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Sensitivity and Uncertainty Analysis of Economic Feasibility of Establishing Wind Power Plant in Kerman, Iran

M. M. Amirrud[1]* and M. Shahin[1]

1. School of Environment, College of Engineering, University of Tehran, Tehran, Iran.

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**Corresponding author: mohammadreza.mataji@yahoo.com (M. M. Amirrud)*

Abstract

The wind energy is considered as a precious replacement for fossil fuels in electricity generation. In this regard, many governments like the one in Iran tend to support the development of this type of renewable energy source. However, fluctuations in Iran's economic conditions and uncertainty in the available wind power have increased the risk of investment. In this work, a methodology is used to address the uncertainty in wind conditions using the probability of occurrence of the minimum wind speed. In addition, a feasibility study is considered for the economic assessment of establishing a wind turbine power plant in the Kerman Province (Iran). A sensitivity analysis is developed to analyze the effect of changes in inflation and currency rates on the project economic viability. The results obtained show that the proposed site enjoys an excellent wind power potential with respect to a wind power density of 971.4 W/m^2 at a height of 100 m. The economic analysis results indicate that the project is viable when its budget is supplied through the governmental resources (providing US dollar at the governmental rate). However, the sensitivity analysis results reveal that the project is no longer viable when its budget is supplied through a foreign exchange market (providing US dollar at the market currency rate). Therefore, this paper suggests that if the government tends to support the development of wind energy in Iran, it is necessary to either provide the project budget by governmental resources (4200 T/$) or to buy electricity higher than 1391.6 T/kWh (845.6 T/kWh more than the current feed-in-tariff). Furthermore, the non-linear relationship between the net present value and the inflation shows that a reduction in the inflation rate can significantly improve the investment pay-off.

Keywords: *Wind energy, Wind potential, Wind uncertainty, Wind economic, Weibull distribution.*

1. Introduction

In the current century, global warming and climate changes have been taken into account as the greatest challenges facing the humankind. The greenhouse gases (GHGs), in particular CO_2, are characterized as the well-known drivers for raising the earth's global temperature. The energy use in all its forms (i.e. electricity generation, space and process heat, transportation, etc.) emits GHGs, particularly CO_2, more than the other human activities. It is due to the energy mainly supplied through fossil fuels in the developing countries with sufficient fossil fuel reserves. On the other hand, the increase in both population and wealth leads to the enhancement of energy demand throughout the world [1]. It results in the growth of energy price due to the limitation of fossil fuel resources. These factors force the societies to provide an energy supply chain with reliable and sustainable renewable energy sources such as the solar, wind, hydro ones. Several investigations indicate that the renewable energy systems consisting of different energy sources are the only way to generate electricity in some regions of the developing countries [2, 3]. This issue gives us more reasons for expanding the implementation of such systems.

Perez *et al*. [4] have estimated that the world has 25 to 70 TW-year annual wind energy reserves. However, the current energy consumption is 16 TW-year. Consequently, the wind energy can be considered as an appropriate alternative for fossil fuels. On the other hand, economic viability is considered as the most important issue in a society's transition from heavy dependence on fossil fuels to renewable energy sources. As a matter of fact, this transition should be accomplished considering several key factors such as the capital cost of renewable systems, government subsidies, and price of fossil fuels.

Iran has been taken into consideration as a country with rich resources of fossil fuels including 9% of the world total oil reserves and 16.2% of the world total gas reserves [5]. Yet, this country has invested in generating electricity from the wind energy since 1998. Figure 1 demonstrates the growth of wind electricity generation in Iran from 1998 to 2018 [5, 6]. Figure 2 illustrates Iran's atlas of annual mean wind speed [7]. It reveals that Iran enjoys an excellent potential for the development of wind power plants.

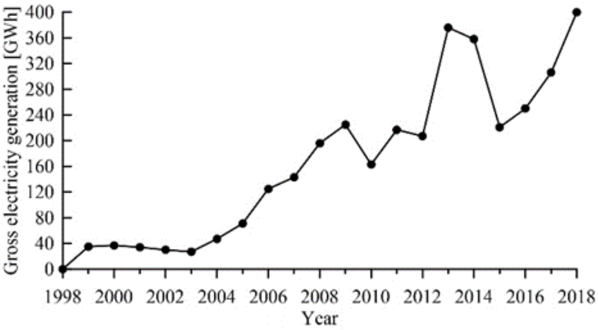


Figure 1. Gross electricity generation from wind energy in Iran [5, 6].

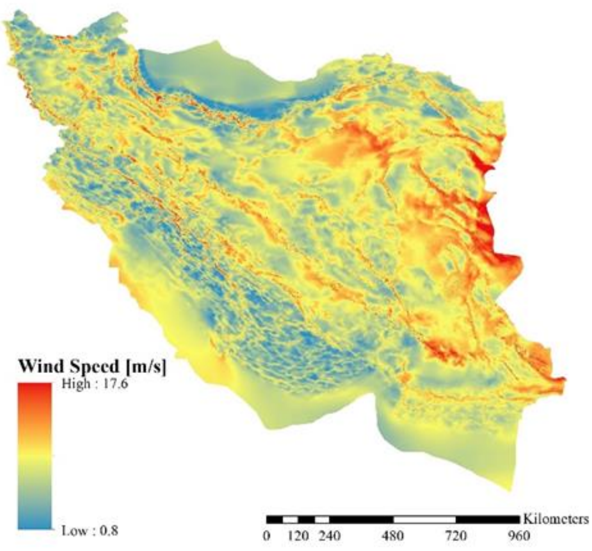


Figure 2. Wind speed atlas of Iran [7].

Many authors have addressed the economic viability for generating electricity from wind in Iran. Mostafaeipour *et al*. [8] have analyzed the mean wind speed data at three-hour intervals from 1997 to 2005. This analysis process was performed to determine the potential of wind power generation in the Shahrbabak City, Kerman Province. In this city, the average value of wind power density is 110.6 W/m^2. This value reveals that the city is not an appropriate place for construction of large-scale wind power plants but it would be suitable for employing the off-grid electrical and mechanical wind driven systems. Economic evaluation has shown that the cost of generating 1 kWh of electricity is 18 cents, which is 5 cents more than the market price.

Mohammadi *et al*. [9] have assessed the wind energy potential in the Aligoodarz City. In this study, the data was measured at three-hour intervals during five years (2005-2009) at a height of 10 m. Also the height of the measured wind data was 10 m. Analysis of six different wind turbines with respect to the rated powers ranging from 20 to 150 kW showed that all the turbines had a lower energy cost than the renewable energy purchase tariff in Iran.

Later, in 2014, Mohammadi *et al*. [10] investigated the potential of wind energy in Jarandagh, Qazvin Province. This study was conducted by analyzing the measured wind speed data at a height of 40 m between 2008 and 2009. The electricity production and economic evaluation were investigated for four large-scale wind turbine models, which operated at a height of 70 m. The results of energy cost estimation convincingly demonstrated that it was economically feasible to invest in wind farm construction through applying all the nominated turbines.

Mostafaeipour [11] has developed an economic evaluation of a small wind turbine installation in the city of Kerman. A long-term wind speed dataset was adopted and analyzed for this study. In this regard, a mean wind dataset was collected in three-hour intervals during 14 years (1991–2004). In this city, the annual mean wind speed was obtained to be 2.743 m/s at a height of 10 m. The results achieved show that the Kerman City has an available wind energy potential for installing some small wind turbines. An economic analysis was performed through the Pay Back Period (PBP) technique. The results obtained indicated that PBPs were acceptable for all the nominated turbine models with a minimum PBP of 7 years.

