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Analysis of Wind Speed Data and Wind Energy Potential for Seven Selected Locations in KSA

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Abstract

Al-Baha region, located in Saudi Arabia, is one of the main tourism and leisure areas. The authority at Al-Baha Governorate plans to use clean and renewable energy in its tourism facilities. The importance of this study is to assess the possibility of building a wind farm in Al-Baha and to select the best site for this purpose. This paper presents an analysis of long-term wind data for the annual and monthly variability in Al-Baha region of southwestern Saudi Arabia. Al-Baha region has an area of 9921 square kilometers and is divided into seven regions (groups) based on their similar measurements and wind speed values. The analysis used 40 years of annual and monthly wind speed data between 1981 and 2020. The analysis showed that Group III has the highest mean wind speed values in the northeastern part of the Al-Baha region, ranging from 5.4 m/s to 5.9 m/s at 50 m above the surface. Group VI (5.1 - 5.6 m/s) east of the Al-Baha area recorded the second-highest mean wind speed, while group V southwest of the Al-Baha area recorded lower values. The maximum wind speeds observed in Group III in January, February, March, and July were 6 m/s or higher. A frequency analysis ensures that 79% of the year's wind speeds exceed 4 m/s at 50 m above the surface of the Group III site. Wind power was considered for 17 wind turbines of different sizes. The Soyut Wind 500 machine was found to produce maximum energy of 1420 MWh/year. The highest performance values for the Soyut Wind 500 machine occurred in winter and summer, while the calculated capacity factor values at a hub height of 50 m were 41% and 32%, respectively. The assessment concluded that generating electricity from wind at G III in the northeast of the Al-Baha region is a good decision.

Keywords

Wind Speed, Wind Energy, Wind Power, Power Factor

1. Introduction

Renewable energy consumption and the use of renewable technologies are emerging as the most economical options for generating electricity. The Kingdom of Saudi Arabia's Vision 2030 aims to increase renewable energy production by at least 9.5 GW over the same period (by 2030) to reduce CO_2 emissions and minimize the cost of electricity generation [1] [2]. Goal 7 of Saudi Arabia's Sustainable Development Goals (SDGs) ensures access to sustainable modern energy for all and significantly increases the global share of renewable energy by 2030 (https://sdgs.un.org/goals). Saudi Arabia's Sustainable Development Goals aim to ensure universal access to green energy suppliers.

The main energy source used by KSA to generate electricity is petroleum (Electricity and Cogeneration Regulatory Authority, https://www.ecra.gov.sa/), which is less common and noisy in other parts of the world [3]. The oil used in the power sector is heavily subsidized. KSA is intended to export oil at international prices rather than subsidized oil for domestic use [4]. KSA sees rapid growth in manufacturing to meet energy demand that is growing at an annual rate of 5% [5], **Figure 1**. Compared to other countries, KSA's national electricity and oil consumption is growing at an alarming rate worldwide [6]. At the same time, it is estimated that a 1% reduction in electricity consumption per year could reduce energy bills by $35 billion [7]. The prevailing grid system powers nearly 80% of the population living in the kingdom's reserves and production centers. It is estimated that the state's energy sector will invest about $117 under the 25-year Tactical Energy Plan [8].

On the other hand, wind power is used to generate electricity, but requires extensive regional networks to provide large amounts of electricity [9] [10]. **Figure 2** shows the average wind speed of some selected locations at an altitude of 100 m in one year covering different regions of Saudi Arabia. Haql has the highest average wind speeds, followed by Dhulom. Al-Baha is a rural area with high average wind speeds [11]. Nejran and Gassim have the lowest average wind speeds [12] [13]. Notably, most of these locations have average wind speeds in excess of 3.5 m/s.

The Kingdom plans to adopt a policy of energy efficiency measures and has established several initiatives to develop renewable energy projects, allocating $109 billion to the renewable energy sector in 2012, which will meet 30% of the Kingdom's electricity needs by 2032 [14]. The government also announced a roadmap to achieve this goal by installing about 60 GW of renewable energy, comprising 66% solar, 22% wind, and 4.5% concentrated solar.

The wind map of Saudi Arabia shows that the country is characterized by the presence of two main regions, the Arabian Gulf and the Red Sea coastal areas. KSA has sufficient wind energy potential with an average wind speed of 7.5 - 8 m/s on the east coast and 7 - 7.5 m/s on the west coast. The average wind speed in the central region is 5 - 6.5 m/s (King Abdullah City for Atomic and Renewable Energy (KACARE), https://www.kacare.gov.sa/). Wind speeds are higher in areas near the northeastern, central, and western mountains. KACARE has set up 10 monitoring stations: in Hafar Al-Batin, Sharurah, two in Yanbu, two in Riyadh, Aljof, Traif, Jeddah and Madina [1] [15] [16].

Figure 1. Saudi power transmission network. Source: Saudi Electricity Company, Annual Report 2007 https://www.se.com.sa/.

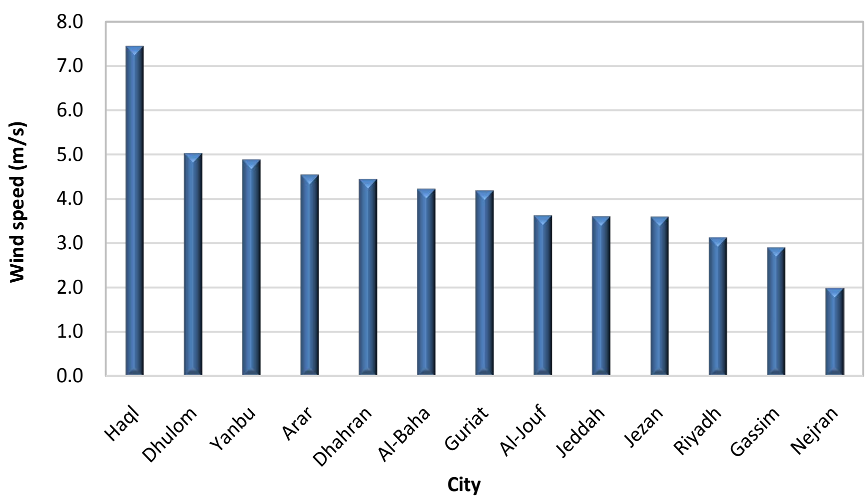


Figure 2. Average wind speed in different locations of Saudi Arabia (Source KACARE. Renewable Energy Sources Atlas, https://www.kacare.gov.sa/), and Al-Baha region.

On the other hand, in a similar area, the characteristics of wind speed data were analyzed using the Weibull distribution at the Al-Salman station in Iraq [17]. The site has wind power potential as it is able to install small wind turbines to generate electricity. The wind energy potential of nine wind farms in Jordan was investigated using three statistical distribution models (Weibull, Rayleigh, and Gamma distributions) and the maximum likelihood method [18]. Elsewhere, energy distribution in terms of wind energy potential characterizes the main wind belt in southern Pakistan [19] [20]. In France, Tazi and Bouzidi [21] describe the current state of pricing policy and the role of the latest market in the industry. Subsequently, various decision-making methods such as TOPSIS, VIKOR, and fuzzy analysis were applied to rank Indian states according to their wind energy potential [22]. A long-term analysis of the availability of wind energy has been carried out in the Republic of Moldova [23]. Algieri *et al.* [24] evaluated the energy efficiency of multi-source power systems for small residential cogeneration applications.

The availability of wind energy resources in the Arabian Gulf was investigated covering 2300 grid points. The summer wind energy density in the central region is particularly promising [24]. Data related to U.S. wind energy progress was analyzed using descriptive statistics to show turbine development and growth patterns from 1981 to 2019 [25]. Power generation projects were studied and analyzed using wind turbines in Malaysia [26]. A new adaptive Darrieus wind turbine design is proposed to enable and extend the operation of weak wind currents, aiming to develop an analytical model to predict the power factor [27]. A new method, called maximum power point tracking, has been proposed to improve and optimize the performance of wind energy conversion systems with small changes in wind speed by combining sliding mode control and fuzzy logic control [28]. The wind energy potential map was created in villages near the Pigguru Reserve in an electronic version using the arc view program [29]. The wind speed characteristics are analyzed using the well-known Weibull distribution function and used to evaluate the wind performance of some selected sites [30].

Smart city building topology is studied to understand the wind speed distribution and power output of wind turbines in the built environment [31] [32]. A review of economic growth in Europe, China, and the United States as a whole, shows that this industry supported by manufacturers and workers is a viable and profitable form of clean energy [33]. The price-based demand response, as active grid management promising tool, is used to optimize distribution grids with substantial wind penetration has become commonplace [34]. Wind speed characteristics and the energy potential in southwestern Nigeria are examined using 51 years of monthly mean wind speed data subjected to 2-parameter Weibull and other statistical analyses [35]. Potential estimates based on fixed wind turbine capacity have been proposed for simulating wind power generation maps in 30 Indian states [36].

To date, there are only a few articles in the literature that describe the wind power potential in the Al-Baha region of Saudi Arabia. Therefore, studying the wind distribution, power density, and capacity factors in different regions is of great significance for evaluating the wind resources and suitability of installing wind turbines in the region. This paper evaluates the wind energy potential of various sites in Al-Baha region of Saudi Arabia to determine the potential of these sites to meet the requirements of the KSA 2030 wind energy plan.

2. Current Power Generation Scenario in KSA

Saudi Electricity Company and Saline Water Conversion Corporation [37], mainly use diesel and natural gas to generate electricity for Saudi Electricity Company. It is estimated that Saudi Arabia will need to increase its power generation from 82 GW in 2018 to 160 GW in 2040. Saudi Arabia started the establishment of the Gulf Cooperation Council (GCC) to develop composite power plants, as shown in **Figure 3**. The potential of GCC countries in terms of solar and wind resources is aimed at meeting climate protection needs and assessing the GCC region's ability to transition to low-carbon technologies [38].

