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Assessment of Wind Energy Potentiality at Ajloun, Jordan Using Weibull Distribution Function

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Abstract: The main objective of this research is to evaluate the potential of wind energy in the northern city of Jordan, Ajloun by utilizing the two parameters Weibull distribution function in order to provide an insight concerning the energy that can be produced from the selected site. The shape parameter k and the scale parameter c were determined in order to assess the wind potential and its annual frequencies. Significant findings included a wind speed recurrence between 3 and 4 m/s with a probability of 31%. The maximum values of k and c were found to be 1.926 and 6.072 in 2014, respectively. Results also showed that the averaged shape and scale parameters were 1.586 and 4.073, respectively, which indicates that the spread in wind speed is small and the wind potential becomes higher over the years. Outcomes of the study also indicated that June has the maximum wind power density while November has the lowest. According to the international standards of wind power generation classification, Ajloun city has poor wind resources but is still a suitable area for small-scale power generation.

Keywords: Wind assessment; Weibull Distribution; Ajloun; wind energy

1. Introduction

Renewable energy sources such as geothermal, wave, tidal, hydro, and wind are environmentally friendly sources of energy and recently they are receiving more interest from energy developers and researchers due to their green impact on the earth and the universe. Among the renewables, wind energy is growing in a fast way and it can produce electrical power without negative impacts on the health and environment[1)]. This is due to the features of the wind as it is a clean source of energy, available in wide ranges around the world, and its viability[2)]. The recent developments in wind machines technology made electricity production from wind turbines more effective than before with an economically viable process[3,4)]. Therefore, to get the full benefits from the energy produced by the movement of the wind, more investigations are required for the economic use of wind energy. Wind turbines have many design parameters that can be developed as the wind blows continuously around the earth which makes them a better energy solution compared to conventional fossil fuel and solar power[5)]. Wind turbines provide solutions for both large and small-scale applications since they are available in various sizes and designs. Generally, there are two main arrangements of wind machines which are Horizontal Axis Wind Turbines (HAWTs) where they are generally used for large-scale power applications, and Vertical Axis Wind Turbines (VAWTs) where they are used for small-scale applications[6)]. Many features can be gained by using the VAWTs as they can accept the wind from all directions, are quiet in operation, have a low cost of maintenance, and are easy to maintain. On the other hand, HAWTs are the most built type as they have the highest efficiency and they are able to work at high wind speed[7)]. The main principle of all wind turbines is converting the available kinetic energy in the wind into useful energy by using mechanical components such as blades, gearboxes, and shafts, and electrical components such as generators, transformers, and sensors[8)].

The wind energy sector has shown a considerable improvement in the last few years as shown in Figure 1. It can be observed from the figure that the installed capacity increases annually with different growth values. In 2020, the installed capacity was about 93 GW with an increase of 52.96% relative to 2019 and 83.43% relative to 2018.

In Jordan, electricity generation mainly depends on the imported natural gas from the neighboring countries whereas a small portion (around 4%) is covered by the domestic energy resources[9)]. However, the high cost of imported gas pressures the Jordanian government to reconsider the energy policies. The current strategy of Jordan's energy aims to cover about 20% of the electricity demand using renewable energy by 2025[10)].

Following the international trend of utilizing green energy sources as an alternative to traditional fossil fuels,

the Jordanian governments have established many wind power plants in different cities. Nowadays, Jordan is being fed by over 370 MW of electricity generated from wind energy. The generation capacity of the country from wind energy for the year 2019 reached 32% growth as compared to 2018[11]. Through the past few decades, only a small number of researches and studies assessed the potential of Jordan wind power; these researches illustrated that the region has an efficient wind potential that can help to reach the country's plan toward the 20% of electricity from renewables. A study on determining the wind potential in Northeast Badia, Jordan has been carried out by Al-Nhoud and Al-Smairan[12]. Their results showed that the region could be used for non-grid connected applications due to the low wind speeds there. Alrwashdeh and Alsaraireh[13] have conducted wind assessments for five different locations in Jordan including Aqaba, Tafilah, Madaba, Al-Salt, and Irbid. The study has concluded that the highest wind power could be generated from Aqaba city. Alrwashdeh[14] has investigated the wind energy potential at different sites in Jordan. The outcomes of the study showed that wind turbines could be utilized in the selected sites and used for electrical power generation with a good power range. Anagreh et al.,[15] have conducted a renewable energy assessment for Aqaba city in Jordan. Results showed that the city has a powerful potential of using stand-alone, grid-connected, or hybrid renewable energy systems.

