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Investigating the Impact of Regional Weather Conditions on Wind Turbine Energy Production: An Exergy and Environmental Analysis

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Abstract: In this study, weather conditions such as air humidity, temperature air, and wind speed were investigated in relation to wind turbine efficiency with the approach of an exergy study. In this study, the wind speed has been investigated in two different climatic regions of Iran with an approximate distance of 1200 km, in the names of Ardabil and Marvast. The amount of wind density of Ardabil is equal to 66 (kW/m^2) and Marvast is equal to 123 (kW/m^2). Power production using a 10 (Kw) wind turbine in the Ardabil region is 2.3 (MWh) and in the Marvast region is 3.2 (MWh) per year. The highest wind turbine exergy efficiency is 0.48 in the Ardabil region, and the highest exergy efficiency in the Marvast region is 0.18. The amount of reduction of CO_2 gas production, using wind turbines in comparison to gas and diesel power plants in Ardabil, are 1.1 and 2.1 tons and in Marvast are 1.5 and 2.9 tons per year. This reduction in CO_2 greenhouse gas per year is equal to using a forest region of 1000 (m^2) to 3000 (m^2). The use of wind turbines reduces the fuel consumption of diesel power plants in the Ardabil region for the amount of 797.4 liters and in the Marvast region for the amount of 1244 liters of diesel per year. According to this review, it can be concluded that in addition to wind speed, air humidity plays a significant role in the selection, installation, and commissioning of wind turbines in the region. According to this survey, it can be seen that in the Ardabil region, the wind speed of the wind turbine has a higher exergy efficiency than in the Marvast region, and it can be concluded that the wind turbine has performed better in the Ardabil region.

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1. Introduction

Today, technology is advancing rapidly, and Technological progress requires energy. In recent years, electricity production with oil is one of the factors of environmental destruction and emission of greenhouse gases. In the 1970s, most environmental pollutant studies have been of CO and SOX gases. After 1980, most studies have been on energy production and economic issues. In recent years, a lot of attention has been focused on the study and investigation of environmental pollutants such as CO_2 gas, chemicals, and toxic substances[1]. In the world, the amount of electricity produced from renewable energy in 2008 was equal to 3725192 (GWh), and this amount in 2017 is equal to 6190948 (GWh); the amount of renewable energy production in the world between 2008 and 2017. Figure 1 shows the graph of renewable energy production in the world [2]. In Iran, until the end of 2022, the amount of electricity produced from renewable sources is equal to 7755 (MWh). By producing this amount of energy from renewable sources, the saving in natural gas consumption is equal to 2200 (MCM). During this period, the emission of gas CO_2 equal to 5154 thousand tons has been prevented. The world's share of electricity production through wind turbines is 34% of the total renewable energy production, which is equal to 324.8 (MW) [3].

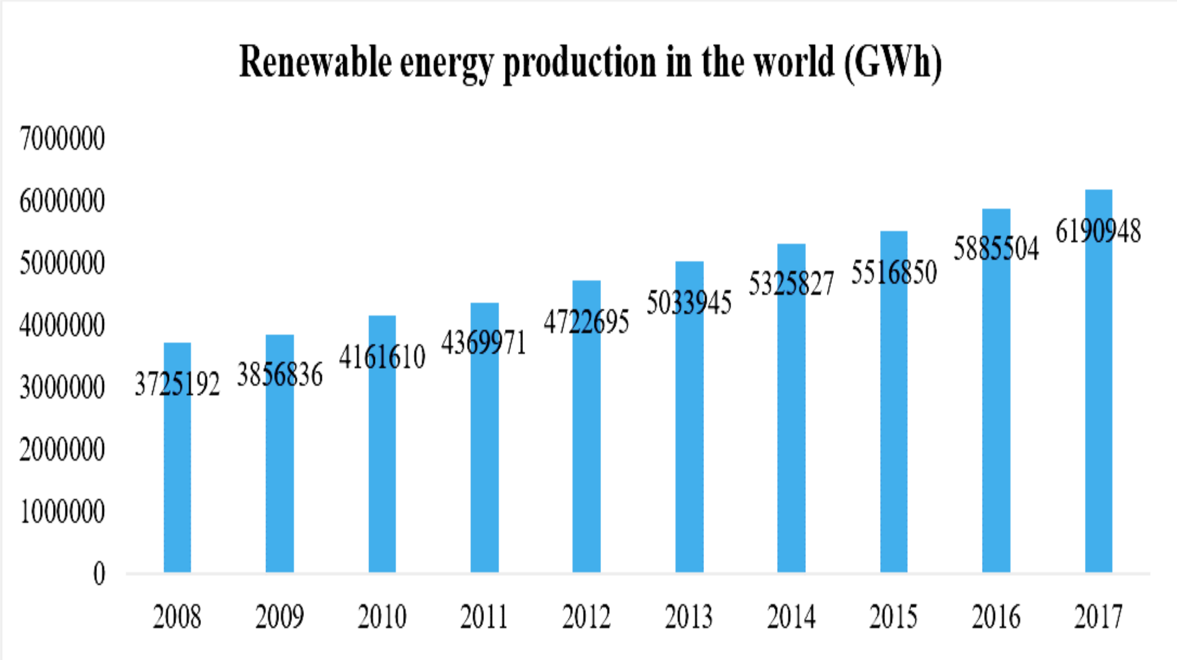

Fig. 1: Electricity production from renewable energies in the world during the years 2008 to 2017 [4]

