Investigation of Wind Power Potential in Al-Aqiq, Saudi Arabia

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Abstract. Saudi Arabia authorities recognize the importance of renewable energy, especially wind, and they intend to invest in this promising power sector. This paper presents a wind data analysis in terms of annual, seasonal, and diurnal variations at Al-Aqiq, which is located in the highlands of the southwestern region of the Kingdom of Saudi Arabia. In the analysis, the diurnal variation of wind speed at 3 m above the roof surface shows that wind speed remains above 2.5 m/s during the period 10:00 AM to 10:00 PM. The overall wind speed is found to be 2.68 m/s, 4.2 m/s, and 5.48 m/s at heights of 3 m, 10 m, and 50 m, respectively, with the main wind direction ranging approximately from south-southeast to south-southwest. The highest average monthly wind speed is recorded in March, with values of 3.09 m/s, 5.11 m/s, and 6.43 m/s at heights of 3 m, 10 m, and 50 m, respectively, and with southwest being the main wind direction. The wind data analysis is then used to estimate wind energy production. Wind energy generation is considered for 21 wind machines of different sizes. At a height of 10 m above ground level, the highest energy estimate is generated using an Enercon E141/4200 wind machine, with a rate of 4898.96 MWh/Year. The lowest energy estimate is generated using a Soyut Wind 100 wind machine, with a rate of 165.54 MWh/Year. The highest capacity factor (26.0\%) is recorded for an Aeronautica Windpower 33-225 wind machine and the lowest capacity factor (5.9\%) is recorded for an Enercon E126/7580. The analysis shows that the power factor is low for wind turbines located at 3 m above roof surface level, but higher heights at Alhaha University, Al-Aqiq, may be suitable for wind farm development.

1. Introduction

Wind energy applications require open areas or available shores for wind energy plants. Saudi Arabia is a vast country with wide-open areas and long shores. The wind speed in most of these areas is high enough to make the application of wind energy economical. Saudi Arabia authorities recognize the importance of renewable energy, especially wind, and they intend to invest billions of SAR in this promising power sector. Even though Saudi Arabia has huge resources of oil, it is interested in playing an active part in the development of new technologies for exploiting and utilizing renewable sources of energy.

The electricity produced by wind could save oil that could then be exported to increase national income. Also, the production of electric power from wind energy would reduce the environmental pollution generated by conventional power plants. Recently, a significant amount of studies have focused on evaluating the applications of wind energy systems in Saudi Arabia, most of which have recommended wind as a promising and economical source of energy in the country [1 - 10].
Alamdari et al. [11] investigated the most important characteristics of wind energy at sixty-eight different locations in Iran by recording wind speed data for heights of 10 m, 30 m, and 40 m at ten-minute time intervals. Similarly, Lashin and Shata [12] analyzed wind speed data measured at a height of 19 m in coastal Port Said in Egypt and found that the wind speed was greater during spring months than in winter months, which is the opposite of the prevailing wind speed parameters in most European countries. Aman et al. [13] estimated the wind energy potential in Karachi, Pakistan, using wind speed data obtained from the Pakistan Metrological Department (PMD) for various heights (i.e., 10 m, 30 m, 50 m, 75 m, and 100 m) over four years. Statistical calculations conducting using SPSS (Statistical Package for the Social Sciences) software indicated that the city has an enormous wind potential. Also, Đurišić and Mikulovic [14] analyzed wind energy resources in the South Banat region using wind parameter measurements taken at the village of Bavaniste. Data were collected at the heights of 10 m, 40 m, 50 m, and 60 m during 2009 and 2010. The results indicated that the region of South Banat has a high wind energy potential and represents a promising region for the development of wind farms. Finally, Yaniktepe et al. [15] investigated wind characteristics and the wind energy potential in Osmaniye, Turkey.