Again, in 2014, Mostafaeipour *et al*. [12] developed a research work to assess the wind energy potential in the city of Zahedan. This research work was conducted by gathering the wind data during five years (2003-2007). The obtained wind power and energy densities were 89.184 W/m^2 and 781.252 kWh/m^2 at a height of 10 m, respectively. The economic evaluation and analysis of four different wind turbines revealed that if the renewable electricity purchase tariff was 0.13 $/kWh, then installation of only one wind turbine model would be economically feasible. In this case, the energy costs were equal to 0.1225 $/kWh and 0.1187 $/kWh at 20- and 30-m hub heights, respectively.

Nedaei *et al*. [13] have developed a research work to investigate the economic feasibility and potential of wind power generation in the city of Mahshahr. In this study, a short-term wind speed dataset was statistically analyzed. The data was measured every 10 minutes at the heights of 10 and 40 m during 19 months. By evaluating the wind data in Mahshahr, it was found that the studied site had an acceptable potential for wind power to generate electricity. A thorough economic evaluation was also considered for this research work. In this regard, if it is assumed that the proposed feed-in-tariff rate is 4400 Rials, and carbon credit is 50 \$/ton CO_2 with an escalation rate of 4%, and then the minimum return period of investment, the highest net present value (NPV), and the minimum cost of energy will be 3.2 years, \$33,403,476, and 4.163 cent/kWh, respectively.

Fazelpoor *et al*. [14] have assessed the wind potential in the cities of Tabriz and Ardabil. In this study, the data was measured every 3 hours at a height of 10 m above the ground level over a six-year period. The cost of energy (COE) method was used for the economic analysis. The results obtained indicated that the monthly mean price of electricity generated by the 25 kW wind turbine, in most of the months of the year, was less than or approximately equivalent to the purchase tariff of the renewable energy in Iran.

In 2017, Fazelpoor *et al*. [15] evaluated the wind energy potential for four areas in the Sistan-Baluchestan Province. The wind data was measured every three hours at a height of 10 m over a 5-year period (2009-13). In this study, the annual energy densities and the annual mean power densities were estimated for four cites including Zabol, Zahak, Zahedan, and Mirjaveh. The annual energy densities were estimated to be 2495.36, 2355.69, 1265.24, and 1214.01 kWh/m^2/year for the cities, respectively. The annual mean power densities were estimated to be 284.97, 269.02, 144.49, and 138.64 W/m^2 for the cities, respectively. Using the COE method, the results obtained showed that Zahedan and Zabol were suitable for large-scale wind turbines. It was due to the fact that the cost of electricity generation was much less than the selling price to the government, whereas Mirjaveh was suitable for small-scale wind turbines.

Soltani *et al*. [16] have developed a study to examine the potential wind resources in the Kahnuj City, Kerman Province. The wind data was measured every 3 hours at an elevation of 10 m above the ground level. The COE analysis indicated that the annual average cost was 0.133 \$/kWh to produce electricity using 25 kW wind turbines. Thus if it is assumed that the purchase tariff is 0.3 \$/kWh, it will be viable to generate electricity from wind turbines.

Hosseinalizadeh *et al*. [17] have provided a feasibility analysis for small wind turbines in residential energy sectors in 88 regions of Iran. This study was accomplished to identify the most affordable conditions for investing and comparing the effects of different parameters. In this investigation, several items including COE, minimum capacity of cost-effective wind turbines, and minimum suitable average wind speed were examined. The sensitivity analyses were also performed to evaluate the capital cost, feed-in tariff, and grid power price. The results obtained showed that the small wind turbines were cost effective in about 30% of the studied regions. The best capacity was 3 kW for wind turbines in residential energy sectors.

Minaeian *et al*. [18] have investigated some wind turbines for three cities including Chabahar, Dehak, and Dalgan in the Sistan-Baluchestan Province. In this research work, five different commercial wind turbines were considered with respect to the capacities from 1.6 to 30 kW. In order to analyze the wind resource, the calculated electricity costs and annual profits were examined. According to the results obtained, the best choice was 10 kW wind turbines in the three heights of 40, 30, and 10 m.

Ehyaei *et al*. [19] have performed the energy, exergy, economic, advanced exergy, and extended energy analyses for a Bergey Excel-S wind turbine with respect to nominal power of 10 kW in two cities comprising Tehran and Manjil. The analyses were concerned with energy, exergy, economic, advanced exergy, and extended energy. The results obtained showed that the wind turbine had a higher energy efficiency in windy areas than other areas but the exergy efficiency was lower in these areas. Furthermore, the cost of electricity generated by the wind turbine was higher in the windy areas.

In addition to the economic analyses, the wind energy potentials were also investigated in some parts of Iran. These studies included Manjil [20], Isfahan [21], Yazd Province [22], Tehran [23], North and South Khorasan [24], Semnan [25], Isfahan and 32 synoptic stations over Iran [26], Abadan [27], Chalus in the Mazandaran Province [28], Zarrineh [29], Chabahar [30], Chabahar, Kish and Salafchegan [31], Zahedan [12], Mil-E Nader region in the Sistan-Baluchestan Province [32], Hormozgan Province [33], Kurdistan [34], Kerman Province [35], Bushehr Province [36], and Zabol [37].

The present investigation was carried out to analyze the effects of the economic parameters (e.g. inflation and currency rate) on establishing a wind power plant in Iran. These parameters vary from country to country. In the recent years, fluctuations in these parameters have been very high, which are due to the economic conditions in Iran. Moreover, this paper provides a robust methodology with the capability of determining the economic pay-off and risk of a wind project. In addition, it allows the user to calculate the probability of economic success. The results obtained can be valuable for the private investors to make accurate decisions. In addition, these results can be utilized by the government agencies to determine proper regulations and support private investors in wind energy.

2. Materials and Method

2.1. Site description

This investigation is focused on the Halili site, which is located in the Kerman Province (Iran). The Renewable Energy and Energy Efficiency Organization in Iran (SATBA) [38] has selected this site as one of the best locations for installing a wind turbine power plant. According to the SATBA's report, the proposed locations are elected based on the national wind potential atlas for development of wind power sites. In addition to the wind potential of locations, several criteria are also considered for electing the sites, as follow:

- Environmental parameters and excluding protected areas, national parks and lakes.
- Distance from power transmission lines and sub-stations.
- Distance from and accessibility to roads.
- Earth topography including mountains, plains, hills, valleys, and slope.
- Land use including farmlands, national lands, etc.
- Preventing form overlapping infrastructures like militaries and generation and transmission of fuels.

The 1132-acre Halili site is located in 28˚11'05.2" North and 58˚39'03.7" East. Figure 3 depicts the site location. This region is located 20 km far from any road, 80 km from the railroad, and 40 km from the nearest power transmission line and sub-station.

