Potential of wind energy in Medina, Saudi Arabia based on Weibull distribution parameters

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Abstract

This study aims to assess the potential of wind energy in Medina by using Weibull probability distribution to provide an insight concerning the energy production from the selected wind turbine Aventa AV-7. Scale factors c and shape k of Weibull distribution, were determined for wind speed frequency. Significant findings included a wind speed recurrence of 2.9 m/s with a probability of 30% approximately. The average c and k were found to be 3.467 m/s and 2.923, respectively. The estimated average k is relatively high, which indicates that the spread in wind speeds is small. Aventa AV-7 turbine was chosen to test the power generation of wind in Medina. It was found that this wind turbine can generate 8,648 kWh/year in the Medina region, which is only 15.2% of the maximum power production. This turbine is expected to generate the maximum possible power output at a wind speed of 7 m/s.

Keywords: Weibull Distribution; Wind Energy; Medina; Wind Speed; Vision 2030, Aventa AV-7, MATLAB.

1. Introduction

Saudi Arabia has witnessed fast growth in population and economic development in the last two decades, which led to a continuous increase in electricity demand. The Saudi Vision 2030 put forward a remarkable goal to produce at least one-fifth of the energy needed using renewable energy sources such as solar and wind sources. The primary motivation for this is the availability of vast open land areas, which provide a suitable environment for establishing solar power plants and wind farms. Wind can be considered a better energy source due to its cleanliness, approximately zero greenhouse gas emissions, low running cost, and safe energy resource. The wind energy program was established in Saudi Arabia in 2018, and the program has been managed and implemented by the ministry of energy and mineral resources. This program was established because Saudi Arabia has long marine beaches capable of producing more than 200 GWatt of wind energy when utilized with an average capacity of 35.2 percent. This is a higher rate than most countries that set plans to produce electric power depending on the wind. A significant advantage of wind generation relative to any thermal-based age (Nuclear, geothermal, fossil fuel, and solar thermal) is that it does not need cooling water. The Kingdom of Saudi Arabia suffers from this, which relies heavily on desalinated water.

Additionally, wind energy generation's potentiality varies with the wind speed cube, which means any slight change in wind speed will substantially impact the wind's energy output in the future [1]. Therefore, energy generation from a clean and renewable resource has become a choice for countries facing high energy demands. If the country's current energy resources are not ecofriendly, non-renewable, and depleting, then the policymakers are deciding to opt for sustainable energy resources.

Wind speed in a locality is a potential candidate to be the backbone of wind energy generation. Therefore, we see that most countries have moved towards developing the wind turbine industry and improving its performance. The frequency distribution under different conditions is also a key parameter to predict wind energy potential. Weibull distribution is a method that enables us to accomplish the theoretical prediction of wind energy potential in a defined location at specific dependent parameters. Moreover, this distribution technique is suitable for analyzing the time-series data of wind velocity at the earth's surface and different elevations [2].

