

Evaluation and validation of wind energy extension (Bahooz) in Manjil region

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ABSTRACT

Development that is not environmentally friendly is not sustainable. One of the methods of sustainable development is the use of renewable energy such as wind. One of the most important sites in Iran with wind energy potential is the Manjil region. Four sites in Manjil region (Manjil, Siahpoosh, Rudbar and Herzeville) were surveyed. In this paper, wind energy potential measurement in onshore and coastal areas evaluates wind energy according to the extensions developed by the authors. The results with scientific achievements and similar software in 4 stages of wind simulation, simulation of conditions the boundary of the range will assess wind power and extractable energy. Summary of spatial fit and arrangement of turbines shows that Manjil power plant in world energy class has sufficient quality of energy production and can be compared with global sites. This site with a nominal capacity of 240 million kilowatt-hours per year is one of the largest sites in the Middle East with a capacity factor of 0.25. Siahpoosh site with a capacity of 410 million kilowatt-hours per year has a limited factor capacity of 8%. This site has a coefficient of variation of 11%, which modeling shows that the choice of 660 MW turbines is not very appropriate and practical. Therefore, it seems that the use of 500 kW turbines has a better capability than 660 turbines on this site. Based on the results, the two sites of Rudbar and Herzeville have a very proportionate factor capacity, so these two sites can be upgraded according to the installation of Class 4 and 3 turbines.

1. Introduction

Energy is one of the most important factors in the progress and development of human societies [1]. On the one hand, population growth and the limitation of fossil resources, and the increase in environmental pollution caused by the burning of these resources, on the other hand, have led to the development of exploration for clean and non-polluting sources [2]. The wind is one of these clean, inexhaustible sources of free energy [3]. Wind energy, like other renewable energy sources, is geographically extensive and at the same time scattered and decentralized, and almost always available [4]. This energy was used as an energy source before the Industrial Revolution, to the extent necessary, but during the Industrial Revolution, the use of fossil fuels replaced wind energy due to its cheapness and high reliability [5]. During this period, the old wind turbines could not compete with the oil and gas energy market, but again in 1973 and 1978, due

to two major oil shocks and the concept of sustainable development, the energy economy of oil and gas was hit hard and In this way, the cost of energy generated by wind turbines improved compared to the global rate of energy prices [6, 7]. Since 1975, significant progress has been made in the field of wind turbines to generate electricity [8]. In 1980, the first wind turbine connected to the national grid was built [9]. Since then, numerous research centers and institutes, and laboratories around the world have studied new technologies for the use of wind energy [10]. In addition, this crisis caused new tendencies in the field of the application of wind energy technology to generate electricity connected to the grid, pumping water, and supplying electricity to different areas [11].

Global installed wind-generation capacity onshore and offshore has increased by a factor of almost 75 in the past two decades, jumping from 7.5 gigawatts (GW) in

1997 to some 730 GW by 2020, according to IRENA¹'s latest data. Production of wind electricity doubled between 2009 and 2013, and in 2016 wind energy accounted for 16% of the electricity generated by renewables [12]. Many parts of the world have strong wind speeds, but the best locations for generating wind power are sometimes remote ones. Offshore wind power offers tremendous potential [13]. The world's wind energy total about 2,700 terawatts of energy. About 25% of it is located 100 meters above the ground [14].

However, unfortunately in Iran, the use of wind energy is not widely developed and it is used in limited places such as Manjil and Binalood. The capacity of 95 MW has reached 303 MW, which is all related to the offshore sector [13].

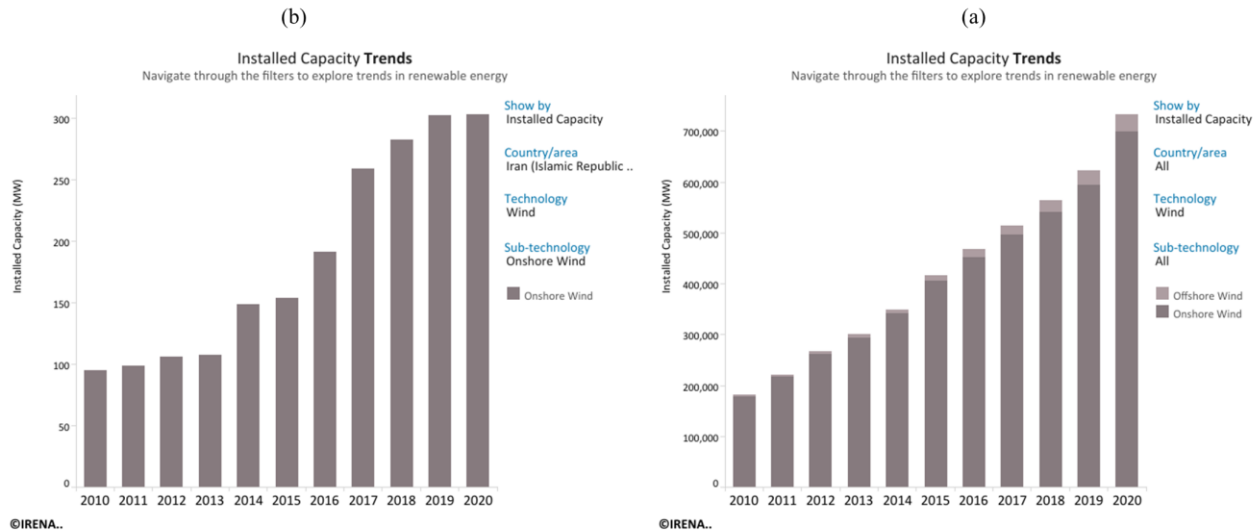


Figure 1. installed wind-generation capacity onshore and offshore in World&Iran; (a): World, (b): Iran

Renewable energy will account for a significant share of the world economy, the share of renewable energy in the world energy portfolio doubling by 2030, the world's gross domestic product will increase by 0.6% or \$ 706 billion [15] According to this study, oil-dependent economies have the highest financial loss [16] and among Asian countries, Japan will have the highest GDP [13]. In 2019, 11 and a half million jobs were created by renewable energy in the world, of which the share of wind energy is 1.17 million people [15]. In this statistic, Iran's share is 468 thousand jobs in all energy and 3400 jobs in wind energy [15].