2.2. Methodology

The probability of occurrence of the minimum mean annual wind speed was considered for the economic analysis of the proposed wind project at the proposed site location [39]. The utilized dataset was provided by SATBA [38]. The dataset was comprised of hourly measured wind data at the heights of 25, 50, 80, 100, 120, and 200 m. The data was collected during 11 years (2005-2015). The average and standard deviations of wind speed, V_{ave} and σ, were calculated using equations (1) and (2).

$$V_{ave} = \frac{\sum_{i=1}^{n} V_i}{n} \tag{1}$$

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n} (V_i - V_{ave})^2}{n-1}} \tag{2}$$

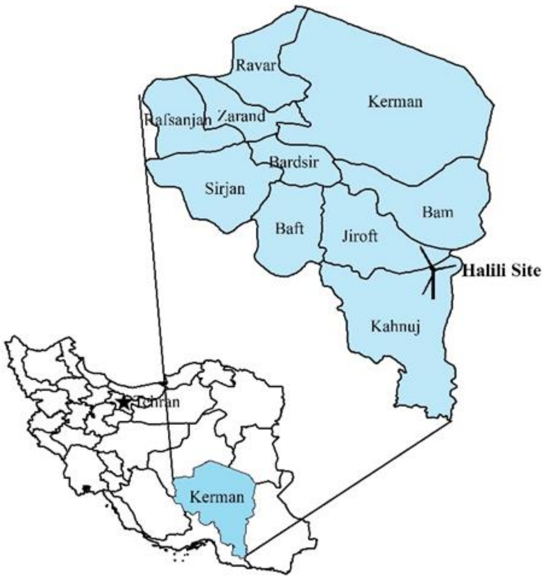


Figure 3. Location of the Halili site.

where V is the velocity, n is the number of data points, and i is the data counter ($i = 1, 2, 3, ...$). The inherent uncertainty in the wind speed data was addressed by evaluating the minimum expected velocity. In this methodology, it is assumed that the annual averaged wind speed follows a Gaussian distribution. Then the standard deviation of the Gaussian distribution at the selected probabilities of 99%, 95%, 90%, 84%, 50%, 16%, and 10% were multiplied by the standard deviation of the wind speed dataset. Afterward, the wind speed data was subtracted from this value. The mean and standard deviations of each probability were calculated from the positive values of the corresponding dataset. The following equation could be used to calculate the average power produced by each one of these probabilistic velocities [40].

$$\bar{W} = \int_0^{\infty} \dot{W}(V) P(V) dV \tag{3}$$

where $\bar{\dot{W}}$ is the average power produced by one turbine, $\dot{W}(V)$ is the power produced by turbine as a function of wind speed, which is obtained from the data given by the turbine manufacturer company, and $P(V)$ is the wind speed probability distribution. Equation (3) is numerically integrated with a step size of 0.5 m/s. If it is assumed that the hourly measured wind speeds for a given site is V_i, the available potential of the wind resource and its power production capabilities can be determined via wind turbines, as follows [40]:

$$\frac{\bar{\dot{W}}_{wind}}{S} = \frac{1}{2}\rho \frac{\sum_{i=1}^{n} V_i^3}{n} \tag{4}$$

where S is the area (m^2), ρ is the air density (about 1.225 kg/m^3), and $\bar{\dot{W}}_{wind}$ is the wind power potential for a given time period and location.

According to a literature survey, the researchers considered different wind speed probability distribution functions for their investigations [40, 41]. In this study, the Rayleigh, Weibull, and lognormal probability distribution functions were applied to the statistical wind data to determine the best fitted function to the collected data. The Rayleigh probability distribution function can be defined as follows [40, 42]:

$$P_R(V) = \frac{V}{V_{\mathrm{mode}}^2}\exp\left(-\frac{1}{2}\left(\frac{V}{V_{\mathrm{mode}}}\right)^2\right) \tag{5}$$

where V_{mode} is the mode velocity given by $V_{\mathrm{mode}} = V_{ave}/1.253314$ [39]. The Weibull probability distribution function is determined by the following equation [40, 42]:

$$P_W(V) = \left(\frac{k}{c}\right)\left(\frac{V}{c}\right)^{k-1}\exp\left[-\left(\frac{V}{c}\right)^k\right] \tag{6}$$

where k and c are the shape and scale factors for the Weibull distribution function. The shape and scale factors are defined by the equations (7) and (8), respectively [40].

$$k = \left(\frac{\sigma}{V_{ave}}\right)^{-1.086} \tag{7}$$

$$c = \frac{V_{ave}}{\Gamma(1+1/k)} \tag{8}$$

where $\Gamma(x)$ is the gamma function, which is defined as follows:

$$\Gamma(x) = \int_0^\infty e^{-z} z^{x-1} dz \tag{9}$$

The gamma function can be approximated by equation (10) [40, 43].

$$\Gamma(x) = \left(\sqrt{2\pi x}\right)\left(x^{x-1}\right)\left(e^{-x}\right)\left(1+\frac{1}{12x} + \frac{1}{288x^2} - \frac{139}{51840x^3} + \ldots\right) \tag{10}$$

The Lognormal probability distribution function is determined by equation (11) [13].

$$P_L(V) = \frac{1}{V\varphi\sqrt{2\pi}}\exp\left(\frac{-(\ln V - \mu)^2}{2\varphi^2}\right) \tag{11}$$

where φ and μ are the lognormal shape and scale parameters, which are defined by equations (12) and (13), respectively [13].

$$\varphi = \sqrt{\ln\left(1+\left(\frac{\sigma}{V_{ave}}\right)^2\right)} \tag{12}$$

$$\mu = \ln V_{ave} - \frac{1}{2}\ln\left(1+\left(\frac{\sigma}{V_{ave}}\right)^2\right) \tag{13}$$

The average power produced by turbine, $\bar{\dot{W}}$, can also be used to calculate a related performance parameter, which is named the capacity factor (CF). The capacity factor is defined for a wind turbine at a given site as the ratio of the energy actually produced by the turbine to the energy that could have been produced if the machine ran at its ideal condition, multiplied by maintenance and icing factors, over a given time period [40]. Thus the capacity factor is introduced as equation (14) [39].

$$CF = \frac{\bar{\dot{W}}}{\dot{W}_{rated}} \times F_{maint} \times F_{ice} \tag{14}$$

where F_{maint} is the maintenance factor (100% is always available) and F_{ice} is the icing factor. For the current study, these values were assumed to be 93% and 100%, respectively.
Finally, the annual energy produced by each wind turbine in kWh/year was calculated as follows:

$$E_{annual} = \dot{W}_{rated} \times CF \times 365.25 \times 24 \tag{15}$$

The annual earning of the project is reached by multiplying three items including E_{annual}, number of turbines, and electricity selling price.
The following relations are used in order to transform the monetary flows to present and future time and to factor out inflation from calculation. Equation (16) is used to convert the future value of an amount (F) to present the value of that amount (P) [1].

$$P = \frac{F}{(1+i)^N} \tag{16}$$

where i is the discount rate (or interest rate) and N is the time horizon. If i in (16) is replaced by the inflation rate (f), then the inflation effect can be factored out from the future money. The tax calculation can be done using the following relation:

$$M_{after-tax} = M_{pretax} \times (1-t) \tag{17}$$

where $M_{after-tax}$ is the amount of money after incurring taxes, M_{pretax} is the amount of money before incurring taxes, and t is the tax rate. Finally, equation (18) can be employed to convert the equal annuity stream (A) to the present value [1].

$$P = A\frac{(1+i)^N - 1}{i(1+i)^N} \tag{18}$$

2.3. Assumptions
Calculation of the economic analysis is done by assuming a 33 MW power plant, which uses 20 AAER 1650-82 wind turbines with a 100 m hub height, a 1650 kW rated power, and an 82 m diameter. The price of each turbine is assumed to be 3 million dollars. The contributions of other costs are assumed as follow: the plant construction, transporting, and installing costs of turbines are 16% of the capital cost [44], the grid connection cost is 13% of the capital cost [44], and the operation and maintenance costs are 1.5% of the turbine price [45] with respect to a turbine lifetime of 20 years. According to the government regulations [38], the importing wind turbines are exempt from customs, and the wind turbine power plants are exempt from income taxes during the first 13 years of establishment. An income tax of 6% is incurred for the rest of the project lifetime [46]. The electricity selling price to the government is 546 Tomans per kilowatt-hour (T/kWh) during the first 10 years of the project lifetime, and it is 70% of this price for the rest of it [38]. It is assumed that the total capital cost of the project is provided by loan from the National Development Fund of Iran [47]. The interest rate of this loan is 3.5% and all of the payments are made based on US dollar. The US dollar inflation rate is assumed to be 1.76% [48]. The inflation rate is assumed to be 8.6% for the electricity producers in Iran [49]. The currency rate is considered to be 4200 T/$, which is based on the price that the Iran's government distributes dollar [50]. Finally, calculation of NPV is accomplished by assuming a minimum attractive rate of return (MARR) of 5%.