The total energy generated by a turbine over some time can be calculated by adding up the energy corresponding to all possible wind speeds in the region in which the system is operational. Hence, along with the power characteristics of the turbine, the probability density corresponding to different wind speeds should also be included in energy calculations. Knowing the wind speeds of a certain city is important in determining the characteristic speeds of the turbine, which are its cut-in velocity, rated velocity, and cut-out velocity. Also, the effective utilization of wind energy entails a detailed knowledge of the wind characteristics at a particular location. Although the wind resource potential in Saudi Arabia is significant, many issues are surrounding its development [16-20]. These include the intermittency of resources, its seasonal and diurnal characteristics, its geographically remote locations, and the electrical grid infrastructure that must be used to transmit the wind energy to load areas. All of these issues pose significant technical barriers to the full development of Saudi Arabia’s wind potential.

This work aims to assess wind energy potential in the Al-Aqiq region, KSA, in terms of annual, seasonal and diurnal variations and to analyze wind availability, and then use the results of this assessment to estimate wind energy in the Al-Aqiq area.

2. Site Description and Weather Station Program

Al-Aqiq is an important city in the south-western region of the Kingdom of Saudi Arabia (see figure 1) in which Albaha University and King Abdul-Aziz airport are located. The latitude and longitude of the city are 20° 10’ 45.588” North and 41° 38’ 8.196” East, and it is 1680 m above sea level. For the current study, data were collected regarding meteorological activity recorded in the period 2015 to 2019. The measured parameters included wind speed, wind direction, temperature, relative humidity, pressure, rain, and many others at 10 m above the ground surface. A total of 8,760 hourly records of wind speed and direction were used.

The data were collected from the Albaha University site (Al-Aqiq area) (see figure 2). The measuring device was fixed to the roof at a height of 3 m above the roof surface. The device (Tier 1 – Research Station, Albaha University — Solar Resource Monitoring Station, https://rratlas.energy.gov.sa/) was used to measure temperature, humidity, rain rate, wind speed, wind direction, barometer, solar radiation, and ultraviolet radiation. This station is the most complete and complex of the monitoring systems in the area and provides the highest quality data with reasonable measurements. The measuring device was set to record a reading every hour and then extract that reading.

Al-Aqiq's climate is fairly hot in summer and fairly cold in winter. Regarding general weather conditions, the recorded temperature varied from a minimum of 7.65°C to a maximum of 35.90°C, with an average of 23.53°C. The highest temperature was recorded in June, July, and August, and the lowest was recorded in January. The surface pressure changed from 829.09 to 840.09 mBar with a mean value of 834.51 mBar. The lowest pressure values were recorded in July and August, and the
highest pressure was in December. The relative humidity varied between 6.56% and 89.32%, with an average value of 30.25%. The lowest humidity percentage was recorded in June and July and the highest value was recorded in December (see figure 3).

**Figure 1.** Geographical locations of meteorological stations.

**Figure 2.** Location of the wind-solar monitor at Albaah University (Al-Aqiq).

**Figure 4.** Average daily wind speed during a year (average from 2015 to 2019).

**Figure 3.** Average monthly temperature, station pressure, and relative humidity during a year (average from 2015 to 2019).
The wind speed was found to reach a maximum of 6.78 m/s, with an average speed of 2.67 m/s at 3 m above the roof ground surface (see figure 4). The main wind direction was between south-southwest and south-southeast. The extracted data were loaded and analyzed using a graphical user interface program called Weather Station Program (WSProg), which was built in-house using Matlab, to calculate the average of each factor by hours, then by day, and finally by month [21].

The main interface of WSProg is shown in figure 5. The WSProg program contains the following modules: (i) Wind Rose Diagram, (ii) Bar & Line Charts, (iii) Calculating Wind Speed Averages & Direction, and (iv) Calculating Power Generated from Turbines. In the Wind Rose Diagram module, the user can generate a wind rose diagram for one day, one week, one month, any season, and one year. In the Bar & Line Charts module, the user can generate a bar or line chart for one day, one week, one month, any season, and one year. In the Calculating Wind Speed Averages & Direction module, the user can extract average wind speed for one day, one week, one month, any season, and one year. Using the Calculating Power Generated from the Turbines module, it is possible to predict the power generated by some common machines.

