# Research Paper: Capacity Measurement of Wind Energy and Sustainability of Rural Settlements (Case Study: Rural Area of Ardestan County in the Center of Iran)

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## ABSTRACT

**Purpose:** Utilization of renewable energies is one of the best possible ways to deal with climate changes on a global scale, air pollution on a local scale, and the sustainable use of energy resources, especially in rural areas. The purpose of this research was to investigate the potential of using wind energy to develop the infrastructure and improve stability of the rural areas of Ardestan County.

**Methods:** The data of wind speed and direction statistics with a 3-hour period, based on a 12-year statistical period of Ardestan meteorological station, were used in this research. The probability function of Weibull distribution was used to predict and estimate the power of wind turbines.

**Results:** The results showed that in almost 90% of the year, there was a wind blowing with a speed between 8.8 and 3.6m/s from the south and southwest d in Ardestan. Although the theoretical power of the turbine was higher in March, when there was the highest wind speed, by applying the density coefficient in relation to temperature and altitude, the practical power of the turbine could be higher in the hot months of July and August. According to the annual average wind speed of 5m/s and the nominal wind speed of 9m/s, by applying the wind speed density factor to temperature and altitude, the annual average practical power of the turbine at a height of 50 meters reached 528 kw/h, which could be considered a very high value for the generation of electricity.

**Conclusions:** Given that the villages of Ardestan County are located in the mountainous region and the prevailing wind blows in this region therefor, install turbines near the villages would be new jobs creation, rural self-sufficiency, a cleaner environment and greater energy independence for rural areas.

**Keywords:**

Wind Direction and Speed, Weibull Probability Function, Rural Areas of Ardestan, Density Coefficient, Wind Turbine

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## 1. Introduction

Many factors including the increasing human need for energy, the limitation of fossil energy resources, climate changes and global warming caused by fossil fuel pollution have all called for the need to pay more attention to sustainable development, especially in rural areas; there is also much emphasis on preserving energy resources for the future generation by using renewable energies such as wind energy. However, given the warning that fossil fuels is likely to run out in the next century, the countries in trouble will face stagnation and crisis (Kaviani, 1995). Therefore, it is inevitable to replace fossil energy sources with other sources, including renewable energies. The progress of this approach is such that the dependency of countries' economies on fossil energies should be reduced or completely cut off, and fossil energies should go out of use due to the intensity of pollution. For example U.S. Department of Energy with the slogan of "A Strong Energy Portfolio for a Strong America" has devoted efforts to the development of renewable energies. Installed wind-power capacity increased from approximately five gigawatts (GW) in 2002 to over 69 GW in 2015 in USA. Most wind turbines are in rural areas and 99.6% of all wind turbines are in rural (non-urban) areas (Xiarchos & Sandborn, 2017). America program during the next 20 years will create $60 billion in capital investment in rural America, provide $1.2 billion in new income for farmers and rural landowners, and create 80,000 new jobs. Wind energy is the fastest-growing energy source in the world, and rural community may be able to reap the benefits (U.S.D.E[1], 2004). On the other hand, wind is one of the most important renewable energies that can be a suitable substitute for fossil energies, especially in rural areas. Based on the wind atlas information prepared and the information received from 60 stations in different regions of the country, the nominal capacity of the country's sites is around 60,000MW. According to the forecasts, the country's economically exploitable wind energy is estimated to be over 18000MW, which confirms the significant potential of the country to build wind power plants and the economic value of investing in the wind energy industry (Satna, 2022). Although some studies have evaluated wind energy at the national level (Kaviani, 1995; Roshan, Ganghermeh & Shahkoei, 2014), due to neglecting small areas owing to the scale of the study and also, the necessity of a more detailed study and examination of the details of the wind energy potential of the windy areas of the country, it is necessary to carry out these studies on a local and regional scale. Ardestan region, one of the windy regions of the country, that was evaluated in this research to explain the details of wind energy potential in this region, as well as preparing a road map for the officials to make a reliable investment to utilize wind energy.