3. Results and Discussion
3.1. Data analysis
Figure 4 illustrates the diurnal average wind speed data during 11 years (2005–2015). The results obtained show a higher wind speed during the day (between 3 and 4 P.M.) and a lower speed during the night. It is a typical characteristic for the diurnal wind speed graphs. This type of wind speed variation is due to the differential heating of the earth's surface during the daily radiation cycle. Also the diurnal variation in the wind speed can vary from month to month or from season to season. Typically, the largest diurnal changes occur in the spring and summer, and the smallest in the winter. However, this variation may significantly change with location and altitude above the sea level.
Figure 5 demonstrates the diurnal variation in the wind speed for different months at a height of 100 m. It reveals that the maximum and minimum variations occur in January and May, respectively. The short-term variation in the wind speed is taken into account as an important factor for the conventional wind turbines. It is because the rotor speed is maintained constant while the blade tip speed changes continuously. This considerably reduces the power performance for the wind turbine, particularly at high wind speeds, where the

tip speed ratio is small. However, this issue can be overcome by the growth of the variable speed generators [51]. Figure 6 illustrates the monthly mean wind speed, which is reached by averaging the data during 11 years. As indicated, the maximum wind speed occurs in August and the minimum one occurs in March and April. These situations occur for all the six different heights.

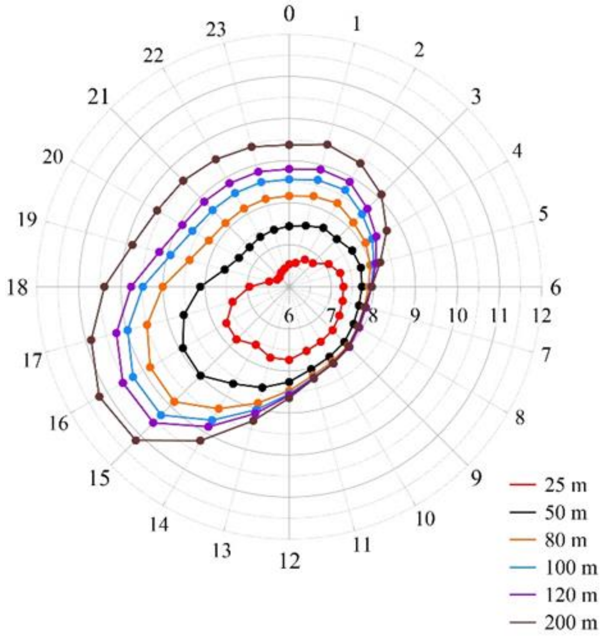


Figure 4. Diurnal variation of wind speed averaged over 11 years wind data. The radius indicates the wind speed (m/s) and the angle indicates the time of day (h).

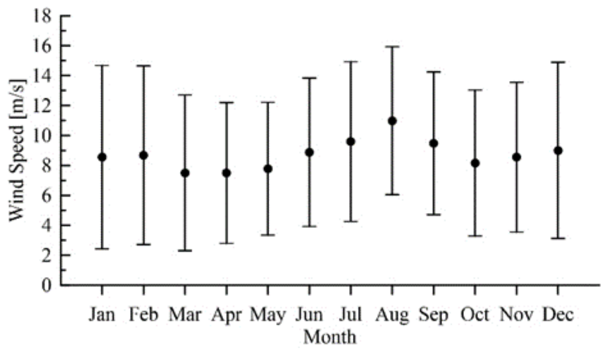


Figure 5. Monthly change in the diurnal wind speed variation at a 100 m height. The dots indicate the average wind speed in each month, and the bars indicate the standard deviation.

From the seasonal viewpoint, the summer and spring involve the highest and lowest wind speeds, respectively.

Figure 7 depicts the inter-annual variation in wind speed during 11 years (2005-2015). A long-term wind speed variation can lead to a large effect on the wind turbine production [52]. The capability of estimating the inter-annual variability at a given site is almost as important as estimating the long-term mean wind speed at a site [40]. This long-term variation reveals that the annual average wind speed varies from 10.15 m/s to 7.36 m/s at a height of 100 m. During eleven years, the total average wind speeds are 7.10, 7.90, 8.45, 8.72, 8.88, and 9.25 m/s at the heights of 25, 50, 80, 100, 125, and 200 m, respectively. By applying (4), the wind power densities were computed to be 514.8, 715.0, 878.2, 971.4, 1033.3, and 1191.5 W/m^2 at these heights, respectively. Comparison of these numbers with the NREL wind power density classification (presented in table 1) reveals that the proposed site enjoys an excellent wind power density, class 6, and it has a great potential for the development of high-power wind farms. Finally, the dominated wind direction was analyzed by a wind rose diagram at a height of 100 m. This case is expressed in Figure (8). The results obtained indicate that the prevailing wind is blown from one dominate direction of North-East. This can improve the quality of the wind power, which is available for the site. As a matter of fact, it decreases perturbation due to the changes in the wind turbine direction.

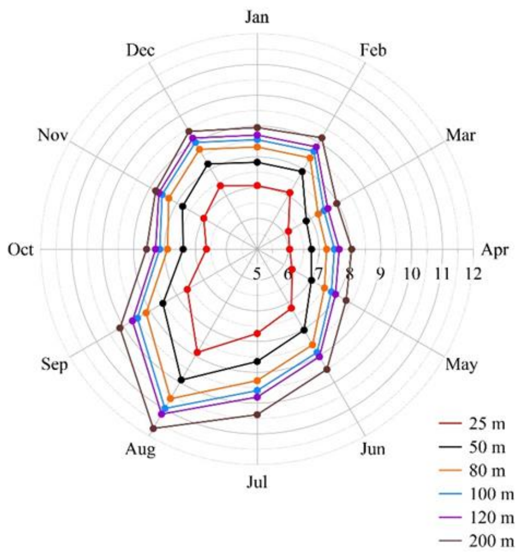


Figure 6. Monthly averaged wind speed at different heights. The radius indicates the wind speed (m/s) and the angle indicates the time (month).

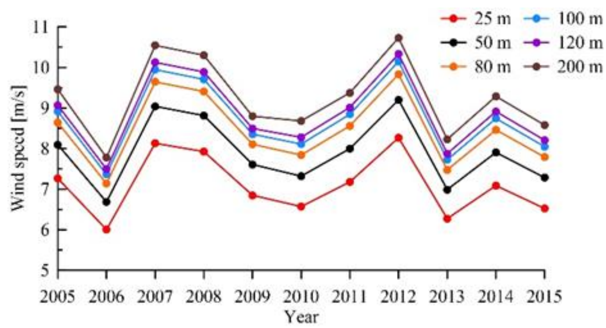


Figure 7. Inter-annual variation of wind speed from 2005 to 2015.

