Determination of the Weibull probability density function requires a knowledge of two parameters: k, shape factor and c, scale factor. Analytical and empirical methods are used to find k and c, such as Justus formulas demonstrated in the following form [22]:

$$\sigma_u = \sqrt{\frac{\sum_{i=1}^{N}(U_i - \bar{U})^2}{N-1}} \tag{2}$$

$$k = \left(\frac{\sigma_U}{U}\right)^{-1.086}, \quad \frac{c}{\bar{U}} = \frac{k^{2.6674}}{0.184 + 0.816k^{2.73855}} \tag{3}$$

where σ_u and $\bar{U}$ represent the standard deviation and mean wind speed, respectively. Standard deviation also is defined through the value of k [22]:

$$\sigma_U = \bar{U}\sqrt{\left(\frac{\Gamma(1+2/k)}{\Gamma(1+1/k)} - 1\right)} \tag{4}$$

Table 6 shows 5-year weibull parameters (k and c) for five areas of Semnan province. It can be concluded that, Damghan has relatively good condition in this aspect. Thus, yearly weibull parameters for two sites of Damghan and one of Garmsar are in Table 7.

Table 6
Five year weibull parameters (k, c) for five areas of Semnan province.

Site	k (dimensionless), c (m/s)	10 m	30 m	40 m
Biarjmand	k	2.12	2.35	2.42
	c	3.80	5.02	5.40
Damghan	k	2.16	2.39	2.46
	c	3.62	4.80	5.17
Garmsar	k	2.09	2.31	2.38
	c	4.22	5.51	5.91
Semnan	k	3.17	3.51	3.61
	c	3.00	4.05	4.39
Shahrood	k	1.79	1.98	2.04
	c	3.38	4.52	4.87

Table 7
Annual Weibull parameters (k, c) for sites in Damghan and Garmsar.

Site	k (dimensionless), c (m/s)	10 m	30 m	40 m
Moalleman	k	1.64	1.697	1.7
	c	5.51	6.52	6.91
Haddadeh	k	1.52	1.58	1.57
	c	5.19	6.09	6.52
Kahak	k	1.78	1.72	1.69
	c	4.28	5.50	5.80

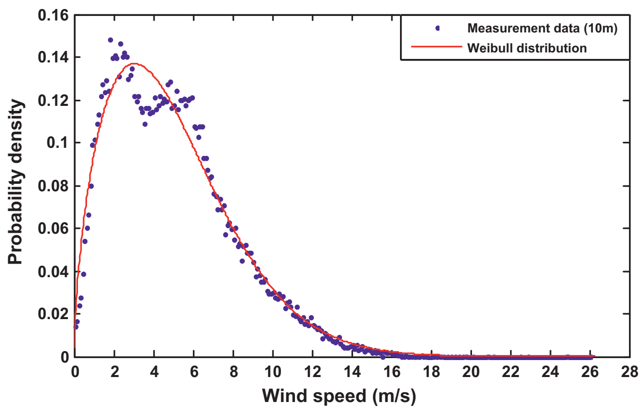

Fig. 6. Wind speed distribution at 10 m.

The corresponding wind data and best fits to a two-parameter Weibull distribution at heights of 10 m, 30 m and 40 m for Moalleman are shown in Figs. 6–8.

The Gust wind speed (maximum speed recorded) and occurance time, standard deviation and max. 10 min average wind speed are presented in Table 8 for three heights.

The energy pattern factor, K_e, whose application is in turbine aerodynamic design can be defined as the total amount of power available in the wind divided by the power calculated from cubing the average wind speed is given by [22]:

$$k_e = \frac{1}{N\bar{U}^3}\sum_{i=1}^{N} U_i^3 = \frac{\overline{U^3}}{\bar{U}^3} = \frac{\Gamma(1+3/k)}{\Gamma(1+1/k)} \tag{5}$$

where N is the amount of data in a year, 52559.