Modeling and validation of models that represent possible wind energy functions are critical [17]. Wind speed has a random nature that in order to model it, it is necessary to select the appropriate cumulative distribution function [18]. In this regard, many studies and researches have been done, which can be referred to as the probability distribution functions of Weibull, Riley, and normal distribution. In studies [18-22], emphasis and support have been on the Weibull model. But some of the other Persian and Latin studies are as follows: they have studied the daily, monthly and annual trends of wind speeds in an area for energy and have considered winds with a speed of 4 to 25 meters per second to be suitable for energy. In energy density

measurement, they used Weibull and Rayleigh distribution functions [23]. Wind energy potential in 21 US states was calculated using Weibull distribution and the amount of wind energy extracted was estimated for the whole country. [24] Especially marine resources were used more efficiently [25]. In Iranian studies, Mostafaiepour et al [26], Hashemi et al [27], Kayhani et al [28], and Ashrafi et al. [29] used a similar method to estimate Weibull distribution parameters using They used a frequency distribution table. Also in the study area, we can mention [30] that have calculated the wind energy potential. But in this study, in addition to evaluating the wind energy situation in the study area, provide an extension is provided to calculate this importance and validate it with the help of conventional methods.

2. Materials and methods:

2.1. Area of study

The study area in the present study is limited to the border of Rudbar city, which is located at latitude and longitude 37 degrees north and 50 degrees west. This city is located in the middle of Alborz Mountains, a continuous valley towards Qazvin plain by the Caspian Sea. The average temperature of this city is 24 degrees

¹ International Renewable Energy Agency (IRENA)

Celsius and it can be seen in different parts of it from desert climate to dense forest. It is important to note that there are several wind sites in this city and the ability to generate wind energy due to climatic conditions and topography has a high speed with an

average of 5.5 meters per second. In the recent study, 4 sites of Manjil, Qazvin, Harzivel and Rudbar in black are studied and evaluated (fig.2).



Figure 2. Study area

Our study in the field of wind energy potential measurement in onshore and coastal areas evaluates wind energy according to the extensions developed by the authors and the results with scientific achievements

and similar software in 4 stages of wind simulation, simulation of conditions the boundary of the range will assess wind power and extractable energy.

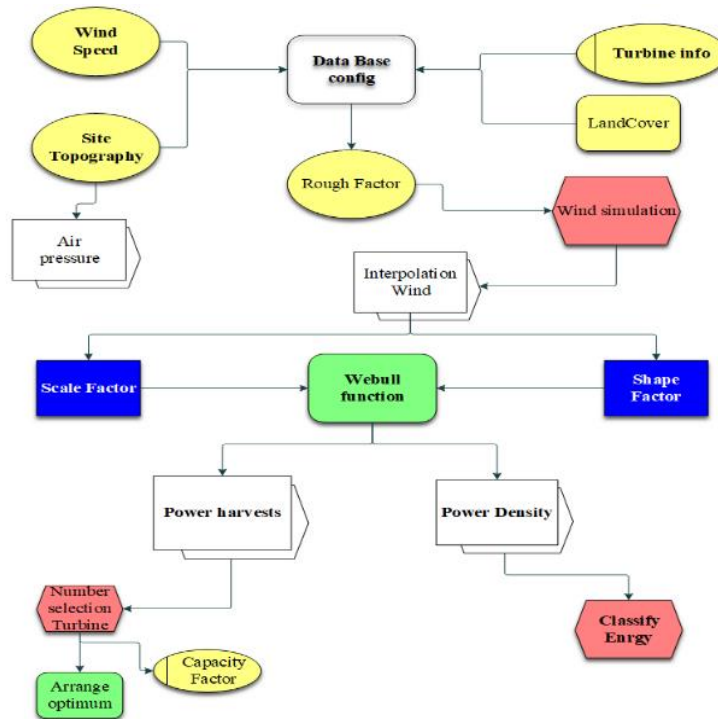


Figure 3. Flow diagram of wind energy software

2.2. Modeling wind data from reference height to turbine rotor height

All meteorological data are collected at a height of 10 meters, so modeling wind speed at the height of the turbine rotor is important. There are two numerical or rule models for wind speed modeling; Which is suitable for smooth surfaces and homogeneous distribution of wind[31]. The first is the logarithmic law, which is derived from the fluid mechanism of boundary layers studied on the basis of theoretical and experimental sciences. The second approach is derived from research into wind energy science, called the law of power. Both models have unknown variables. In the present study, the power law profile has been used. This rule is presented in a simplified form based on Equation (1).

$$\frac{V}{V_R} = \left(\frac{Z}{Z_R}\right)^\alpha \tag{1}$$

2.3. Wind scattering probability modeling

Usually, various statistical functions such as Weibull and Rayleigh functions are used to model wind energy[31]; Many studies have been done to evaluate the accuracy of these models, which in general, the Weibull function has a more accurate response to the facts; But in general, it can be understood that the accuracy of these statistical functions depends on the type and accuracy of the study of their parameters[23]. To verify these methods, many studies have been done that almost all studies in the field of wind energy, the use of standard deviation methods for studies for which there is no information is appropriate. In the continuation, the most likely neighborhood method can be used[32]. After calculating the wind speed, the probability of wind in a period can be calculated with statistical functions. In the study of wind energy, the

Weibull function has the most application and has a good accuracy[33]. This function is a special discussion of the third-class distribution of the Pearson function, which was presented by Weibull in 1937[34]. This function has two functions for wind speed: 1- Probability density function 2- Cumulative distribution function. These functions are indicators of time changes for wind speed. Thus Equation (2) represents the Weibull probability density function:

$$f(v) = \frac{\kappa}{\lambda} \left(\frac{v}{\lambda}\right)^{\kappa-1} e^{-\left(\frac{v}{\lambda}\right)^\kappa} \tag{2}$$

In Equation (2), respectively, they represent the shape and scale factors, which is a dimensionless numerical shape factor, which in a way represents the wind speed variability. It is lower, on the other hand, the scale factor is expressed in m / s-1. In fact, this factor indicates the concentration of wind speed in a certain range. The small size of the scale factor helps to increase the probability of wind speed. In other words, changes in this factor affect the scale value of the base curvature of the distribution [31] e is equal to the Napier number. And v, f (v) indicates wind speed and wind speed probability, respectively.