Previously, wind energy investigations and wind characteristics were the subjects of consideration by many researchers. Rahman found that the values of scale parameter and shape parameters are 3.91 and 2.40 m/s, respectively. The study was based on Weibull distribution parameters determination by using the maximum likelihood method. The typical mean values of the scale and shape were exploited to evaluate wind energy's potentiality [2]. Rehman also investigated Saudi Arabia’s west coast area of Yanbu, and the analysis of many years, time-series wind-speed data was analyzed. The wind period availability was expressed as the percentage of hours at which the wind persisted within such intervals of wind speed. Their wind speed was recorded to remain over 3.5 m/s at altitudes of 40-80 meters above the ground level for 69 percent of the time throughout the year [3]. Furthermore, Al-Abbadi investigated the various sites of Saudi Arabia under variable climatic conditions as a potential resource of wind power. The proportion of events and wind speed distribution was determined as critical factors in explaining wind energy's potentiality at these locations [4]. North-East, Nigerian was also analyzed by Fagbenle at two sites Maiduguri and Potiskum, to investigate sustainable wind energy resource potential. Results showed that the mean monthly wind speed varied from 3.90 m/s to 5.85 m/s [5]. Youm analyzed the wind energy potential of Senegal north on the coast along the Atlantic Ocean. The two-parameters of Weibull probability were investigated to study collected wind statistics for two years for different sites. It was also found that wind energy in these locations utilized water pumping in countryside areas [6]. In the Rafha region, Rahman evaluated wind speed data and energy availability using 600, 1000, and 1500 kW wind machinery supplied by three different makers. They found that the minimum values were 2.5 m/s for wind speed that was maximally recorded to be 4.9 m/s for years 2002 and 1990, respectively [7]. Eltamaly introduced a computer program to choose the most appropriate wind turbine applied in five locations in Saudi Arabia. For these five sites, the Weibull parameters are computed numerically and graphically. The Weibull parameters obtained graphically were shown to be identical to those found numerically [8]. Amran reviewed the current status, growth, potential, resources in Saudi Arabia, according to Saudi Vision 2030. The review aimed to provide a detailed perspective on the promising uses of renewable and sustainable energy technologies for developing a sound energy policy to achieve sustainable energy and minimize the costs [9]. An analysis of five-year data of various Omani weather stations was analyzed by AL-Yahiya and explained the area of Qayroon Hyriti as the best among all for wind power [10]. Fyrippis involved Rayleigh and Weibull distribution to analyze wind power around the Koronos locality [11]. Mahbub evaluated plant capacity, energy yield, wind shear exponent, wind power, and air turbulence intensity by measuring the wind speeds at different elevations. They found that it is valuable to establish a connection between grid and wind turbines to obtain a power yield of 11.75 GWh yearly and a plant capacity factor of almost 50% [12]. Ilkiliç worked on Turkey's power systems, evaluated wind power's potential, and examined the future wind-power transduction system project and theoretical analysis of wind energy potential in Turkey [13]. Nouri studied whether it is technically feasible to establish two different sites with wind farms in Morocco. The main objective was to determine the most applicable site to forecast wind's behaviors for the distant future [14]. Tizpar analyzed wind energy feasibility in the Mil-E Nader region depending on a few minutes of measuring wind data. They estimated the Weibull parameters at 40 m above ground to express airstream distribution data and frequencies [15]. Nawri investigated the Iceland area and used forecasting and weather research statistics to assess significant wind energy [16]. Shu selected various random locations in Hong Kong and used a statistical method to explain wind characteristics and potential using Weibull distribution [17]. Allhibi analyzed statistics for wind from diverse locations of Saudi Arabia and explained the potential of power generation as one of the promising energy resources to overcome the greenhouse gas emissions from the buildings [18]. Brahimi presented the idea of using Artificial Neural Networks (ANNs) to determine wind speed daily in Saudi Arabia by utilizing meteorological stats from various localities. The importance of this work depends on how functional it is to forecast wind speed daily, select a location for turbine installation, and guide operators to manage power generation efficiently [19]. Huilo estimated Hawke's bay site's statistics for wind speed and feasibility of wind power to compute the annual energy yield, wind power density, and volume aspects at 30-80 m above ground [20]. Kılıç analyzed the data of wind speed for seven years, i.e., 2009 to 2016, for four different sites in Burdur [21]. El Khchine also studied the Moroccan site’s metrological data for finding the feasibility of wind power using Weibull probability density function. They found that the average of Weibull shape parameters for Taza and Dakhla are 5.01 m/s and 9.04 m/s respectively [22]. Rathi provided a methodology to establish an accountable policies to maximize the use of renewable source by examining the wind power density in India [23]. Salah investigated the feasibility of generating power from wind in different sites over the land of Saudi Arabia by using data from different 12 sources and locations [24]. By reviewing previous studies, it was found that there is a lack of field studies as well as theoretical ones in Madinah region, and from here the importance of the study emerges for the following reasons. First, it will address a new area of study that differs in its topography and location from other regions. Secondly, this study deals with a recent period of time extending for a period of 20 years from 1999 to 2019. Third, additional software was used to analyze the results and variables. Fourth, the study results were applied to a wind turbine to assess its efficiency and the possibility of using it in the region. In order to manage energy needs in Medina city, this study is based on Weibull probability distribution and has employed existing literature as a guidance tool for this study. All the mentioned above factors are considered to be motivating factors for conducting this study in the Medina region. The key parameters k and c are employed in this study to demonstrate the selected wind turbine's efficiency. Consequently, this study has aimed to assess and assist the potential wind energy in medina using a selected wind turbine (Aventa AV-7).

2. Materials and Method

According to the World Meteorological Organization (WMO) recommendation, wind speed measurement should be made 10 m above ground level to be effective. The frequency of the extent depends on the purpose for which the data is going to be used. For some applications, such as estimating the highest possible gust or evaluating turbulence intensity at a site. For energy studies, mean wind speed is used, which is generally based on different averaging periods from 10 minutes to 1 hour in other countries. Wind data available at a site is presented on an annual basis. One method of presenting wind speed statistics is drawing a histogram of hours each year across a particular band across wind speed. Sometimes the data is normalized by obtaining a ratio after taking the total number of hours as a denominator. The result is a probability versus wind speed histogram.

During this study, the wind energy potential is modeled upon the Weibull distribution function for Medina, Saudi Arabia, using Weather Underground OEMA airport weather station daily wind speed data between 1999 and 2019 [25]. Table 1 shows the average wind speed for each month for the study period.