1. U.S. Department of Energy.

## 2. Literature Review

Given the importance of wind energy in providing a part of the country's energy needs, many studies have been conducted nationally and regionally. Perhaps the first study on wind energy in the country can be that of Thaghafi (Kaviani, 1995). In his book, "Wind Energy and its Applications in Agriculture", he analyzed the methods of calculating wind energy and wind turbines. Further, a number of specialized studies investigated wind energy in local and regional scales. The study of wind density and power using the Weibull function in Ardabil by Zahedi, Salahi & Jamil (2005) also showed that the practical power of wind energy at Ardabil station was 465.6w/m$^2$, which, in this station, was 41.7 percent. During the year, the turbine can produce wind energy with acceptable power without stopping, and it is stopped only in 3.6% of the time. Evaluation of wind energy production potential in the selected stations of Iran by Roshan, Qanqormeh & Shahkoei (2014) showed that Zabul station had the highest wind energy production capacity, while Gorgan had the least one in the country. Also, spring and summer had the highest wind energy power density. However, the highest wind energy power has been obtained in Zabul, Ardabil and Kish stations with the values of 3042, 1675 and 1042W/m$^2$, respectively, at a height of 40 meters. The investigation of the characteristics of wind power for energy production in Yazd province by Omidvar and Tazarjani (2012) showed that the ability to operate a wind turbine at a height of 50 meters was equal to 4008.5w/m$^2$, with economic justification for installing the windy turbine. Also, investigation of the wind energy potential in 5 stations of Mazandaran province showed that Beldeh station, with a density of 300w/m$^2$ and a higher percentage of wind, had a high power for generating wind energy (Janbazghobadi, 2019). Other research studies in wind energy include: economic evaluation of wind energy in the north of Khuzestan province (Bgleri, Asareh, Nedai & Poltangari, 2014), the potential measurement of wind energy for the installation of wind turbines in Ilam province (Razavieh & Sadaghat, 2014), evaluation of wind energy for electricity generation in Pars Abad Mughan (Kayhani-e-Nasab, Mesri Gandshammin, & Zargarrshadi, 2018), assessment of wind energy capabilities in

Kermanshah and Kurdistan provinces (Mojarad & Hemati, 2013), assessment or construction of wind power plants in five metropolises of Iran (Razmi, Hakimi-Asl, Nasrolahi & Hakimi-Asl 2018), economic evaluation of wind energy and efficiency of wind turbines in Kermanshah province with climatic considerations (Refati, Sam-Daliri & Karimi, 2018), potential measurement of wind energy in Sistan and Balochistan province and economic analysis for the construction of a wind power plant (Minaian, Sadaghat & Alam Rajabi, 2013), study of zoning and forecasting the potential of wind energy in Hamedan province (Marianchi, Abbasi & Hosseini, 2017), estimation of the spatial distribution pattern of wind speed to determine the potential of wind energy production in Iran (Delbari, Kohkha-Mqadam, Mohammadi & Ahmadi, 2016), methods of estimating Weibull distribution parameters for wind energy production in Eastern Azarbaijan province (Jahanbakhsh, Din-Pajoh and Rezaei Banafsheh & Esmailpour, 2015), and determination of places prone to installing wind turbines in terms of access roads, power transmission lines, population centers and rural areas in Damghan county (Yousefi, Mousavi & Noorollahi, 2016).