In short, it can be said that the Weibull function is affected by the accuracy of two factors, shape and scale. If the shape factor is decreasing, the changes around the average wind speed are also reduced. For example, if the scale factor is constant and the shape factor is less than 2.6, right skewing occurs, while in contrast, negative skewing occurs above 3.6. If this value is between 2.6 to 3.6, the elongation coefficient is zero. Now, on the opposite side, the scale factor is minimal, indicating the concentration of wind speed in a certain value, for example, if the shape factor and the scale factor increase, the graph is stretched to the right. Pulls to the left and increases the height of the chart. To further understand this, we can look at Figure 4.

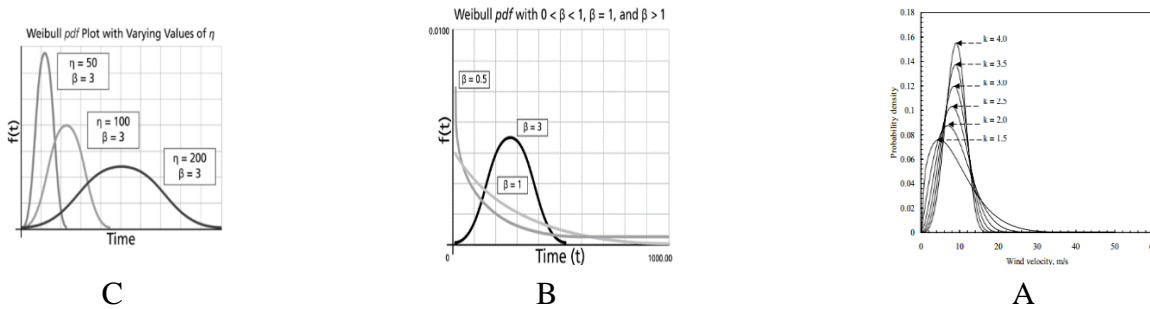


Figure 4. A: shows the frequency of shape and scale factors and their effect on the probability function, B: the effect of the shape factor on the probability curve, C: the effect of the Mughal factor on the probability

There are different methods for calculating the two factors of shape and scale. But two methods are

commonly used: 1- Standard deviation 2- The most probable neighborhood are the most used. It should be

noted that the first method is most useful for identifying wind sources from which little field information is available [35] but the second method is the most accurate in calculating energy and increasing the accuracy of power plant output calculations among a variety of methods [25]. The method of calculating these methods is presented in the equations below, respectively.

$$\lambda = \frac{v_m}{\Gamma\left(1 + \frac{1}{\kappa}\right)} \quad (3)$$

$$\lambda = \frac{v_m \times \kappa^{2.6674}}{0.184 + 0.816 \times \kappa^{2.73855}} \quad (4)$$

$$\kappa = \left(\frac{\sigma_v}{v_m}\right)^{-1.090} \quad (5)$$

Equation (3) represents the scale factor. In this equation, Γ represents the gamma function. Numerous studies have used Equation (4) to increase the accuracy of calculations. Equation (5) also shows the method of calculating the shape factor from the standard deviation and the average wind speed [36].

2.4. Power density

Dominant energy assessment on a site is an essential component of wind energy projects. In fact, the density of energy concentration is to measure the energy per unit area of the rotor and time. Energy concentration density the site design method and turbine blades are very effective. To investigate the amount of energy per unit area and its suitability for the construction of wind farm sites can be rewritten from Equation (5) and easily used [37].

$$PD = \frac{1}{2} \rho \sum_{j=1}^n (f(v_j) \cdot v_j^3) \quad (5)$$

In Equation (5), PD represents the density of a concentration in a given area in terms of (watts per square meter). ρ also indicates the density of air. $F(v_j)$ and v_j indicate the probability of wind gusts at a given speed and wind speed, respectively.

The air boundary layer is one of the most important components in various calculations. This component is directly affected by the earth's surface [38]. But other physical parameters such as acceleration, temperature, humidity change rapidly per unit time and place. In wind energy engineering, identifying the variance of vertical wind speed plays a very important role in

designs [39]. 1- Directly on turbine energy production at the characteristic height of the tower 2- Significant effect on the lifespan of turbine blades. Air density is an important factor in the boundary layer under the influence of temperature and pressure. Equation (6), which is the ideal gas law, can be used to calculate air density.

$$\rho = \frac{P}{RT} = 3.4837 \frac{P}{T} \quad (6)$$

In Equation (6) p shows the air pressure. T stands for air temperature in Kelvin. Therefore, air density is calculated in kilograms per cubic meter.

The International Atmospheric Standard assumes sea level temperature and air pressure to be 288.15 Kelvin and 101.325 kpa, so the air density is 1.225 kg / m³ [40]. Therefore, with increasing altitude, the air density decreases. To calculate the air density less than 500 meters, Equation (7) presented by the organization [40] can be used.

$$\rho = 1.225 - (1.194 \times 10^{-4})z \quad (7)$$

In Equation (7) z represents the height of the turbine to calculate the wind speed.