Table 1: Average monthly wind speed data in m/s for the study period

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wind speed m/s	**2.82**	**3.24**	**3.38**	**3.42**	**3.21**	**3.25**	**3.61**	**3.41**	**2.89**	**2.50**	**2.87**	**2.77**

One of the globally recommended methods approximating Weibull distribution constraints for wind power analysis is the maximum likelihood approach. Therefore, the shape and scale parameters are calculated by the process of maximum likelihood [26]. For all experiments, MATLAB software was used along with online software developed by METEOTEST company to detriment the power generation for each wind speed [27].

Equation (1) [2] shows the mathematical expression for wind speed using the Weibull distribution function:

$$f(v) = \left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1} e^{-\left(\frac{v}{c}\right)^{k}} \quad (1)$$

Equation (2) [28] explains the above as an accumulative function

$$F(v) = 1 - e^{-\left(\frac{v}{c}\right)^{k}} \quad (2)$$

Where v represents wind speed, k is explaining the shape parameter, and c denotes scale parameter.

Large scale numerical iterations are required to use this approach, which calculates the shape equation (3) and the scale parameter equation (4) [28]

$$k = \left(\frac{\sum_{i=1}^{n} v_i^k ln(v_i)}{\sum_{i=1}^{n} v_i^k} - \frac{\sum_{i=1}^{n} ln(v_i)}{n}\right)^{-1} \quad (3)$$

$$c = \left(\frac{\sum_{i=1}^{n} (v_i)^k}{\sum_{i=1}^{n} v_i^k}\right)^{\frac{1}{k}} \quad (4)$$

Where,

v_i: Wind speed.

n: Number of wind speeds.

3. Results and Analysis

Wind power generation at a particular site depends on the area's characteristics and that of the wind machine. For analyzing energy generation potential at a specific locality, the hourly mean values for wind speed from the histogram and annual hours were requested to obtain total hours in a year to be used as a standard value. As evident from the equation, that cube of wind speed is a function proportional to power assimilated by it. Accordingly, the rate may be replaced by power on the X-axis to obtain the power–duration curve.

Most wind data is modeled analytically by assuming that it follows a Weibull probability distribution function. The scale and shape parameters are expressed as *k* and c, respectively, where prior is having dimensions of velocity and later is dimensionless. Determining *k* and *c* is done by analyzing the annual mean of wind speed average of a few years of data for a specific location.

Table 1 shows the wind speeds' data for Medina observed over 20 years from 1999 to 2019 by the Weather Underground OEMA airport weather station. The annual average values for all years and the overall average values are calculated and presented in Table 2.

The average values for yearly wind speed in Medina varied amongst 2.426 m/s and 3.737 m/s, which is unconsidered to be the potential to generate wind energy. However, these wind speeds can generate power for small wind turbines and long periods of applications.

Table 2: Average wind speed and Weibull distribution parameters of 1999-2019

Year	Average wind speed m/s	k	c (m/s)
1999	3.190	3.245	3.557
2000	3.183	3.229	3.547
2001	2.826	2.403	3.174
2002	2.426	2.841	2.721
2003	3.327	2.880	3.718
2004	3.677	3.166	4.094
2005	3.440	3.404	3.813
2006	2.782	2.762	3.124
2007	2.647	2.639	2.977
2008	2.745	2.429	3.086
2009	2.762	1.972	3.093
2010	2.745	2.733	3.082
2011	2.875	1.995	3.222
2012	3.004	2.343	3.355
2013	3.119	3.298	3.475
2014	3.540	3.707	3.918
2015	3.737	3.561	4.139
2016	3.386	3.311	3.771
2017	3.287	3.251	3.665
2018	3.284	3.013	3.674
2019	3.234	3.195	3.612
Combined	3.105	2.923	3.467

As explained earlier, *'k'* is the shape parameter, so the range of values for *k* was found to range within 1 and 3. A low *k*-value means that the wind is not constant and vice versa. Table 2 shows that the most deficient *k* was 1.972 in 2009, and the highest *k* was 3.707 in the year 2013. The '*c'* parameter represents the Weibull distribution scale, which measures the distribution's wind speed characteristics. The calculated *c* values vary between 2.721 m/s and 4.139 m/s, with a mean of 3.467 m/s.

Figure 1 shows the variation in *k* values along the measured years. The shape parameter's average is 2.923, which is acceptable and can be dependable to predict the upcoming years' shape parameter. The average *k* is quietly high, which means that the spread in wind speeds is small. A higher *k*-value is needed to generate wind power if the wind speeds were satisfying the wind turbine's needs.