Table 1. Classification of wind power density at a 50 m height. Wind speeds are for standard sea-level conditions [53].

Wind power class	Wind power density [W/m^2]	Wind speed [m/s]
1	0-200	0-5.6
2	200-300	5.6-6.4
3	300-400	6.4-7.0
4	400-500	7.0-7.5
5	500-600	7.5-8.0
6	600-800	8.0-8.8
7	800-2000	8.8-11.9

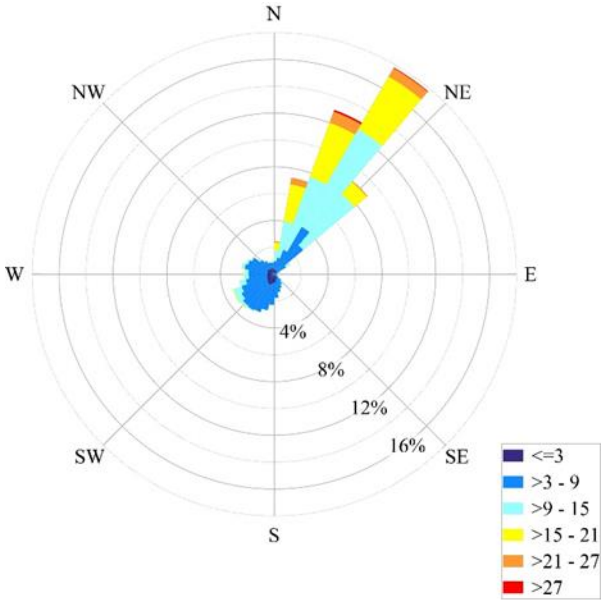


Figure 8. Wind rose diagram at a 100 m height.

In order to estimate the amount of electricity generation by each turbine, one should first evaluate the wind probability distribution function. Three most common probability distribution functions were used for testing and finding the best fit to data. These probability distribution functions are comprised of Rayleigh, Weibull, and Lognormal. Figure 9 shows how these probability distribution functions are fitted to the statistical data. In order to choose the best function that represents the wind speed distribution, a probability-probability goodness-of-fit plot [54] was provided in accordance with Figure 10. It can be observed that at a 100 m hub height, the highest and lowest deviations from the reference line are associated with the Lognormal and Weibull distributions, respectively. In addition, two well-known goodness-of-fit tests were performed, namely coefficient of correlation (R^2) [35, 42, 55, 56, 57] and root mean square error (RMSE). The results obtained are presented in Figure 10. It can be concluded that the Weibull distribution provides the most accurate representation for the actual wind data.

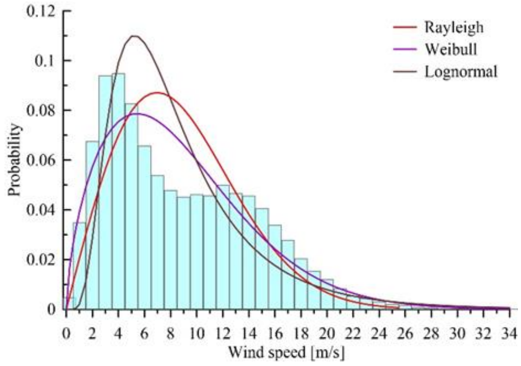
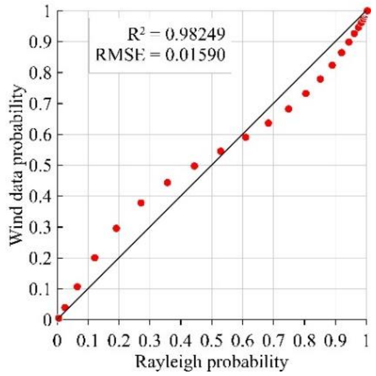
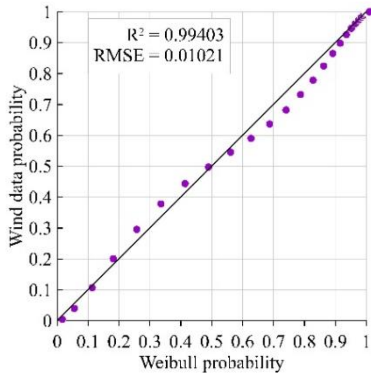


Figure 9. Probability distribution functions at a 100 m height.



10. a



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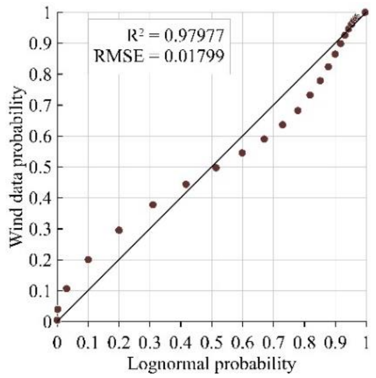

10. c

Figure 10. Probability-probability plot of a) Rayleigh b) Weibull, and c) Lognormal probability distributions for the wind speed data at a 100 m height.

Thereafter, the power curve of the turbine (Figure 11) was obtained through the data provided by the turbine's manufacturer company. The turbine starts generating power as the wind speed crosses its cut-in velocity of 4 m/s. The power increases with respect to the wind speed up to the rated wind velocity of 11 m/s. In this situation, it can generate its rated power of 1650 kW. Among the rated velocity and cut-out velocity (20 m/s), the system generates the same rated power of 1650 kW, irrespective of the increase in the wind velocity. This happens because harnessing the power in its full capacity at higher velocities than the rated wind speed requires over-designing the turbine to accommodate higher levels of power. Also with further increase in the velocity, the rotor may further speed up, and finally, it reaches the run-away situation. On the other hand, the probability is very low for such high wind velocities. Thus it is not logical to over-design the system to accommodate the available extra power for a very short span of time [45].

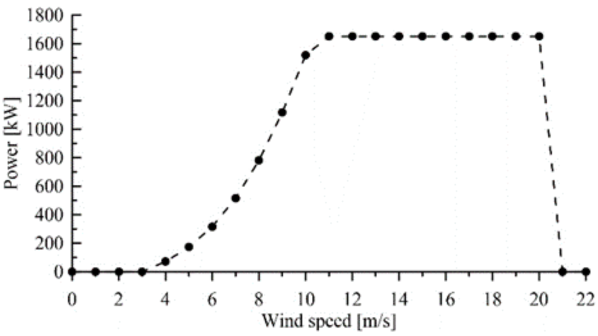

Figure 11. Power produced by one turbine as a function of wind speed.

Using (1) and (2), the annual and total average wind speeds and standard deviation of annual average data were calculated. Then assuming a Gaussian distribution, the minimum expected wind speeds were evaluated at the aforementioned probabilities. The Weibull probability distribution function was calculated for each one of these minimum expected velocities. Figure 11 and equation (3) determine the average power produced by one turbine at each probability. Finally, (14) and (15) express the annual energy generated by the wind turbine. The results obtained are presented in table 2.

3.2. Economic Analysis

The economic analysis is started for the project through calculation of the NDF's loan. The loan's monetary flow is presented in table 3. Initially, the total amount of loan was transferred to the fourth year through applying (16) and considering an interest rate of 3.5%. Then (18) was employed to calculate the annual payback for the next five years. Since the NDF's interest rate included the dollar inflation rate, the real money was calculated using (16) and considering an inflation rate of 1.76%. In the last column, the net monetary flow was presented for the loan. It indicates that the National Development Fund of Iran earns 12,238,533 dollars at the end of the 8^{th} year.