In regard to studies of wind energy potential in other countries, one can refer to the evaluation done according to long-term wind data in three locations in South Korea, using the Weibull method; then the amount of wind energy was predicted in a period of 1 to 50 years with the Gamble distribution. In the following, five different turbines were evaluated and suggested for use in different places based on the International Standards Guide of the Electrotechnical Commission (IEC). Also, the economic sensitivity and the effect of turbine height on the energy obtained from wind power were analyzed (Sajid, Lee & Jang, 2017). The technical and economic evaluation of wind energy potential in 8 points in northern Egypt also showed that the distribution of the maximum values was consistent with the real data of some regions; also the distribution of Weibull and Gamble was in agreement with the real data of some other regions. The results also showed that Pipkarpaz region could be the best place to install wind turbines and the Aeolos-V2 model wind turbine with a power of 5KW/h had the lowest cost of energy production (Alayat, Kassem & Camour, 2018). Evaluation and economic analysis of wind energy in Hyderabad, Pakistan, also showed that the Hyderabad region could be suitable for the development of wind power generation projects. Small-scale turbines can be used to generate electrical energy for some areas where energy transmission is not possible (Gul, Tai, Huang, Nadeem & Yu, 2019). Types of renewable energy included hydropower, solar, wind and geothermal energy were investigated for rural development in Turkey. The results showed that some intensive renewable energy installations can compete with tourism activities. For example while wind turbines can be compatible with farming activities, their impact on landscape can be intense (Kaygusuz, Guney & Kaygusuz 2019). Clausen and Rudolph (2020) examined different ways renewable energy may contribute to rural development and explore how the synergetic conflation of renewable energy and rural development. They showed that energy transition policies and recommendations driven by sustainable development and green growth imperatives tend to take Rural Development (RD) potentials for granted but have largely fallen short in unlocking these potentials in an advanced energy transition context. The effect of wind power investments studied on rural wages in rural Counties in the US. The result showed that wind power investments in rural counties have a positive but modest overall effect on wages. For example a large wind farm located in a rural county is estimated to raise wages by 2% (Mauritzen 2020). Gargallo, Garcia-Casarejos and Salvador (2020) showed that although three most valued outcomes would be from of substitution of fossil energies by renewables energies in Spanish rural area included: Improvement in services and facilities, Decrease in pollution and Income increase. But the environmental issue has a higher valuation in the medium term than the economic aspects in perceptions of rural local population. The economic evaluation of the energy potential of four types of wind turbines in eastern Iran based on the information obtained from 22 weather stations showed that investing in wind energy farms in eastern Iran could be very profitable and reduce the dependence of the electricity industry on fossil fuels. The highest wind speeds were observed during the day, especially in the afternoons, while the lowest ones were observed in the mornings. Also, in all stations, the wind speed from April to September (hot season) was higher than that from October to March (cold season) in the eastern areas of Iran (Mohammadi, Saeedi, Firoozi and Zang-Abadi & Veisi, 2021). Evaluation of the potential of wind energy in India using global reanalysis data with high resolution also showed that coastal areas could be more suitable for installing wind turbines than the continental areas and western India would be more appropriate for establishing small wind turbine farms (Gubbala, Rao Dodla & Desamsetti, 2021).

## 3. Methodology

Ardestan County is located between the longitudes 51° 49' and 53° 16" in the center of Isfahan province and the latitudes 32° 52' to 34° 25' in the north of this province. This county, with an average temperature of 20 degrees Celsius and a total annual rainfall of 112mm, is considered one of the regions with a dry climate based on the Domarton index.

In this research, the wind direction and speed data of Ardestan synoptic station were used based on a three-hour period in the statistical period 2009-2020. According to these considerations, while investigating the general condition of wind, the Weibull distribution function was used to estimate wind energy. The Weibull distribution function is undoubtedly one of the most powerful and accurate models for wind energy estimation; in general, this distribution has been used by nearly all authors (Sajid, Lee & Jang, 2017). The general form of the Weibull function and cumulative distribution function (SDF) can be expressed by the following relationship: The Weibull distribution function is a special case of the Weibull distribution. This function is more flexible than others such as Rayleihg (Salahi, 2013: 92).

Eq.1: $$P(V)=\left(\frac{K}{C}\right)\left(\frac{V}{C}\right)^{K-1}\exp\left[-\left(\frac{V}{C}\right)^{K}\right]$$

In this equation, (K) and (C), which are calculated in meters per second and are dimensionless, are known as shape parameter and scale parameter. These parameters, which are defined as Weibull distribution parameters, express the horizontal dimensions and width of wind speed data distribution. Both of these parameters express the regional characteristics of wind speed. Therefore, the estimation of these two parameters is very important to estimate the accuracy of wind distribution (Sajid, Lee & Jang, 2017). Different methods for estimating (K) and (C) have been used by researchers, but the least square fitting method has been applied by most researchers, which is obtained based on the cumulative probability function. For this purpose, a linear relationship between wind speed and the probability of its occurrence is obtained, which is as follows:

Eq.2: $$Y = Ax + b$$

In this equation, A is the slope of the line and b is the width from the origin. The values related to the linear relationship between Xi and Yi to determine the values of A and b are calculated as follows:

Eq.3: $$X = Ln\left(Vi\right)$$

Eq.4: $$Y=Ln\left\{-Ln\left[1-P\left(V\right)\right]\right\}$$

In these relationships, Vi is the middle of the wind speed classes and P(V) is the percentage of the cumulative frequency of each class. The values of K and C, which are related to A and b in the regression equation, are as follows:

$$C = exp\left(\frac{-B}{A}\right) \quad \text{and} \quad A = K$$

Figure 2, shows the fitting of the slope curve of the relationship between wind speed and probability of occurrence for the annual data. Based on the slope of the line, which is 1.6073, and the width from the origin, which is 2.786, the K coefficient of the Weibull function is equal to 1.6073 and the C coefficient of the Weibull function is to 5.653809.