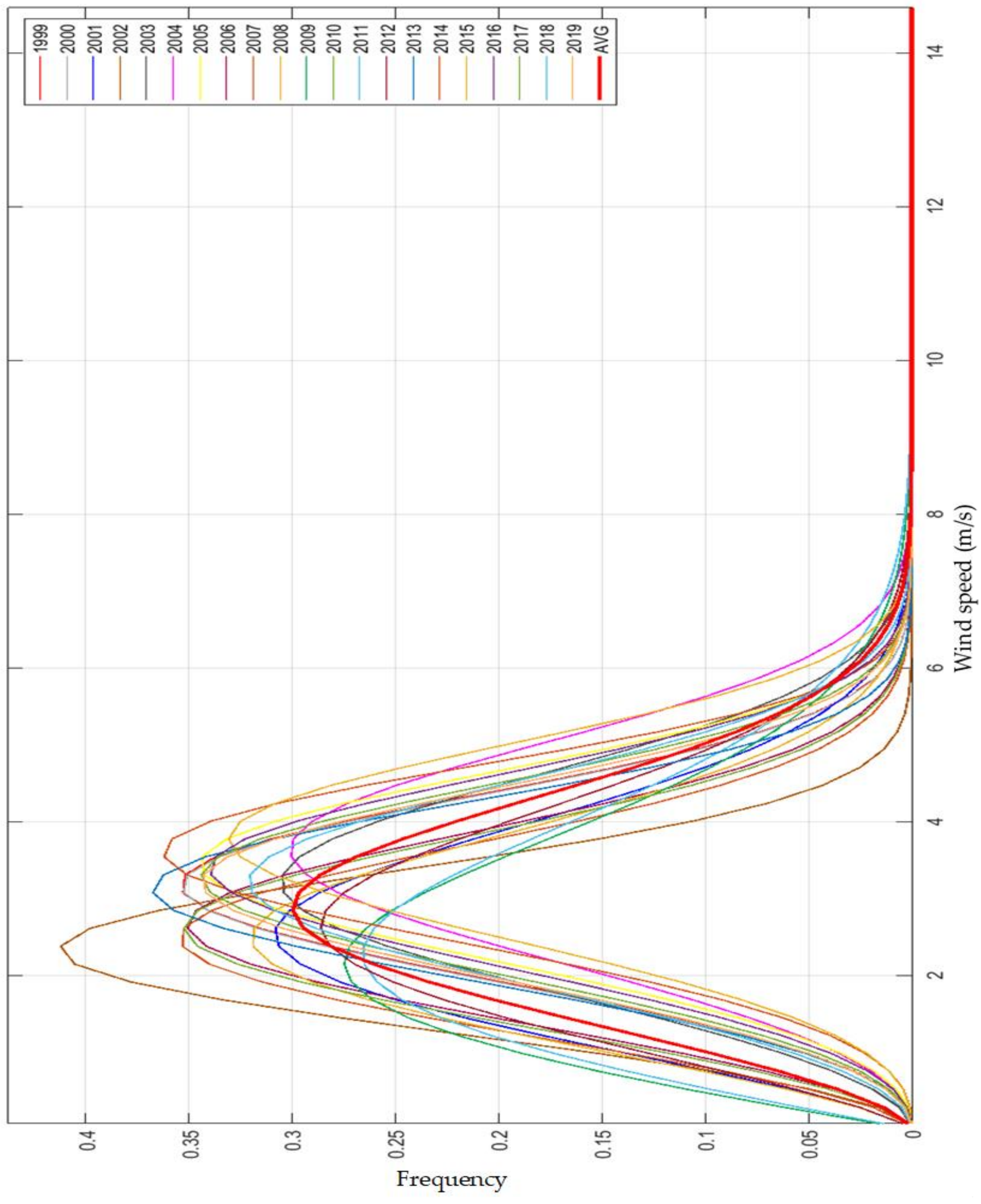

Figure 1*:* The Weibull Distribution 1999-2019

Figure 2 shows the plots of the Weibull distribution among the histogram of the wind speeds. It concludes that the most frequent rate falls at 2.9 m/s with a probability of 30% approximately.