3. Estimating the Power Curve of a Wind Turbine
For energy calculation purposes, several wind turbines were selected. These were: Aeronautica Windpower (2), Dewind (2), Enercon (6), Leitwind (1), Soyut Wind (3), Wobben (2), Nordex (3), and SouthWest (2) — making up a total of 21 wind machines. The technical data and power curves of these machines are available on the Internet. Wind turbines of different sizes and made by various manufacturers were selected to estimate the potential energy produced if they were installed at Al-Aqiq, KSA. The technical data and specifications for some of the selected wind turbines are summarized in table 1. Figure 6 shows the power curve for the selected wind turbines. For energy analysis, the wind speed bins were centered at 0.0, 0.5, 1.0, 1.5, 2, 2.5, … etc.

4. Results and Discussion
This section covers the annual, seasonal, and diurnal variation of mean wind speed; the wind availability in terms of a frequency distribution; and the energy calculations conducted for the selected
Wind machines. Wind machines were selected to cover a wide range of rated powers, from 100 kW to 7580 kW. The rotor diameters ranged from 1.17 m to 141 m, and cut-in wind speeds ranged from 1.5 m/s to 3.6 m/s.

![Diagram of wind turbine power curves](image)

(a) Rated power range = 250 kW.
(b) Rated power range = 1200 kW.
(c) Rated power range = 3500 kW.
(d) Rated power range = 7850 kW.

**Figure 6.** Sample of wind turbine power curves, kW.

**Table 1.** Sample of wind turbine specifications

| No | Type/Model                  | Main data | Rotor | Wind speeds (m/s) |
|----|-----------------------------|-----------|-------|------------------|
|    |                             | Rated     |       |                  |
|    |                             | power (kW)|       |                  |
| 1  | Aeronautica Windpower 29-225| 225       | 29    | 3                |
| 2  | Aeronautica Windpower 33-225| 225       | 33    | 3                |
| 3  | Dewind D4-600               | 600       | 48    | 3                |
| 4  | Dewind D6-1000              | 1000      | 62    | 3                |
| 5  | Enercon E7/2300             | 2300      | 71    | 3                |
| 6  | Enercon E8/2300             | 2300      | 82    | 3                |
| 7  | Enercon E12/6200            | 4200      | 127   | 3                |
| 8  | Enercon E14/4200            | 4200      | 141   | 3                |
| 9  | Enercon E16/7500            | 7500      | 127   | 3                |
| 10 | Enercon E12/7500            | 7580      | 127   | 3                |
| 11 | Leitwind LTW77-800          | 800       | 77    | 3                |
| 12 | Soyut Wind 250              | 250       | 41.5  | 3                |
| 13 | Soyut Wind 200              | 200       | 36.8  | 3                |
| 14 | Soyut Wind 100              | 100       | 26    | 3                |
| 15 | Wobben E12/6200             | 7580      | 127   | 3                |
| 16 | Wobben E12/7500             | 7580      | 127   | 3                |
| 17 | Nordex N27/150              | 150       | 27    | 3                |
| 18 | Nordex N17/2400             | 2400      | 117   | 3                |
| 19 | Nordex N13/3000             | 3000      | 131   | 3                |
| 20 | SouthWest Air X             | 280       | 11.7  | 3                |
| 21 | SouthWest Skystream 3.7     | 2400      | 3.72  | 3                |
4.1. Analysis of wind speed variation

Table 2 shows the average wind speed and direction for the station located at Albaha University in Al-Aqiq (average of each month during the period 2015 to 2019). The seasonal changes in mean wind speed provide insight into the availability of suitable wind throughout the year. The monthly mean wind speed values for 10 m and 50 m were obtained from NASA Prediction of Worldwide Energy Resources (https://power.larc.nasa.gov).