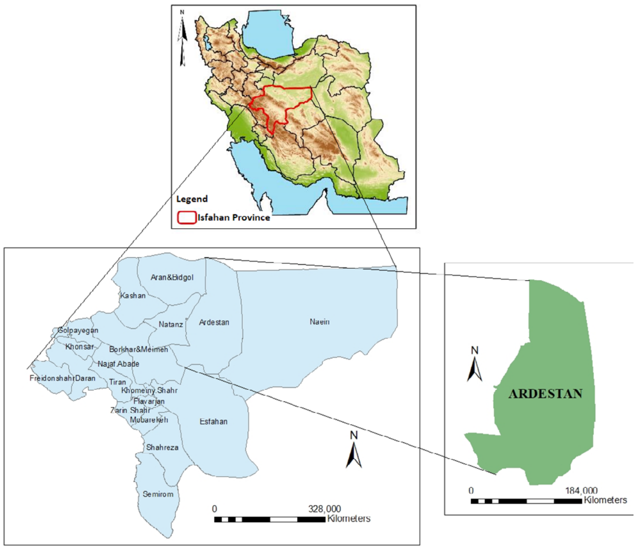


**Figure 1.** Location map of Ardestan County in Isfahan province

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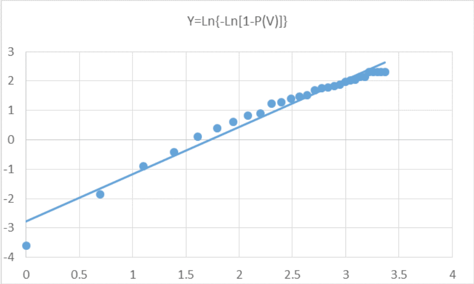


**Figure 2.** Fitting the curve of the slope of the wind speed and the probability of its occurrence

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The power obtained from wind energy at the Ardestan synoptic station was obtained using the following equation:

$$\text{Eq.5}: \frac{P_a}{S} = \frac{1}{2} r.c^3 G\left(1+\frac{3}{k}\right)$$

In this equation, Γ is the gamma function, c and k are the parameters of the Weibull function and ρ is the air density. The density of air in the standard conditions of sea level with a temperature of 15 degrees Celsius is equal to 1.225 kg/m2, which is calculated for Ardestan station with a height of 1381 meters above the sea level, and it is 1.083kg/m2. If we want to calculate the above formula in a certain time period T, it is written as follows.

$$\text{Eq.6}: \frac{P_a}{S} = \frac{1}{2} r.c^3 G\left(1+\frac{3}{k}\right) T$$

Nominal speed means the lowest speed at which the maximum output load speed is produced. At speeds higher than the rated speed, the output power is always fixed at the maximum output load value by the control systems. Nominal speed is the speed that produces the most energy throughout the year and is one of the important parameters in the design of wind turbines and can be calculated from the following equation:

$$\text{Eq.7}: V_{mec} = C\left(1+\frac{2}{k}\right)^{\lambda}$$

In this formula: λ=1/k

The most probable wind speed is 3.08 meters per second based on the following formula for Ardestan station:

$$\text{Eq.8}: V_{mp} = C(1-\lambda)^{\lambda}$$

According to the most possibility wind speed at Ardestan station, which is equal to 3.08m/s, considering that the starting and stopping speed of most turbines is between 4 and 25m/s, respectively (Salahi, 2004) the speed of 3m/s was taken as the start-up speed; also, the speed of 25m/s as the stopping speed of the turbine. The probability of the occurrence of wind speeds between 3 and 25m/s was calculated using equation 9.

$$\text{Eq.9}: P(V_1(V(V_2) = \exp\left[-\left(\frac{V_1}{C}\right)^K\right] - \exp\left[-\left(\frac{V_2}{C}\right)^K\right]$$

## 4. Findings

According to preliminary investigations based on local observations, Ardestan region experienced wind and relatively strong winds in most times of the year; therefore, it has a high potential for using wind energy. Therefore, determining the potential of wind blowing in Ardestan could be regarded as a research priority in the province. Ardestan County have 165 rural points, which providing electricity to scattered rural points (Figure 3) not only imposes a large cost on the transmission network, but also includes the cost of maintaining the power transmission network and also the waste of electrical energy during transmission. This issue will challenge rural areas in terms of energy supply. Therefore, determining the production potential of wind energy can significantly contribute to sustainable rural development.