Figure 4 shows the electricity generation and unit price (Riyals/kWh) in Saudi Arabia between 1981 and 2020. During this period, electricity production gradually increased until 2014 and remained almost unchanged from 2015 to 2017. The peak occurred in 2016 at about 135 GWh. From 2017 to 2019, electricity production in Saudi Arabia declined steadily due to high electricity prices.

3. Data Collection and Site Description

This work aims to analyze long-term wind speed data, assess the possibility of harnessing wind energy for electricity generation in the Al-Baha region, and identify optimal locations. Wind speed data will be collected at various locations in the Al Baha region and the electrical power that can be generated by multiple commercial turbines will be calculated. Therefore, according to the higher power and capacity factor, suitable turbines are determined for each location within Al-Baha province.

Al-Baha region is a province in the southwest of the Kingdom of Saudi Arabia, **Figure 5**. It is located between latitude 19˚30'00" and 20˚36'18.36" north and longitude 41˚4'48.04" and 42˚3'3.28" east, with an altitude between 66 m and 2534 m.

This study collected data on meteorological activity from 1981 to 2020. The parameters obtained include wind speed, relative humidity, temperature, pressure, rainfall, etc. Daily wind speed records have been used for 40 years. A total of 34 sites were obtained from NASA's Global Energy Projections (https://power.larc.nasa.gov/). The locations have been grouped into similar areas representing similar weather and wind data values. **Table 1** lists the latitude, longitude, and altitude for these locations. Based on similar values of wind speed, humidity, temperature, pressure, rainfall, etc., the final number of sites studied was reduced to seven groups.

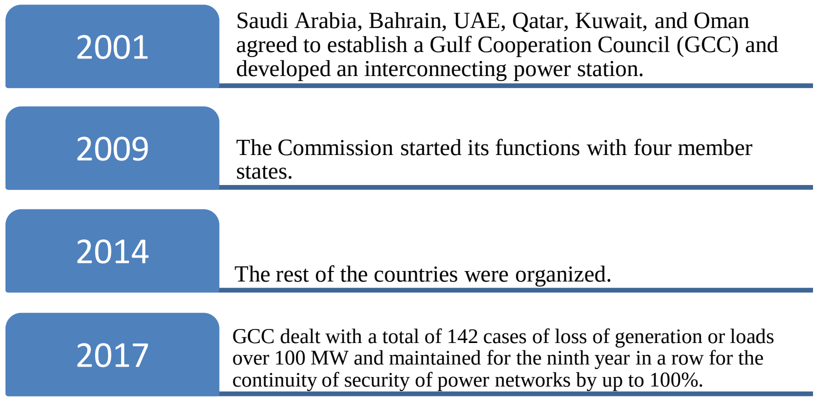


Figure 3. Saudi Arabia started to establish a Gulf Cooperation Council (GCC) to develop an interconnecting power station.

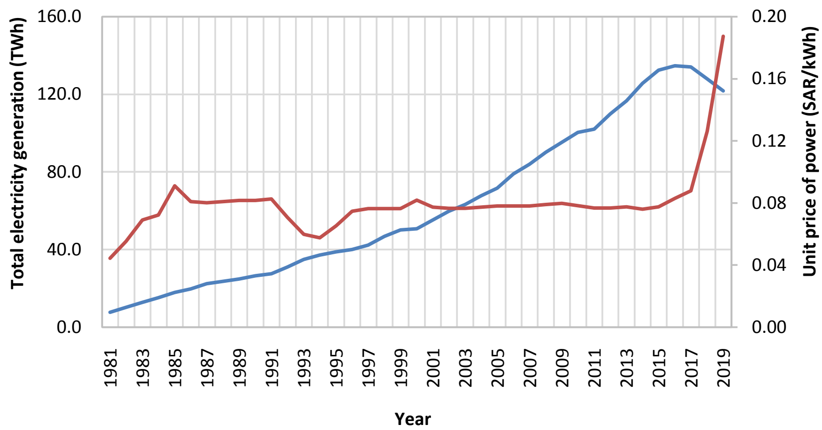


Figure 4. Electricity production and change of unit price of power in Saudi Arabia. Adopted from Electricity and Cogeneration Regulatory Authority, https://www.ecra.gov.sa/.

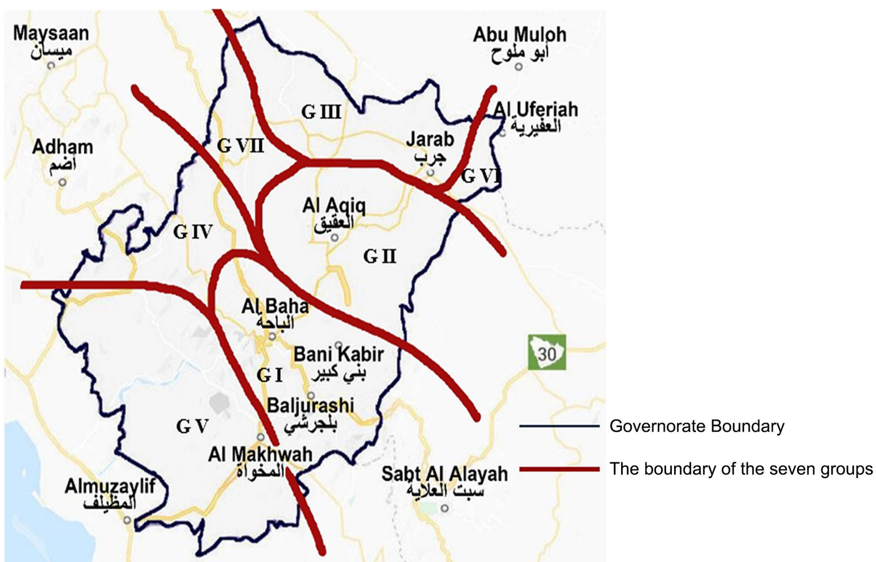


Figure 5. Geographical locations of the collected meteorological data for the seven groups.

Table 1. The latitude, longitude, and altitude of the selected locations in Al-Baha region.

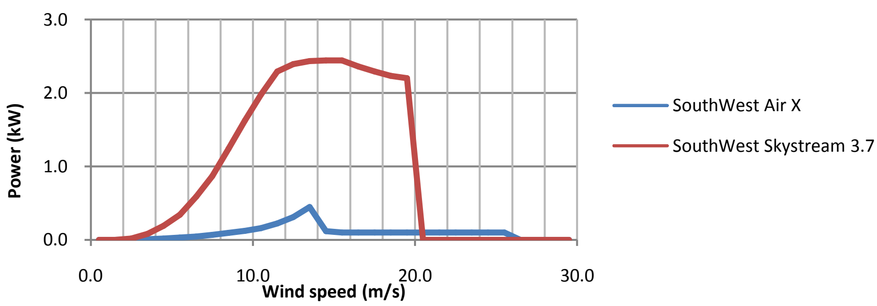
No	Location	Latitude	Longitude	Altitude
G I	Almorasaa (1)	19.99001	41.53001	2245
	Almorasaa (2)	19.99731	41.54991	2244
	Almorasaa (3)	19.99485	41.53097	2245
	Baljurashi	19.87001	41.57001	2018
	Dar Aljabal Mountain	19.95813	41.50068	2480
	Prince Mishary Hospital at Baljurashi	19.82013	41.62004	2180
	Prince Miteb Park—Baljurashi Road	19.95921	41.53372	2380
	Baljurashi Dam	19.91730	41.67570	1970
	Al-Baha (Southeast)	19.50000	41.87500	600
G II	King Saud Airport at Al-Aqiq	20.29601	41.63001	1663
	Al-Baha University	20.17001	41.63001	1654
	Near to Jarab	20.45716	41.91634	1340
	On the Road to Jarab (30 km to Jarab)	20.42965	41.86521	1389
	Allehian	20.18098	41.60522	1660
	Bani Kabeer	20.04100	41.83560	2110
G III	Jarab	20.51001	41.98001	1440
	Road 1111 (Near to Joaba)	20.51333	41.84667	1360
	Al-Qara (Mekkah Boarder—North)	20.60510	41.73390	1377
	Al-Qara (Near to Health Center)	20.50750	41.60444	1521
G IV	Wadi Dose	20.23180	41.23130	1023
	Qarn-Dhabi	20.09001	41.42001	2398
	Al-Mandaq	20.10001	41.28001	2244
	Raghadan Mountain (1) (R.S. of Baidan)	20.02044	41.42110	2522
	Raghadan Mountain (2) (R.S. of Baidan)	20.02939	41.42592	2534
	Raghadan (Old Faculty of Engineering)	20.04111	41.44639	2285
G V	Al-Muzailef (1)	19.54001	41.09001	69
	Al-Muzailef (2)	19.68001	41.08001	111
	Al-Mekhwah	19.75001	41.42001	367
	Al-Mikhwah (Nawan)	19.54694	41.18674	66
	Qalwa (Shaza Mountain)	19.84410	41.39000	2099
G VI	Joaba (1) (Asir Boarder)	20.34737	42.05091	1200
	Joaba (2) (Asir Boarder)	20.35100	42.07520	1200
	Al-Afriya	20.49528	42.09639	1201
G VI	Al-Baha (Northwest)	20.50000	41.25000	1600

4. Selection of Wind Turbines for Power Generation in Saudi Arabia

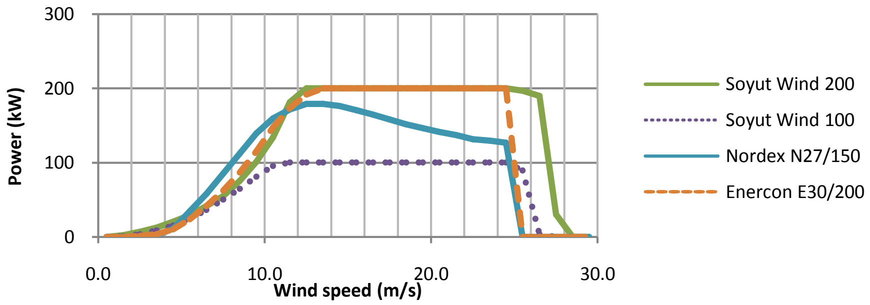
Several wind turbines of different sizes, made by different manufacturers, were selected to estimate the potential energy produced if they were installed in Al-Baha region of Saudi Arabia. They are: Aeronautica Windpower (2), Dewind (1), Enercon (4), Soyut Wind (4), Nordex (2), and SouthWest (2)—a total of 15 wind turbines. Technical data and power curves for these machines are available on the Internet [39]. The wind turbines were chosen to cover a wide range of power ratings from 400 W to 600 kW. Rotor diameters range from 1.17 m to 48 m, with cut-in wind speeds from 1.5 m/s to 4 m/s. **Table 2** summarizes the technical data and specifications of some selected wind turbines. **Figure 6** shows the power curves for selected wind turbines. For energy analysis, the wind speed bins are centered at 0.0, 0.5, 1.0, 1.5, 2, 2.5, etc. [11] [39] [40] [41] [42].