The investment monetary flow is presented for the project in appendix. These values are calculated for a probability of occurrence of 50%. The calculations were carried out for other probabilities in the same manner. In the second column of the table (A.1), the capital cost was represented for the project in Tomans, which equaled the amount of loan multiplied by the currency rate. The annual operation and maintenance costs were presented in the third column. These types of costs are gained using (18) and considering an inflation rate of 8.5%. In the fourth column, the total electricity generation was evaluated for the power plant. It was computed through considering the number of wind turbines multiplied by the generated electricity per each turbine. The fifth column presents the total earning from selling electricity to the government. The annual monetary flow before and after incurring tax were denoted in the sixth and seventh columns, respectively. These computations were performed using (17). In the eighth column, the inflation effect was factored out using (16) and considering an inflation rate of 8.5%. In order to consider the effect of paying installments, the eighth column of table (A.1) was aggregated with the fifth column of table 3 (it was done in Tomans). The achieved results are given in the ninth column. Finally, by considering MARR at 5% and using (16), the present value of money for each year and net present value (NPV) were demonstrated in the tenth column. Table 4 expresses NPVs for other probabilities, which are calculated in the same manner.

Table2. Annual energy generated by each turbine at various probabilities.

Probability, %	99	95	90	84	50	16	10
σ [m/s]	2.326	1.645	1.282	0.994	0.000	-0.994	-1.282
V [m/s]	7.261	7.584	7.789	7.967	8.723	9.588	9.837
Energy generated [kWh/year]	4923716	5211057	5399991	5566529	6301028	7132964	7360391

Table 2. Annual payback calculation of loan.

Year	Loan [$]	Annual payback (actual money) [$]	Annual payback (real money) [$]	Net monetary flow [$]
0	84,507,042	0	0	84,507,042
1	0	0	0	0
...	...	...	...	...
4	0	-21477885	-20030100	-20030100
5	0	-21477885	-19683667	-19683667
6	0	-21477885	-19343227	-19343227
7	0	-21477885	-19008674	-19008674
8	0	-21477885	-18679908	-18679908
۹	۰	۰	۰	۰
...	...	...	...	...
۲۰	۰	۰	۰	۰
Total	84,507,042	-107,389,424	-96,745,575	-12,238,533

Table 3. NPV at different probabilities.

Probability %	NPV [T]
10	146,871,263,403
16	131,491,931,229
50	75,233,813,998
84	25,564,744,592
90	14,302,882,538
95	1,797,285,257
99	-17,904,250,571

3.3. Sensitivity analysis

The inflation and currency rates are taken into consideration as two important economic parameters that vary in developing countries and unstable economies such as Iran. A sensitivity analysis is performed in order to determine how these parameters affect the economic viability of the project. This process is done by varying one parameter at a time and considering the assumption that the parameter does not have dependency on the other parameters. Figure 12 demonstrates the variations in NPV with respect to the inflation rate. As shown in the figure, at low inflation rates, an increase in inflation leads to a sharp decline in NPV. However, this trend decelerates at higher inflation rates. Thus it can be inferred that recuperating the current economic condition and reduction in inflation can significantly improve the investment pay-off. Moreover, it can be observed that if the inflation rates become higher than 12.3%, NPV gets negative, and thus the project is no longer viable.

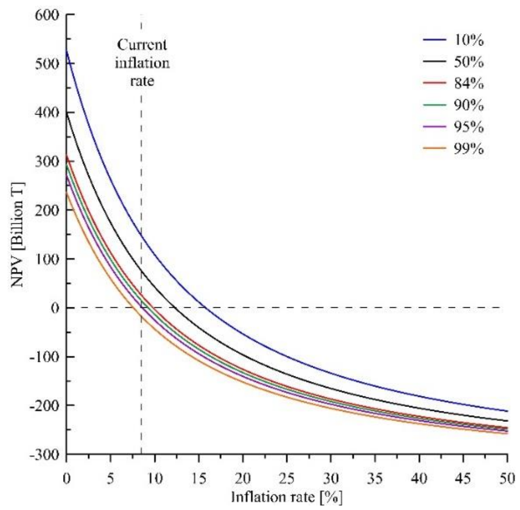

Figure 12. Variation in NPV with inflation rate at different probabilities.

The effect of variation in the currency rate on NPV is illustrated in figure 13. According to this figure, an increase in the currency rate results in a linear decrease in NPV. It should be noted that the sign of NPV changes at a currency rate of 5100 T/$. Thus the proposed project is profitable as long as the budget project is supplied through governmental resources (providing dollar at the governmental rate). Calculation of NPV at the market currency rate leads to a huge amount of loss of money. Figure 14 denotes the variation in NPV with respect to the electricity selling price to the government at the market currency rate. The purpose of this figure is to help the government to configure and regulate the economic policies for supporting wind turbine power plants in the current economic condition. It is revealed that the project is viable as long as the electricity selling price to the government is more than 1391.6 T/kWh (845.6 T/kWh more than current feed-in-tariff) at 13000 T/$ currency rate. Therefore, the main result is that if the government tends to support the private wind power plants, it is essential to either provide currency at the governmental rate or buy electricity higher than 1391.6 T/kWh.

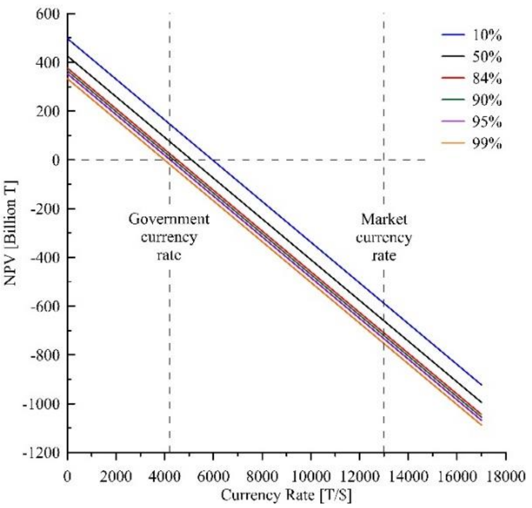

Figure 13. Variation in NPV with currency rate at different probabilities.

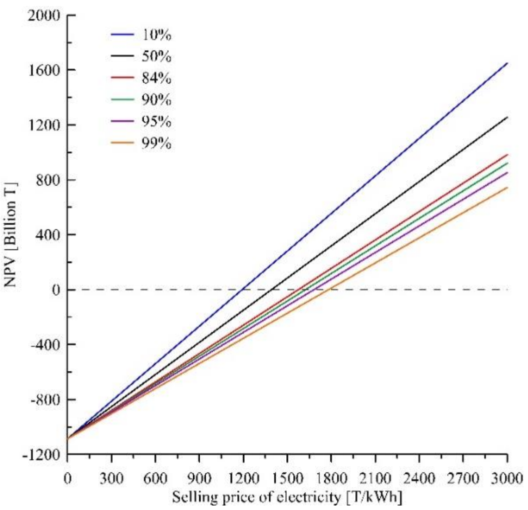

Figure 14. Variation in NPV with selling price of electricity at the market currency rate for different probabilities.