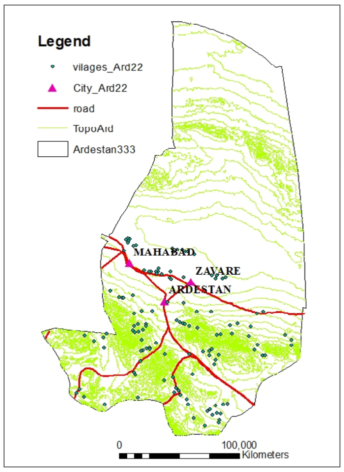


**Figure 3.** Dispersion of rural areas in Ardestan County

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The statistical study of the frequency of wind blowing in Ardestan confirmed the initial observations, showing that only in almost 10% of the time of the year, the weather was calm or the wind was less than 1m/s; in fact, there was wind blowing in more than 90% of the time of the year (Figure 4). The 12-year average wind speed in Ardestan was 4.9 or 5m/s, which could be taken as a suitable speed for using wind energy. The frequency of wind speed, which was equal to 5m/s from 2009 to 2017, could be assigned to calm weather in 2018, and it was equal to 3 and 2m/s in 2019 and 2020, respectively.

As can be seen in Figure 4, more than 55% of the wind in Ardestan had a speed between 3.5 and 6.7m/s, which had the highest percentage of wind frequency. So, assuming a wind speed of 5.8-8.5m/s, more than 88% of the wind will have a speed of 3.6-8.8m/s, indicating that the area is windy with an acceptable speed for setting up wind turbines. Considering that the most probable wind speed is 3.08m/s and that the speed required to start the turbine is at least 3m/s, in more than 88% of the time, the turbine can start moving and there is the possibility to produce wind energy; so it has a high potential for producing wind energy. On the other hand, the nominal wind speed at this station is 9m/s, which emphasizes the high potential of the region to produce wind energy.

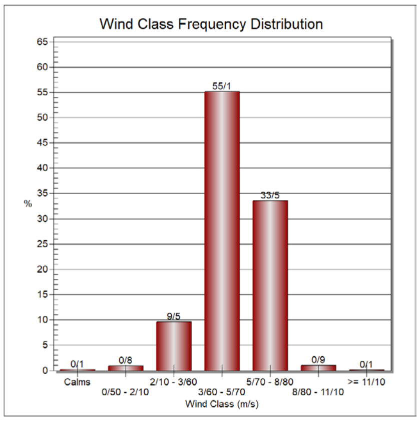



**Figure 4.** 12-year average graph of wind frequency percentage in Ardestan station

The statistical study of the wind direction azimuth showed that the average wind direction in Ardestan was Azimut-183 degrees, the mean of wind direction was Azimut-188 degrees and the mode of wind direction was Azimut-190 degrees; thus, the dominant wind in Ardestan was the south wind, which tended to the southwest. Also, the statistical study of the wind speed during the 12-year period showed that in Ardestan station, the average wind speed was 4.9953 or 5m/s, the mean wind speed was 4.9163m/s and the mode of wind speed was 4m/s; this means the highest frequency of the corresponding wind speed. The wind was 4m/s, but the average and the mean coincided at 5m/s. According to windrose plot in Figure 5, the wind with a speed between 3.6 and8.8m/s (red and blue colors) could be regarded as the dominant wind in the region, which blows from the south and southwest; it is a reliable speed for setting up wind turbines. Considering that only 10% of the year in Ardestan region is calm, not only in terms of wind speed, but also in terms of the frequency of wind blowing, there is enough confidence to install a wind turbine. As the wind is flowing at a reliable speed for starting and producing electricity in Ardestan around 90% of the time of the year, it can be used well.