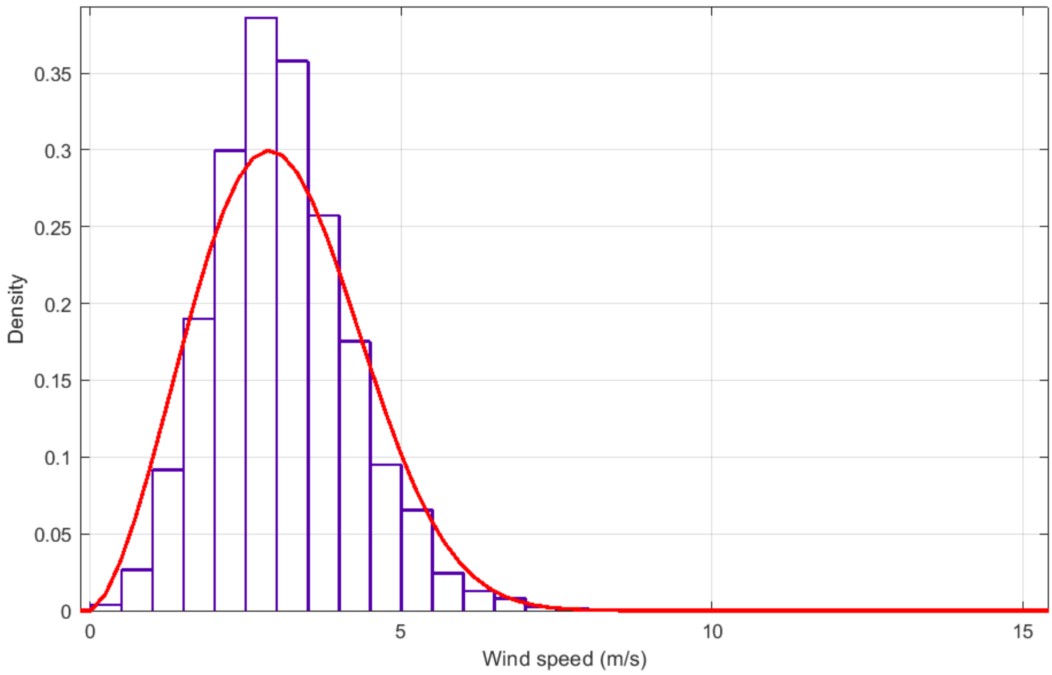

Figure 2: Histogram of the Weibull wind density distribution

Figure 3 explains the four separate wind turbine power and speed (zero to cut-rate the low-speed region). Furthermore, this region's turbine position is taken as braked unless the lowest wind speed referred to as zero-cut is established. Zero-cut is explained as a value below which the turbine efficacy becomes zero, so it is a threshold value to start turbine functions. Another region explained here in Figure 3 is the maximum power coefficient region. This region defines pitch control where the turbine is operated at maximum efficiency at a constant tip-speed ratio for the highest output.

Furthermore, a Constant power region is also part of Figure 3, explaining a constant turbine speed even in great wind scenarios. During this continuous turbine speed, the rotor is restricted to higher acceptable worth created based on design and system components—lastly, the region of Furling speed that explains a Cut-out speed and above stats. This study analyzes that if the cut-out values are bypassed, then the rotor is switched off. The power generation is stopped to protect the blades, just like negative feedback in the system to the generator and other system components.

A Medina turbine's power production estimation was conducted based on a website that simulates the power generation of wind turbines by METEOTEST. The average calculated values for *k* and *c* with an air density of 1.171 kg/m³ were used to estimate the power generation. The turbine's availability is assumed to be 100% (no losses due to downtime, icing, transformer losses, park effects). The selected test wind turbine is going to be Aventa AV-7 with a 6.5 kW power capacity. This wind turbine was chosen because it does not need high wind speed to run it, which is the case in the Medina region. According to METEITEST, the estimated power generation of Aventa AV-7 regarding wind speeds is listed in Table 3.

Table 3: Aventa AV-7's power generation due to wind speeds

Wind speed (m/s)	**Power (KW)**
0	**0**
1	0
2	0.1
3	0.7
4	1.5
5	3.1
6	5.8
7	6.2
8	6.2
9	6.2

10	6.2
11	6.2
12	6.2
13	6.2
14	6.2
15	0
16	0
17	0

As shown in Table 3, this wind turbine only needs two m/s to generate power, and it starts generating the maximum possible power at a wind speed of 7 m/s. According to the data, it cuts off at 14 m/s, which is impossible to happen in the region of Medina.

Table 4 shows the results given by (METEOTEST) an online power calculator the website, and it shows that this wind turbine can generate 8,648 kWh/year in the Medina region. The capacity factor was 15.2%, which means that the annual production is only 15.2% of the specified wind turbine's maximum technically possible production. However, wind turbines are not designed to reach the optimal capacity factor, and a factor of 30-40% are considered very excellent.

Table 4: Results of power generation of Aventa AV-7 for Medina

Producer	**Event**
Type	AV-7
Capacity	7 kW
Rotor diameter	12.9 m
Power Production	8,648 kWh/year
Capacity factor	15.2%

Full load hours	1,330 h/year
Operating hours	8,035 h/year

Figure 3 also indicates that wind speeds of 3.1 m/s are the most frequent, which is less by 0.2 m/s than the number shown in Figure 2, which states a slight error in these results. Moreover, the most frequent power production is found with a four m/s wind speed. Therefore, this turbine is expected to generate almost 1.5 kW of power at wind speeds of 4 m/s.