4. Conclusion

Uncertainty in the available wind potential and economic profitability of a wind power plant are considered as the major causes of ambiguity for investing in wind energy. In particular, Iran, which is a developing country, experiences severe fluctuations in the economic parameters such as the currency and inflation rates. In this work, we analyzed a construction procedure for a 33 MW wind power plant in a proposed site in the Kerman Province (Iran). In this work, the Renewable Energy and Energy Efficiency Organization in Iran (SATBA) provided the required wind dataset for analyzing the process. The wind data was hourly measured at the heights of 25, 50, 80, 100, 125, and 200 m during eleven years (2005-2015). The results obtained show that the proposed location enjoys an excellent wind power potential with respect to a wind power density of 971.4 W/m^2 at a 100 m hub height. The inherent uncertainty in the wind speed was addressed by means of the probability of occurrence and applying the projected annual mean wind speed and standard deviation of the annual mean wind speed. The economic analysis indicated that NPV was about -18, 75, and 147 billion Tomans at the mean wind speeds of 7.261 m/s (99%), 8.723 m/s (50%), and 9.837 m/s (10%), respectively. The results of the sensitivity analysis in NPV with respect to inflation and currency rates showed that reduction in the inflation could significantly improve the investment pay-off. Moreover, the project is viable as long as the government provides the project budget at the governmental currency rate (4200 T/$). In contrast, providing the project budget at the market currency rate (13000 T/$) leads to a huge amount of loss of money. Therefore, this research work suggests that the price of electricity should be higher than 1391.6 T/kWh (845.6 T/kWh more than the current feed-in-tariff) if the project budget is provided at the market currency rate. Thus if the government tends to support the development of wind energy in Iran, it is essential to either provide currency at the governmental rate or buy electricity higher than 1391.6 T/kWh.

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References

[1] Vanek, F., Albright, L., & Angenent, L. (2008). Energy systems engineering. McGraw-Hill Professional Publishing.

[2] Shaahid, S.M. & Elhadidy, M.A. (2003). Opportunities for utilization of stand-alone hybrid (photovoltaic+ diesel+ battery) power systems in hot climates. Renewable Energy, Vol. 28, No. 11, pp. 1741-1753.

[3] Tina, G., Gagliano, S., & Raiti, S. (2006). Hybrid solar/wind power system probabilistic modelling for long-term performance assessment. Solar energy, Vol. 80, No. 5, pp. 578-588.

[4] Perez, R. & Perez, M. (2009). A fundamental look at energy reserves for the planet. The IEA SHC Solar Update, Vol. 50, No. 2.

[5] BP statistical review of world energy. (2019). BP.

[6] The International energy agency (IEA) website (2020), Available: https://www.iea.org/fuels-and-technologies/renewables.

[7] The Global wind atlas website (2020), Available: https://globalwindatlas.info/area/Islamic%20Republic%20of%20Iran.

[8] Mostafaeipour, A. *et al*. (2011). Wind energy feasibility study for city of Shahrbabak in Iran. Renewable and Sustainable Energy Reviews, Vol. 15, No. 6, pp. 2545-2556.

[9] Mohammadi, K. & Mostafaeipour, A. (2013). Economic feasibility of developing wind turbines in Aligoodarz, Iran. Energy Conversion and Management, Vol. 76, pp. 645-653.

[10] Mohammadi, K. *et al*. (2014). Electricity generation and energy cost estimation of large-scale wind turbines in Jarandagh, Iran. Journal of Energy, Vol. 2014.

[11] Mostafaeipour, A. (2013). Economic evaluation of small wind turbine utilization in Kerman, Iran. Energy Conversion and Management, Vol. 73, pp. 214-225.

[12] Mostafaeipour, A., *et al*. (2014). An analysis of wind energy potential and economic evaluation in Zahedan, Iran. Renewable and Sustainable Energy Reviews, Vol. 30, pp. 641-650.

[13] Nedaei, M., Assareh, E., & Biglari, M. (2014). An extensive evaluation of wind resource using new methods and strategies for development and utilizing wind power in Mah-shahr station in Iran. Energy conversion and management, Vol. 81, pp. 475-503.

[14] Fazelpour, F. *et al*. (2015). Assessment of wind energy potential and economics in the north-western Iranian cities of Tabriz and Ardabil. Renewable and Sustainable Energy Reviews, Vol. 45, pp. 87-99.

[15] Fazelpour, F., Markarian, E., & Soltani, N. (2017). Wind energy potential and economic assessment of four locations in Sistan and Balouchestan province in Iran. Renewable Energy, Vol. 109, pp. 646-667.

[16] Soltani, N. & Fazelpour, F. (2016). Evaluation of wind energy potential and economics for the city of Kahnuj in Kerman Province, Iran. In 2016 IEEE 16th International Conference on Environment and Electrical Engineering (EEEIC). IEEE, pp. 1-6.

[17] Hosseinalizadeh, R. *et al*. (2017). Economic analysis of small wind turbines in residential energy sector in Iran. Sustainable Energy Technologies and Assessments, Vol. 20, pp. 58-71.

[18] Minaeian, A. *et al*. (2017). Exploring economy of small communities and households by investing on harnessing wind energy in the province of Sistan-Baluchestan in Iran. Renewable and Sustainable Energy Reviews, Vol. 74, pp. 835-847.

[19] Ehyaei, M.A., Ahmadi, A., & Rosen, M.A. (2019). Energy, exergy, economic and advanced and extended exergy analyses of a wind turbine. Energy conversion and management, Vol. 183, pp. 369-381.

[20] Mostafaeipour, A. & Abarghooei, H. (2008). Harnessing wind energy at Manjil area located in north of Iran. Renewable and Sustainable Energy Reviews, Vol. 12, No. 6, pp. 1758-1766.

[21] Rajabi, M.R. & Modarres, R. (2008). Extreme value frequency analysis of wind data from Isfahan, Iran. Journal of wind Engineering and industrial Aerodynamics, Vol. 96, No. 1, pp. 78-82.

[22] Mostafaeipour, A. (2010). Feasibility study of harnessing wind energy for turbine installation in province of Yazd in Iran. Renewable and Sustainable Energy Reviews, Vol. 14, No. 1, pp. 93-111.

[23] Keyhani, A. *et al*. (2010). An assessment of wind energy potential as a power generation source in the capital of Iran, Tehran. Energy, Vol. 35, No. 1, pp. 188-201.

[24] Saeidi, D. *et al*. (2011). Feasibility study of wind energy potential in two provinces of Iran: North and South Khorasan. Renewable and Sustainable Energy Reviews, Vol. 15, No. 8, pp. 3558-3569.

[25] Mirhosseini, M., Sharifi, F., & Sedaghat, A. (2011). Assessing the wind energy potential locations in province of Semnan in Iran. Renewable and Sustainable Energy Reviews, Vol. 15, No. 1, pp. 449-459.

[26] Rahimzadeh, F. *et al*. (2011). Wind speed variability over Iran and its impact on wind power potential: a case study for Esfehan Province. Meteorological Applications, Vol. 18, No. 2, pp. 198-210.

[27] Mojtaba, N. (2012). Wind resource assessment in Abadan airport in Iran. International journal of renewable energy development, vol. 1, No. 3, pp. 87-97.

[28] Nedaei, M. (2012). Wind energy potential assessment in Chalus county in Iran. International Journal of Renewable Energy Research (IJRER), Vol. 2, No. 2, pp. 338-347.

[29] Mohammadi, K. & Mostafaeipour, A. (2013). Using different methods for comprehensive study of

wind turbine utilization in Zarrineh, Iran. Energy conversion and management, Vol. 65, pp. 463-470.

[30] Biglari, M. *et al*. (2013). An initial evaluation of wind resource in the Port of Chabahar in South East of Iran. Glob J Sci Eng Technol, Vol. 2, No. 14, pp. 142-148.