As an effect of global warming, the climate will change and the temperature will rise, this rising in temperature will affect the movement of wind and will cause variations in its speed and direction in several regions around the world[16]. Based on these changes, the current assessment will utilize the most updated wind data aiming to provide an accurate analysis of the wind potential in the last decade. Wind energy potential for a specific region can be assessed based on the characteristics of the wind in that region including wind speed, wind direction, and availability. In similar terrains, the wind speed distribution may vary in high ranges as a result of the variations in the wind characteristics which may cause different power outputs. Hence, the distribution of wind energy at various time scales is substantial to be able to evaluate the wind potential resources in a specific area. On the other hand, wind speed varies with the elevation of the terrain; it rises with the rise of elevation. Additionally, the wind flow will face different obstacles leading to the wind with high turbulence.

Based on the literature, there is a lack of studies that focus on the potential of wind energy in Ajloun city. Thus, in this research, the potential of wind energy of the northern city of Jordan, Ajloun has been assessed using the Weibull distribution function with two parameters in order to provide a better understanding of the wind characteristics in the city. The investigations include fundamental properties, such as mean wind speed and wind speed probability distribution. The potential was determined over a period of eleven years from 2010 to 2020.

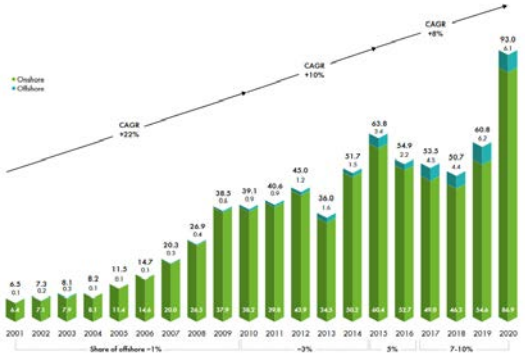

Fig. 1: Annual installed capacity in GW[17]

2. Data and site description

Ajloun (32.3326° N, 35.7517° E) is a hilly town in the north of Jordan (Figure 2). The city is located 76 Km North West of the capital city Amman. Ajloun Governorate has a population of over 199,400 widespread in 27 villages and towns over an area of about 420 km². It is characterized by different topography, there are high areas and low areas, where the altitudes vary from 1240 m to 590 m above sea level. Ajloun weather is characterized by dry summer and mild, wet winters. The average temperature is about 16.7 C° and the annual rainfall is about 467 mm. The hourly wind speed data was collected from Jordan meteorological department for each year of study. The data was collected at a high of 10 m above the surface of the ground through a period of 11 years (from 2010 to 2020).

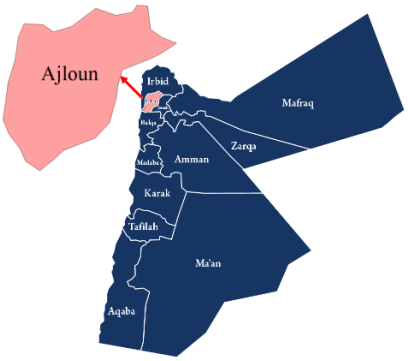

Fig. 2: Map of Ajloun, Jordan

3. Analysis procedure

Wind speed values collected with different measuring methods have large ranges. Thus, in the analysis of wind power, it is preferred to reduce these data to only a few key parameters that can demonstrate the behavior of these data. The most functional way for this process is to utilize a probability function that can provide a good insight into the wind distribution. Wind speed distribution and

frequency curves can be described using several probability functions. The most commonly used functions are Weibull, Rayleigh, and Lognormal. In this paper, the two parameters of Weibull distribution have been implemented due to the features of this function such as simplicity and accuracy. The mathematical model of this function can be written as follows[2]:

$$F(v) = \left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1} \exp\left[-\left(\frac{v}{c}\right)^{k}\right], k > 0, v > 0, c > 0 \quad (1)$$