The monthly mean wind speed values for 3 m, 10 m, and 50 m above the ground are plotted in figure 7. Higher wind speed of 3.13 m/s, 5.1 m/s, and 6.43 m/s were observed at heights of 3 m, 10 m, and 50 m, respectively. These speeds occurred during January, February, and March. Lower wind speeds of 2.12 m/s, 3.38 m/s, and 4.33 m/s were observed at heights of 3 m, 10 m, and 50 m, respectively. These speeds occurred during May and November. The main wind direction ranged approximately from south-southeast to south-southwest: the wind blew from a southwest direction in the period January to June, from a northwest direction in the period July to September, and from a south-southeast direction in the period October to December.

Table 2. Average wind speed and direction (from 2015 to 2019).

| Month   | Wind Speed (m/s) | Wind Direction |
|---------|------------------|----------------|
|         | At height 3 m    | At height 10 m  | At height 50 m  |
| January | 2.42             | 4.62            | 5.99            | SW |
| February| 3.09             | 4.92            | 6.31            | SW |
| March   | 3.13             | 5.11            | 6.43            | SW |
| April   | 2.90             | 4.38            | 5.46            | SW |
| May     | 2.50             | 3.38            | 4.33            | SW |
| June    | 2.81             | 3.72            | 4.93            | SW |
| July    | 3.12             | 4.61            | 5.85            | NW |
| August  | 2.99             | 3.84            | 4.92            | NW |
| September| 2.55            | 3.63            | 5.03            | NW |
| October | 2.35             | 4.17            | 5.89            | E  |
| November| 2.12             | 3.85            | 5.21            | E  |
| December| 2.22             | 4.11            | 5.44            | SE |
| Average | 2.68             | 4.20            | 5.48            | SW |

The diurnal variation of wind speed provides information about the availability of suitable winds during the entire 24 hours of the day. To study this pattern, overall hourly mean values of wind speed are shown in figure 8. The figure shows that the wind speed at a height of 3 m above the roof surface remained above 2.5 m/s from 10:00 AM to 10:00 PM and below it during the rest of the hours of the
day. During the entire day, the mean wind speed varied between a minimum of approximately 1.5 m/s at 06:00 AM and a maximum of approximately 3.87 m/s at 05:00 PM.

Figure 9. Monthly wind rose diagram for Albaha University, Al-Aqiq (average from 2015 to 2019).

A wind rose diagram provides information about the occurrence of the number of hours or percentage of time during which wind remains in a certain wind speed bin in a particular wind direction. Wind roses are constructed using hourly mean wind speed and corresponding wind direction.
values. Like wind speed, wind roses also vary from one location to another and are known as a form of a meteorological fingerprint. Hence, an in-depth examination and understanding of the wind rose are extremely important for siting wind turbines effectively. For instance, if the wind rose diagram shows that a large share of wind or wind energy comes from a particular direction, then the wind turbines should be placed or installed against that direction.

Figure 9 shows the wind rose diagrams generated for Albaha University in Al-Aqiq (an average from 2015 to 2019). It was observed that the main wind direction ranged approximately between south-southeast and south-southwest. From January to April, the wind direction was southerly. The highest monthly wind speeds were recorded in March, with values of 3.13 m/s, 5.11 m/s, and 6.43 m/s at heights of 3 m, 10 m, and 50 m, respectively, and with a predominantly south-westerly direction. The lowest monthly wind speeds were recorded in May and November, with values of 2.12 m/s, 3.38 m/s, and 4.33 m/s at heights of 3 m, 10 m, and 50 m, respectively, and with predominantly south-westerly and easterly wind directions. The highest seasonal wind speed was 6.778 m/s with a mainly south-southeasterly direction and recorded in winter (see figure 10).

Figure 10. Seasonal wind rose diagram for Albaha University, Al-Aqiq (average from 2015 to 2019).

