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WIND ENERGY ASSESSMENT FOR THE CAPITAL CITY OF JORDAN, AMMAN

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In this study, the meteorological statistics recorded of seven-year wind speed data of the capital city of Jordan, Amman at height 10 m is utilized to assess the potential of wind energy. Also, statistical assessment of wind characteristics is evaluated by the two-parameter Weibull function. Monthly and annual wind speed variation is also analyzed. The study shows that Amman city is more suitable for small-scale wind turbine farms with the current wind speeds. The values of the shape Parameter K, and scale Parameter c show a various ranges between (1-1.5) and (1.5 m/s - 3.5 m/s), respectively. It was also noticed that the annual mean wind speed $\bar{v}$ is between 2.2 and 3.02 m/s. Results also showed that the highest wind power density is in June whereas the lowest is in October. In wind direction estimation, it was found that most of wind direction for the seven-years is between the southwest and the northwest, i.e. (135°-215°).

Key words: Wind energy, Weibull distribution, Amman, Jordan

INTRODUCTION

Exploitation of energy resources is a paramount index of country development and economic prosperity. A big part of the world's electricity demand has been covered by the generated power from burning fossil fuels in thermal power plants. Environmental pollution and pollutants released from sundry sources such as carbon dioxide, sulfur oxides and nitrogen oxides have been causing negative impact on the ozone layer and the atmosphere. Due to the risks of burning fossil fuels, such as environmental pollutions and health damage, World organizations have made great efforts towards the use of clean sources of energy like renewable energy. Among the renewables, a concern in wind energy has been increasing and researchers have endeavored the development of wind energy systems to make it more reliable and more economical [1]. Wind energy considered as one of the most paramount clean energy sources by virtue of its sustainability, availability, environmentally friendly and cost-effective. It has been estimated that there is more than 10 million MW of wind energy are constantly available on the earth's surface [2]. Wind power industry has shown a great development in the recent years since the use of wind turbines for electricity generation. The global annual installed wind capacity between the years 2001 and 2017 is shown in Figure 1. The installed capacity increased in a continuous way in the years 2001-2015 except the year 2013 were the capacity decreased by about 25% relative to 2012. In 2017, the installed capacity was about 52.49 GW with an annual decrease of 3.8% relative to 2016 and 17.5% relative to 2015 [3].

Electricity generation in Jordan depends heavily on the imported gas for meeting the demand on the power. The domestic energy resources cover about 4% only of the country's power demand [4]. The high price of importing fuel puts a pressure on the government to reconsider the policies of energy consumption. The new strategy of Jordan's energy requires that at least 10% of the country's energy must be generated from renewable resources by 2020.

Wind energy in Jordan is being taken into account because of the international trend of the utilization of renewable sources of energy instead of the fossil fuels [5]. The generated power from wind resources was 449.2 GWh in 2017 with an annual growth rate of 15% compared to the year 2016, which covers only 2.71% from the peak load [6].Over the past two decades, a few studies evaluated the potential of wind energy in Jordan;the studies showed that the country has an effective wind potential on sundry locations [7,8,9]. The global warming led to climate changes like rising the temperature; this rising will impact the wind energy and cause a large change in wind speeds in several places in the world [10]. This study will use the last available wind data in order to assess the potential of wind energy in the last 8 years.

Potential of wind energy can be Determined for a specific location through investigating the cognizance of wind characteristics, like the wind direction, speed and availability. The distribution of wind speed ranges varies greatly in the similar geographic terrain due to wind system characteristics that may result in uneven power output. Thus, wind distribution at various timescales or wind speed modeling is important to assess the potential of the wind resources of a specific location duly [11]. Moreover, the speed of the wind increases with the increase of the altitude, particularly in the coastal regions. Wind is also flowing through and over land constrictions, leading to regions of higher or lower flow and turbulence with a constant influence due to its large period of oscillation which means a small frequency [12]. In this paper, we determine the potential of wind energy in the capital city