Wind energy is one of the renewable resources that can be accessed in different parts of the world. Wind energy can be used by using a wind turbine [5]. The optimal use of wind energy depends on the wind turbine and the wind speed of the region. Through the study of wind turbine exergy, the loss and irreversibility of energy can be used to upgrade, optimize, and improve the wind turbine system. By using the exergy method, it is possible to obtain the value of the deviation of the state of a system with its surrounding environment. By using the exergy method in a system, it is possible to make a connection between the second law of thermodynamics and environmental effects [6]. In 2020, Duke has conducted a survey and research in Nigeria. He has researched the subject of comparative evaluation of thermal-economic and advanced wind energy exergy performance for distributed generation in four sites in Nigeria. He has used the air temperature and wind speed of the studied sites. Used Weibull statistical parameters to mathematically model the thermodynamic performance of wind turbines selected for the sites. The results show that the standard energy and exergy efficiency of the sites varied from 0.44, 0.16, and 0.05. The economic performance results showed that the Jos site is the best site with the lowest average monthly COE value of 0.15($/kWh), Katsina and Enugu have COE values of 0.19($) and 0.84 ($/kWh) respectively, while Kaduna is the worst performer with the highest COE value of 1.13($/kWh). In 2015, Irfan Asgari and Mehdi Ali Ahyaei studied the exergy analysis and optimization of a wind turbine, using genetics and search algorithms on the exergy of the wind turbine. They have developed an improved approach for exergy analysis and the optimization of the Bergey Excel-S wind turbine with a genetic algorithm search method, which examines the mathematical modeling of wind turbines. The results showed that the genetic algorithm is a more efficient optimization method than the search method [7]. Caliscan conducted research on new approaches to advanced environmental analysis based on exergy and economics for energy systems in 2014. He achieved results such as advanced environmental analysis based on exergy and economics for energy systems; these methods are named "Exergoenvironment" (EXEN) and "Exergoenviroeconomic" (EXENEC). According to the output of the EXEN method, it is possible to control greenhouse gases and reduce CO_2 in the process. Also, EXENEC analysis can provide the cost of CO_2 released in an operational form in a certain period of time. EXENEC analysis is a good method for economic management and greenhouse gas control [Caliskan, 2014]. Jamali et al. in 2024 a study on Energy and Exergy Analysis with Regression and Optimization Wind Power Plant of Jamshoro Pakistan was done. They investigate the wind power plant with the method of energy and exergy analysis to determine the effectiveness of the energy system. To ascertain the system performance precisely, quantitatively, and qualitatively, the comprehensive and combined energy (first law) and exergy (second law) techniques were employed. They found that neither energy nor exergy efficiency could go beyond 59.3% in the wind power plant and the rotor power is dependent on wind speed [8]. This study is divided into several parts. Section 2.1 describes the study region's geographical location and climate. In this part, the study of regions and the reason for choosing two different geographical regions is to investigate and compare the effect of weather in regions with wind speeds close to each other on the energy and exergy of a wind turbine. In section 2.2, the mathematical modeling related to the energy and exergy of the wind turbine is written according to the wind speed in the studied regions. In section 2.2, the mathematical modeling related to the energy and exergy of the wind turbine is written according to wind speed in the studied regions. In section 2.3, the mathematical model, related to the economic and environmental issues of using wind turbines in the study regions, is given. Part 3 is related to the results and discussion, which includes the results of the study of the wind density of the study areas, the results of the wind turbine production power (energy), and the amount of exergy studied in both study regions. The economic results of using wind turbines in the mentioned areas and the issues related to environmental pollution and environmental benefits are written in this section. Today, in the world, most of the studies done in the field of exergy are related to wind turbine power plants, and most of them are the comparisons of two or more power plants. This study aims to investigate the exergy of small-sized wind turbines in two regions with different geographical and climatic conditions, which have not been investigated in Iran so far. By studying the exergy of a small-size wind turbine, it is possible to investigate the influencing parameters of weather and the production power of the selected turbine in the context of its use. In Figure 2, for a better understanding of this study, the flow chart of the steps taken to study and examine the exergy, biological, and economic environment of the Ardabil and Marvast regions is shown. This study's innovation compares two climate zones with a wind turbine in Iran and calculates the production power and efficiency of the wind turbine by calculating its exergy. Another innovation of this study is using Retscreen software to calculate problems. The environmental and economic aspects of those two areas are studied.

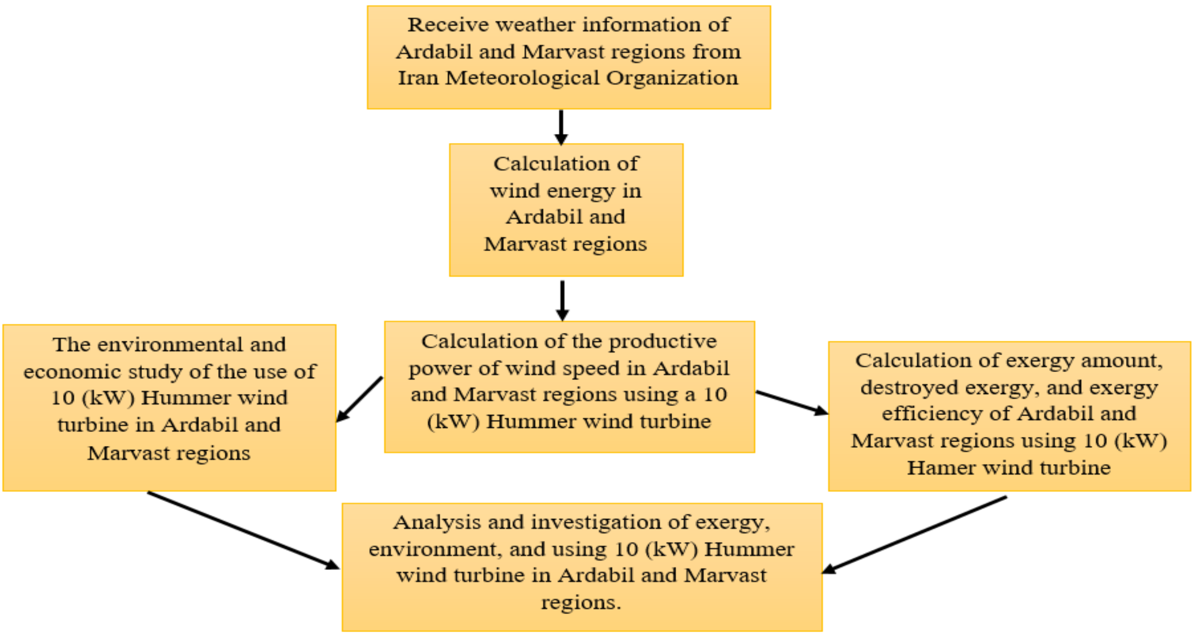

Fig. 2: Flowchart of the steps of studying and investigating the exergy, biological, and economic environment of Ardabil and Marvast regions

2. Materials and Methods

2.1. Description of the Study Regions

In this study, to obtain the amount of energy and exergy from the wind turbine, two climate zones in two different regions of Iran have been investigated. The city of Ardabil is located in the northwestern and the city of Marvast is in the central region of Iran, as shown in Figure 3. In terms of geographical location, Ardabil is in the northwest of Iran. The geographical location of Ardabil is 38.25 °N and 48.30 °E. The city of Ardabil is located at an altitude of 1500 (m) above sea level and between the mountains of Talesh and Sablan, located in the Alborz mountain range in the plateau of Iran. Three weather flows with different characteristics affect the climate and the weather of Ardabil. The Mediterranean flows with a moderate nature from the west of Ardabil, which is an important source of atmospheric precipitation along with the adjustment of temperature and air humidity. The Siberian air flow of Central Asia with a cold and dry nature enters from the northeast and after passing through the Caspian Sea and absorbing the water vapor of air Ardabil in the summer, causes a sharp decrease in heat and the cooling of the air. Marvast is located in the central part of Iran. The geographical location of this city is 30.4783 °N and 54.2117 °E. The height of Marvast is 1547 (m) above sea level. Marvast has a dry and cold climate. This region is located at the end of the Zagros mountain range, the highest mountain in the province after Shirkoh in the Chenarnaz region called Dahar. Marvast is bordered by the city of Mehriz in the north, the cities of Taft and Abarkoh in the northwest, the city of Bowanat in the west, Sarchehan in the southwest, the city of Khatam in the south, and Shahrbabak in Kerman province in the east (refer Figure 3).