In this equation, the term F(v) expresses the probability density at a certain wind speed v. Whereas k and c represent the shape and scale parameters, respectively. Shape and scale parameters could be utilized as a description of the wind potential in a certain area. The scale parameter, c, identifies the wind availability in the site, while the shape parameter k is an indicator of the width of the wind distribution[18]. Shape and scale parameters can be written as[2]:

$$k = 0.83\,\bar{v}^{0.5} \quad (2)$$

$$c = \frac{\bar{v}}{\Gamma(1+\frac{1}{k})} \quad (3)$$

In this equation, $\bar{v}$ represents the averaged wind speed, whereas the symbol Γ is the gamma function.

The two parameters Weibull distribution revealed high accurate results in many studies[19-21]. However, this function can't be used for sites with very slow wind velocity ($\bar{v}$ < 1) accurately[22].

3.1 Wind power and energy density

One of the best indicators of the wind resource is wind power density as it considers the frequency distribution of the wind velocity, the density of the air, and the cube of the wind speed. The density of wind power can be estimated through the utilization of the Weibull function as follows[23]:

$$\frac{P}{A} = \int_0^{\infty} \frac{1}{2}\rho v^3 f(v)dv = \frac{1}{2}\rho c^3\,\Gamma\left(\frac{k+3}{k}\right) \quad (4)$$

Wherein P represents the wind power, A represents the swept area of the turbine, and ρ represents the wind density.

Wind energy density can be evaluated immediately after estimating the density of the wind power in a specific region, and it can be directly evaluated through a specific time interval T as below[24]:

$$\frac{E}{A} = \frac{1}{2}\rho c^3 \Gamma\left(\frac{k+3}{k}\right) T \quad (5)$$

3.2 The most probable wind speed and wind speed carrying maximum energy

The most probable wind speed V_{mp} and the wind speed that has the maximum amount of energy $V_{(max,\,E)}$ can be evaluated utilizing the two parameters of the Weibull function c and K. consequently, the two velocities can be expressed as follows, respectively[25].

$$V_{mp} = c\left(1-\frac{1}{k}\right)^{\frac{1}{k}}\ (m/s) \quad (6)$$

$$V_{max,E} = c\left(1+\frac{2}{k}\right)^{\frac{1}{k}}\ (m/s) \quad (7)$$

4. Results and discussion

The data of the wind speed for the northern city Ajloun over a period of eleven years (2010 – 2020) were collected and analyzed. Based on the collected wind speeds, the analysis of the data was accomplished by utilizing the two parameters Weibull distribution function. The estimation of the wind energy potential of the location was also carried out by assessing wind power and wind energy densities.

4.1 Variations in wind speed

The averaged wind data of Ajloun city throughout the different months of the year is illustrated in Figure 2. This data was recorded at 10 m height above the ground level over eleven years. It can be observed from the figure that the average monthly wind speed varies remarkably from month to month and from year to year. The months from September to December show the lowest wind speed whereas the months between June and August exhibits the highest seasonal prevailing winds. This difference is in the range of about 1 m/s and 3.5 m/s. The lowest wind speed is found to be 1.88 m/s in November for the year 2010 and the highest speed is found to be 5.33 m/s in June 2015. The main source of the high wind speed in June is the low-pressure hot dry air that flows from the desert which generates a strong wind with high kinetic energy. According to the Jordanian electric power company, the highest demand for electric power occurs in the summer season (June to September). This may be attributed to the high utilization of air conditioners due to the hot dry weather. Consequently, this promotes adopting the advantage of wind energy as the wind speeds are the highest through these months.

Moreover, according to the collected data, the prevailing wind direction was found to be 280 degrees from the true north for the years 2015 and 2016, whereas in the years 2017 and 2018 the prevailing wind direction was 275 degrees from the true north. For the last 2 years of assessment (2019 and 2020), the prevailing wind direction was found to be 270 from the true north.