Extractable energy

There is no question that not all energy in the environment can be used. Rather, our energy extraction will be limited to the environmental conditions and capabilities of existing technology. Therefore, the extraction of energy from the total energy will be in a certain range and range of wind speed and time. Because energy exchangers have a significant effect on energy that can be extracted from the environment. Therefore, we can simply refer to Equation (8) with which the extractable energy of the turbine can be extracted experimentally [41].

$$P_{avail} = \frac{1}{2} \rho A v^3 C_p \quad (8)$$

Equation (8) shows the extractable energy and A represents the surface area of the sweeper. In the continuation of the same equation, C_p expresses the specific characteristics of the turbine, which depend on the number of impellers per unit time and its diameter.

According to all the topics mentioned in the extraction discussion, the elimination of ancillary parameters and increasing the focus on general parameters causes a greater degree of confidence in the extraction of energy calculations. Since the wind blows in a unit of time and continuously, so the calculation of the speed of

extractable energy must also be done in this range. Therefore, the use of equation (9) for modeling extractable energy is more applicable [41].

$$p(v) = \begin{cases} 0 & V < V_c \text{ or } V > V_f \\ \Pr & V_r < V < V_f \\ \left(\frac{V^m - V_c^m}{V_r^m - V_c^m} \right) & V_c \leq V \leq V_r \end{cases} \quad (9)$$

$$HE = nday \times \frac{P}{P_0} \times P_{rate} \times \left(\int_{V_c}^{V_r} \frac{V - V_c}{V_r - V_c} \times f(V) dV + \int_{V_r}^{V_f} f(V) dV \right) \times (1 - loss)$$

According to Equation (9) HE is equal to the energy recoverable for one year, Nday is equal to the consideration, usually 365 days. Prate is equal to the maximum power of the turbine used, and f (v) is the probability of wind speed. v_c and v_o are the assumed wind speed and the assumed speed for maximum output and the wind speed required to start the turbine and finally the assumed speed for stopping the turbine to prevent damage, respectively. In this regard, the loss value will be used for the reduction coefficient of the turbine.

3. Results and Discussion:

One of the important pieces of information in wind energy modeling is related to the dominant land cover[42]. This causes the local flow in different parts with fluctuations in height and speed or by creating a dam to cause different rotations in wind speed and direction. In the study area from the north, focusing on the Rudbar valley, there is more forest cover at high altitudes. Forest cover accounts for 27% of the area. But in the southern part, due to its location in the opposite direction of the Caspian Sea, it is less under the influence of prevailing air currents, which has caused 68% of the area to be dense rangeland cover with an average height of 65 cm and of course poor cover shrublands. In the area in question, 0.80 of the total area is water levels and 0.31 of the total area is urban areas. According to the roughness map extracted from the land cover section, there is the least friction in the southern part of the region. Only two urban settlements with the lowest area in the region have the highest coefficient.

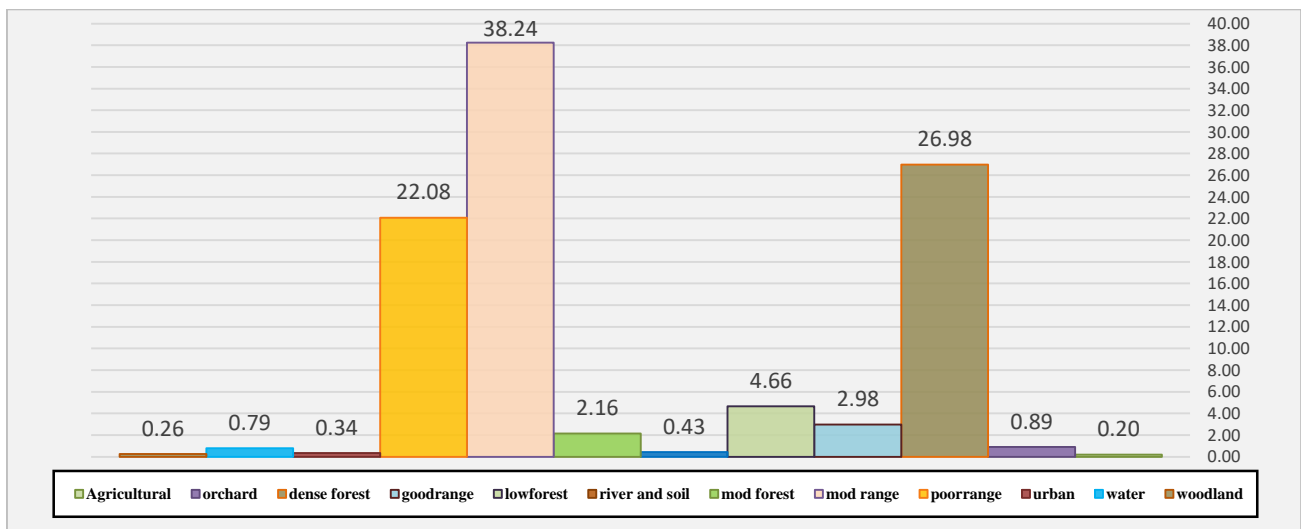


Figure 5. Percentage chart of land cover frequency

(b)

(a)