Fig. 3: showing the geographic location of the study areas on the map of Iran

2.2. Mathematical Modeling

2.2.1. Wind Energy

The wind turbine can convert the kinetic energy of the wind into mechanical energy by means of its blades. The generator installed in the nacelle of the wind turbine converts the generated mechanical energy into electrical energy; figure 4 shows the input and output data of a wind turbine caused by wind flow and weather conditions.

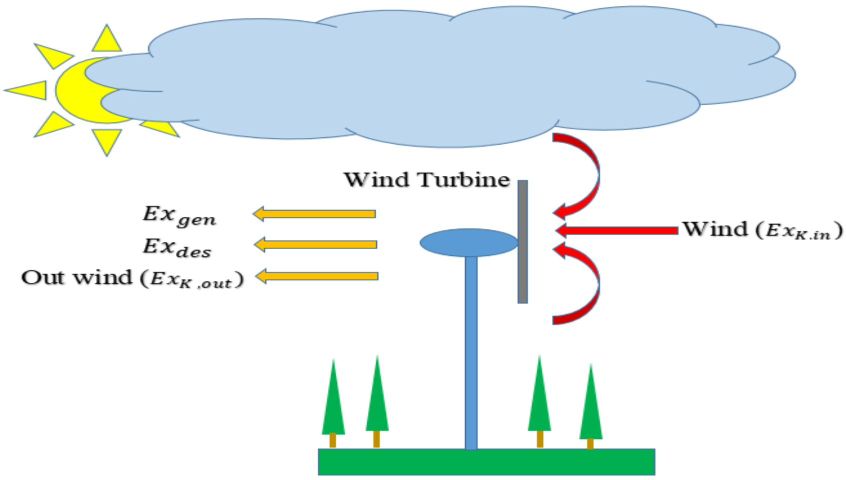

Fig. 4: Display of wind turbine with wind turbine input and output terms

The wind turbine power can be calculated from equation number 1[9].

$$p = \frac{1}{2}\rho A C_p\ V^3 \quad (1$$

To extract the amount of wind energy in a region, it is possible to use the information recorded in the meteorological systems of the country's meteorological organization. For a set of N recorded wind speed data, which are divided into NB speed classes with width w_j, the middle point is m_j and the number of events in each class is f_j which is calculated and extracted by equation number 2. The average wind speed can be obtained from equation number 3.

$$N = \sum_{j=1}^{N_B} f_j \quad (2$$

From the equation number 4, the average production power by wind energy in the weather region is obtained[10].

$$\overline{V} = \frac{1}{N}\sum_{J=1}^{N_B} m_j\ f_j \quad (3$$

$$\overline{P_w} = \frac{1}{N}\sum_{J=1}^{N_B} P_w(m_j) f_j \quad (4$$

Using P_w (m_j), the energy produced by the wind can be obtained from equation 5:

$$E_w = \sum_{j=1}^{N_B} P_w\ (m_j) f_j \Delta t \quad (5$$

In order to calculate the wind density energy, the Weibull function equation can be used, which is defined as equation 6 [10]:

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

The least squares method was used to obtain K and C of the Weibull function using the cumulative probability function. Using a regression equation, one can calculate the linear relationship between wind speed values and their probability of occurrence. For this reason, the frequency of wind speed data recorded by the Meteorological Organization was first calculated; then, the wind speed Vi, which is the median of the floors m_j, and P (V), which is the probability of the cumulative frequency of each floor in the wind speed, were calculated. In the end, the values of X and Y, using the results of calculations and relations number 7 and 8, were calculated.

$$X = \text{Ln}\ V \quad (7$$

$$Y = \text{Ln}\ (-\text{Ln}\ (1 - P(V)) \quad (8$$

Using the values of X and Y, obtained from equations 7 and 8, made it possible to determine the linear equation between the values of wind speed and the probability of their occurrence by using relation number 9. By plotting X and Y points with the help of Excel software, the values of B and A were obtained, respectively, A and B were the coefficient of the angle and the width of the point of intersection of the line with the Y axes. With relationship number 9 and 10 can obtain A and B and can extract the parameters C and K of the Weibull function.

$$Y = AX + B \quad (9$$

$$C = \exp\left(\frac{-B}{A}\right) \quad , \quad K = A \quad (10$$

Considering that the wind speed information recorded in the Meteorological Organization was done at a height of 10 m above the ground, equation number 11, the wind speed at different heights can be obtained [9].

$$V_H = V_{ref} * \left[\frac{H}{H_{ref}}\right]^M \quad (11$$

$$M = 0.28$$

The maximum wind speed of region is calculated from equation number 12[11]:

$$V_{max} = C(1 + \frac{2}{K})^{\frac{1}{K}} \quad (12$$

From equation number 13, the maximum wind speed that had the probability of blowing wind in a region is calculated.

$$V_{MP} = C(1 + \frac{K-1}{K})^{\frac{1}{K}} \quad (13$$

The average wind speed of the study region is obtained from equation number 14:

$$V_{AVR} = C\Gamma(\frac{K+1}{K}) \quad (14$$

Gamma function is extracted from relation number 15 [10].

$$\Gamma(t) = \int_0^\infty x^{t-1}e^{-x}dx \quad (15$$

The wind energy density (energy) in the studied areas could be determined from equation number 16 [12].

$$\frac{P}{A} = \frac{1}{2}\rho C^3 \Gamma(\frac{K+3}{K}) \quad (16$$

2.2.2. Exergy

In the discussion of energy analysis, the second law of thermodynamics can be used. Exergy indicates the quality of energy. By analyzing the exergy of a system, it is possible to calculate the maximum work that can be obtained from a system if it reaches equilibrium with a reference environment [4]. In wind turbine exergy analysis, the characteristics of the reference environment, in which the wind turbine starts working such as temperature, pressure, and chemical properties, should be considered. To analyze the exergy of the wind turbine system and, according to the second law of thermodynamics, equation 17 can be written [12]:

$$Ex_{K,in} - Ex_{K,out} - Ex_{gen} - Ex_{des} = 0 \quad (17$$

The kinetic exergy of a turbine can be calculated from relations 18 according to the speed of the input air and the speed of the output air from the wind turbine blades [13]:

$$Ex_{K,in} = \frac{1}{2}mV^2$$
$$Ex_{K,out} = \frac{1}{18}mV^2 \quad (18$$

In the above equation, V is equal to the speed of the wind entering the turbine (V_{in}).