In the study of wind energy feasibility, to determine maximum energy in all over the year, the nominal wind speed is used, as a speed that produces maximum energy along the year. This speed is

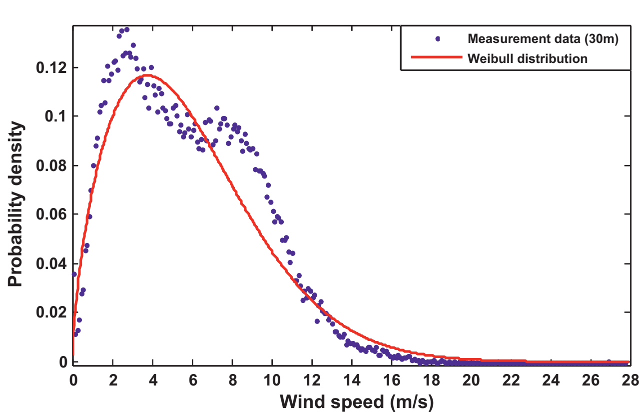

Fig. 7. Wind speed distribution at 30 m.

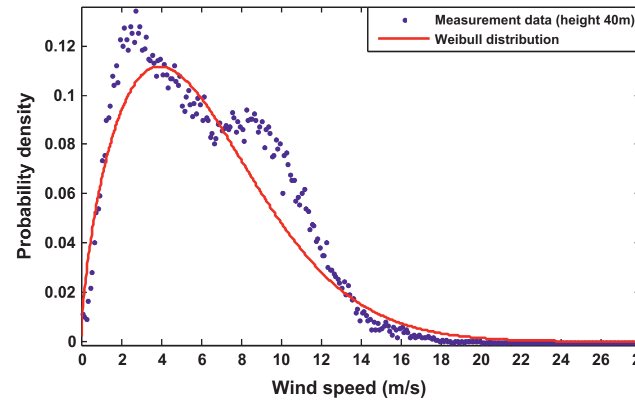

Fig. 8. Wind speed distribution at 40 m.

one of the significant characters in turbine designing and is given by [22]:

$$U_{me} = c\left(\frac{k+2}{k}\right)^{1/k} \tag{6}$$

It can be also found that the most probable wind speed for the area from [22]:

$$U_{mp} = c\left(1-\frac{1}{k}\right)^{1/k} \tag{7}$$

In Table 8, the cases that described above were represented for three heights.

It is also noticed also that the Weibull distribution gives a good fit to experimental data. Weibull distributions reveal that the wind speed 4.1, 3.86 and 3.1 m/s have the highest wind frequency at 40 m, 30 m and 10 m during the year with frequency being equal to 11.31%, 11.97% and 13.94%, respectively.

It reveals that Moalleman has a good condition for using wind energy. As more can be said in weibull distribution, expansion of curve leads to higher speeds and illustrates that produced energy of this site is desirable.

One way to define the probability density function is that the probability of a wind speed occurring between U_a and U_b, is given by [22]:

$$p(U_a \le U \le U_b) = \int_{U_a}^{U_b} p(U)dU \tag{8}$$

Also, the total area under the probability distribution curve is given by:

$$\int_0^{\infty} p(U)dU = 1 \tag{9}$$

For example, the probability of a wind speed happen upper than 5 m/s is shown in Table 8.

Another important statistical parameter is the cumulative distribution function $F(U)$. It represents the time fraction or

Table 8
Wind characteristics of Moalleman.

Height	10 m	30 m	40 m
Standard deviation	3.0892	3.5284	3.7335
Max. 10 min average wind speed (m/s)	26	27.7	27.9
Gust wind speed (m/s)	32.8	33.7	34
	6/5/2007	6/5/2007	4/15/2007
	22:20′	22:20′	17:40′
Energy pattern factor	2.4038	2.2969	2.2918
U_{me}	8.975	10.318	10.9216
U_{mp}	3.1008	3.8601	4.1014
$P(U > 5\,\text{m/s})$	42.66%	52.88%	56.18%

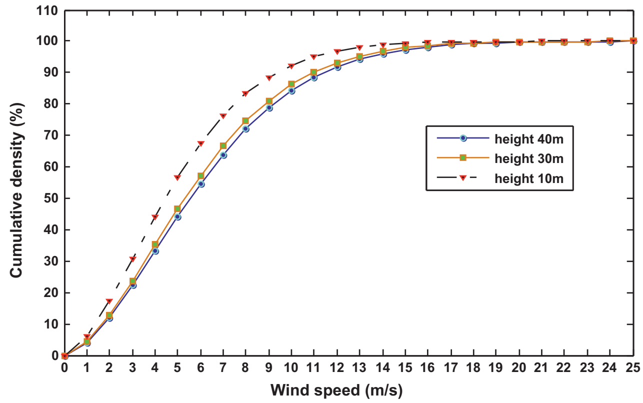

Fig. 9. Cumulative density at three heights.

probability that the wind speed is smaller than or equal to a given wind speed, U. It can be shown in [22]:

$$F(U) = 1 - \exp\left[-\left(\frac{U}{c}\right)^k\right] \tag{10}$$

Fig. 9 shows the cumulative distribution for Moalleman at three heights. It can be noted that, for example, the wind speed at 10 m, 30 m and 40 m heights is greater than 4 m/s for 56%, 64% and 67% of the time in the year, respectively. The 4 m/s limit is important since this is the cut-in speed of many commercial turbines. The cut-out speed is generally 20–25 m/s and such speeds are rare at this site.