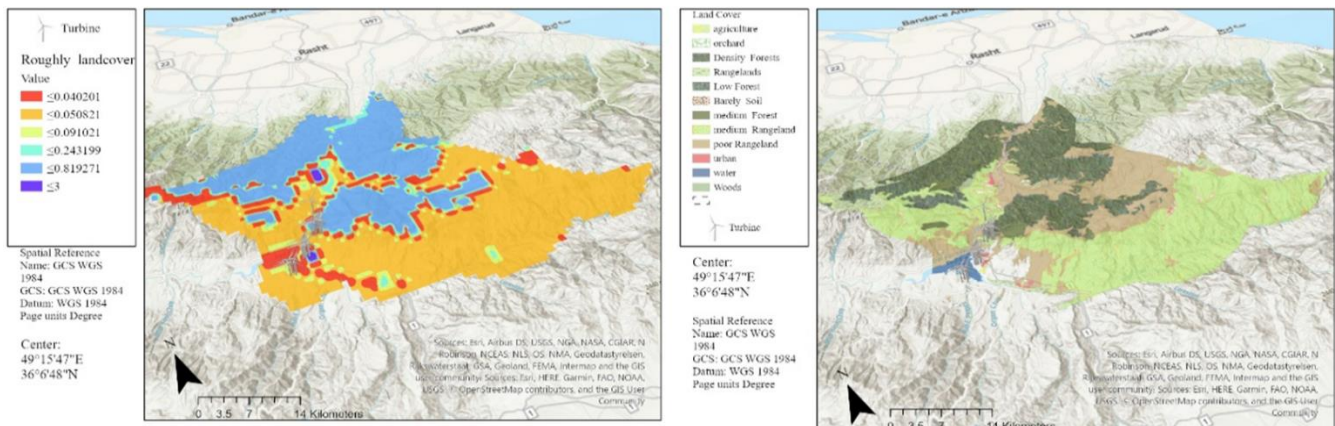


Figure 6. Status maps; (a): Land cover, (b): Ambient roughness coefficient

An important parameter of the output of the atmospheric pressure simulation model in the region with emphasis on the existing experimental model. In this model, altitude and topographic shape play a major role in creating local wind flow. The existence of the Rudbar River and the existing valley causes airflow from the Qazvin desert to the Caspian Sea and vice versa. In the study area, the elevation difference of 250 meters from the riverbed to 3000 meters of Alborz peaks is very important and effective in twisting and creating a strong local mountain stream. One of the important features of the region according to the output model is the atmospheric pressure parameter. In the

Manjil-Rudbar valley area, the level of pressure or air density according to the air density map is equal to 1.21 Pa; which is significant pressure for the area and in terms of functionality at the coastal level. On the slopes of the existing valley, the density decreases by 1.1. The average density of 0.92 in the whole region limits the development for the construction of wind farms. In the study of 4 sites in the study area, the Herzeville site with the highest height on the southern slope (1000 meters) and the Rudbar site with a height of 1125 meters have the lowest power density level and this factor reduces the efficiency of turbine systems in higher production capacity.

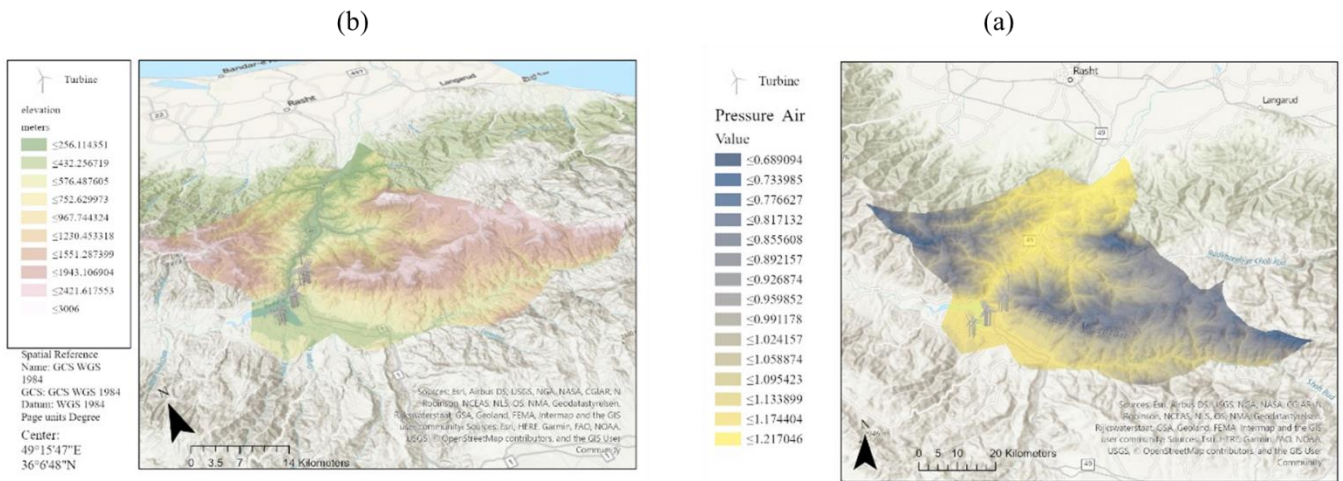
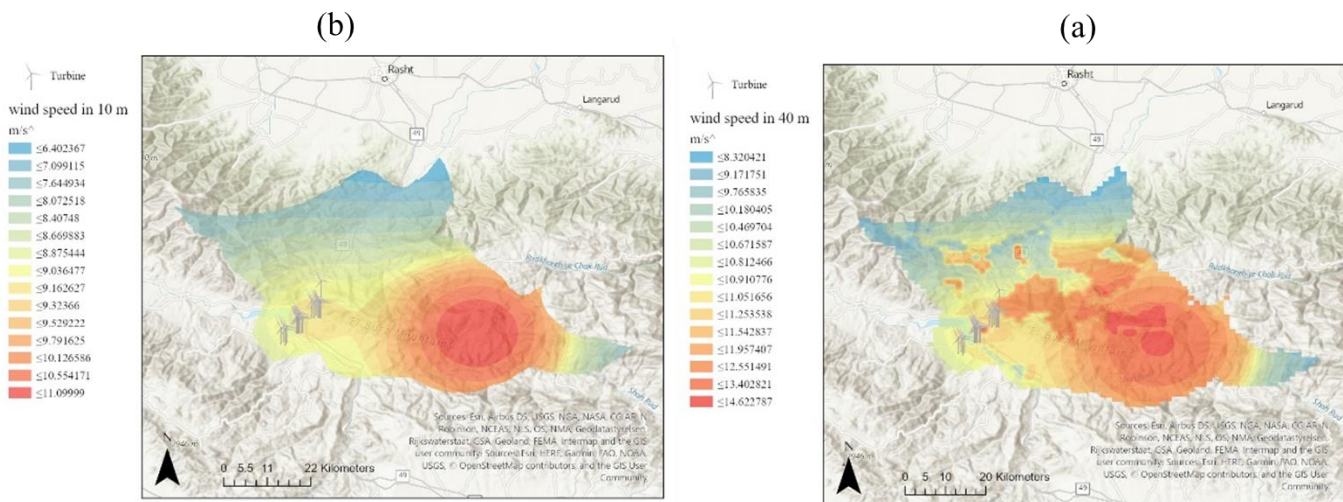


Figure 7. Status maps; (a): Elevation , (b): air pressure

According to the model output of the average and the deviation of the average wind speed at the level of 10 and 40 meters, the effect of the ambient roughness parameter in the speed disorder shows itself more. In our study, the Jirandeh region has the highest speed and standard deviation due to the low time of the statistical period. But in other areas, the trend is normal.