The amount of exergy of the flow can be obtained from equation 19:

$$\dot{E}_X = \dot{m}\psi_\alpha \quad (19$$

In order to obtain the specific exergy of moist air, which is indicated by (ψ_α) can use equation 20: [14, 15]:

$$\psi_\alpha = (c_{pa} + \omega c_{pv})T_0\left[\frac{T}{T_0} - 1 - Ln\left(\frac{T}{T_0}\right)\right] + (1 + 1.6078\omega)RT_0 Ln\frac{P}{P_0} + RT_0\left\{(1 + 1.6078\omega)Ln\left[\frac{1+1.6078\omega_0}{1+1.6078\omega}\right] + (1 + 1.6078\omega)Ln\frac{\omega}{\omega_0}\right\} \quad (20$$

In the relation above, the humidity rate is represented by ω and can be obtained using the average monthly humidity and the average monthly temperature of the studied region, used from relation number 21[16]:

$$\omega = \frac{\dot{m}_w}{\dot{m}} \quad (21$$

In relation number 21, $\dot{m}_w$ is the mass of water in the air, and m is the mass of air entering the turbine surface. The value of m needed to extract exergy can be obtained from equation 22:

$$\dot{m} = \frac{2}{3}\rho A V_{in} \quad (22$$

The air density of the studied region depends on the height of the region, compared to the sea level, and it can be extracted from relation number 23 [17]:

$$\rho = \rho_0 e^{-\left(\frac{0.297H}{3048}\right)} \quad (23$$

The p value of the secondary pressure behind the turbine blades can be calculated from equation number 24:

$$P = P_0 + \frac{V_{in}}{2} \quad (24$$

The amount of destroyed exergy can be calculated from the following equation:

$$Ex_{des} = \dot{m}\psi_\alpha + \left(\frac{1}{2}mV^2 - \frac{1}{18}mV^2\right) - P \quad (25$$

The exergy efficiency of the wind turbine can be obtained from equation 26 [13]:

$$\text{Exergy Efficiency} = \frac{P}{\dot{m}(Ex_{K,in} - Ex_{K,out})} = \frac{P}{\frac{8}{27}\rho A V^3} \quad (26$$

In the above two equations, p is the production power of the wind turbine.

2.3. Environmental and Economic

To investigate the environmental issue of using wind turbine the turbine output energy was calculated from the following equation:

$$E_{out} = E \times C_F \quad (27$$

And the amount of electricity produced during the useful life of the wind turbine was obtained from equation 28:

$$E = yer \times 365 \times T(hour) \times P \quad (28$$

In this study, the average life of a wind turbine is considered to be 20 years.

(CF) depends on the characteristics and geographical conditions of the region in terms of weather and actually the amount of wind. The value of (CF) is obtained from the following equation:

$$C_F = \frac{\exp\left(-\left(\frac{V_i}{c}\right)^k\right) - \exp\left(-\left(\frac{V_r}{c}\right)^k\right)}{\left(\left(\frac{V_r}{c}\right)^k\right) - \left(\left(\frac{V_i}{c}\right)^k\right)} - \exp\left(-\left(\frac{V_0}{c}\right)^k\right) \quad (29$$

In the production of electricity in non-renewable power plants, on average, 660 grams of CO_2 is produced per (kW) of electricity produced [10]. In the economic part of wind turbine installation and operation, the cost of purchasing the turbine, equipment, supplies, installation and operation, repair and maintenance during the useful life of the turbine can be considered. The cost of installing and operating a wind turbine can be calculated from the following equation:

$$PVC = I + C_{act}\left[\frac{(1+i)^n}{i(1+i)^n}\right] - S\left[\frac{1}{(1+i)^n}\right] \quad (30$$

In this section, Retscreen economic and environmental software--an engineering software developed by Canada for analyzing renewable and biological energies--was used for highly accurate calculation. Using Retscreen software for technical, economic, and environmental evaluation of the projects related to wind turbine systems can be one of the key measures to reduce costs and investment return time. This software, due to its the weather database, provides a good tool for the technical, economic, and environmental evaluation of the renewable energy project [18].

3. Results and Discussion

3.1. Results of Wind Speed and Energy of the Studied Regions

Using the wind speed information of the study areas obtained from the Meteorological Organization, the analyses of the wind information of the two cities of Ardabil and Marvast are written in the table's number (A) and (B) in the appendix. In order for the values of wind speed to be obtained, Xi and Yi values should be extracted using the linear relationship of equation number 9 and using table numbers (A) and (B), which show the drawn curve for the Ardabil and Marvast regions in Figures 5 and 6. The values of A and B can be obtained by drawing the above linear relationship from the information in Tables A and B. According to equation 10, the values of K and C can be obtained. After extracting the values of K and C, the nominal wind speed components (maximum speed), the most probable wind speed, and the average wind speed of the region can be obtained.

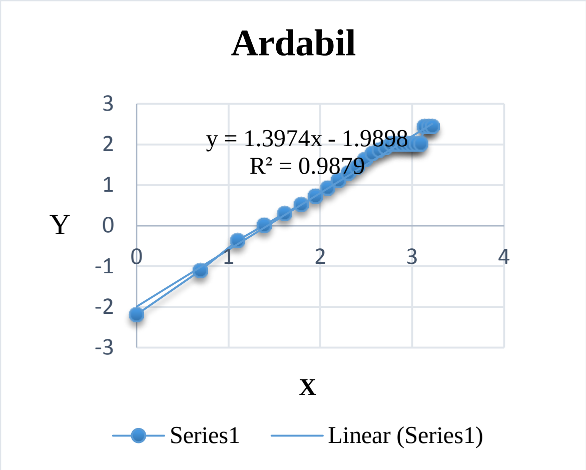

Fig. 5: Y=AX+B line curve in Ardabil region

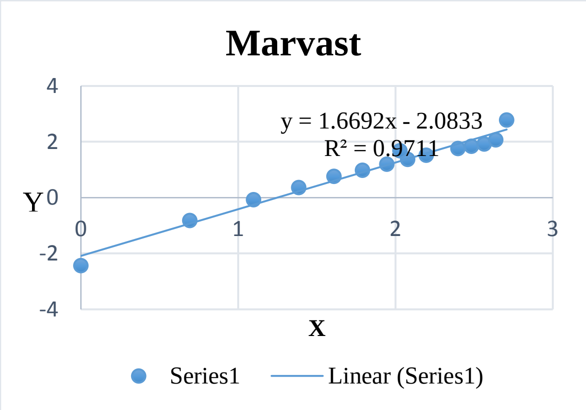

Fig. 6: Y=AX+B line curve in Marvast region

Applying equations number 10 and 12 to 16 and using the climate information of the studied regions, the results are presented in Table 1.