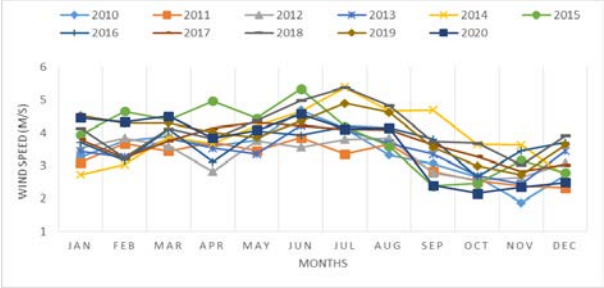

Fig. 2: Variations of wind speed through the period between 2010 and 2020

4.2 Variations of monthly shape and scale Weibull parameters

Shape parameter k and scale c have been evaluated for the full-time scale (11 years) and tabulated as illustrated in Table 1. The shape parameter can be used as an indicator for the wind stability and its distribution at a specific site, while, the scale parameter can be used as an indicator for the wind strength at a particular site. It can be observed from the table that the maximum shape parameter during the study was 1.926 in July 2014, whereas, the lowest value of the shape parameter was 1.138 in November 2010. On the other hand, the highest and lowest values of the scale parameter were 6.072 and 1.971, respectively. The shape parameter variations in 2010, 2015, and 2020 were 1.498, 1.648, and 1.753, respectively for January, which indicates that the wind distribution becomes more stable over the years. On the other hand, the scale parameter values were 3.609, 4.408, and 5.009 m/s during the years 2010, 2015, and 2020, respectively, which indicates that the wind becomes stronger over the years. Based on both parameters, it can be concluded that the wind potential has been improved through the years which promotes the utilization of wind turbines for generating electricity in Ajloun city.

Table 1. Monthly shape and scale parameters for the northern city of Jordan, Ajloun.

Month	Parameters	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
January	k	1.498	1.460	1.558	1.540	1.371	1.648	1.599	1.617	1.689	1.765	1.753
	c	3.609	3.420	3.923	3.829	2.986	4.408	4.143	4.242	4.642	5.082	5.009
February	k	1.610	1.590	1.627	1.498	1.444	1.790	1.476	1.492	1.495	1.720	1.729
	c	4.200	4.091	4.294	3.609	3.341	5.231	3.499	3.577	3.593	4.818	4.870
March	k	1.636	1.539	1.572	1.625	1.632	1.738	1.682	1.609	1.685	1.720	1.761
	c	4.346	3.824	3.997	4.283	4.320	4.921	4.600	4.195	4.621	4.818	5.056
April	k	1.573	1.601	1.396	1.558	1.590	1.851	1.465	1.691	1.621	1.663	1.626
	c	4.002	4.153	3.103	3.923	4.091	5.601	3.441	4.652	4.263	4.497	4.289
may	k	1.611	1.542	1.609	1.519	1.702	1.750	1.672	1.724	1.737	1.630	1.675
	c	4.205	3.840	4.195	3.719	4.714	4.994	4.543	4.844	4.916	4.309	4.564
June	k	1.799	1.628	1.566	1.706	1.788	1.917	1.645	1.704	1.855	1.732	1.774
	c	5.283	4.299	3.965	4.740	5.221	6.016	4.393	4.725	5.627	4.890	5.138
July	k	1.687	1.518	1.617	1.678	1.926	1.698	1.700	1.682	1.924	1.838	1.683
	c	4.632	3.714	4.242	4.580	6.072	4.694	4.704	4.600	6.062	5.519	4.606
August	k	1.512	1.589	1.626	1.592	1.793	1.572	1.689	1.680	1.825	1.784	1.689
	c	3.682	4.085	4.289	4.106	5.252	3.997	4.642	4.590	5.442	5.195	4.642
September	k	1.453	1.396	1.384	1.520	1.799	1.281	1.620	1.583	1.602	1.563	1.284
	c	3.383	3.103	3.045	3.724	5.283	2.572	4.257	4.054	4.158	3.950	2.588
October	k	1.352	1.322	1.328	1.363	1.585	1.300	1.355	1.504	1.593	1.437	1.220
	c	2.896	2.758	2.785	2.949	4.064	2.657	2.912	3.640	4.111	3.304	2.310
November	k	1.138	1.283	1.346	1.296	1.582	1.475	1.542	1.395	1.442	1.369	1.272
	c	1.971	2.582	2.870	2.641	4.049	3.493	3.840	3.098	3.330	2.976	2.534
December	k	1.369	1.263	1.457	1.542	1.359	1.385	1.598	1.447	1.643	1.583	1.309