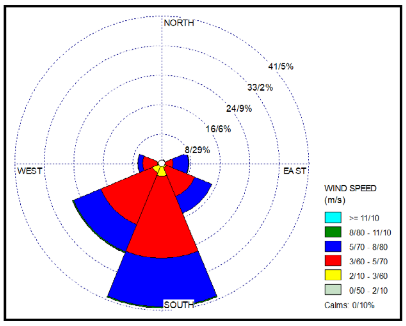
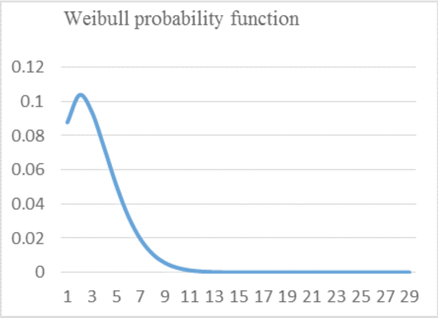



**Figure 5.** The annual windrose plot of Ardestan station

Examining the probability of wind blowing using the Weibull probability function showed that winds with an average speed of 3m/s had the highest probability of blowing. The diagram of the Weibull probability function and the percentage of wind occurrence probability based on the Weibull relation can be seen in Figure 6. As shown, the probability of occurrence of winds with a speed of 2 to 3m.s is the highest; winds with a speed of 3 to 6m/s have a high probability of occurrence, while those with a speed more than 12m.s have a very low probability of occurrence.

Currently, the most common use of wind energy is the installation of wind turbines to generate electricity. The use of wind turbines depends on several factors, including the mechanical characteristics of the turbines and local wind conditions. However, in this article, the conditions of wind blowing for the production of electricity and the factors affecting the power of wind turbines have been examined. As the wind speed is raised with the increase of altitude, it is necessary to calculate the wind speed at different altitudes so that the authorities can take the necessary measures to install wind turbines. The following equation is used to calculate the wind speed at different heights (Zahedi, Salahi, & Jamil, 2005):

$$\text{Eq.10: } \frac{V}{V_r}=\left(\frac{H}{H_r}\right)^{0.2}$$



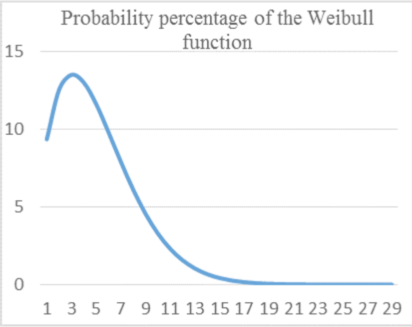




**Figure 6.** Diagram of probability function and Weibull probability function percentage JSRD

In this equation: V and H are the wind speed at the desired height, and Vr and Hr are the wind speed at the height of the station (10 meters above the ground). With regard to the 12-year average wind speed at Ardestan station, which is 4.99 or 5m/s at a height of 10 meters from the ground, the average wind speed at different heights could be calculated according to Table 1.

The power of turbines to produce wind energy does not depend only on wind speed, but factors such as air temperature at different heights can overshadow the practical power of the turbine. Therefore, the theoretical and practical power of the turbine under different conditions including the station temperature and the height of the installed turbine were investigated. The theoretical power of wind turbines was calculated from the following equation (Zahedi, Salahi, & Jamil, 2005):

$$\text{Eq.11: } P = \frac{1}{2} r.A.V^3$$

In this equation: ρ is the air density at the height and temperature of the station in terms of (Kg/m$^3$), A is the turbine blade area in square meters and V is the wind speed in m/s.

The air density, under the altitude and temperature conditions of the station, as compared to the air density at the conventional conditions, that is, the air density at sea level height and temperature of 15.5 degrees Celsius, which was equal to 1.225, was calculated. The ratio of the air density at the height of the station to that in normal sea level conditions is called the height density ratio; it is indicated by DRA, and some of its values are shown in Table 2 (Kaviani, quoting Saghafi, 1995).

Air density changes with different degrees of air temperature. The ratio of air density at different temperatures to that at 60°f (15.5°c) is called the temperature density ratio, as indicated by DRT, examples of which are shown in Table 3.

**Table 1.** Estimation of the average wind speed at different heights of turbine installation

| Height | 10m | 20m | 30m | 40m | 50m |
|---|---|---|---|---|---|
| Wind Speed | 5 | 5.74 | 6.23 | 6.60 | 6.90 |

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**Table 2.** Examples of the values of the density coefficient at different heights

| Height (feet) | 0 | 2500 | 5000 | 7500 | 10000 |
|---|---|---|---|---|---|
| Density coefficient at different height | 1 | 0.912 | 0.832 | 0.756 | 0.687 |

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**Table 3.** Values of density coefficient at different air temperatures

| Temperature in F° | 0°F | 20°F | 40°F | 60°F | 80v | 100°F | 120°F |
|---|---|---|---|---|---|---|---|
| Density coefficient at different temperature | 1.30 | 1.083 | 1.04 | 1 | 0.963 | 0.929 | 0.897 |