Table 2. Comparison of wind turbines with their specifications.

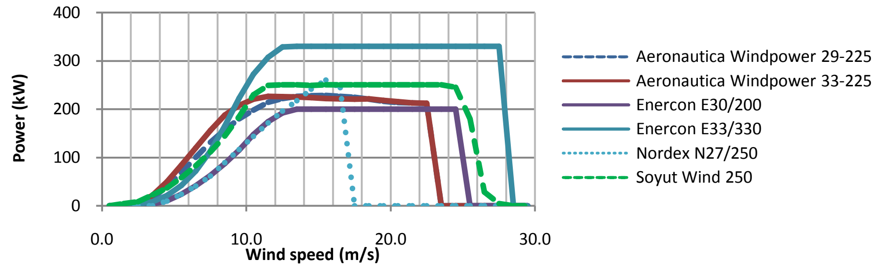
No	Manufacturer/Model	Table Column Head							
		Rated power (kW)	Rotor diameter (m)	Swept area (m^2)	Power density (m^2/kW)	Max speed (rad/min)	Cut-in (m/s)	Rated (m/s)	Cut-off (m/s)
1	Aeronautica Windpower 29 - 225	225	29	660.5	2.94	37.9	2	14	23
2	Aeronautica Windpower 33 - 225	225	33	855.3	3.8	33	2	12	23
3	Dewind D4-600	600	48	1809.6	3.02	29.2	2.5	12	19
4	Enercon E30/200	200	30	706.9	3.53	48	2.5	13	25
5	Enercon E33/330	330	33.4	876.2	2.66	39	2.5	13	28
6	Enercon E40/500	500	40	1256.6	2.51	34	2.5	13.5	25
7	Enercon E40/600	600	40	1256.6	2.09	34.5	2.5	13	25
8	Soyut Wind 500	500	39.2	1206.9	2.41	NA	1.5	12.5	24.5
9	Soyut Wind 250	250	41.5	1333.2	5.33	NA	1.5	12	28
10	Soyut Wind 200	200	36.8	1063.6	5.32	NA	1.5	12.5	28
11	Soyut Wind 100	100	26	530.9	5.31	NA	1.5	11.5	26.5
12	Nordex N27/150	150	27	572.6	3.82	36	3	13	25
13	Nordex N27/250	250	27	572.6	2.29	40	4	16	16.5
14	SouthWest Air X	0.40	1.17	1.07	NA	0	3.6	12.5	26
15	SouthWest Skystream 3.7	2.60	3.72	10.87	NA	50 - 330	3.5	13	20



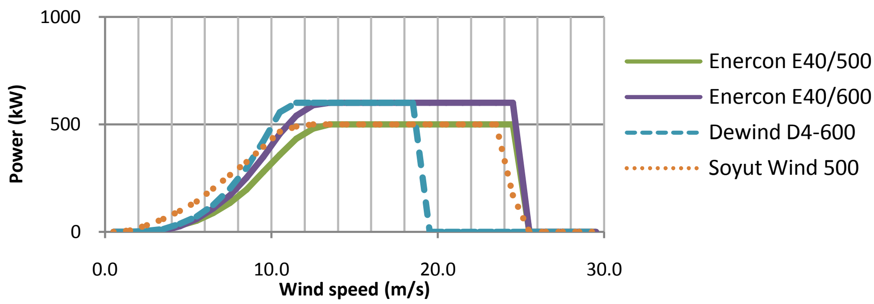
(a) Rated power range up to 2.6 kW



(b) Rated power range up to 200 kW



(c) Rated power range up to 330 kW



(d) Rated power range up to 7850 kW.

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

5. Results and Discussion

Long-term annual, and monthly variation in mean wind speed; wind availability in terms of frequency distribution, energy is estimated using different turbines with different power ratings. The estimation of capacity factors and their variation with turbine size and hub height were also evaluated. To study the annual wind speed behavior, the monthly and annual mean values for 40 years from 1981 to 2020 were obtained using the monthly mean wind speed values. The annual changes in the average wind speed at 50 m above the ground in different groups (7 groups) are shown in **Figure 7**. The average wind speed in these regions agrees with the average wind speed readings from weather stations in the different regions [1] [40] [42].

The graph shows that the average wind speed value of the third group is higher than the other groups. In this group, the average wind speed exceeded 5.5 m/s between 1980 and 1989 and increased to about 5.9 m/s between 1990 and 1994. In 1995-1997 it was 5.4 m/s, and in 1998 it rose to 5.9 m/s. In the past two years

(2018-2020), the average wind speed has increased to around 5.9 m/s. In general, the average wind speed for the Group III 40-year period (1981-2020) ranged from 5.4 m/s to 5.9 m/s. As can be seen from the figure, the second-highest average wind speed is group VI (5.1 - 5.6 m/s), while the lower value is group V (3.4 - 4.0 m/s).

The monthly variation in average wind speeds provides insight into whether there are suitable wind speeds throughout the year. The monthly average wind speed at 50 m above the ground is shown in Figure 8. The graph shows that the third group has higher average wind speeds than the other groups. The graph also shows that higher wind speeds of 6 m/s or higher were observed from January to March and July. The average wind speed value of groups III and VI in July exceeded 6.4 m/s, and the wind speed values for the remaining months were reduced to 6 m/s. As can be seen from the graph, the lower wind speed values for all groups were in May. Due to the seasonal trend in wind speed corresponding to the Saudi Arabia Kingdom's electricity load trend in winter and summer, more electricity is required to increase heating and cooling loads [1]. The wind speed value of group V is lower than the other groups.

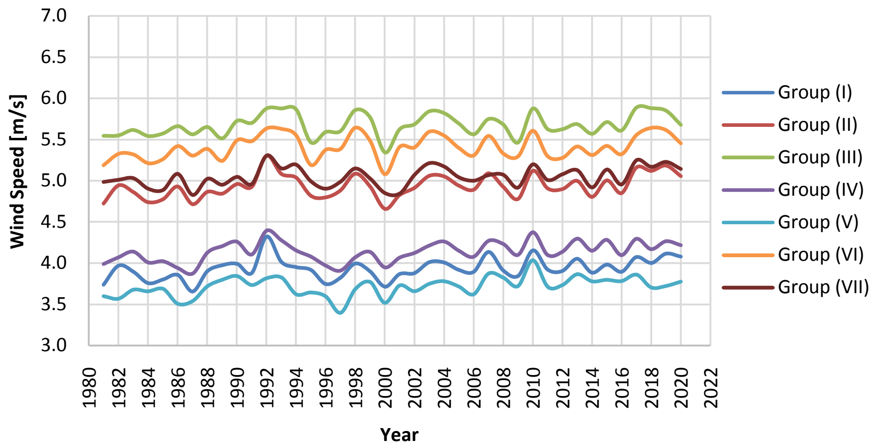


Figure 7. Annual variation of the mean wind speed for the seven groups (from 1981-2020).

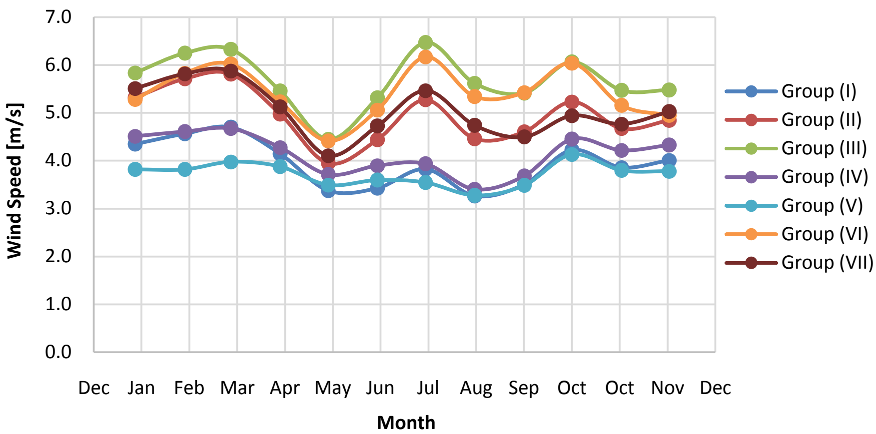
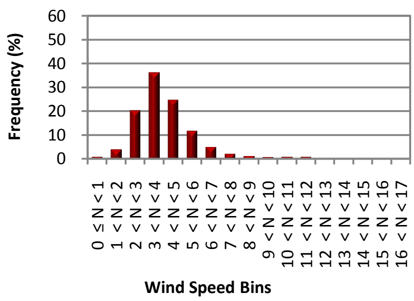


Figure 8. Monthly variation of the mean wind speed for the seven groups (1981-2020).