Table 1: The results of the calculations made in the two regions of Ardabil and Marvast

region	Ardabil	Marvast
medium speed(m/s)	3.14	3.78
Max speed (m/s)	5.67	7.84
Min speed (m/s)	2.019	1.68
Γ	0.9	0.9
Density wind (W/m^2)	66.07	123.97
C	3.5	4.15
K	1.66	1.39

3.2. Results Related to Wind Turbine Energy and Exergy in the Studied Regions

3.2.1. Energy Related Results

A 10 (kW) Hummer wind turbine was used to investigate the efficiency and exergy losses in the Ardabil and Marvast regions. The specifications of the wind turbine used are illustrates in Table 2.

Table 2: specifications of 10 (kW) Hummer wind turbine [19]

Model	Hummer 10 (kW)
Power rated	10 (kW)
Cut-in wind speed	3 (m/s)
Rate wind speed	10 (m/s)
Swept area	50.2 (m^2)
Number of blades	3
Working wind speed	3 (m/s)-25 (m/s)
Generator efficiency	0.8

Table 3: Weather information of Ardabil city [20]

Month	air temperature (C^0)	air temperature (k)	relative humidity	Atmospheric pressure (kPa)	wind speed V1(m/s)
January	-0.2	273.95	79.90%	87.7	3.3
February	0.5	274.65	76.30%	87.6	3.3
March	4	278.15	71.90%	87.5	3
April	9.9	284.05	65.80%	87.5	2.7
May	14.4	288.55	62.50%	87.6	2.4
June	18.5	292.65	59.10%	87.5	2.6
July	20	294.15	62.10%	87.4	2.8
August	20.2	294.35	63.90%	87.6	2.8
September	17.2	291.35	67.70%	87.8	2.8
October	12.5	286.65	72.20%	88	2.8
November	6.5	280.65	76.90%	87.9	2.8
December	1.8	275.95	79.70%	87.8	3.2

Table 4: Weather information of Marvast city [20]

Month	air temperature (C^0)	air temperature (k)	relative humidity	Atmospheric pressure (kPa)	wind speed (v1)
January	3.1	277.25	53.30%	80.7	4.4
February	5.1	279.25	48.80%	80.7	5
March	9.4	283.55	41.70%	80.6	4.9
April	15.3	289.45	33.20%	80.7	4.2
May	21.5	295.65	21.00%	80.7	4
June	26	300.15	14.40%	80.4	4.1
July	27.3	301.45	16.40%	80.3	4.7
August	25.6	299.75	16.20%	80.5	4.6
September	22	296.15	15.80%	80.7	3.8
October	16.5	290.65	22.60%	81	3.3
November	10.1	284.25	35.80%	81	3.5
December	5.1	279.25	48.80%	80.9	4.1

Figure 7, depicting the obtained power, is of a 10 (kW) wind turbine, according to the wind speed of the studied regions. Using equation number 1, the monthly power of the wind turbine is obtained using the information in tables 3 and 4.

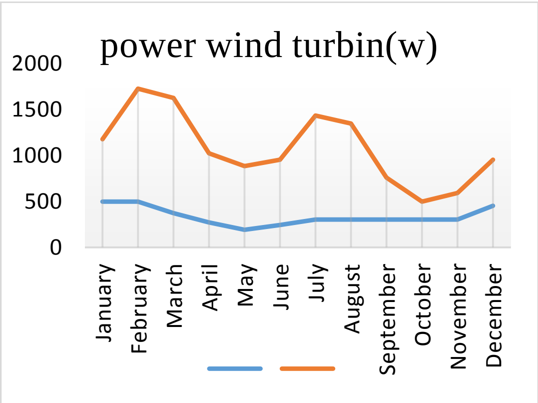

Fig. 7: Showing the power of a 10 (kW) wind turbine according to the monthly wind speed of the studied regions

3.2.2. Exergy Related Results

The rate of specific humidity was denoted by (ω). According to the relative humidity and monthly temperature of the studied regions, which are written in Tables 3 and 4, the specific humidity rate was calculated according to equation 21. The specific humidity of the studied regions was written in Table 5.

Table 5: Showing the specific humidity (ω) rate of the studied regions [20]

Month	Ardabil	Marvast
January	0.003	0.0024
February	0.0035	0.0033
March	0.0037	0.0029
April	0.0044	0.0036
May	0.0065	0.0032
Jun	0.007	0.0023
July	0.009	0.0035
August	0.0095	0.0034
September	0.0082	0.0025
October	0.0064	0.0028
November	0.0042	0.0027
Decem	0.0029	0.0026

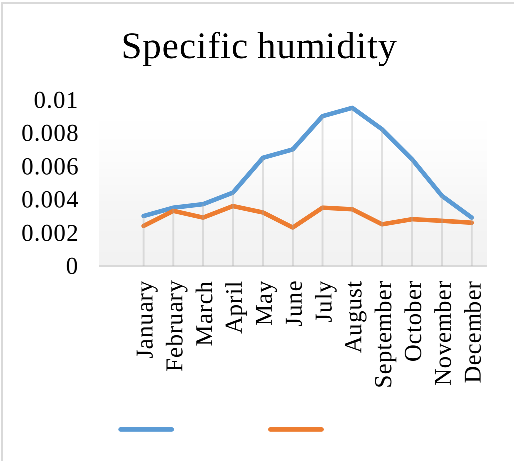

Fig. 8: The curve of the specific rate of humidity in Ardabil and Marvast

According to the curve Figure 8, the exergy efficiency has a direct relationship with the relative humidity of the environment and the air temperature of the region. Contrary to the wind speed of the study regions and based on the climate data, the exergy efficiency with the Hummer turbine in Ardabil region was more than that of Marvast region. According to equation 22, the amount of air mass entering the turbine is calculated and illustrated in the Table 6.

Table 6: Air mass(m^2) entering the wind turbine in the studied regions

Month	Ardabil	Marvast
January	175.40	232.77
February	175.4	264.51
March	159.46	259.22
April	143.51	222.19
May	127.56	211.61
Jun	138.20	216.90
July	0.148.4	248.64
August	148.8	243.35
September	148.83	201.03
October	148.831	174.5
November	148.8	185.15
Decem	170.09	216.9

By using the weather information of the studied regions and the relationships of 25 and 26, exergy destruction and exergy efficiency of the studied wind turbine in the Ardabil and Marvdast regions can be calculated and the results are presented in Tables 7 and 8.