According to our study, the average of 11 to 9 meters per second is excellent and causes the turbines to operate at their maximum power. The mean deviation at the level of study sites shows that the Manjil site is in the most optimal point with the highest speed and the lowest standard deviation (9.54 and 1.4), respectively.



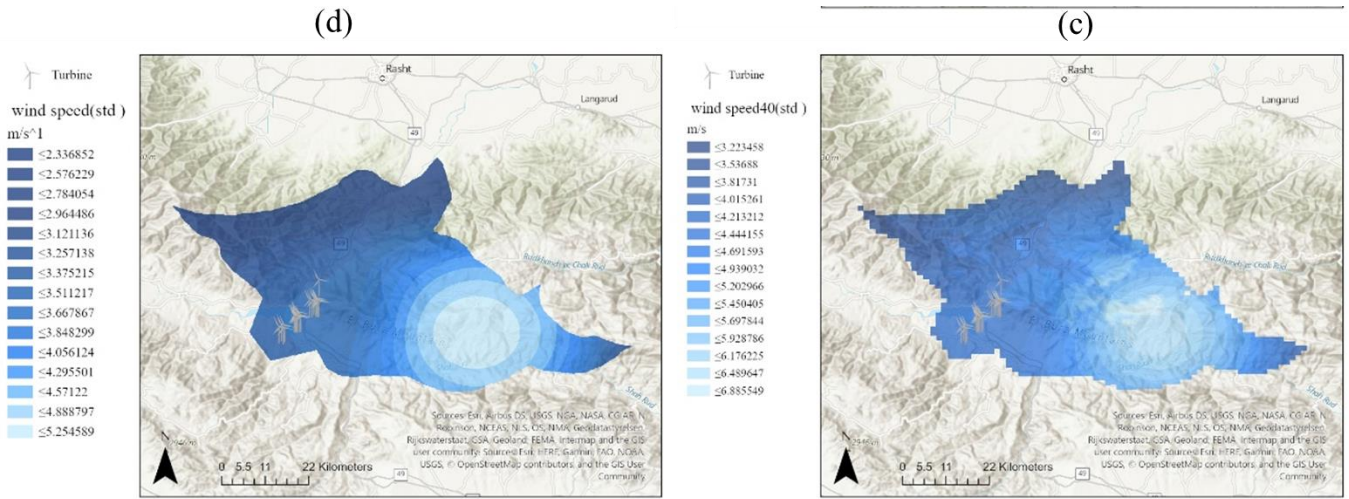


Figure 8. Average and average wind speed deviation;
(a): At a height of 40 meters, (b): At a height of 10 meters
(c): At a height of 40 meters, (d): At a height of 10 meters

Based on the results of modeling, the probability distribution function of the Weibull function of the k-statistic for the region is 2.32. This function will ensure that the speed is repeated. The experimental Weibull function model in the equation for the wind shape index or C states the value of 10.79, which shows a lower estimate according to the wind speed map at a height of 40 meters above the surface. In general, among the existing methods, the EPF experimental scattering index has shown that the scattering probability will have a range of 1.8, which is a good condition. A noteworthy point according to the wind speed chart is the presence of two peaks in Manjil wind speed. The first peak is related to the continuous flow of wind speed in the range of 2 meters per second, which is referred to as non-functional wind in the power plant. The second peak that makes the Manjil region significant is in the range of 12 meters per second due to the morning flow from the Caspian Sea and the mountains to the Qazvin plain. The Weibull

distribution diagram has a skew to the right, which is why the average velocity estimate is less than the reality in the speed range of 6 meters per second. This difference causes the probability estimator to have a negative tendency towards a low probability density and to count the estimate as lower.

The wind energy power map shows that the power density range is 145 to 305 watts per square meter. The high power of the region, considering the average of 238 watts per square meter, shows that the construction of small and large power plants will be potentially profitable. In general, based on the output of the model, the highest wind energy power is located around the city of Manjil. The highest power point is located at the shore of Manjil Dam and at the Manjil site. In total, 23% of the total area is in Class 5 of the World Wind Energy Classification Standard. From the total area of the study area, modeling estimates show that 50% is in the optimal class 4 with a range of 200 to 250 watts. The other 30% of the region has low thrust power, so it does not have the efficiency of industrial power plants.