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Considering the 1380m height of Ardestan station, the density coefficient was calculated in relation to the height of DRA=0.847008. Also, according to the average temperature of the station, which was 20°c, the density coefficient was calculated for Ardestan=0.9852 DRT. Based on this, according to Tables 2 and 3, the density of Ardestan station under the altitude and temperature conditions of the modified station would be equal to ρ=1.022. Wind turbine blades do not take all the kinetic energy of the wind. According to Betz's estimate, as quoted by Kaviani (1995), the maximum wind power that can be converted into mechanical energy in the turbine is equal to 59.3%, which is called the maximum power factor. Usually, the real power of wind turbines is considered equal to e=30%. Accordingly, the real power of wind turbines can be calculated from the following equation (Kaviani, 1995):

Eq.12: $P=K.e.DAR.DRT.A.V^3$

In this equation: If the wind speed is in meters per second and the turbine blade area is in square meters, the coefficient K is equal to $K=\frac{1}{2}$ In this way, according to equation 3 and 5, the theoretical and practical power of the turbine at different heights is as described in the diagram represented in Figure 7. As shown, by applying the density coefficients of temperature and height, the practical power of the wind is about $\frac{1}{4}$ of the theoretical power of the turbine at the same height. In other words, at all heights from 10m to 50m, the practical power of the turbine is less than $\frac{1}{4}$ of the practical power. This shows the effect of temperature and altitude on air density for wind energy generation. Although increasing the height of the turbine installation has an effect on the theoretical and practical power of the turbine, it can increase the power of the turbine up to 2.6 times from a height of 10 to 50m. In this way, the practical power of the turbine is increased from 195kw/h at a height of 10 meters to 511kw/h at that of 50m.

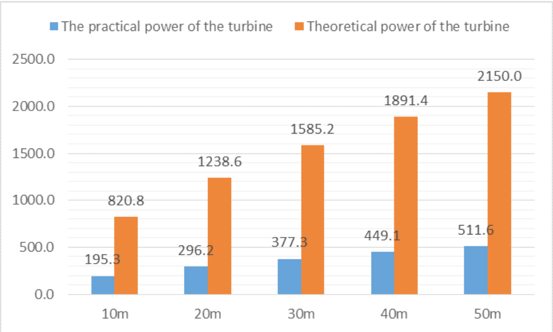


**Figure 7.** Average annual comparison of the practical and theoretical power of the turbine with a diameter of 4m at different installation heights (kw/h)

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Considering that the theoretical power of the turbine depends only on the speed factor and air density, in March, when the wind speed is higher, the theoretical power of the turbine is increased. However, due to the fact that the practical power of the turbine is affected by the temperature and altitude of the station and the air density, as a factor effective on the power of the turbine, is dependent on the temperature and the altitude of the station, the practical power of the turbine in March is less than that in the hot months of the year; also, the practical power of turbine shows a significant increase in July and August, which are the hottest months of the year. The practical power of the turbine in different months of the year and at different altitudes is compared in Figure 8. However, the significant decrease in the practical power of the turbine is quite evident in the cold months of November, December and January, and this decrease is more evident in turbines with higher altitudes. In this way, the efficiency of turbines at higher installation heights in the cold season is greatly reduced. Moreover, the efficiency of the turbine at higher installation heights increases significantly in the hot season months. In fact, the practical power of the turbine at a height of 50m is 676.5kw/h in August, while it is 312.8kw/h in December that is 363.7kw/h. In August, the power of the turbine is more than that in November. However, this difference is not very significant at the height of 10 meters, and the power of the turbine is 260.2kw/h in August and 116.4kw/h in November; it is only 114.8kw/h more than that in the cold month. In this way, by increasing the height of the turbine, rise of the temperature has a greater effect on its practical power.