Table 7: Destruction of exergy and efficiency of exergy using 10 (kW) Hummer turbine in Ardabil region

Month	Exergy destruction in Ardabil (J)	Exergy efficiency in Ardabil
January	15145.45	0.181687
February	15081.26	0.1816872
March	13507.74	0.241473
April	11964.58	0.330754
May	10436.19	0.470247
Jun	11336.71	0.370224
July	12175.61	0.296711
August	12181.3	0.296711
September	12269.47	0.296711
October	12396.13	0.296711
November	12533.22	0.296711
Decem	14638.32	0.199161

Table 8: Destruction of exergy and efficiency of exergy using 10 (kW) Hummer turbine in Marvast region

Month	Exergy destruction in Marvast (J)	Exergy efficiency in Marvast
January	19407.13	0.077425
February	19407.13	0.052917
March	22590.72	0.056196
April	220059.93	0.088935
May	18148.12	0.102854
Jun	17170.29	0.095556
July	17730.21	0.063618
August	20763.87	0.067525
September	20268.13	0.119847
October	16237	0.18255
November	13832.79	0.153159
Decem	17813.4	0.095556

According to the curve Figure 9, can be seen that in the Ardabil region, in addition to the lower monthly wind speed, the wind turbine had a higher exergy efficiency compared to the Marvast region, and can be concluded that the wind turbine had a better performance in Ardabil region.

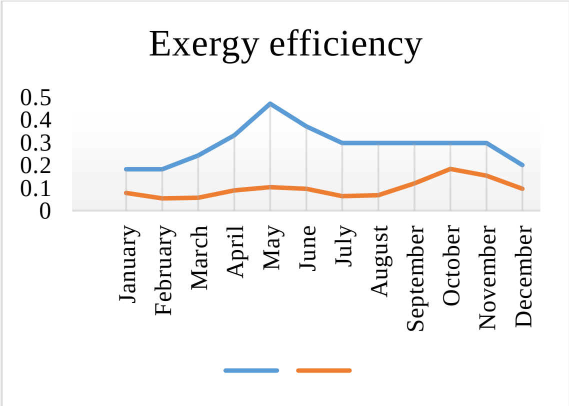

Fig. 9: Comparison of exergy efficiency in Ardabil and Marvast region using 10 (kW) Hummer wind turbine

The density of dry air is higher than humid air. In dry air, the production power of the wind turbine increases. The increase in temperature can reduce the humidity of the air and increase the power of the turbine. With the increase in temperature and air pressure, it reduces exergy efficiency. Exergy is more lost in the wind turbine rotor [21]. According to Tables 3 and 4, which are related to the climate data of the two studied regions, the only reason for the increase in the exergy efficiency of the wind turbine in Ardabil compared to Marvast can be called the temperature difference between the two regions. In Ardabil, the lowest temperature is -2 C°and the highest temperature is 20.2 C°. The lowest temperature is 3.1 C° and the highest temperature is 27 C°.

4. Results of the Environmental and Economic Survey of Wind Turbines Used in the Studied Regions

4.1 Results of Investigating the Environmental Problem of Wind Turbines

In order to obtain the amount of savings in greenhouse gas production, the electricity produced by the wind turbine in one year can be obtained from equation number 27. Using 10 (kW) Hummer wind turbine and the monthly weather information in the tables number 3 and 4. The possibility of estimating savings in carbon dioxide gas production and the reduction of fossil fuel consumption, compared to power plants, has been investigated in regions. Calculated estimate savings in carbon dioxide gas production with natural gas and diesel fuel are presented in table 9 and 10.

Table 9: Report of the environmental output data of the use of a Hummer wind turbine in Ardabil region

region	Electricity produced per year (theory) (MWh)	Power plant type	The reduction of CO_2 gas production per year	Reduction in oil consumption per year	The amount of forest area required to absorb CO_2 gas
Ardabil	2.3 2.3	gas oil	1.1 ton 2.1 ton	477.9 lit 897.4 lit	0.1 hec 0.2 hec

Table 10. Report of the environmental output data of the use of a Hummer wind turbine in Marvast region

region	Electricity produced per year (theory) (MWh)	Power plant type	The reduction of CO_2 gas production per year	Reduction in oil consumption per year	The amount of forest area required to absorb CO_2 gas
Marvast	3.2 3.2	gas oil	1.5 ton 2.9 ton	662.5 lit 1244 lit	0.1 hec 0.3 hec

An example of environmental issues of a 10 (kW) wind turbine by RETScreen software in the Marvast region compared to a gas-fired power plant is shown in Figure 10 and the general results of the investigations are written Tables 9 and 10.

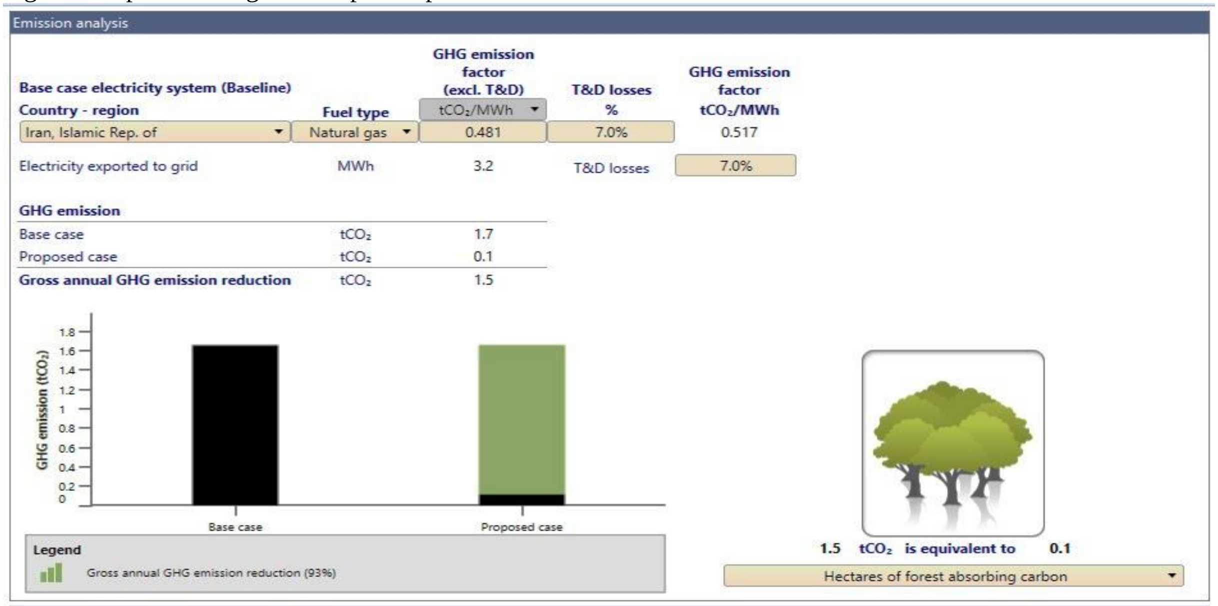

Fig. 10: Showing the environmental assessment of wind turbines in Mrvast region compared to gas-fired power plants with RETScreen software