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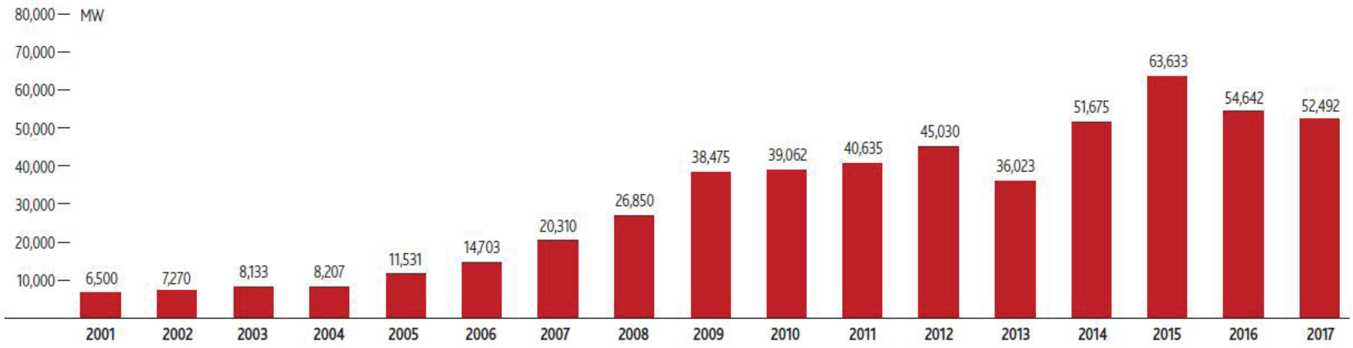

Figure 1: Global annual installed wind power generation capacity for 2001–2017 [3]

of Jordan, Amman. The Weibull distribution function is employed utilizing 7 years data (2010-2016). Moreover, the annual and monthly wind speed variation is analyzed. The Weibull distribution, wind power density and wind energy density are also determined.

Jordan climate

Jordan is an Arab country located in south-west Asia, strategically at the intersection of the continents of Asia, Africa and Europe, with a total area of 89,342 km^2. Jordan is bordered by Iraq from the northeast, the kingdom of Saudi Arabia (KSA) from the south, Syrian Arab republic from the north and Israel, Palestine from the west. It lies at (32.05N) latitude and (36.06E) longitude. It is mainly consists of an extensive plateau between 700 m and 1,200 m high, divided into ridges by valleys and gorges, and a few mountainous areas. Jordan climate varies throughout the country. It is mainly has three ecological zones as shown in Figure 2. The Jordan valley characterized by the moderate climates; warm in winter (19^o-20^{o}C) and hot in summer (38^o-39^{o}C). The western highlands, with a cold winter (9^o-13^{o}C) and warm summer (26^o-29^{o}C). The Badia with a cold winter (14^o-16^{o}C) and hot summer (35^o-37^{o}C) [13,14,15]. The first rainy day start at the mid of November and continues to the end of March. Snow occasionally falls in Amman, Ajloun, Jarash, Irbid and some of the western mountain ranges during December- February.

Data collection and site description

Amman (31^{o}59'N 35^{o}59'E), is the capital city of Jordan. It lies in north-central of the country with an elevation of 772 m, and a land area of 1680 km^2. It is the main and highest populated city in Jordan. At the 2016 census, its population was four million, which represents more than 42% of the country's population [17]. The data on wind speeds for the current study are taken from Jordan meteorological department. It was measured and recorded at the height of 10 m above the ground surface for seven-year period (2010-2016).