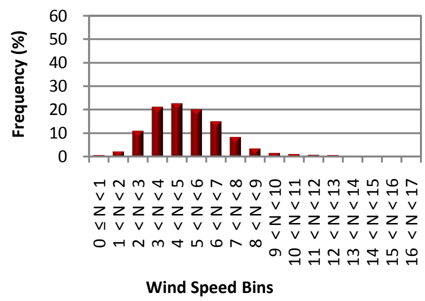
The annual percentage frequency distribution of the seven groups of average wind speeds in different bins is shown in **Figure 9**. In Group III, the wind speed remained between 0 and 3.0 m/s for almost 8% of the entire data collection period. The graph also shows that the wind speed remained between 4.0 and 10.0 m/s almost 79% of the time. It remains above 10.0 m/s about 3% of the time. Since most modern wind turbines typically start generating electricity at speeds above 3.5 m/s, 79% of wind speeds are above the cut-in speed of the wind turbines, which is a good indication that Group III is a potential site for wind farm development. In Group VI, wind speed remained between 0 and 3.0 m/s for almost 10% of the time during the entire data collection period. In Group VI, the wind speed remained between 4.0 and 10.0 m/s almost 74% of the time. Compared to Groups III and VI, the available wind speed values for the other groups are lower than the cut-in speed of the wind turbines. In general, the available wind speed values for Group III are higher than for Group VI and other groups.

From this, it can be concluded that the third group is the best in terms of wind speed and year-round availability. The selected area is almost flat and located almost in the center of the Kingdom of Saudi Arabia with good access. Additionally, its borders are linked to multiple provinces, so the electricity generated can easily be connected to the kingdom's main grid to generate electricity and/or power neighboring provinces.

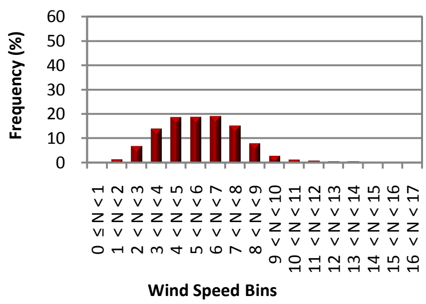
The seasonal percentage frequency distribution of the mean wind speed in different bins is shown in **Figure 10**. It can be seen that the wind speed remains between 4.0 and 10.0 m/s for 53%, 44%, 29%, and 38% of the time in winter, spring, summer, and autumn, respectively. Availability with wind speeds above the turbine cut-in speed is a good indicator of the winter followed by the spring season with higher availability values.



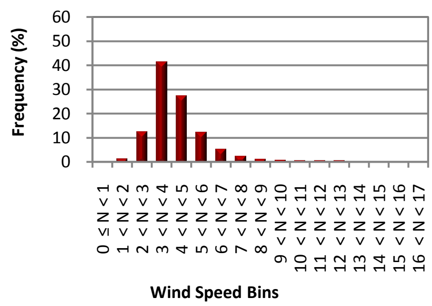
(a) Group I



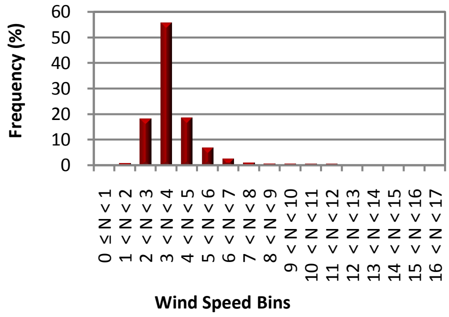
(b) Group II



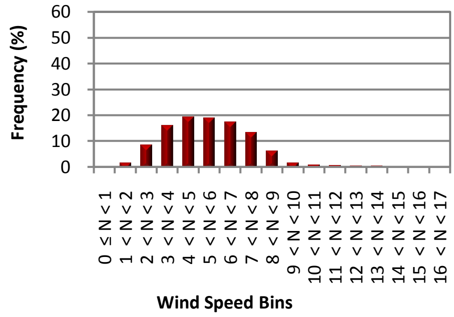
(c) Group III



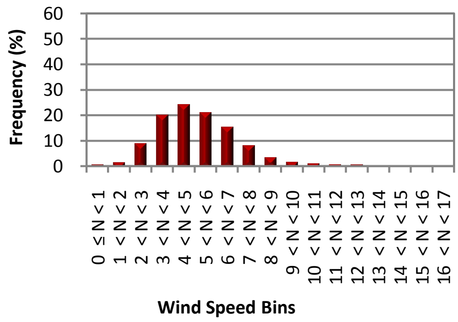
(d) Group IV



(e) Group V

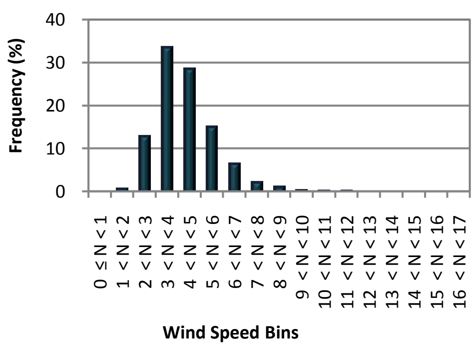


(f) Group VI

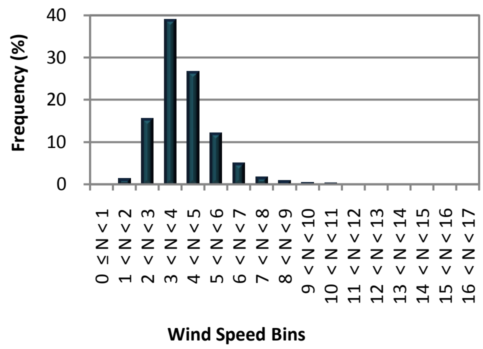


(g) Group VII

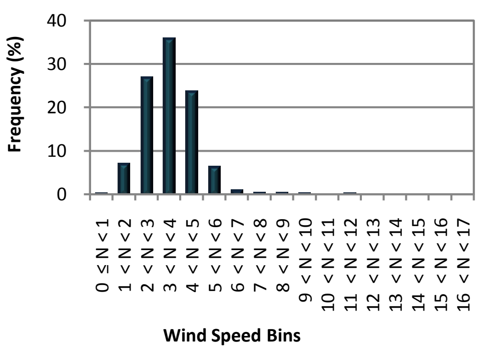
Figure 9. Annual percent frequency distribution of mean wind speed at 50 m above the ground level for the seven groups at different bins.



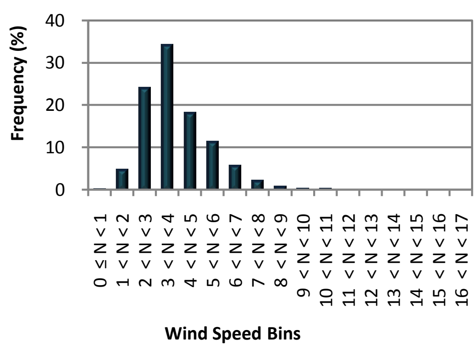
(a) Winter.



(b) Spring.



(c) Summer.

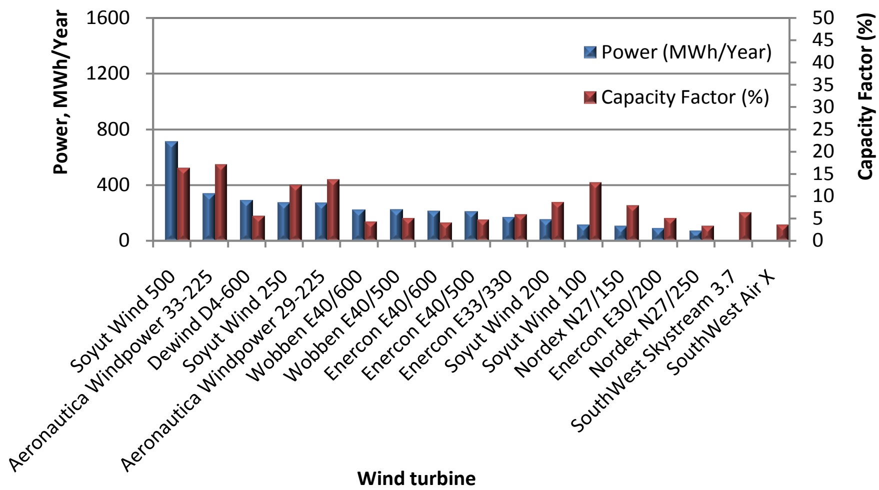


(d) Autumn.

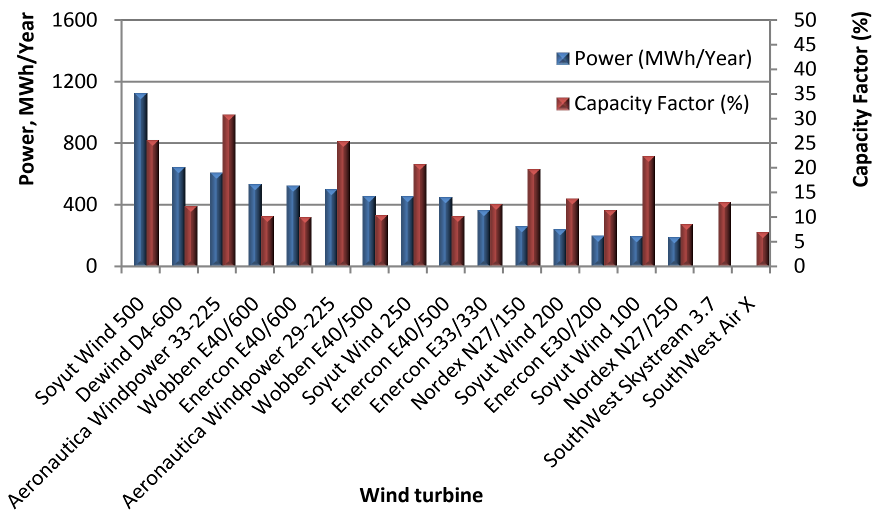
Figure 10. Seasonal percent frequency distribution of mean wind speed at 50 m above the ground level at different bins (Group III).