	c	2.976	2.491	3.404	3.840	2.928	3.050	4.138	3.351	4.382	4.054	2.699

4.3 Wind Power and Energy Density

Wind power and wind energy densities have been evaluated and illustrated in figures 3 and 4, respectively. It can be noticed from the graphs that the energy and power densities curves are following the same trend as the velocity curves. This is due to the fact that the wind power and wind energy are proportional to the cube of the velocity which means that the power and energy are rising with the increase of the velocity and decrease with the reduction in velocity. Thus, the highest amount of power can be produced in June with a value of 118.86 w/m^2, whereas, the lowest amount of power can be found in November with a value of 42.38 w/m^2. Hence, the lowest potentiality of wind can be found in November and starts to increase until reaching its maximum values in Jun and then starts to drop down again.

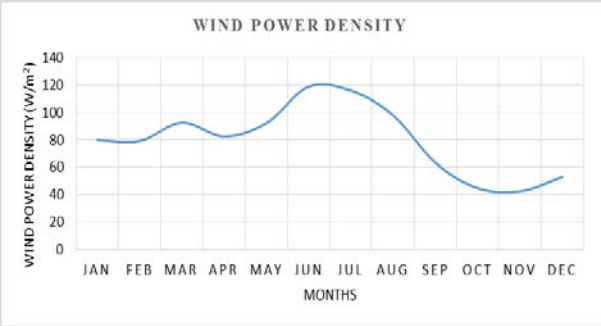

Fig. 3: wind power density for Ajloun city

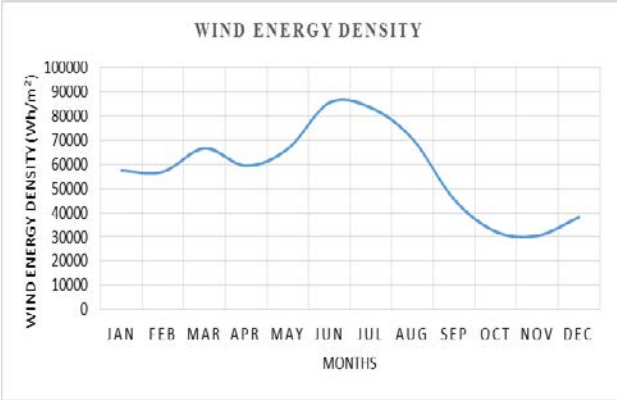

Fig. 4: wind energy density for Ajloun city

4.4 Weibull distribution parameters

The annual parameters of the Weibull distribution, the most probable wind speed, and the wind carrying the maximum energy are evaluated during all the years of study and tabulated in Table 2. It can be observed from the table that the most probable wind speed values range between 1.659 and 2.689 m/s which indicates that the most available wind in the city is within this range. Moreover, the wind speed that carried the maximum energy was ranging between 6.282 and 7.328 m/s. These values can be very useful in designing and selecting the most appropriate wind turbines for the location since the wind turbine operates most efficiently at its rated wind speed.

Table 2. Annual Weibull distribution parameters for northern city of Jordan, Ajloun.

Parameter	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
$v_{average}$	3.396	3.194	3.317	3.448	3.905	3.858	3.673	3.706	4.107	3.982	3.620
k	1.529	1.483	1.511	1.541	1.640	1.630	1.590	1.597	1.682	1.656	1.579
c (w/m^2)	3.770	3.533	3.678	3.831	4.365	4.310	4.094	4.133	4.599	4.454	4.033
P/A	63.392	55.167	60.107	65.619	87.568	85.106	75.907	77.486	98.557	91.640	73.421
E/A (Kwh/m^2)	555.31	483.26	526.54	574.82	767.10	745.53	664.94	678.77	863.36	802.76	643.17
v_{mp}	1.884	1.659	1.796	1.943	2.460	2.406	2.197	2.234	2.689	2.547	2.137
v_{maxE}	6.513	6.282	6.423	6.573	7.097	7.043	6.831	6.869	7.328	7.185	6.771

Moreover, the two parameters (k and c) of the Weibull distribution were evaluated and presented in Table 1 for the monthly variations and in Table 2 for the annual variations. The monthly shape parameter was ranging between 1.138 and 1.926 whereas the monthly values of the scale parameter were in the range between 1.971 and 6.073. On the other hand, the maximum value of the annual shape parameter is found to be 1.682 in 2018, whereas, the maximum value of the scale parameter is found to be 4.599 in 2018. The high ranges of the shape parameter k indicate that the studied site has a stability of wind speeds, while the high ranges of the scale parameter c indicate that the location is windy.