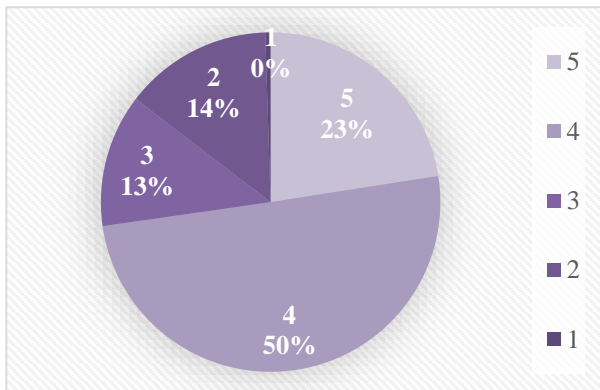


Figure 9. Graph of the frequency of energy classes in the study area

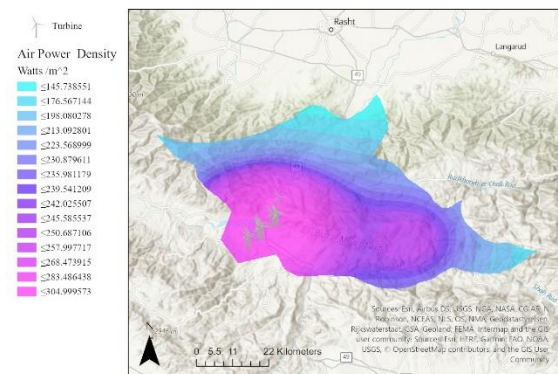


Figure 10. Power density zone map

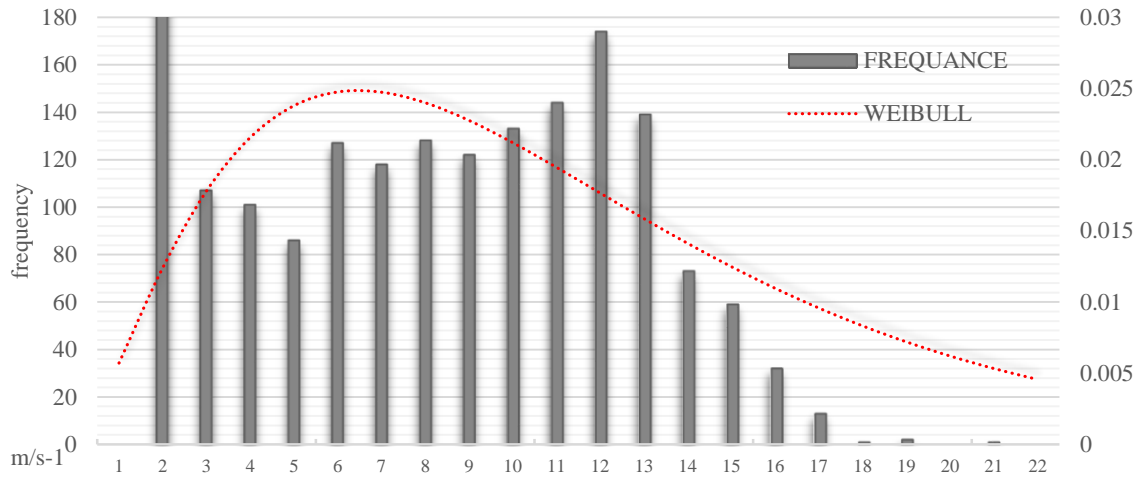


Figure 11. Frequency diagram of wind speed and Weibull probability distribution

Based on the results, the nominal energy potential generated for the four wind turbine models available at the study sites shows the high efficiency of the 550 models with a maximum power of one million watts per year with a factor coefficient of 42%, which is close to optimal capability and efficiency. The issue of 300

MW turbines with a capacity factor of 28% has a lower efficiency in energy production due to the limitation of wind speed due to the speed range in the region. The results of the model show that the use of heavier turbines with power class more than 5 capacities has a more limiting factor of 29%.

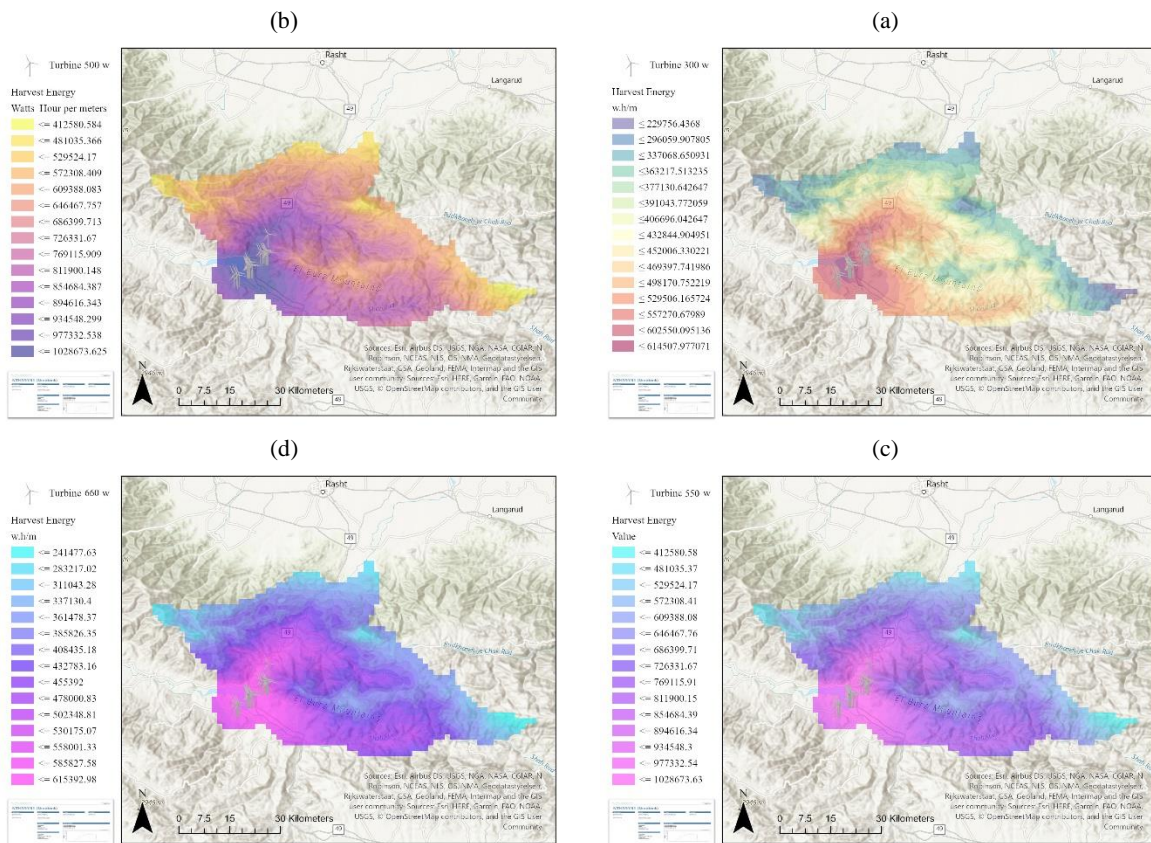


Figure 12. Turbine harvest energy;
(a): 300 w, (b): 500 w
(c): 550w , (d): 660 w

To evaluate the existing wind energy power model with the existing reality in the four power plants show that there is a significant negative difference in harvest energy. Separating the turbines and the site separately, Table 1 shows that the 300-megawatt turbines at the Manjil site generate 9.25 million watts per year,