2.3. Surface roughness

Although there are a number of ways to arrive at a prediction of a logarithmic wind profile (e.g., mixing length theory, eddy viscosity theory, and similarity theory), a mixing length type analysis given by Wortman (1982) is by the log law [22]:

$$\frac{U(z)}{U(z_r)} = \frac{\ln(z/z_0)}{\ln(z_r/z_0)} \tag{11}$$

where $U(z)$ is the wind speed at height z, $U(z_r)$ is the reference wind speed at reference height z_r, and z_0 is the surface roughness length, which characterizes the roughness of the terrain.

With respect to mean wind speeds at 10 m, 30 m and 40 m, and curve fitting with Logarithmic profile (log law), it can be found the equivalent surface roughness length of terrain. It was 31.83 mm for Moalleman. Regarding follow field for this area, it is relatively consistent with Table 2.2 in [22].

2.4. Wind direction

The wind direction is of paramount importance for the possibility assessment of using wind energy and plays a significance role in the optimal positioning of a wind farm in a given area.

Above we have estimated the mean wind speed without evoking the influence of the direction in the distribution of this parameter. In this section the frequency with which the wind direction falls within each direction sector is evaluated, so we present the data collected in the form of wind rose.

Changes in wind direction are due to the general circulation of atmosphere, again on an annual basis (seasonal) to the mesoscale (4–5 days). The seasonal changes of prevailing wind direction could be as little as 30° in trade wind regions to as high as 180° in temperate regions.

Figs. 10 and 11 illustrate the monthly prevailing wind direction for two heights (30 m and 37.5 m). Limitation of wind direction has a significant preference for wind powerhouse. Also the annual mean wind directions are 185.3° and 184.37° at 30 m and 37.5 m, respectively.

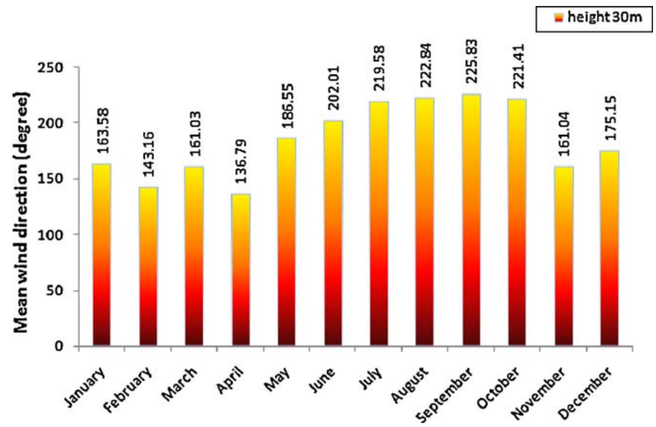

Fig. 10. Monthy mean wind direction at 30 m.

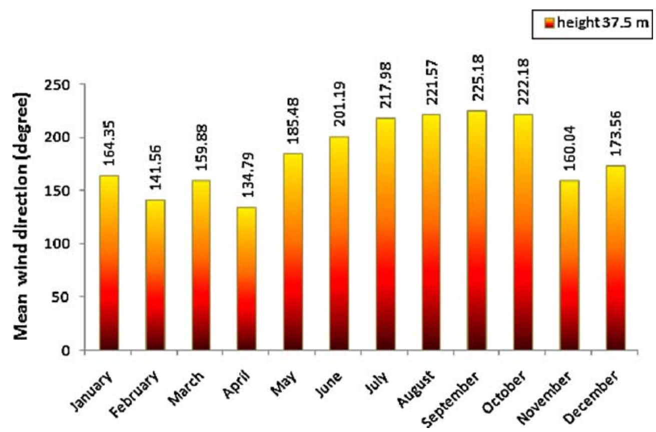

Fig. 11. Monthy mean wind direction at 37.5 m.