The Weibull distribution frequencies for the years 2010, 2015, and 2020 are illustrated in Figures 5, 6, and 7, respectively. These frequencies have the ability to predict the power that can be produced by the wind turbine machines in the location. It can be noticed that the three years (2010, 2015, and 2020) have a similar frequency

trend. Additionally, the most frequent speed was between 1m/s and 4 m/s throughout all the years of study.

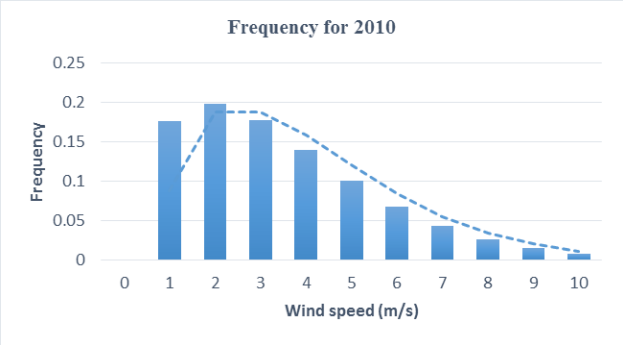

Fig. 5: frequencies of the Weibull wind speed of Ajloun in 2010

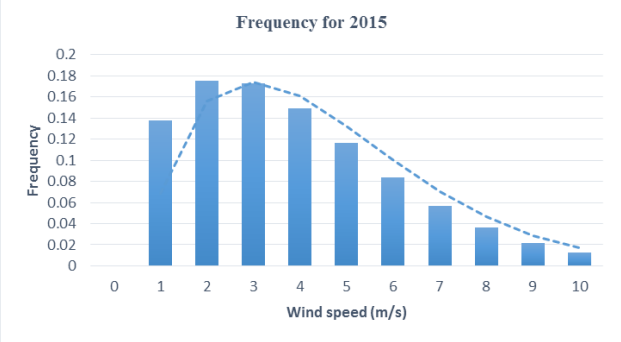

Fig. 6: frequencies of the Weibull wind speed of Ajloun in 2015

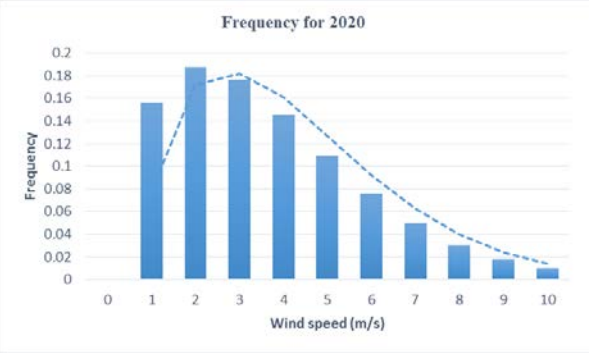

Fig. 7: frequencies of the Weibull wind speed of Ajloun in 2020

5. Conclusion

In this paper, the assessment of the wind energy potential of the northern city of Jordan, Ajloun has been done for 11 years (2010 – 2020). The assessment was carried out using the Weibull distribution function based on the two parameters shape and scale parameters. The main findings of the current study are summarized as below:

-At a height of 10 m where the wind speed was recorded, Weibull distribution results showed that a wind speed ranges between 3 and 4 m/s is the most frequent in Ajloun with a probability of 31%

-The averaged shape and scale parameters were 1.586 and 4.073, respectively, which shows that the wind spread is low.

-Wind speed variations showed that the wind speed increases over the years in the area.

- According to the international standards of wind power generation classification, Ajloun city has poor wind resources but is still a suitable area for small-scale power generation.

-It has been found that the peak amount of wind power density can be found in June while the lowest can be found in November.

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