The energy output (MWh) and a capacity factor of all wind turbines at each site are shown in **Figure 11**. From this graph, it is clear that the Soyut Wind 500 machine has the highest power output in Group III (14,200 MWh/yr), while the second highest in the same machine in Group VI (1350 MWh/yr). In the third group, the Soyut Wind 500 machine had a capacity factor of 34%, while in the sixth group it was 28%. The second maximum power output of the Dewind D4-600 machine in Group III (970 MWh/year) and Group VI (830 MWh/year). The capacity factor of this machine is 17% in Group III and 15% in Group VI. In the third group, the graph also shows that all machines outperformed the other groups.

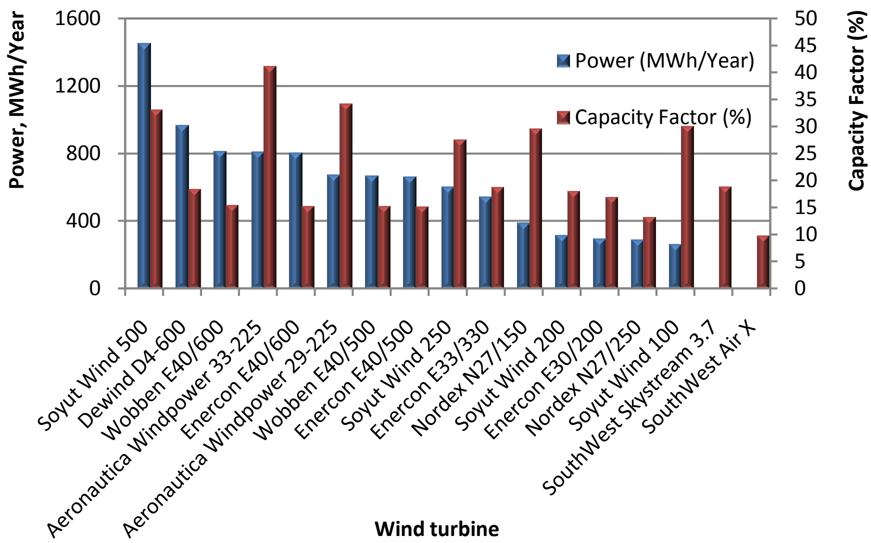
As shown in **Figure 12**, the Aeronautica 33 - 225 wind turbine has the highest capacity factor at 41% in Group III, from machine used. For the same machine in Group VI, the second-highest capacity factor of 37% was obtained. It also has the highest capacity factor of all groups except the V group. Nordex N27/250 machines have the lowest capacity factor values in Groups I, IV, and V, while Southwest X machines have the lowest capacity factor values in Groups II, III, VI, and VII.