2.4.1. Wind rose

A wind rose is a diagram showing the temporal distribution of wind direction and azimuthal distribution of wind speed at a given location (Fig. 12). A wind rose is a convenient tool for

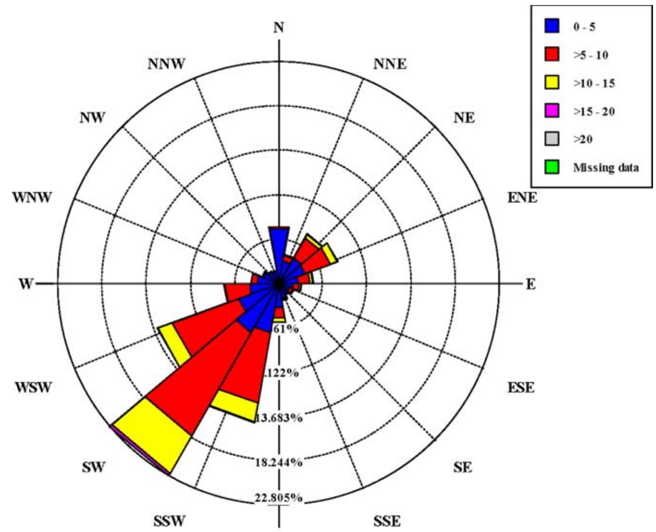

Fig. 12. Wind rose diagram at 30 m.

displaying anemometer data (wind speed and direction) for sitting analysis. This figure illustrates the most common form, which consists of several equally spaced concentric circles with 16 equally spaced radial lines (each represents a compass point). The line length is proportional to the frequency of the wind from the compass point, with the circles forming a scale. The legend of wind rose shows special colors for each wind velocity limit. The frequency of calm conditions is indicated in the center. The longest lines identify the prevailing wind directions ($\approx 250^{\circ}$).

Fig. 12 proves that the west direction contributes about 22.8% of the total available energy at 30 m. It is concluded that the most windward directions and the directions where the wind is strongest are southwest.

2.5. Turbulence

Turbulence in the wind is caused by dissipation of the wind's kinetic energy into thermal energy via the creation and destruction of progressively smaller eddies (or gusts). Turbulent wind may have a relatively constant mean over time periods of an hour or more, but over shorter times (minutes or less) it may be quite variable. Turbulence can be thought of as random wind speed fluctuations imposed on the mean wind speed. These fluctuations occur in all three directions: longitudinal (in the direction of the wind), lateral (perpendicular to the average wind), and vertical. Existence of turbulence decreases the power, causes the fatigue stress in the wind turbine too. Besides the mean wind speed, the variability of a set of data is represented by the standard deviation.

2.5.1. Turbulence intensity

The most basic measure of turbulence is the turbulence intensity. It is defined by the ratio of the standard deviation of the wind speed to the mean [22]:

$$TI = \frac{\sigma_U}{\bar{U}} \tag{12}$$

The length of this time period is normally no more than an hour, and by convention in wind energy engineering it is usually equal to 10 min. The study of a wind speed time history measured with sufficiently high resolution enables its most important parameters to be defined (Figs. 13 and 14). Turbulence intensity changes with the mean wind speed, with the surface roughness, with the atmospheric stability and with the topographic features [23].

Ignoring short-term fluctuations, the level of prevailing wind speed determines the mean wind speed $\bar{U}$. It is generally averaged over a period of 10 min. Thus, the turbulence is the instantaneous, random deviation from the mean wind speed. Maximum of turbulence intensity is shown 2.4 and 4.7 for 40 m and 30 m, respectively. Also the average of it is 0.136 and 0.144, respectively.

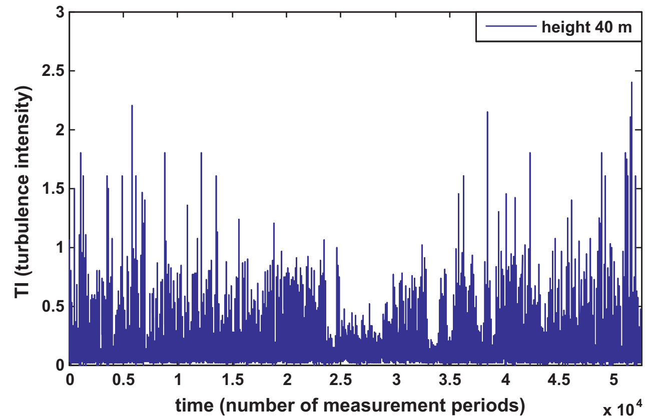

Fig. 14. Measured time history of wind speed at 40 m.