Table 3. Average seasonal wind speeds at heights of 3 m, 10 m, and 50 m and expected electric power generated during different seasons.

| Season | Wind direction | @ 3 m | % | Ave speed | kW | @ 10 m | % | Ave speed | kW | @ 50 m | % | Ave speed | kW |
|--------|----------------|-------|---|-----------|----|--------|---|-----------|----|--------|---|-----------|----|
| Winter | SSE            | 2.72  | 10.17 | 80403 | 4.73 | 18.05  | 74831 | 6.08 | 20.72 | 77942 |
| Spring | SSW            | 2.79  | 10.47 | 85142 | 4.81 | 16.37  | 88098 | 6.17 | 19.87 | 94081 |
| Summer | SSW            | 2.77  | 12.29 | 106742 | 3.99 | 18.31  | 109423 | 5.09 | 22.25 | 112949 |
| Autumn | SE             | 2.91  | 7.31  | 70566 | 4.03 | 15.53  | 77814 | 5.25 | 18.30 | 73195 |
| Year   | SSE-SSW        | 2.67  | 40.24 | 342853 | 4.20 | 68.25  | 350166 | 5.48 | 81.14 | 358167 |
The lowest seasonal wind speed was 4.968 m/s with a mainly southeasterly direction and recorded in Autumn. It is evident from this figure that the wind in the area blows predominantly from the south-southwest and south-southeast. Hence, wind turbines should be installed against these directions — provided there are no or minimal high rise buildings and the terrain is smooth — for optimal energy output. It was found that the percentage shares for wind were 25%, 25%, 26%, and 24% for directions of south-southeast, south-southwest, and southeast during winter, spring, summer, and autumn, respectively. Table 3 lists the average seasonal wind speed at heights of 3 m, 10 m, and 50 m and the expected electric power generated during the different seasons.

In order to construct the wind rose diagram and analyze the frequency distribution, all hourly average wind speeds and wind directions were used, and the resulting wind rose diagram is shown in figure 11. It is evident from this figure that the wind blew predominantly from south-southeast to south-southwest direction for approximately 60% of the time, and from different directions the rest of the time. Hence, wind turbines could be installed against these directions — provided there are no or minimal high rise buildings or very large trees and the terrain is smooth — for optimal energy output.

4.2. Wind energy calculations
Wind turbines can safely produce energy at particular wind speed, usually between 10.5 m/s and 16 m/s. The following formula illustrates factors that are important to the performance of a wind turbine. The rotor swept area, $A$, is important because the rotor is the part of the turbine that captures the wind energy. So, the larger the rotor, the more energy it can capture.

$$P_w = \frac{1}{2} \rho A V^3 C_p$$

where:
- $P_w$ = power output, watts;
- $C_p$ = maximum power coefficient, ranging from 0.25 to 0.45, dimension less;
- $\rho$ = air density, kg/m$^3$;
  - $= 1.226$ kg/m$^3$ at sea level;
  - $= 1.055$ kg/m$^3$ at 1680 m height;
- $A$ = rotor swept area, m$^2$;
- $V$ = wind speed, m/s.

Figure 11. The wind rose diagram for Albaха University, Al-Aqiq (average from 2015 to 2019).

The best measure of wind turbine performance is the annual energy output. An estimate of the annual energy output from a wind turbine (kWh/year) is the best way to determine whether a particular wind turbine will produce enough electricity to meet consumer requirements. Capacity factor (CF) estimation was calculated for each machine and listed in table 4.
A wind turbine power curve can help estimate expected energy production. The estimation is based on the average annual wind speed at a site, the frequency distribution of the wind, and the number of hours that the wind will blow at each speed during an average year [22].