4.2. Results of Examining the Economic Problem of Wind Turbine

To calculate the economic issue of wind turbines, the relation number 30 can be used. In order to estimate and analyze the amount of cost and investment and to obtain the amount of the return on investment and the amount of profit, the parts used in the system must be calculated along with their number and price. The cost of installation and operation of the power plant without the cost of design is presented in Table 11. According to the announcement of the new energy organization of Iran, the guaranteed purchase after 10 years of power production will decrease by 30% (Effective income tax rate) which should be applied in the financial part of the software for calculation. In order for the economic value of wind turbines to be calculated better, the inflation rate (average taken from the 10-year inflation announced by the central bank Iran) and the discount rate (the interest rate that an investor earns in a safe and risk) and the adjustment factor should be calculated; These calculations are depicted in Table 11.

According to Table 11 and entering this information in the relevant part of the financial analysis of the software, the output of the software can be seen in the form of curves and graphs. Figures 11 and 12 show the economic analysis of RET Screen software in Ardabil and Marvast region. According to the economic curve and graph in Figures 11 and 12, it can be seen that the purchase rate of the power produced by a small-size wind turbine with the amount of 0.0345 $, announced by the new energy organization of Iran, has the high cost of installing and operating. The low wind speed in Ardabil and Marvast regions has caused the economic analysis graph to be negative. It also indicates the uneconomical use of wind turbines in these regions, so the investment return period is longer than the life of the wind turbine.

Table 11: Inflation rate, capital discount rate, escalation rate, setup fee and annual service[22]

Row	Items	%
1	Inflation rate	24.5%
2	Discount rate	20%
3	Escalation rate	12%
4	The cost of installing and operating a 10 (kW) wind turbine	3000$
5	Annual repair and service cost per kilowatt hour per year (one percent of startup cost)	30$
6	Sales amount per (kWh)	0.0345$
7	Turbine lifetime	20 years

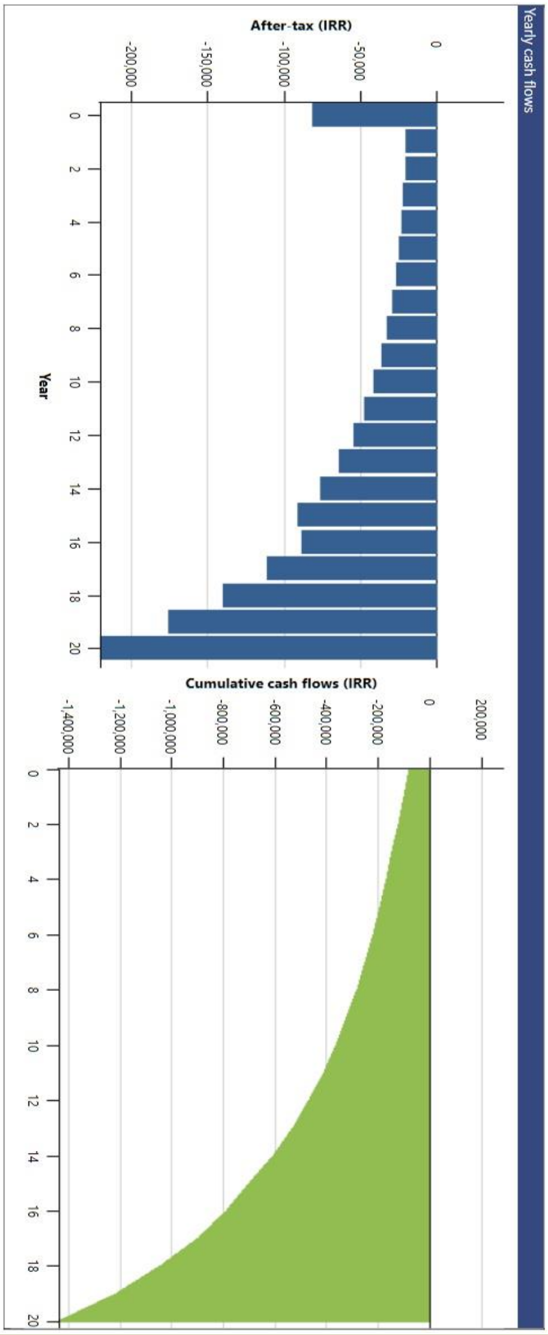

Fig. 11: Showing the economic analysis curve of the 10 (kW) Hummer turbine in Ardabil region