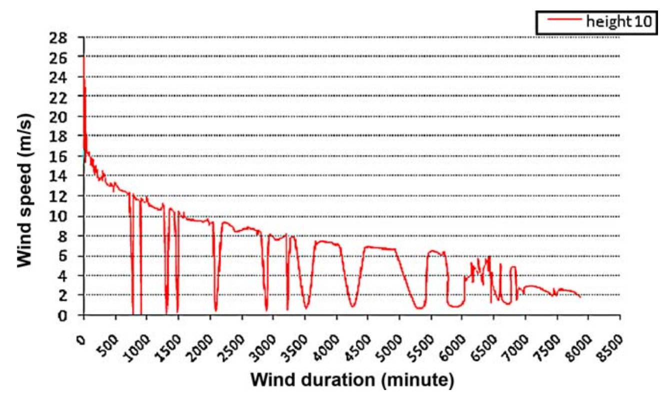

Fig. 15. Velocity duration curve at 10 m.

2.6. Wind velocity duration curve from data

Velocity duration curves can be useful when comparing the energy potential of candidate wind sites. As defined in this paper, the velocity duration curve is a graph with wind speed on the *y*-axis and the number of hours in the minute for which the speed equals or exceeds each particular value on the *x*-axis (Figs. 15–17).

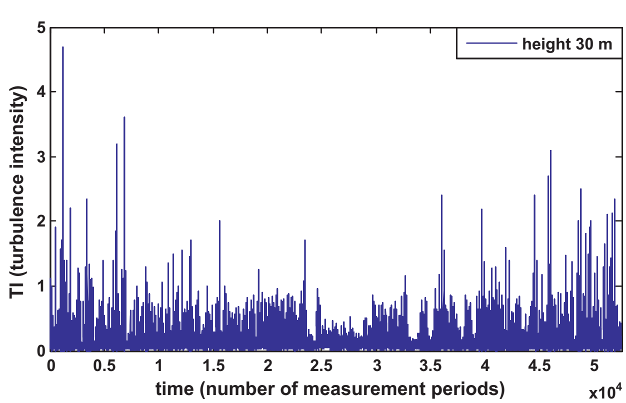

Fig. 13. Measured time history of wind speed at 30 m.

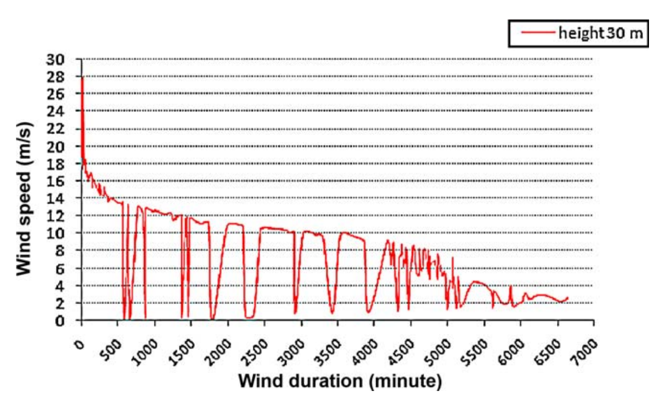

Fig. 16. Velocity duration curve at 30 m.

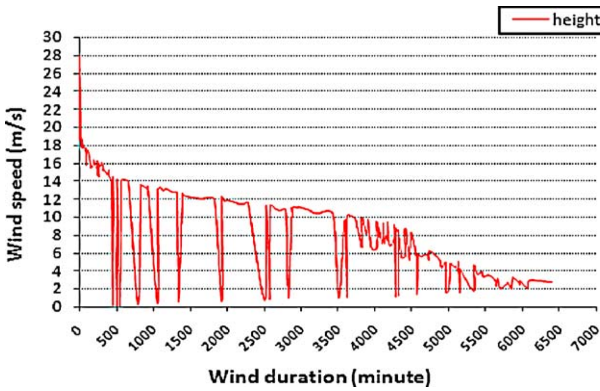

Fig. 17. Velocity duration curve at 40 m.