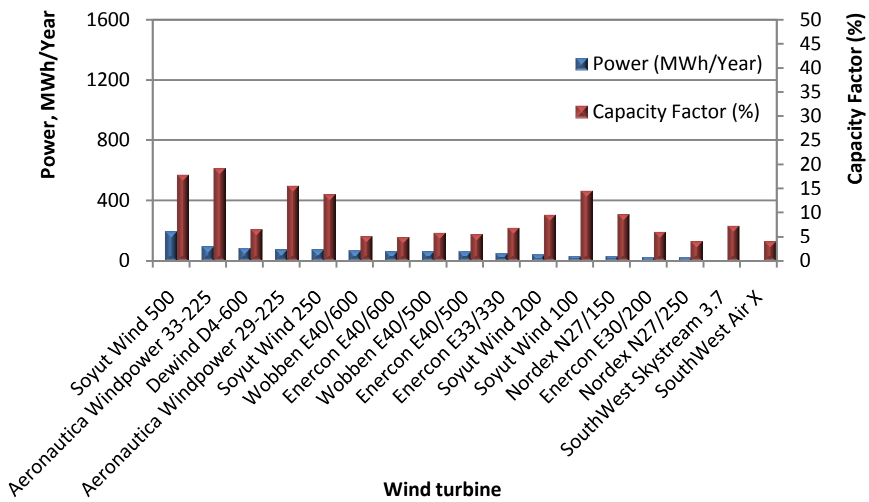
(a) Group I



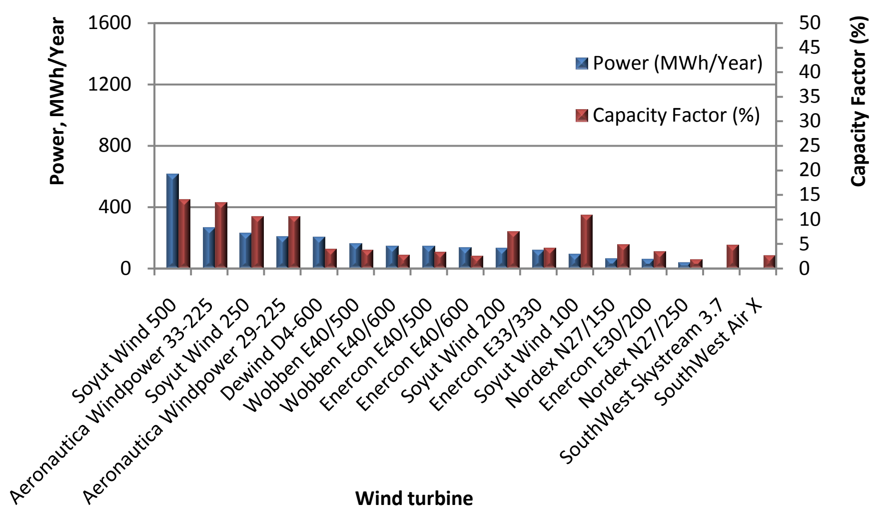
(b) Group II



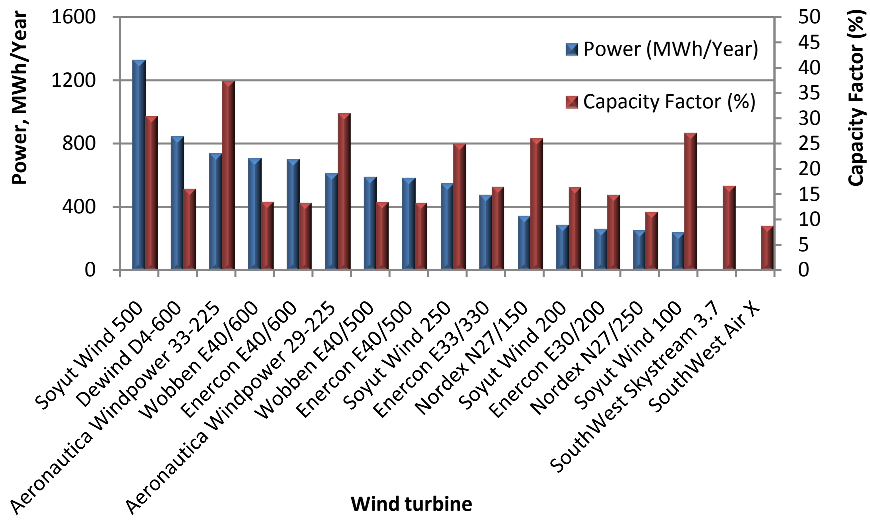
(c) Group III



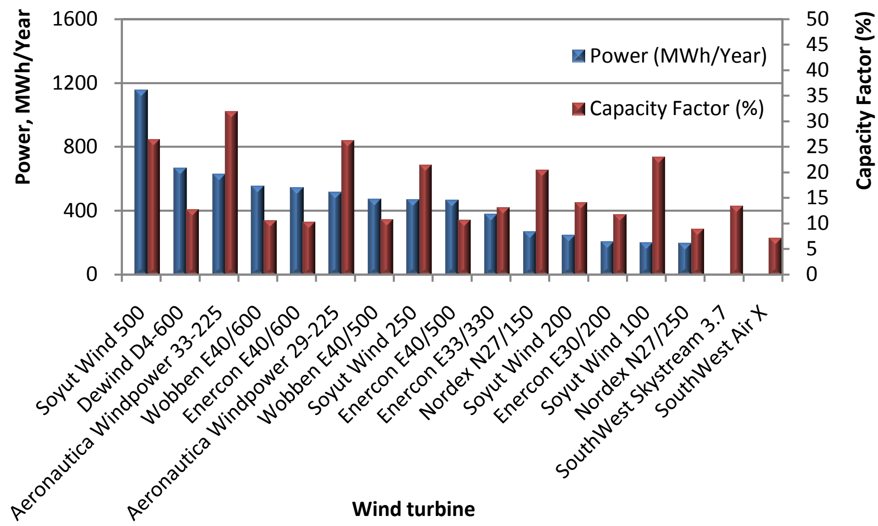
(d) Group IV



(e) Group V

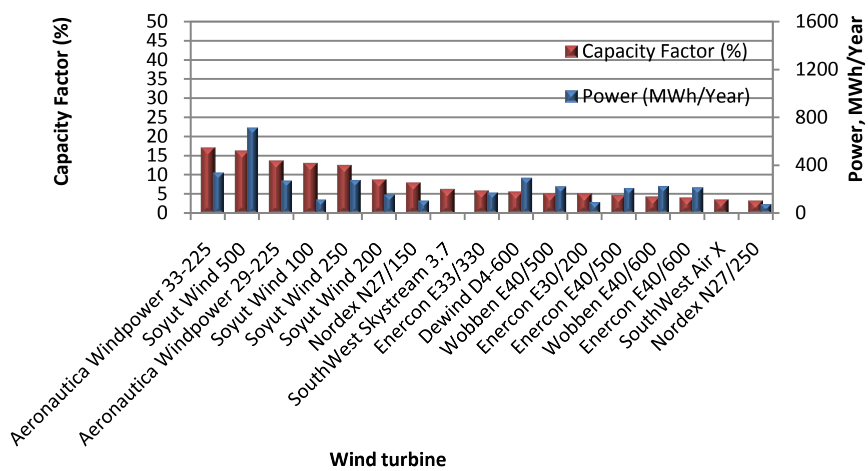


(f) Group VI

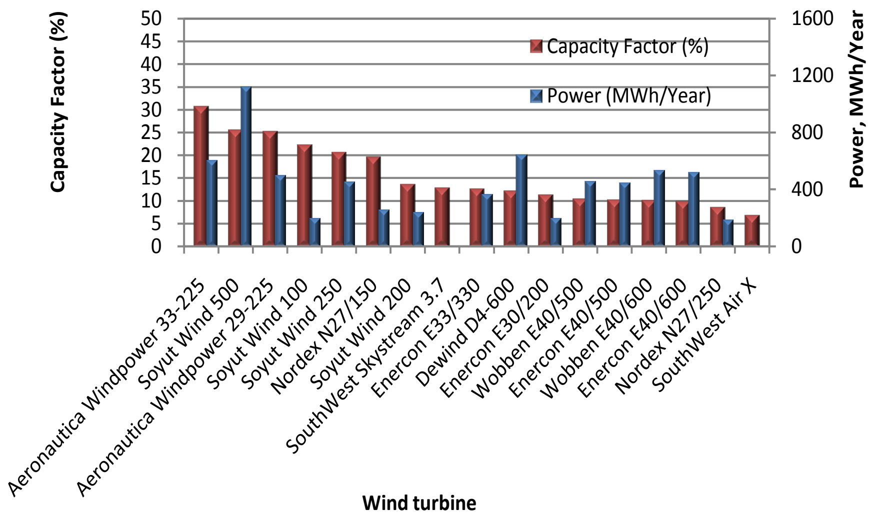


(g) Group VII

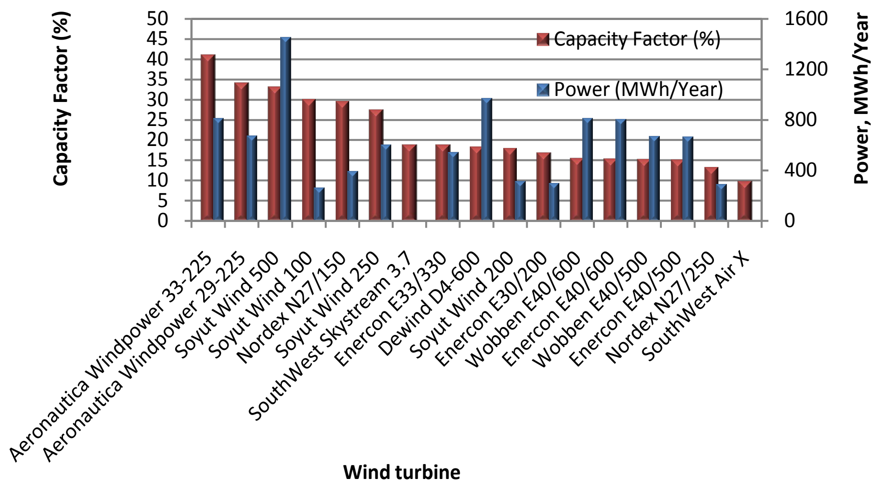
Figure 11. Power output for wind machines at 50 m above the ground level at 7 groups.