Table 4. The energy is produced from the wind turbines and estimation of capacity factor.

| No | Type/Model | At height 3 m | CF (%) | At height 10 m | CF (%) | At height 50 m | CF (%) |
|----|------------|---------------|--------|----------------|--------|----------------|--------|
| 1  | Aeronautica Windpower 29-225 | 119.494 | 6.1 | 419.943 | 21.3 | 699.857 | 35.5 |
| 2  | Aeronautica Windpower 33-225 | 155.547 | 7.9 | 512.292 | 26.0 | 832.159 | 42.2 |
| 3  | Dewind D4-600 | 107.626 | 2.0 | 531.894 | 10.1 | 1175.400 | 22.4 |
| 4  | Dewind D6-1000 | 148.986 | 1.7 | 862.619 | 9.8 | 1922.111 | 21.9 |
| 5  | Enercon E70/2300 | 326.569 | 1.6 | 1435.567 | 20.5 | 2631.089 | 37.5 |
| 6  | Enercon E82/2300 | 346.597 | 1.7 | 1759.422 | 8.7 | 3948.962 | 13.3 |
| 7  | Enercon E126/4200 | 865.137 | 2.4 | 3959.403 | 10.8 | 8211.143 | 22.3 |
| 8  | Enercon E141/4200 | 1156.672 | 3.1 | 4898.962 | 13.3 | 9648.598 | 26.2 |
| 9  | Enercon E126/7500 | 930.010 | 1.4 | 4232.793 | 6.4 | 9329.714 | 14.1 |
| 10 | Enercon E126/7580 | 148.191 | 6.8 | 388.681 | 17.7 | 661.007 | 30.2 |
| 11 | Leitwind LTW77-300 | 340.784 | 4.9 | 1435.567 | 20.5 | 2631.089 | 37.5 |
| 12 | Soytur Wind 250 | 148.191 | 6.8 | 388.681 | 17.7 | 661.007 | 30.2 |
| 13 | Soytur Wind 200 | 86.782 | 5.0 | 204.470 | 11.7 | 358.089 | 20.4 |
| 14 | Soytur Wind 100 | 58.097 | 6.6 | 165.357 | 18.9 | 286.697 | 32.7 |
| 15 | Wobben E126/7580 | 930.010 | 1.4 | 4232.793 | 6.4 | 9329.714 | 14.1 |
| 16 | Wobben E70/2300 | 260.377 | 2.2 | 214.538 | 16.3 | 434.186 | 33.0 |
| 17 | Nordex N27/150 | 805.250 | 3.1 | 4193.251 | 16.0 | 8367.633 | 31.8 |
| 18 | Nordex N117/3000 | 53.203 | 2.2 | 197.991 | 8.1 | 402.991 | 16.4 |
| 19 | SouthWest Air X | 86.782 | 5.0 | 204.470 | 11.7 | 358.089 | 20.4 |
| 20 | SouthWest Skystream 3.7 | 58.097 | 6.6 | 165.357 | 18.9 | 286.697 | 32.7 |

The Weibull distribution of wind at Albahia University in Al-Aqiq was derived from wind rose analysis presented in the previous sections. The percent frequency distribution of mean wind speed in
the different bins is shown in figure 12. Figure 12(a) shows that at 3 m, the wind speed remained between 0.0 m/s and 2.0 m/s for 31.9% of the time and above 2.0 m/s for almost 68.1% of the time during the entire period of data collection. Figure 12(b) shows that at 10 m, the wind speed remained between 0.0 m/s and 2.0 m/s for 14.5% of the time and above 2.0 m/s for almost 85.5% of the time during the entire period of data collection. Figure 12(c) shows that at 50 m, the wind speed remained between 0.0 m/s and 2.0 m/s for 6.0% of the time and above 2.0 m/s for almost 94.0% of the time during the entire period of data collection. It is also clear from this figure that the wind remained above 2.0 m/s for almost 40.2%, 68.3%, and 94.0% of the time at 3 m, 10 m, and 50 m, respectively.

The total energy output per year of the different-sized wind turbines was calculated. Then, a capacity factor analysis was conducted, as presented in table 4. The capacity of a wind energy
conversion system is obtained by dividing the actual energy produced by the rated power and number of hours in a year, as in Eq. (2). Capacity factors are different from the average power of a station: the calculation includes the entire duration time, including the whole day, not just the time the turbine is in full working condition and not just the period in which it actively produces power.

$$CF = \frac{P_w}{P_r \times 24 \times 365} \times 100\%$$

where,

- $CF$ = capacity factor, %;
- $P_r$ = wind turbine rated power, kW;
- $P_w$ = power output, kWh/Year.