compared to the estimated 8.64 million watts in the model, which is 6.6% lower than reality. The 500-watt turbine has a very small difference of -0.2%. At the Manjil site, 550-watt turbines with 11 units have the highest difference of 10.56% - the model has suffered the most negative errors in this section. On the other

hand, due to the high power density of the Manjil site, 660 MW turbines with 22 units on the shore of Manjil dam have a low error of 1.53%. Siahpoosh site in the west of Manjil and south of Manjil dam lake has a uniform and homogeneous composition in the level of turbines, this site with 24 660 MW turbines has a lower error in all sites with -0.18%. Herzeville site at the top of Mount Manjil has estimated the highest error of the model in terms of error. In this site, the effect of the topographic parameter is more visible and the threshold error has reached -10 and -12%. At the Rudbar site, the high altitude has caused the effect of topography and local flow to create a certain torsion, which makes the model estimate the reality lower than usual. Finally, an

overall estimate of the energy production field report for the one-year period shows that 123.2 million kilowatts of energy were produced, compared to the model estimate of 116.7 million kilowatts. The difference in the percentage of error changes is negative -5.31% of the total, an acceptable error in the negative direction, which is due to the Weibull estimator due to the right Skewness. Therefore, according to the results of the wind speed filter and the removal of noise below the threshold speed of 4 meters per second, the experimental estimator of Weibull is stretched to the peak. On the other hand, the correction of wind gauges is more important in bringing the equations closer to reality.

Table 1. Site specifications and changes in Power plant and Model output

Sites	Turbine type	Number	Power plant output (KWh hours per year)	Model output (KWh hours per year)	CV ²
Manjil	300	14	9,256,350.00	8,639,849.75	-6/6%
	500	1	1,030,693.00	1,028,673.63	-0/2%
	550	11	18,970,572.00	16,967,415.00	-10/56%
	660	22	29,840,981.00	29,383,395.25	-1/53%
Siahpoosh	660	24	31,490,390.00	31,433,565.00	-0/18%
Herzweil	300	12	7,447,500.00	6,663,163.50	-10/53%
	660	15	20,658,421.00	18,209,512.50	-11/85%
Rudbar	500	1	993,080.00	925,867.63	-6/77%
	550	3	3,508,149.00	3,393,483.00	-3/27%
total	-	93	123,196,136.00	116,644,925.25	-5/31%

Summary of spatial fit and arrangement of turbines shows that Manjil power plant in world energy class has sufficient quality of energy production and can be compared with global sites. This site with a nominal capacity of 240 million kilowatt-hours per year is one of the largest sites in the Middle East with a capacity factor of 0.25. Therefore, it has the lowest coefficient of modeling and design changes. For this reason, this site is considered an excellent control fuehrer with its appropriate density and layout. According to the obtained results, the Siahpoosh site with a capacity of

410 million kilowatt-hours per year has a limited factor capacity of 8%. This site has a coefficient of variation of 11%, which modeling shows that the choice of 660 MW turbines is not very appropriate and practical. Therefore, it seems that the use of 500 kW turbines has a better capability than 660 turbines on this site. Based on the results, the two sites of Rudbar and Herzeville have a very proportionate factor capacity, so these two sites can be upgraded according to the installation of Class 4 and 3 turbines.

Table 2. Compare different powers and capacity factor of sites

Sites	Area (meters)	CV	The calculated power of the model	Reported power	Nominal power	capacity factor
Manjil	3875	0.3	56019333.63	59098596	240637200	25%
Siahpoosh	11616	11.1	31,433,565.00	31490390	410493600	8%
Herzeville	9680	5	4319350.63	4501229	18834000	24%
Rudbar	3872	0.28	24872676.00	28105921	118260000	24%

² coefficient of variation

4. Conclusions

Comparison of production capacity of Manjil site in Rudbar based on energy production capacity model and comparison of its capacity with coastal and offshore sites shows that this site is comparable to sites such as Robin Riga America with a capacity of 180 MWh due to the topographic parameter [43]. Also, according to the reports provided, the good power that is on this site will be able to provide energy consumption for 300,000 inhabitants. Compared to the London Array site, with a capital of less than \$ 200 million, it has a higher capability of using 500 MW turbines.

Based on the most basic input parameters, the model has a high detection in identifying the potential and actual power of sites because the output specifications and details show that the model has a prediction error of less than 5% for power measurement. And in comparison with the estimates of the scattering parameters of the Weibull function to evaluate the power of wind energy and to evaluate the accuracy of models in reality in the United States by [44] who stated the error is 20% of the total, the model emphasizes low error. Compared to identifying wind energy power models and comparing reality using ARMA time series models in Canada by [45] the model uses artificial intelligence algorithms to filter its dynamics in filtering time noise and data incompetence. Expresses it in a more optimal way. Therefore, compared to the study and general review of various wind energy estimation methods and MONTE CARLO simulation revision in power plant power output estimation in China [46], this model has specific spatio-temporal frequencies compared to non-functional filters such as [47]. This software package utilizes the use of fuzzy techniques and neural networks to increase the speed of calculations and increase the accuracy of models to assess the accuracy of power plants in the Netherlands [48] native capability for a large area of Iran and its diverse climate has found.

5. References

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