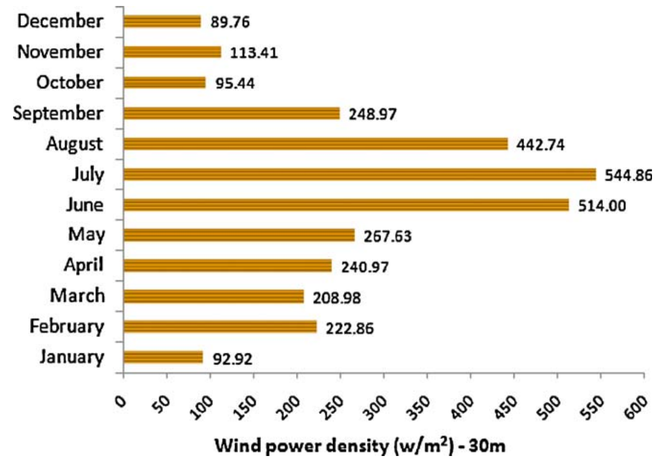

Fig. 19. Monthly power density at 30 m.

2.7. Air humidity and temperature

In the mentioned site the average relative humidity and air temperature are 32.26%, 19.91 °C, respectively.

2.8. Power and energy density

The best way to evaluate the wind resource available at a potential site is by calculating the wind power density. It indicates how much energy is available at the site for conversion to electricity by a wind turbine. The wind power per unit area, *P*/*A* or wind power density is [22]:

$$\frac{\bar{P}}{A} = \frac{1}{2}\rho \int_{c}^{\infty} U^3\, p(U)dU = \frac{1}{2}\rho c^3 \Gamma(1+3/k) \approx \frac{1}{2}\rho \overline{U^3} \qquad (13)$$

And also wind energy density is:

$$\frac{\bar{E}}{A} = \left(\frac{\bar{P}}{A}\right)(N\Delta t) \qquad (14)$$

where N is the number of measurement periods, Δt.

For standard conditions (sea-level, ISOC) the density of air is 1.225 kg/m^3. Figs. 18–20 show the monthly wind power density at the three heights. There are mainly two ways to estimate the power density in the site. The first is based on the measured data and the second on the probability distribution function. However, the first method is more precise because of its uses.

2.8.1. Monthly power density

In Figs. 18–20 the monthly power density at three heights are determined by measured data; and it is found that maximum monthly power density for each figure is related to mid months of year 2007.

2.8.2. Annual power and energy density

The yearly power density is determined using Eq. (4), and also energy density per unit area can be calculated from:

$$E_w = \sum_{i=1}^{N} p_w(U_t(\Delta t)) \qquad (15)$$

Some sample qualitative magnitude evaluations of the wind resource are [22]:

$$\frac{\bar{P}}{A} < 100\frac{W}{m^2} - \text{poor}$$

$$\frac{\bar{P}}{A} \approx 400\frac{W}{m^2} - \text{good}$$

$$\frac{\bar{P}}{A} > 700\frac{W}{m^2} - \text{great}$$

From above criteria, it is found that the site has a relatively good situation with respect to power density.

Fig. 21 also compares the results from the measurement data and Weibull distribution and found little difference between them. Maximum difference is related to height 40 m that equals to 8.7%. Difference between annual energy density and annual power density is only in a time coefficient, thus this was not considered.

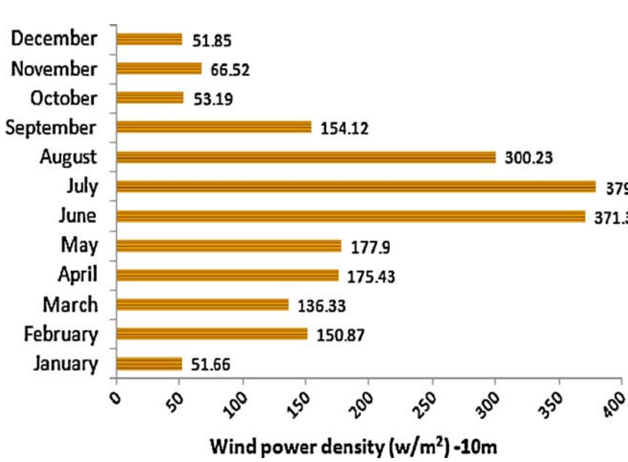

Fig. 18. Monthy power density at 10 m.