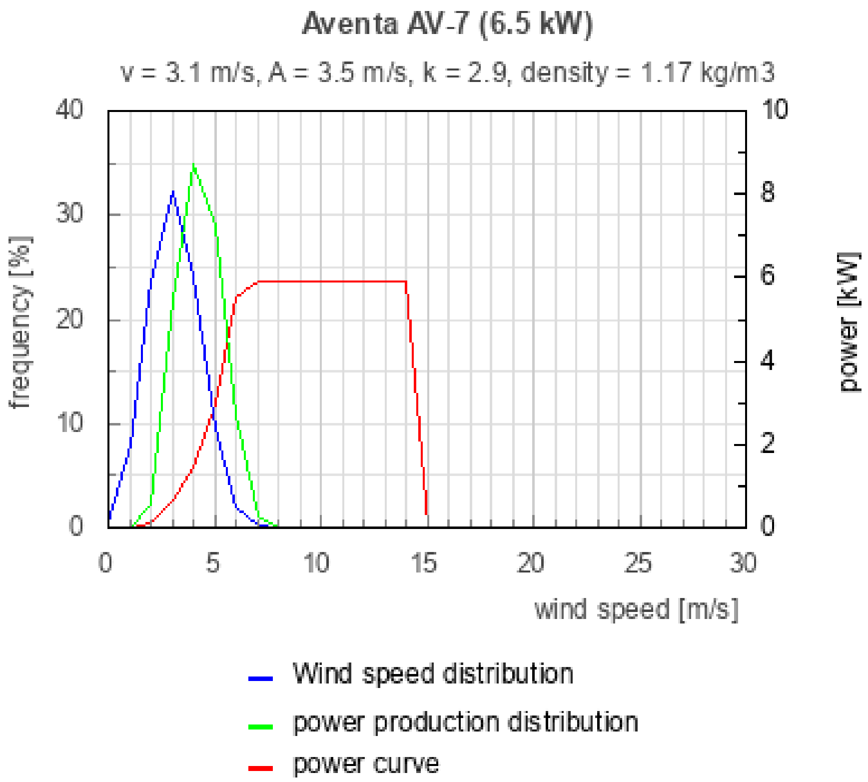

Figure 3: Power plot for Medina region

From the previous three figures and tables, it can be seen that several factors are responsible for the distribution of wind energy in Medina. The great mountains massifs influence the circulation of air currents, surface roughness or friction, owing to the resistance that different elements of the earth surface offer to air circulation affect the nature of wind, hills, trees, buildings and similar obstruction impairs the streamline airflow.

4. Discussion

Rehman et al. (1994) had demonstrated that the annual wind speed distribution values differ between 1.95 and 2.6. According to the monthly and annual wind speed data, the Weibull distribution, including k and c parameters, were observed from ten Saudi Arabia locations. Moreover, the k parameter's minimum values were detected in the central region (i.e., Riyadh and Gassim area) and maximum values in the northern region area (i.e., Al-Wajh, Al-Jouf). However, identical values of k were encountered at Dhahran and Jeddah, indicating comparability between the two sites, and the scale parameter had fluctuated between 3.07 and 4.98. Simultaneously, maximum c parameter values had observed at Al-Jouf and Al-Wajh, but minimum values were observed at Nejran. However, the average values of c around 3.5 were observed in the central region. According to the monthly wind speed distribution, the shape parameter's maximum values were observed during June and July in all cities except for Gizan and Nejran. Consequently, maximum values of scale parameters were observed in March, April, May, and June; however, minimum values were observed in October, November, and December [2; 7].

Frank et al. (2001) had illustrated that the chief outcome of the mesoscale modeling is that the wind atlas files acquired from simulations with KAMM are independent of the mesoscale model's resolution comparatively in flat areas such as Denmark or Ireland. Consequently, Wind Atlas Analysis and Application Program (WAsP)-like rectifications registered to the stimulated winds is linked with the “small-scale” alterations of the mesoscale topography. Thus, it is suggested to use big grid sizes for comparative regions, rescue computing resources, and sheath a larger area with a similar quantification amount [30].

The rated power generated by the winds is for 1% of the time and is associated with a hub height of 100 meters [31]. Rehman (2012) had discussed that a reducing wind speed trend of 0.01852 m/sec every year was observed annually in mean wind speed values elicited from the algebraic mean of the trend coefficient (a) of all the stations used currently [32]. Concurrently, this study's findings suggest different factors that are found to be accountable for measuring wind energy potential, including air currents, surface roughness, and other kinds of resistances due to wind and hills. Moreover, about 2.426 m/sec and 3.737 m/sec wind speed was observed in Medina, such wind speeds can produce power for small wind turbines and are applicable for long periods. Moreover, Aventa AV-7 (6.5 kW) wind turbine is not very dependable on high wind speed; it requires minimum force to produce maximum wind potential; however, its cut-off value of 14 m/sec has never been observed in Medina. Moreover, this study has followed a Weibull probability distribution function to represent wind data collected from Medina. This study has been found to assist the existing literature concerning wind energy potential using Weibull probability distribution. It has also discussed important facts regarding wind speed and AV-7 efficiency by employing Weibull distribution to the collected data.