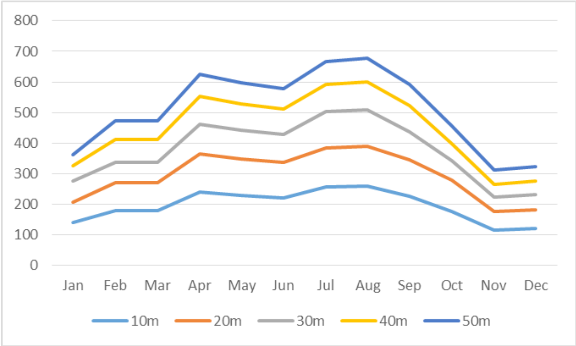


**Figure 8.** Practical turbine power in different months (kw/h)

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The villages of Ardestan County are located in the mountainous region of the south of this area; they are, in fact, mostly are located on the slopes facing north (Figure 3). Given that the Ardestan weather station, whose wind information was used in this research, is located in the mountain slopes to the north of this county and the prevailing wind blows from the southern mountainous region to the northern plains of Ardestan (Figure 4). It is possible to install turbines near the villages located in the mountainous region, especially those located on the slopes facing the north; as a result, the cost of electric energy transmission is reduced too.

Currently, there are 13,000 rural households that have access to electricity; on average, they consume 1-2kw/h (General Directorate of Electricity of Ardestan County). Considering that in 88.6 percent of the time, the wind is blowing between 8.8 and 3.6m/s in Ardestan County (Graph 2), if 88% of the power of the turbine at a height of 50 meters is considered as the actual power of electricity generation, the permanent power of the turbine will be 450kw. On the other hand, if we assume the average consumption to be 1.5kw/h at most, one turbine is able to provide electricity for 300 households. Given that rural households having electricity subscription. In Ardestan County is about 13,000 County, almost 43 wind turbines at a height of 50m are needed to provide electricity to all these rural subscribers. It is, therefore, obvious that the distribution and location of turbines installed depends on village's populations (number of households and electricity subscribers) and the distribution of villages.

## 5. Discussion

Using renewable energy can be regarded as one of the best ways to fight environmental pollution and the resulting climate change. The use of this energy is also one of the best ways to develop the infrastructure of diffused rural settlements due to the lack of power transmission lines. Meanwhile, the use of wind energy is superior to other renewable energy sources due to better technological maturity and lower costs. Toward this goal, it is necessary to estimate the potential of different regions in terms of renewable energy production. Ardestan is one of the regions that, due to its windy nature, can be among the areas that could be suitable for using wind energy; this energy can be used in a balanced way in the whole County , including rural areas. According to the survey, quiet times in this area are very low, about 10%. Considering that 88% of the frequency of wind blowing has a speed between 3.6 and 8.8m/s and the nominal wind speed at this station is 9m/s, it has a good potential for generating wind energy. On the other hand, the statistical analysis of the wind in this region showed that the average annual wind speed in this region was 5m/s and the frequency mode of the wind speed was 4m/s. Considering that the mean and the average were equal to 5m/s, with a high speed of 5m/s, it can be the basis for the design of wind turbines. Examining the Weibull probability function of wind speed also showed that winds with a speed of 2 to 3m/s had the highest probability of occurrence; also, winds with a speed of 3 to 6m/s had a high probability of occurrence. The analysis of wind energy to use it for the production of wind electricity in Ardestan, thus, showed that the theoretical power of the turbine, which depends only on the air speed and density factor, was higher in March, when the wind had the highest speed. However, when the density coefficient was corrected for the temperature and the height of the turbine installation, the hot months of July and August were expected to have a higher power to produce wind energy; meanwhile, the practical power of the turbine in March was less than that in the hot months of the year. Given that the villages of Ardestan County are located in the mountainous region and the prevailing wind blows from the southern mountainous region therefor, it is possible to install turbines near the villages located in the mountainous region. New jobs Creation, rural self-sufficiency, a cleaner environment, and greater energy independence for rural area would be innovation and results of this research that have been not considered in any research. The results of this research are adapted with researches of Clausen and Rudolph (2020) and Xiarchos and Sandborn, 2017). Considering the dispersion of rural settlements in Ardestan city, as wind occurs in the whole city of Ardestan, the installation of wind turbines in the city, especially in rural areas, can improve the standard of living. This would lead to the following advantages for a village

1. The dependence of rural areas on electricity and thermal power should be reduced; at the same time, sustainable, cheap and clean energy should be available to rural areas.

2. As self-reliance and self-sufficiency can be regarded as one of the features of the village, installing wind turbines can reduce the dependence of villagers on the national electricity grid and strengthen self-sufficiency in this important community.

3. It strengthens the spirit of paying attention to nature and preventing the destruction of the environment and dealing with climate changes among the villagers, thus reducing the destruction of pastures and forests.

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## Conflict of Interest

The authors declared no conflicts of interest.

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