[31] Mohammadi, K., Mostafaeipour, A., & Sabzpooshani, M. (2014). Assessment of solar and wind energy potentials for three free economic and industrial zones of Iran. Energy, Vol. 67, pp. 117-128.

[32] Tizpar, A., et al. (2014). Wind resource assessment and wind power potential of Mil-E Nader region in Sistan and Baluchestan Province, Iran–Part 1: Annual energy estimation. Energy conversion and management, Vol. 79, pp. 273-280.

[33] Nedaei, M. (2014). Wind resource assessment in Hormozgan province in Iran. International Journal of Sustainable Energy, Vol. 33,No. 3, pp. 650-694.

[34] Arefi, F., Moshtagh, J., & Moradi, M. (2014). The Wind Energy Potential of Kurdistan, Iran. International scholarly research notices, Vol. 2014.

[35] Alavi, O., Sedaghat, A., & Mostafaeipour, A. (2016). Sensitivity analysis of different wind speed distribution models with actual and truncated wind data: a case study for Kerman, Iran. Energy conversion and management, Vol. 120, pp. 51-61.

[36] Dabbaghiyan, A. *et al.* (2016). Evaluation of wind energy potential in province of Bushehr, Iran. Renewable and Sustainable Energy Reviews, Vol. 55, pp. 455-466.

[37] Pishgar-Komleh, S.H. & Akram, A. (2017). Evaluation of wind energy potential for different turbine models based on the wind speed data of Zabol region, Iran. Sustainable Energy Technologies and Assessments, Vol. 22, pp. 34-40.

[38] The Renewable energy and energy efficiency organization (SATBA) website (2019), Available: http://www.satba.gov.ir/en/home.

[39] Friedman, P.D. (2010). Evaluating economic uncertainty of municipal wind turbine projects. Renewable Energy, Vol. 35, No. 2, pp. 484-489.

[40] Manwell, J.F., McGowan, J.G., & Rogers, A.L. (2010). Wind energy explained: theory, design and application. John Wiley & Sons.

[41] Evans, M., Hastings, N., & Peacock, B. (2001). Statistical distributions. IOP Publishing.

[42] Morgan, E.C. *et al*. (2011). Probability distributions for offshore wind speeds. Energy Conversion and Management, Vol. 52, No. 1, pp. 15-26.

[43] Jamil, M. (1994). Wind power statistics and evaluation of wind energy density. Wind Engineering, Vol. 18, No. 5, pp. 227-240.

[44] Renewable Energy Technologies: Cost Analysis Series, Wind Power. (2012). IRENA.

[45] Mathew, S. (2006). Wind energy: fundamentals, resource analysis and economics. Springer.

[46] The Iranian national tax administration website (2019), Available: https://www.evat.ir/.

[47] The National development fund of Islamic Republic of Iran website (2019), Available: http://en.ndf.ir/About-NDF/By-Law.

[48] The in2013dollars website (2019), Available: https://www.in2013dollars.com/inflation-rate-in-2019.

[49] The Statistical center of Iran, Producer price index report in Iran - Spring 2018 website (2019), Available: https://www.amar.org.ir/english.

[50] The Central bank of the Islamic Republic of Iran website (2019), Available: https://www.cbi.ir/ExRates/rates_en.aspx.

[51] Sedaghat, A., Assad, M.E.H., & Gaith, M. (2014). Aerodynamics performance of continuously variable speed horizontal axis wind turbine with optimal blades. Energy, Vol. 77, pp. 752-759.

[52] Abidoye, L.K., et al. (2020). Effects of environmental and turbine parameters on energy gains from wind farm system: Artificial neural network simulations. Wind Engineering, Vol. 44, No. 2, pp. 181-195.

[53] The NREL classes of wind power density website (2020), Available: https://rredc.nrel.gov/wind/pubs/atlas/tables/1-1T.html.

[54] Gan, F. & Koehler, K. (1990). Goodness-of-Fit Tests Based on P-P Probability Plots. Technometrics, Vol. 32, No. 3, pp. 289-303.

[55] Garcia, A. *et al*. (1998). Fitting wind speed distributions: a case study. Solar energy, Vol. 62, No. 2, pp. 139-144.

[56] Ramírez, P. & Carta, J.A. (2006). The use of wind probability distributions derived from the maximum entropy principle in the analysis of wind energy. A case study. Energy Conversion and Management, Vol. 47, No. 15-16, pp. 2564-2577.

[57] Carta, J.A., Ramirez, P., & Velazquez, S. (2009). A review of wind speed probability distributions used in wind energy analysis: Case studies in the Canary Islands. Renewable and sustainable energy reviews, Vol. 13, No. 5, pp. 933-955.

Table A.1. Investment monetary flow at the probability of 50%.

Year	Capital investment [T]	O&M (actual money) [T]	Annual energy generation [kWh/year]	Annual energy income [T/year]	Net flow (pre-taxing) (actual money) [T]	Net flow (after taxing) (actual money) [T]	Net flow (real money) [T]	Investment and loan monetary flow [T]	NPV at MARR = 5%
0	-3.5493E + 11	0	0	0	-3.5493E + 11	-3.5493E + 11	-3.5493E + 11	0	0
1		-4,101,300,000	126020555.1	68807223093	64705923093	64705923093	59636795477	59636795477	56796948074
2		-4,449,910,500	126020555.1	68807223093	64357312593	64357312593	54668659426	54668659426	49586085647
3		-4,828,152,893	126020555.1	68807223093	63979070200	63979070200	50089732190	50089732190	43269393966
4		-5,238,545,888	126020555.1	68807223093	63568677205	63568677205	45869522756	-38256896766	-31474043648
5		-5,683,822,289	126020555.1	68807223093	63123400804	63123400804	41979928807	-40691474025	-31882834651
6		-6,166,947,183	126020555.1	68807223093	62640275909	62640275909	38395049592	-42846501934	-31972719435
7		-6,691,137,694	126020555.1	68807223093	62116085399	62116085399	35091013449	-44745416903	-31799732402
8		-7,259,884,398	126020555.1	68807223093	61547338695	61547338695	32045818847	-46409792741	-31411974510
9		-7,876,974,572	126020555.1	68807223093	60930248521	60930248521	29239187877	29239187877	18847841209
10		-8,546,517,410	126020555.1	68807223093	60260705682	60260705682	26652431223	26652431223	16362280767
11		-9,272,971,390	126020555.1	48165056165	38892084775	38892084775	15853826596	15853826596	9269404063
12		-10,061,173,959	126020555.1	48165056165	38103882207	38103882207	14315692715	14315692715	7971513371
13		-10,916,373,745	126020555.1	48165056165	37248682420	37248682420	12898057802	12898057802	6840115434
14		-11,844,265,513	126020555.1	48165056165	36320790652	34141543213	10895992934	10895992934	5503216847
15		-12,851,028,082	126020555.1	48165056165	35314028083	33195186398	9764028511	9764028511	4696664660
16		-13,943,365,469	126020555.1	48165056165	34221690696	32168389254	8720743328	8720743328	3995072999
17		-15,128,551,534	126020555.1	48165056165	33036504631	31054314353	7759190164	7759190164	3385308967
18		-16,414,478,414	126020555.1	48165056165	31750577751	29845543086	6872966050	6872966050	2855859354
19		-17,809,709,079	126020555.1	48165056165	30355347086	28534026261	6056169631	6056169631	2396631972
20		-19,323,534,351	126020555.1	48165056165	28841521814	27111030505	5303361872	5303361872	1998781313
Sum					616,384,570,751	602,594,143,108	157,178,591,781	105,776,753,427	75,233,813,998