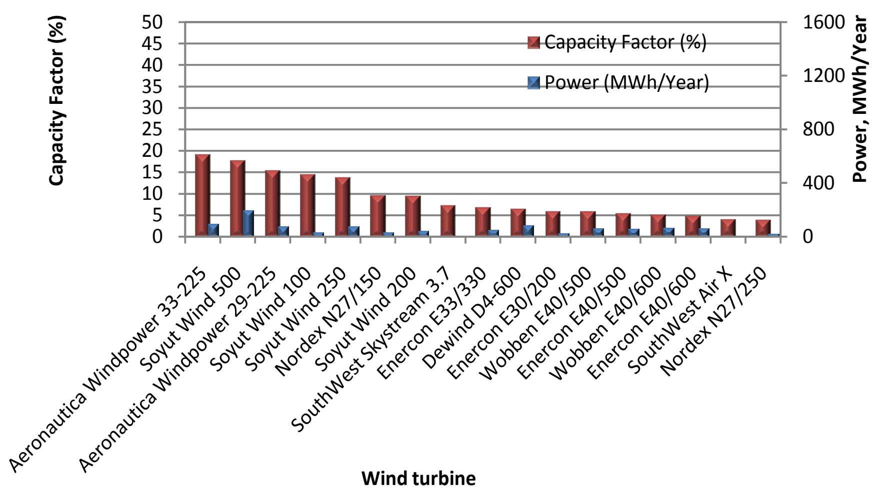
(a) Group I



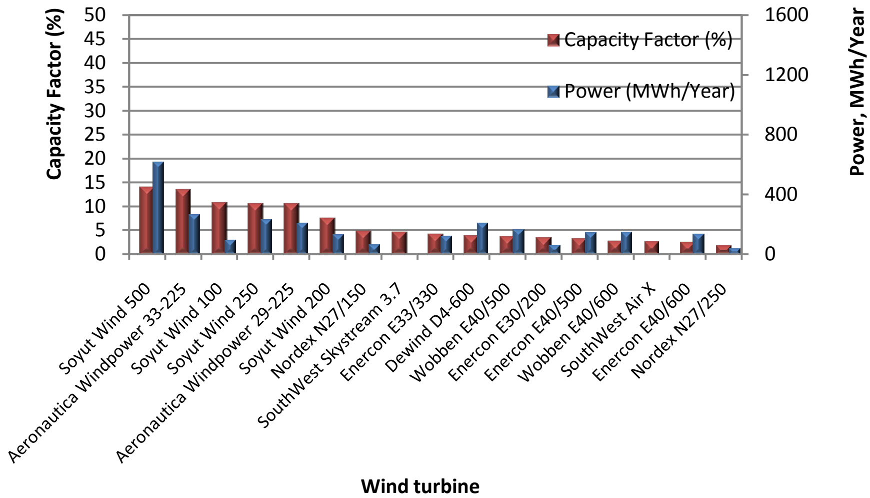
(b) Group II



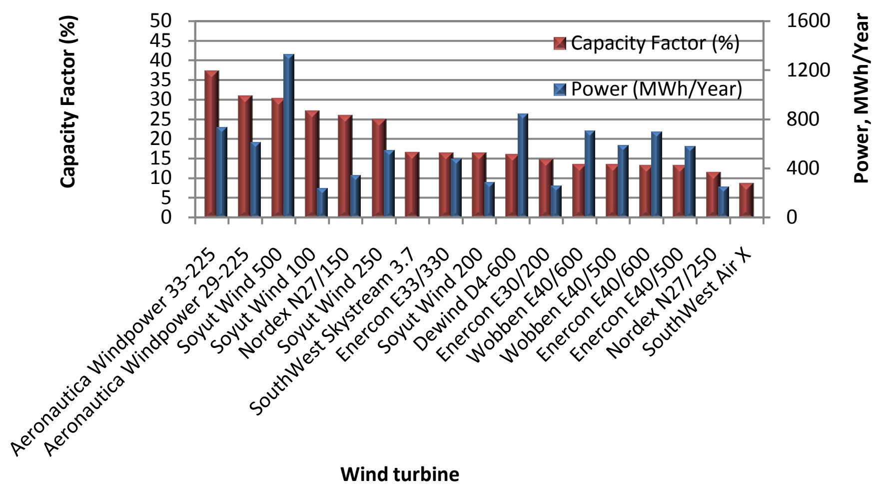
(c) Group III



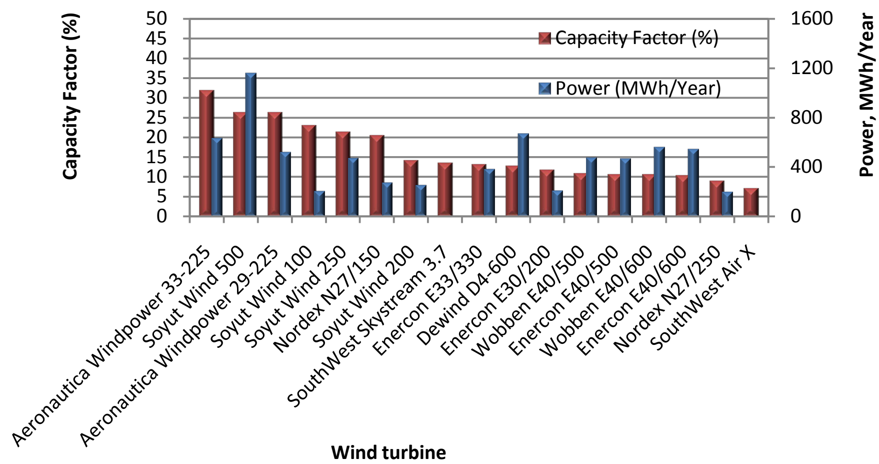
(d) Group IV



(e) Group V



(f) Group VI

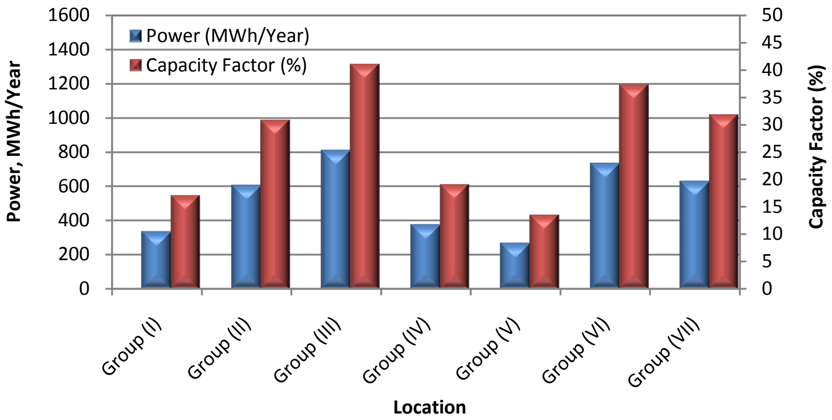


(g) Group VII

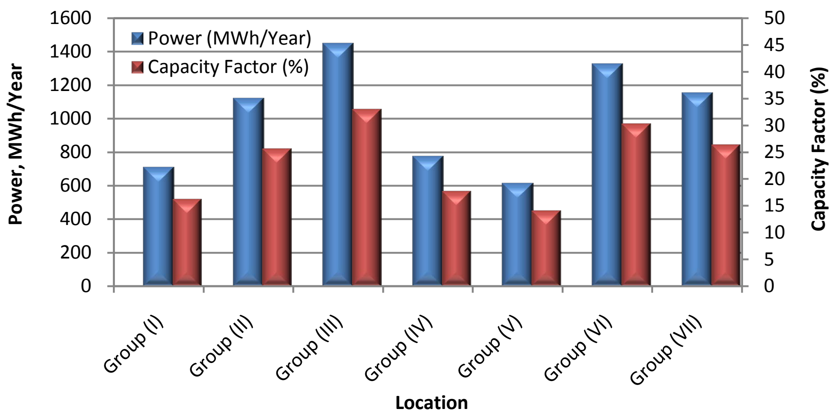
Figure 12. The capacity factor for wind machines at 50 m above the ground level.

Figure 13 shows a comparison between the two machines with the highest power output and capacity factor (Aeronautica Wind Power 33 - 225 and Soyut Wind 500), in the third group. Figure 13(a) shows that the Aeronautica Wind 33 - 225 machine has the highest load factor at 41%, which was also the highest value among all groups. Overall, the highest capacity factor for this machine was found in Group III, while the next highest value was found in Group VI. Figure 13(b) shows the power output of the different groups of Soyut Wind 500 machines at 50 m above the ground. It can be seen that Group III has the highest power output (1420 MWh/year), which is also the highest power value compared to all groups obtaining Soyut Wind 500 machines. Overall, this machine achieved the highest performance in Group III, followed by the value in Group VI (1380 MWh/year). It should also be clarified that the choice of wind turbines depends on the nature of the area, as well as the appropriate wind speeds, and its basic cost and operating cost. It also means that some turbines may work well in some regions but not in another.

Seasonal power output and capacity factors for each machine in the third group are shown in Figure 14. The graph shows the change in power output and

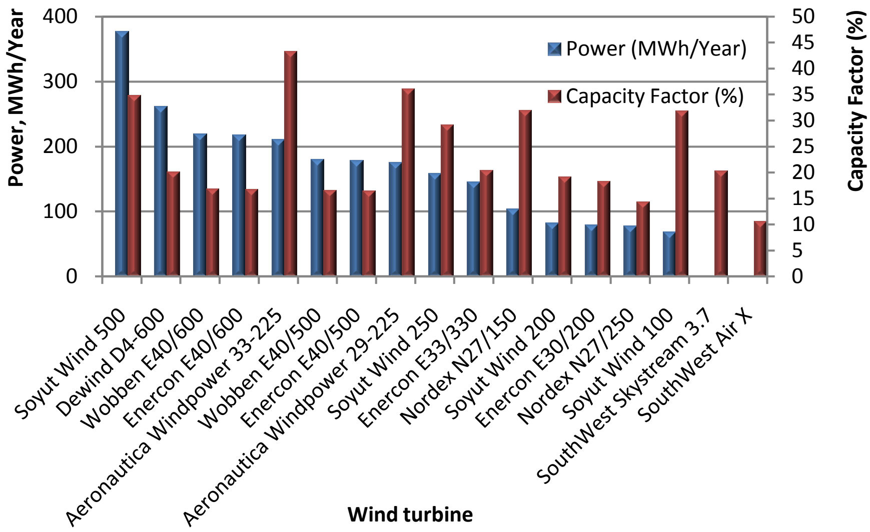


(a) Aeronautica Wind power 33 - 225

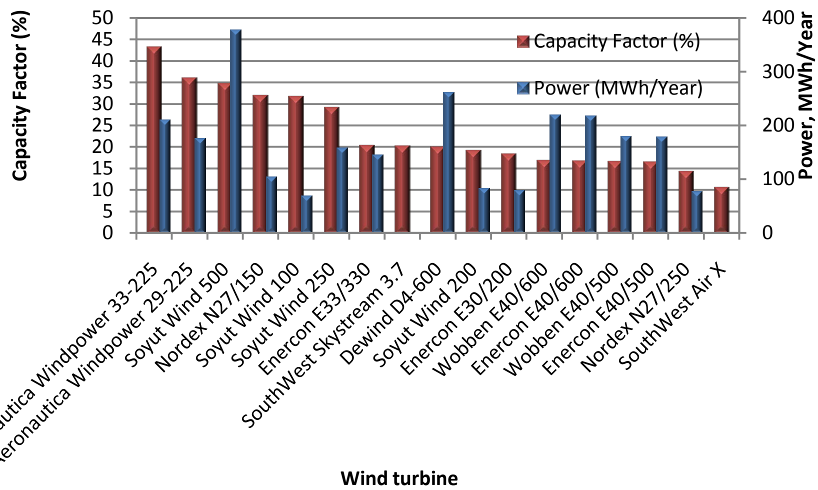


(b) Soyut Wind 500

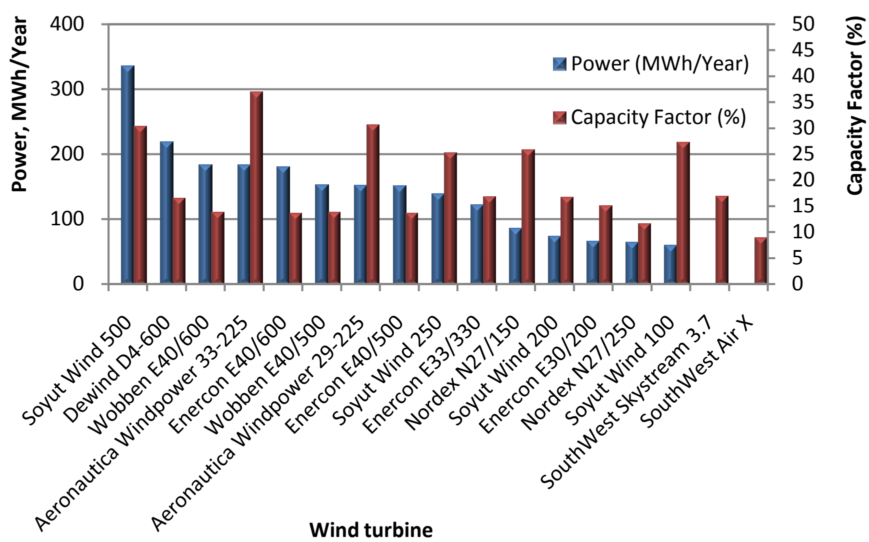
Figure 13. Comparison between Aeronautica wind power 33 - 225 and Soyut wind 500 machines for all groups.



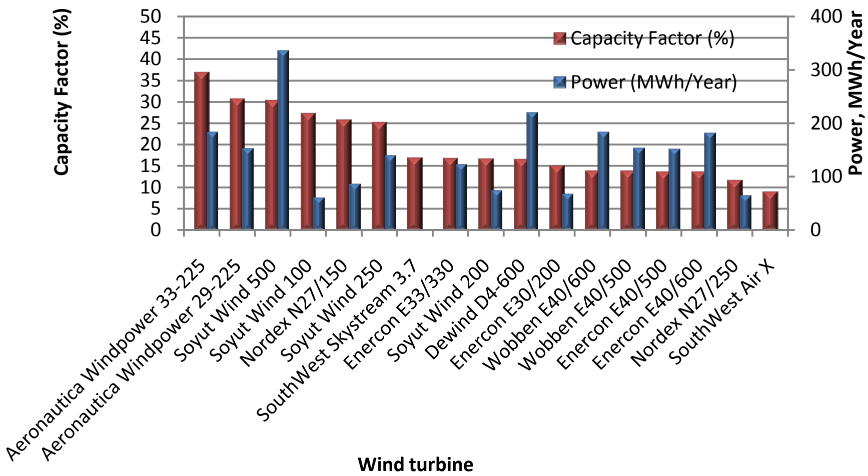
(a) Power (Winter)



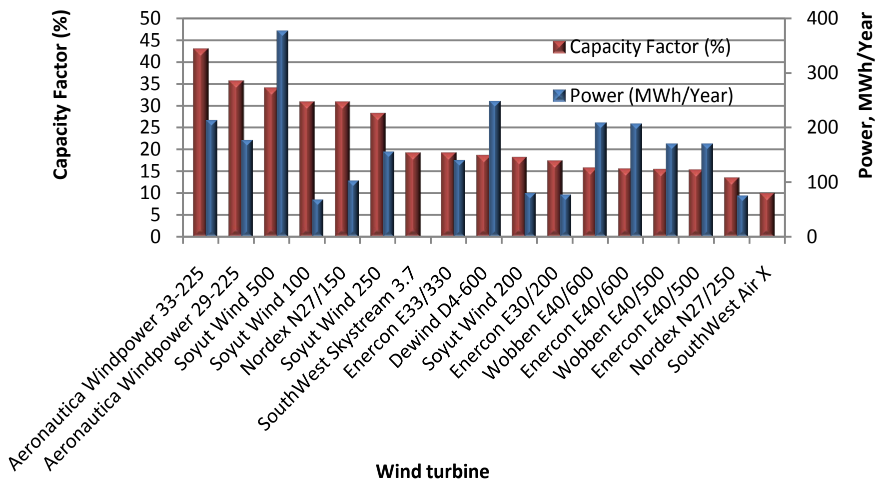
(b) Capacity factor (Winter)