5. Conclusions

Wind as a source of energy is currently considered promising and commercially attractive among other renewable sources in Saudi Arabia. This study is aimed to statistically analyze the characteristics of the wind in the region of Medina according to daily wind speed data of the last two decades taken from Weather Underground OEMA airport weather station. Weibull distribution results indicated that a wind speed of 2.9 m/s is the most frequent in

Medina, with approximately 30%. The average *c* was found to be 3.467 m/s, and the average *k* was found to be 2.923. The founded average k is quietly high, which indicates that the spread in wind speeds is small in Medina. Aventa AV-7 turbine was chosen to test the ability of wind in Medina to generate substantial power. It was found that this wind turbine can generate 8,648 kWh/year in the Medina region, which is only 15.2% of the maximum power production. In Medina, this turbine is expected to generate the full possible power at a wind speed of 7 m/s, which is very rare according to the data. The most frequent power production is 1.5 kW, with a four m/s wind speed. This power is not enough to meet the demands of the city. It may still be used for small applications that may be far away from the grid-like water pumping system in the palm farms, remote areas to replace Diesel generators and gas stations, and shops spread on the external roads far away the power stations. Nevertheless, further work is essential for the generation of increased power wind turbines that can fulfill the energy requirements of Medina City.

Author Contributions

K. AlQdah conceptualized the study and supervised the work. R. Alahmdi set the methodology. M.Abualkhair curated the data. A. Alansari and R. Alahmdi analyzed the data. A. Almoghamisi, M. Abualkhair, A. Alansari, and R. Alahmdi drafted the manuscript. K. AlQdah and M. Awais reviewed and edited the manuscript. All contributing authors agree to the corresponding author for taking any pledge for publication of this manuscript.

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References

[1] Ishugah TF, Li Y, Wang RZ, Kiplagat JK. Advances in wind energy resource exploitation in urban environment: A review. Renew Sustain Energy Rev 2014;37:613–26. https://doi.org/10.1016/j.rser.2014.05.053.

[2] Rehman S, Halawani TO, Husain T. Weibull parameters for wind speed distribution in Saudi Arabia. Sol Energy 1994;53:473–9. https://doi.org/10.1016/0038-092X(94)90126-M.

[3] Rehman S. Wind energy resources assessment for Yanbo, Saudi Arabia. Energy Convers Manag 2004;45:2019–32. https://doi.org/10.1016/j.enconman.2003.11.009.

[4] Al-Abbadi NM. Wind energy resource assessment for five locations in Saudi Arabia. Renew Energy 2005;30:1489–99. https://doi.org/10.1016/j.renene.2004.11.013.

[5] Fagbenle RO, Katende J, Ajayi OO, Okeniyi JO. Assessment of wind energy potential of two sites in North-East, Nigeria. Renew Energy 2011;36:1277–83. https://doi.org/10.1016/j.renene.2010.10.003.

[6] Youm I, Sarr J, Sall M, Ndiaye A, Kane MM. Analysis of wind data and wind energy potential along the northern coast of Senegal 2005;8:95–108.

[7] Rehman S, El-Amin IM, Ahmad F, Shaahid SM, Al-Shehri AM, Bakhashwain JM. Wind power resource assessment for Rafha, Saudi Arabia. Renew Sustain Energy Rev 2007;11:937–50. https://doi.org/10.1016/j.rser.2005.07.003.

[8] Eltamaly AM, Farh HM. Wind energy assessment for five locations in Saudi Arabia. J Renew Sustain Energy 2012;4. https://doi.org/10.1063/1.4705116.

[9] Amran YHM, Alyousef R, Alabduljabbar H, El-Zeadani M. Clean production and

properties of geopolymer concrete; A review. J Clean Prod 2020;251. https://doi.org/10.1016/j.jclepro.2019.119679.

[10] AL-Yahyai S, Charabi Y, Gastli A, Al-Alawi S. Assessment of wind energy potential locations in Oman using data from existing weather stations. Renew Sustain Energy Rev 2010;14:1428–36. https://doi.org/10.1016/j.rser.2010.01.008.

[11] Fyrippis I, Axaopoulos PJ, Panayiotou G. Wind energy potential assessment in Naxos Island, Greece. Appl Energy 2010;87:577–86. https://doi.org/10.1016/j.apenergy.2009.05.031.

[12] Mahbub AM, Rehman SJ, Al-Hadhrami LM. Wind Speed and Power Characteristics at Different Heights for a Wind Data Collection Tower in Saudi Arabia. Proc World Renew Energy Congr – Sweden, 8–13 May, 2011, Linköping, Sweden 2011;57:4082–9. https://doi.org/10.3384/ecp110574082.