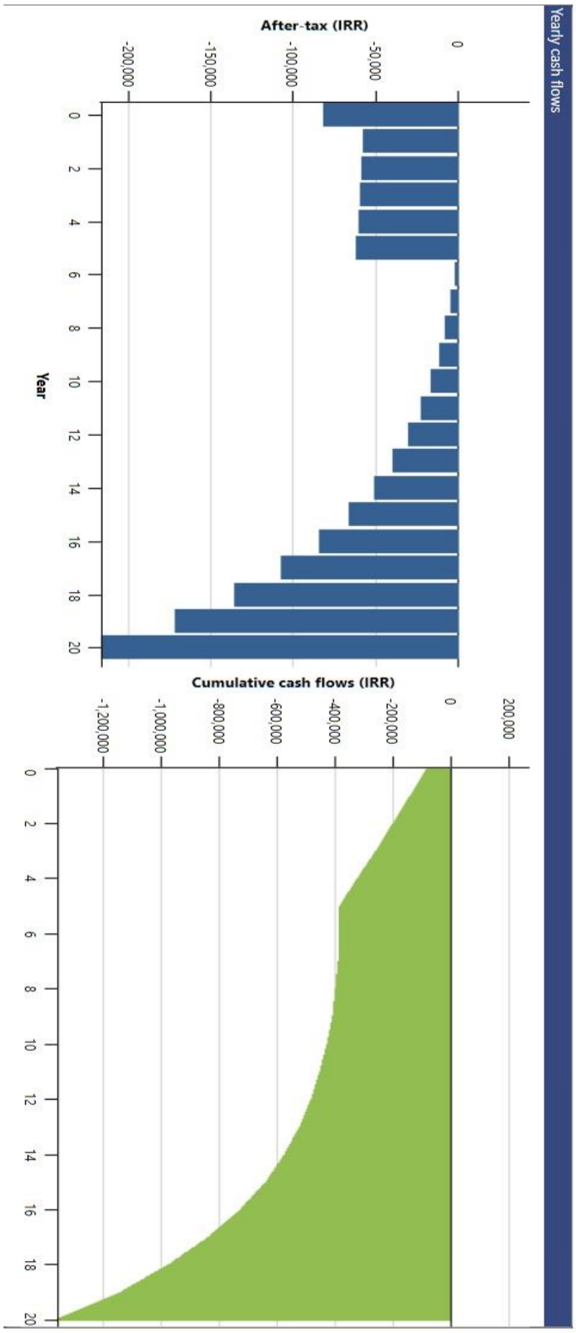

Fig. 12: Showing the economic analysis curve of the 10 (kW) Hummer turbine in Marvast region

According to the cost graphs of the two studied areas, which are shown in figures 11 and 12, completely show the unprofitability of using wind turbines. Both cost graphs of the studied areas are negative for twenty years. The reason why wind turbines have not been profitable in these two regions, especially over 20 years, can be said to be the low wind speed in these two regions and the high inflation of 24.5% in Iran. Another reason for the lack of profitability is the difference between the high cost of buying a wind turbine and the cost of selling electricity to the grid. It is possible to expand the installation of small-size wind turbines in Iran if the Iranian government removes the subsidy for electricity generation from fossil fuels. To subsidize this type of energy is to support clean energy.

5. Validation of Wind Analysis Results

For validation, Shahbazi et al article, which was written in 2019 on the topic of using wind turbines to supply a part of greenhouse electricity, was used. In this study, they used weather data from 6 regions and wind potential measurements [10]. By using the wind density, obtained in Rabat Karim region in their research, which wa close to the Ardabil region in this research, the output such as mean speed and K and C parameters were compared as shown in the following table. As shown in table 12, K and C parameters are not much different from Rabat Karim region.

Table 12: Comparing the data of Rabat Karim and Ardabil region to validate the results

region	Ardabil	Robatkarim
Γ	0.9	0.88
Density wind(W/m^2)	66.07	62.9
C	3.5	4.78
K	1.66	1.77

6. Conclusion

In this study, the result of thermodynamic performance showed that the efficiency and estimation of energy and exergy can be different with wind potential, and energy efficiency is always greater than exergy efficiency. In these two studied regions, Marvast is the best site for establishing a small-size wind turbine and is suitable for scattered production. Ardabil has the lowest performance. The exergy efficiency, obtained under the exergy analysis method, was extracted for different months of the year. It was that the average wind speed in Ardabil was lower than in the one Marvast, but the efficiency of exergy in this city was more in comparison, which shows that the factors such as temperature and humidity in the performance of the turbine are very important and should be considered in the design and selection of the wind turbine in order to increase the power conversion in the wind turbine. From the economic point of view, the use of wind turbines both in Ardabil and Marvast regions is not cost-effective which requires the construction of a turbine and a start-up at a lower price, and the price of buying electricity from the producer should be increased. The performance of wind turbines to produce electricity in both regions of Ardabil and Marvast in Iran, using the energy estimation method, exergy, and economic analysis with RET Screen software and a 10 (kW) Hummer wind turbine, showed that the amount of production power in Ardabil region 2.3 (MWh) and in Marvast region is 3.2 (MWh) per year. The amount of savings in terms of CO_2 greenhouse gas production, compared to gas and oil power plants, was equal to 1.1 and 2.1 tons in the Ardabil region and 1.5 and 2.9 tons in Marvast per year which shows the effect of wind turbines on reducing greenhouse and environmental gases. The reduction of CO_2 greenhouse gas per a year, by comparing gas and oil power plants, is equal to the use of forest regions of 1000 to 3000 (m^2). Through the use of wind turbines, the reduction of fossil fuel consumption in gas-fired and oil-based power plants in the Ardabil region is 477.9 and 797.4 liters, respectively and in the Marvast region, it is 662.5 and 1244 liters of diesel per year.

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Nomenclature

ρ	Volumetric mass of air (kg/m^3)	V_{ref}	Wind speed height of 10 m (m/s)
A	swept area of the turbine (m^2)	H_{ref}	height of 10 (m)
V	wind speed (m/s)	H	Turbine installation height (m)
$\overline{P_w}$	Average wind production power(kW)	M	equal to 0.28
$P_w(m_j)$	Average output power of wind turbine (W)	m	air mass
PW	Extracted power (W)	ψ_α	Special exergy of humid air
Mj	middle point	c_{pa}	Specific heat of air - 1.004-1.005 (kJ/kgK)
f_j	number of wind speed events in each floor	c_{pv}	Specific heat of steam 1.869(kJ/kgK)
Δt	time interval(s)	R	Gas constant 0.287 (kJ/kgK)
$P_w(m_j)$	Energy produced	P_0	Reference environmental pressure (dead state) (Kpa)
K	The shape factor of the Weibull function, (dimensionless)	T_0	reference ambient temperature (dead state) 25c,291k
C	Weibull function scale factor (m/s)	ω_0	humidity rate in the air in the reference environment (Kg water/Kg air) is 0.098
CO_2	carbon dioxide	ω	Specific humidity rate (Kg water/Kg air)
$Ex_{K,in}$	Kinetic exergy of incoming air	$\dot{m}$	amount of air mass entering the turbine surface
$Ex_{K,out}$	Kinetic exergy of exhaust air	$\dot{m}_w$	mass of water in the air
Ex_{gen}	Generator exergy in wind turbine system	ρ_0	(Kg/m^3)
Ex_{des}	Destroyed exergy	Γ	Gamma function
p	Secondary pressure(pa)	Million square meter	MCM
P_0	Air pressure entering the turbine(pa)	hec	hectar
E_{out}	turbine output energy (kW/h)	E	Turbine production energy(kW/h)
C_F	Wind turbine capacity in the region (kW/h)	V_i	Minimum wind speed(m/s)
V_r	Nominal wind speed(m/s)	V_m	Maximum wind speed(m/s)
PVC	Total turbine cost($)	I	Investment cost($)
C_{act}	cost of operating the turbine, maintaining and repairing the turbine during the period during its useful life($)	n	Turbine lifetime
i	Interest rate	S	The cost of scrapping and collecting the wind turbine($)