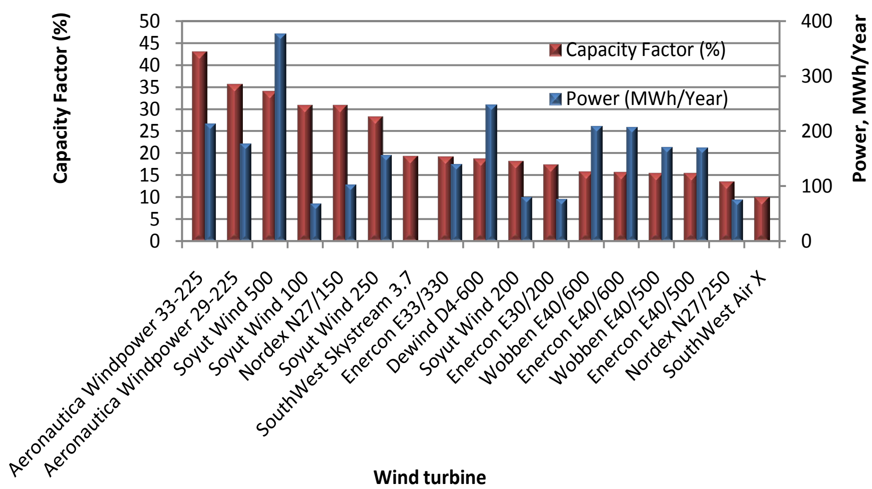
(c) Power (Spring)



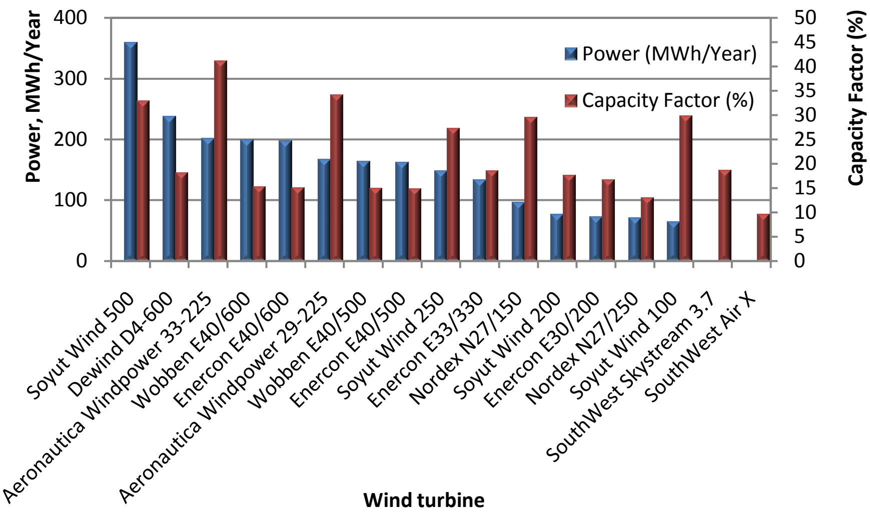
(d) Capacity factor (Spring)



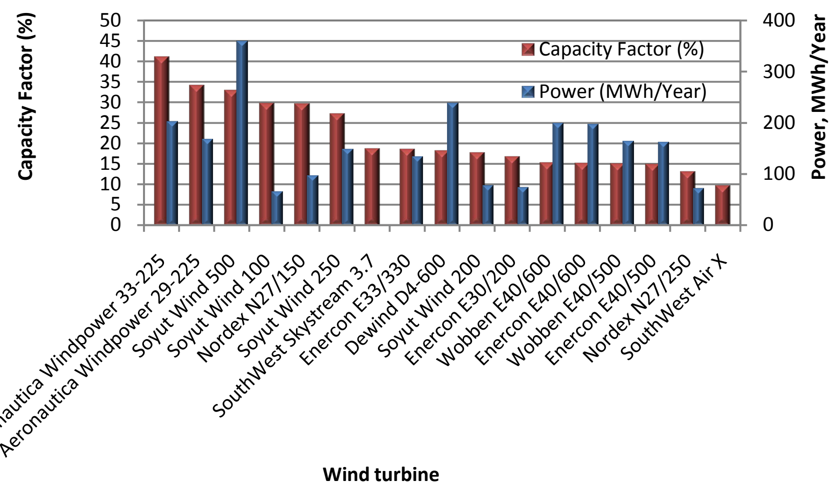
(e) Power (Summer)



(f) Capacity factor (Summer)



(g) Power (Autumn)



(h) Capacity factor (Autumn)

Figure 14. Seasonal power output and capacity factor from different machines in group III.

power factor in different seasons. The Soyut Wind 500 machine had the highest power output values in winter and summer (375 MWh/year), while the capacity factor values were 41% and 32%, respectively. The next highest value of electricity output occurred in autumn (355 MWh/year), while the capacity factor value was 32%. The capacity factor value for this machine (Soyut Wind 500) is 30% of the spring minimum power output value (325 MWh/year).

Figure 15 shows the annual output and capacity factors for various machines in Group III. It can be seen that there are differences in the performance and capacity factors of the machines used. The Soyut Wind 500 machine (1420 MWh/yr) achieved the highest power output value with a capacity factor value of 41%.

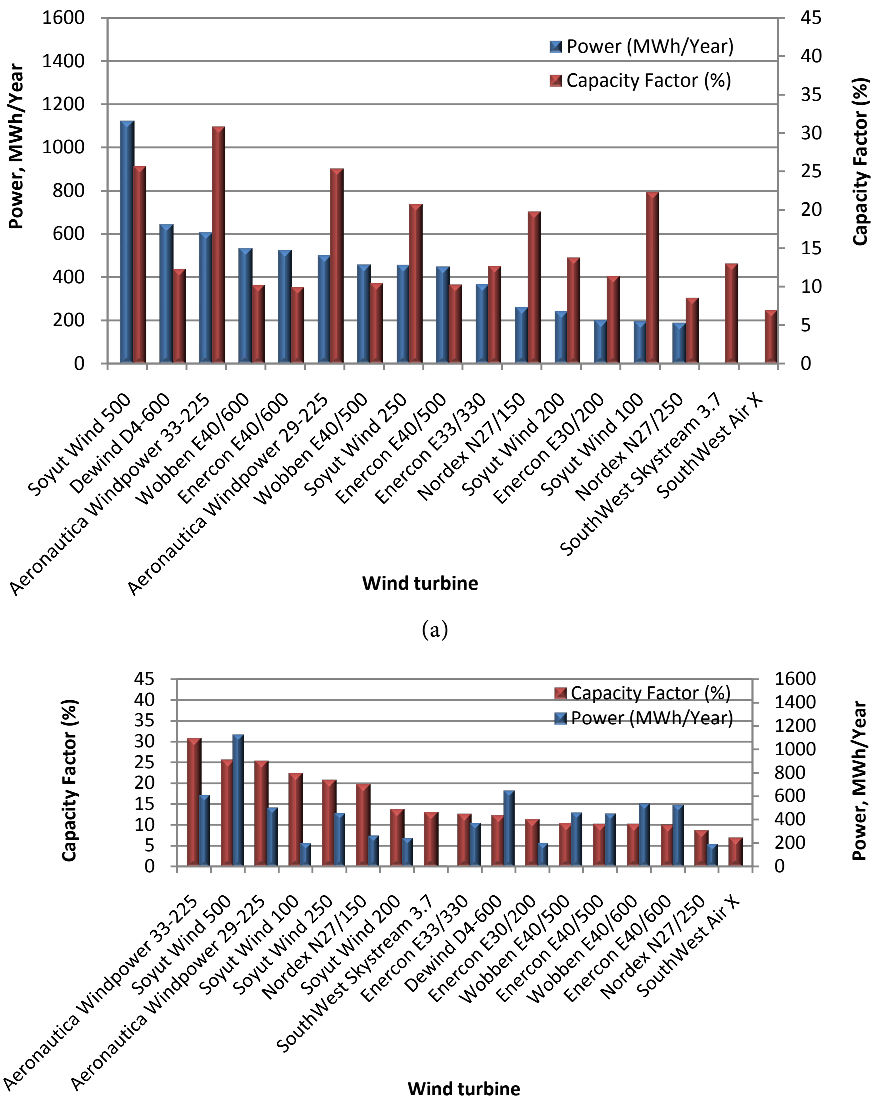


Figure 15. Annual power output and capacity factor from different machines at group III.

6. Conclusion

The wind data analysis presented in this paper in terms of annual, and seasonal variations in Al-Baha region, which is located in the south of Saudi Arabia. It can be concluded that in group III, the mean wind speed was ranged from 5.4 m/s to 5.9 m/s during 40 years (1981-2020) at 50 m above ground level. The second highest mean wind speed for group VI (5.1 - 5.6 m/s), while the lower values in group V. The highest wind speed 6 m/s or more is observed in group III from January to March and also for July. The frequency analysis assures the availability of wind above 4 m/s for 79% of the time during the entire year at 50 m above the ground surface at the site of group III. Wind energy generation was considered for fifteen wind machines of different sizes. It was found that the Soyut wind 500 machines with a rotor diameter of 39.2 m at 50 m hub height and with a rated power of 500 kW produced maximum energy of 1420 MWh/Year.

The highest power output values occur in the winter and summer seasons (375 MWh/Year) from Soyut wind 500 machines, while the capacity factor values were 41% and 32%, respectively. The highest capacity factor of 41% was obtained at 50 m hub height for Soyut wind 500 machines. The main outcome of this work is to help policymakers with long-term planning, wind energy development, and attracting investment in the northeast area of Al-Baha region, KSA.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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