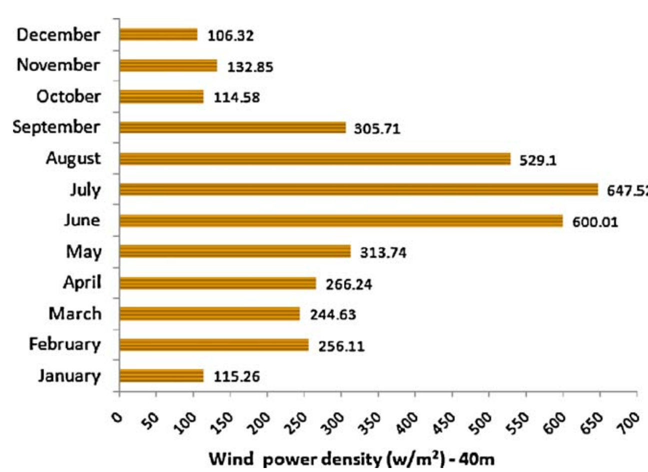

Fig. 20. Monthly power density at 40 m.

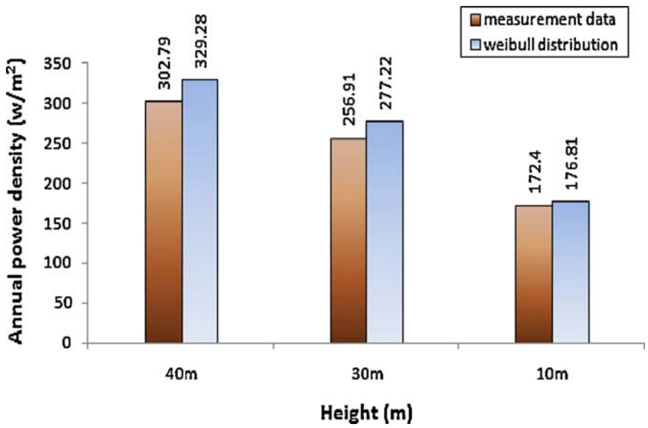

Fig. 21. Annual power density at 10 m, 30 m and 40 m.

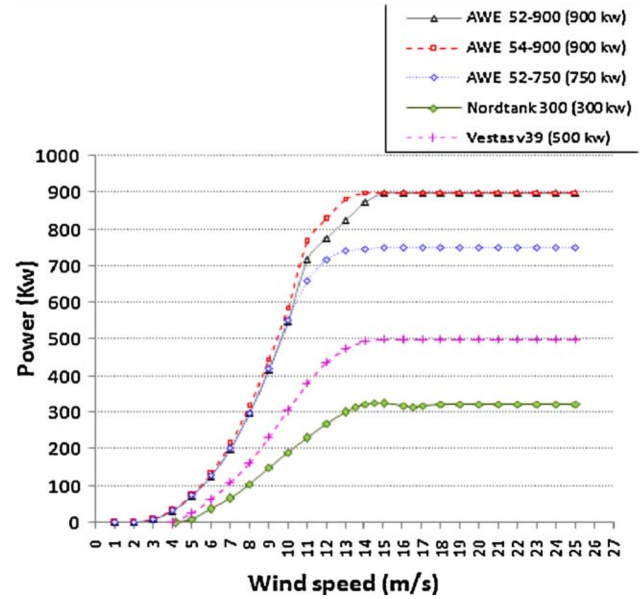

Fig. 22. Characteristic machine power curves.

2.9. Wind turbine energy production

For a given wind regime probability distribution, $P(U)$, and a known machine power curve, $P_w(U)$, the average wind machine power, $\bar{P}_W$, is given by:

$$\overline{P_w} = \int_0^{\infty} p_w(U)\, p(U) dU \tag{16}$$

Therefore, with a summation over N, bins, the following expression can be used to find the average wind machine power [24]:

$$\overline{P_w} = \sum_{i=1}^{N_B} \frac{1}{2} (U_{i+1} - U_i)(p(\mathrm{U}_{i+1}) P_w(U_{i+1}) + p(U_i) P_w(U_i)) \tag{17}$$

In the following, some real horizontal axis wind turbine models are used to find amount of energy that each one can capture. In this part of paper the productions of the five wind turbines were calculated. The wind turbine characteristics presented by three manufacture companies are in Table 9 [25–27].