Power was calculated for the 21 turbine models made by Aeronautica Windpower, Dewind, Enercon, Leitwind, Soyut Wind, Wobben, Nordex, and SouthWest. The estimated power of the different wind turbines is listed in Table 4. The highest energy estimation was generated for the Enercon E141/4200 wind machine, with rates of 9648.60 MWh/Year, 4898.96 MWh/Year, and 1156.67 MWh/Year at 50 m, 10 m, and 3 m, respectively. The capacity factors were calculated as 26.2%, 13.3%, and 3.1% at 50 m, 10 m, and 3 m, respectively. The second highest energy estimation was generated for the Wobben E126/7580 wind machine, with rates of 9329.71 MWh/Year, 4232.79 MWh/Year, and 930.01 MWh/Year at 50 m, 10 m, and 3 m, respectively. The capacity factors were calculated as 14.1%, 6.4%, and 1.4% at 50 m, 10 m, and 3 m, respectively.

The lowest energy estimation for 10 m and 50 m was generated for the Soyut Wind 100 wind machine, with rates of 165.54 MWh/Year and 286.697 MWh/Year with capacity factors of 18.9% and 32.7% at 10 m and 50 m, respectively. The lowest energy estimation for 3 m was generated for the Nordex N27/150 wind machine, with a rate of 28.38 MWh/Year with a capacity factor of 2.2% at 3 m, as shown in Figure 13.

The highest capacity factor was recorded for the Aeronautica Windpower 33-225 wind machine, with rates of 7.9%, 26.0%, and 42.2% at 3 m, 10 m, and 50 m, respectively. Also, the estimated energy was recorded as 155.547 MWh/Year, 512.29 MWh/Year, and 832.16 MWh/Year at 50 m, 10 m, and 3 m, respectively. The lowest capacity factor was recorded for the Enercon E126/7580 wind machine, with rates of 1.1%, 5.9%, and 13.6% at 3 m, 10 m, and 50 m, respectively. Besides, estimated energy was recorded as 762.02 MWh/Year, 3946.61 MWh/Year, and 9015.68 MWh/Year at 50 m, 10 m, and 3 m, respectively.

5. Conclusion

This study investigated the wind characteristics and wind potential for Albaha University in Al-Aqiq, KSA, using data recorded during the years 2015–2019. The average wind speed and wind direction for the station located at Albaha University, Al-Aqiq, from 2015 to 2019 were calculated. The overall wind speed was found to be 2.68 m/s, 4.2 m/s, and 5.48 m/s at heights of 3 m, 10 m, and 50 m, respectively. These values were recorded during January, February, and March. The main wind direction in these months ranged approximately from south-southeast to south-southwest. The highest average monthly wind speed was recorded in March, with values of 3.09 m/s, 5.11 m/s, and 6.43 m/s recorded at 3 m, 10 m, and 50 m, respectively.

The main wind direction during this month was southwesterly. The lowest average monthly wind speed was recorded in November, with values of 3.09 m/s, 5.11 m/s, and 6.43 m/s recorded at 3 m, 10 m, and 50 m, respectively. The main wind direction during this month was easterly. The diurnal variation of the wind speed at 3 m revealed that the wind speed remained above 2.5 m/s from 10:00 AM to 10:00 PM. During an entire day, the mean wind speed varied between a minimum of approximately 1.5 m/s at 06:00 AM and a maximum of approximately 3.87 m/s at 05:00 PM. Wind energy generation was considered for 21 wind machines of different sizes. The capacity factor analysis showed, in general, that small wind machines have a higher capacity factor. The capacity factor was low for wind turbines located at 10 m above ground level, which is a fairly good indication of Al-
Aqiq, KSA, being a suitable site for wind farm development. Generally, wind turbines located at higher levels generate higher power and have a better capacity factor.

6. References
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