[13] Ilkiliç C. Wind energy and assessment of wind energy potential in Turkey. Renew Sustain Energy Rev 2012;16:1165–73. https://doi.org/10.1016/j.rser.2011.11.021.

[14] Nouri A, Ait Babram M, Elwarraki E, Enzili M. Moroccan wind farm potential feasibility. Case study. Energy Convers Manag 2016;122:39–51. https://doi.org/10.1016/j.enconman.2016.05.058.

[15] Tizpar A, Satkin M, Roshan MB, Armoudli Y. Wind resource assessment and wind power potential of Mil-E Nader region in Sistan and Baluchestan Province, Iran - Part 1: Annual energy estimation. Energy Convers Manag 2014;79:273–80. https://doi.org/10.1016/j.enconman.2013.10.004.

[16] Nawri N, Petersen GN, Bjornsson H, Hahmann AN, Jónasson K, Hasager CB, et al.

The wind energy potential of Iceland. Renew Energy 2014;69:290–9. https://doi.org/10.1016/j.renene.2014.03.040.

[17] Shu ZR, Li QS, Chan PW. Statistical analysis of wind characteristics and wind energy potential in Hong Kong. Energy Convers Manag 2015;101:644–57. https://doi.org/10.1016/j.enconman.2015.05.070.

[18] Allhibi H, Chowdhury H, Zaid M, Loganathan B, Alam F. Prospect of wind energy utilization in Saudi Arabia: A review. Energy Procedia 2019;160:746–51. https://doi.org/10.1016/j.egypro.2019.02.184.

[19] Brahimi T, Alhebshi F, Alnabilsi H, Bensenouci A, Rahman M. Prediction of Wind Speed Distribution Using Artificial Neural Network: The Case of Saudi Arabia. Procedia Comput Sci 2019;163:41–8. https://doi.org/10.1016/j.procs.2019.12.084.

[20] Hulio ZH, Jiang W, Rehman S. Techno - Economic assessment of wind power potential of Hawke's Bay using Weibull parameter: A review. Energy Strateg Rev 2019;26:100375. https://doi.org/10.1016/j.esr.2019.100375.

[21] Kılıç B. Determination of wind dissipation maps and wind energy potential in Burdur province of Turkey using geographic information system (GIS). Sustain Energy Technol Assessments 2019;36:100555. https://doi.org/10.1016/j.seta.2019.100555.

[22] El Khchine Y, Sriti M, El Kadri Elyamani NE. Evaluation of wind energy potential and trends in Morocco. Heliyon 2019;5:e01830. https://doi.org/10.1016/j.heliyon.2019.e01830.

[23] Rathi R, Prakash C, Singh S, Krolczyk G, Pruncu CI. Measurement and analysis of wind energy potential using fuzzy based hybrid MADM approach. Energy Reports

2020;6:228–37. https://doi.org/10.1016/j.egyr.2019.12.026.

[24] Salah MM, Abo-khalil AG, Praveen RP. Wind speed characteristics and energy potential for selected sites in Saudi Arabia. J King Saud Univ - Eng Sci 2019:0–9. https://doi.org/10.1016/j.jksues.2019.12.006.

[25] Weather History for Medina, Saudi Arabia. Weather Undergr n.d.

[26] Seguro J V., Lambert TW. Modern estimation of the parameters of the Weibull wind speed distribution for wind energy analysis. J Wind Eng Ind Aerodyn 2000;85:75–84. https://doi.org/10.1016/S0167-6105(99)00122-1.

[27] METEOTEST. Die Website Für Windenergie-Daten Der Schweiz n.d. https://doi.org/https://wind-data.ch/tools/powercalc.php.

[28] Indhumathy D, Seshaiah C V, Sukkiramathi K. Estimation of Weibull Parameters for Wind speed calculation at Kanyakumari in India. Int J Innov Res Sci 2014;3:8340–5.

[29] Baseer MA, Meyer JP, Alam MM, Rehman S. Wind speed and power characteristics for Jubail industrial city, Saudi Arabia. Renew Sustain Energy Rev 2015;52:1193–204.

[30] Frank HP, Rathmann O, Mortensen NG. the KAMM / W AsP Method. vol. 1252. 2001.

[31] Al-Abbadi NM, Rehman S. Wind speed and wind power characteristics for gassim, Saudi Arabia. Int J Green Energy 2009;6:201–17. https://doi.org/10.1080/15435070902785068.

[32] Rehman S, Alam MM, Meyer JP, Al-Hadhrami LM. Long-Term Wind Speed Trends over Saudi Arabia. World Congr Water, Clim Energy 2012.