These models are selected based on their tower heights. All mentioned turbines have pitch control system except Nordtank – 300 kw that is stall control. Indeed the heights are consistent with our statistical calculations. Their power curves are also in Fig. 22.

Using Eq. (10) for the average wind machine power, it is possible to calculate the annual energy captured from wind turbine as can be seen from Moalleman:

$$\bar{E}_W = \bar{P}_W \times N \times \Delta t \tag{18}$$

As shown in Fig. 23, it can obtain about 2000 MWh energy during the year; that is acceptable quantity for the wind energy. With installing a wind farm, it is possible to produce more energy at this site. Wind farms or wind parks, as they are sometimes called, are locally concentrated groups of wind turbines that are electrically and commercially tied together. There are many advantages to this electrical and commercial structure. Profitable wind resources are limited to distinct geographical areas. The introduction of multiple turbines into these areas increases the total wind energy produced. From an economic point of view, the concentration of repair and maintenance equipment and spare parts reduces costs. The number of turbines in the wind farm is practically different. However, as the number and size of wind farms increase, the interaction between wind farms and grids become more important [28]. Then, associated with the total amount of power connected to a distribution network, some power quality problems can arise due to the fluctuating nature of the wind, e.g., voltage and power disturbances which deteriorate the network performance.

Numerous technical issues arise with the close spacing of multiple wind turbines. The most important are related to the question of where to locate and how closely to space the wind turbines (common terms for referring to wind turbine array spacing) .The wind resource may vary across a wind farm as a result of terrain effects. In addition, the extraction of energy by those wind turbines that are upwind of other turbines result in lower wind speeds at the downwind turbines and increased turbulence. These wake effects can decrease energy production and increase wake-induced fatigue in turbines downwind of other machines. Wind turbine spacing also affects fluctuations in the

Table 9
Characteristic wind turbines [25–27].

Model	Power (KW)	Tower height (m)	Rotor diameter (m)
AWE54-900	900	40	54
AWE52-900	900	40	52
AWE52-750	750	40	52
Vestas V39	500	40.5	39
Nordtank-300	300	31	31

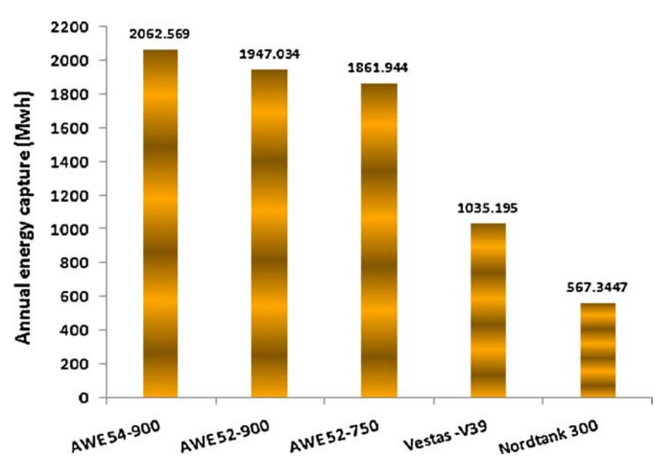

Fig. 23. Annual energy captured from wind turbines.

output power of a wind farm. The fluctuating power from a wind farm may affect the local electrical grid [22].

3. Conclusion

Detailed statistical study of wind at 10 m, 30 m and 40 m height in Semnan province is presented. The most important outcomes of the study can be summarized as follows:

1. Wind speeds are modeled using Weibull probability function. The Weibull parameters k (dimensionless) and c (m/s) are shown in Tables 6 and 7.
2. The results of 5-year wind speed and Weibull distribution show that Damghan has better condition; and among its sites, Moalleman was the best one. As a result, focused on this site and other essential characteristics for feasibility of the province are determined.
3. The winds are giving power densities of between (172–177) W/m^2 at 10 m, (257–277) W/m^2 at 30 m and (303–329) W/m^2 at 40 m.
4. Wind Rose analysis showed that prevailing wind directions are about (200–260°) for 30 m height and as an obvious result for 37.5 m height; which is generally at Southwest direction for most of the months.
5. Extractable annual energy from five wind turbines were calculated, showing the possibility of producing higher than 2000 MWh energy with larger one only during the year 2007.
6. An evaluation of the wind resource available in Moalleman that is a class 3 wind power site (with consideration to wind power density classes published by U.S. department of Energy) indicates its suitability for both grid connection and stand-alone activities such as water pumping and battery charging.

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