ANALYSIS PROCEDURE

One of the most critical factors in evaluating the potential of wind energy in a specific location is to measure

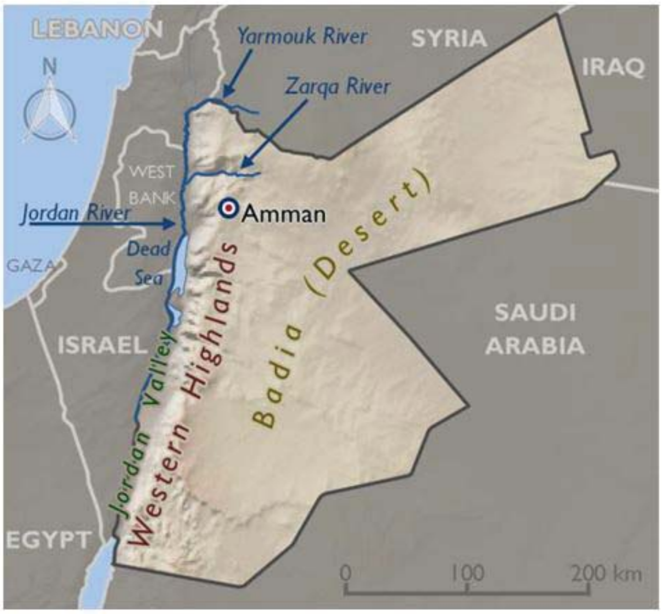

Figure 2: Jordan ecological zones map [16]

the wind speeds in that site. The availability of the wind speed distribution from the site means that the power potential and the economic feasibility can be determined in an easy way. However, the obtained wind speed data has a wide range and different observation techniques, which require more parameters to explain the behavior of the collected data. One of the most effective and practical procedures is the use of a distribution function [18]. Among the used distribution methods in the literature on wind energy and the methods used to evaluate their parameters, the Weibull distribution was a very effective way with a number of advantages over the other methods [19]. The Weibull distribution consists of two parameters which they provide an accurate description of the wind speed distribution frequency and wind energy density. The Weibull distribution function for wind speed can be expressed as follows:

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

This equation refers to the fraction of time whereby the wind speed dominates at specific direction of the particular site [19,20]. Where F(v)is known as the probability of observing wind speed v, c is the Weibull scale parameter and k is the dimensionless Weibull shape parameter.

The Weibull parameters kandc, together they can describe the wind potential of a particular region. The scale parameter, c, is an indicator of how much the available wind for the location, whereas the shape parameter k is an indicator of how peaked the wind distribution is [22]. According to Justus et al. [23] the parameters can be expressed as follows:

$$k = 0.83\,\overline{v}^{\,0.5} \tag{2}$$

$$c = \frac{\overline{v}}{\Gamma(1+\frac{1}{k})} \tag{3}$$

Where $\overline{v}$ is the averaged wind speed and Γ is the gamma function.

Weibull distribution function showed a high effective result in several studies [23, 24, 25,26]. The main drawback of this method is that it can't evaluate the probabilities of observing zero or very low wind speeds accurately [28].

Wind power density

The total obtainable power from the wind that is naturally flowing through the swept area of the turbine blade, and it can be expressed as follows:

$$P(v) = \frac{1}{2}\rho A v^3 \tag{4}$$

From this equation, we can note that the power is directly proportional to the cube of wind stream velocity. By dividing power on the swept area of the blade, we can note that the power depends only on the density of the air and the velocity of the wind, which means the size of the turbine, will not affect the estimated values of the power density. The average wind power density can be calculated through the use of the Weibull function as follows:

$$\frac{P}{A} = \int_0^{\infty} \frac{1}{2}\rho v^3 f(v)dv = \frac{1}{2}\rho c^3\,\Gamma\left(\frac{k+3}{k}\right) \tag{5}$$

Where ρ is the density of the air at sea level with a temperature of 15°C and a pressure of 1 atm.

Wind energy density

The density of wind energy can be determined directly after evaluating the wind power density of a site, and it can be easily calculated through a desired time duration T as follows [29]:

$$\frac{E}{A} = \frac{1}{2}\rho c^3\left(\frac{k+3}{k}\right)T \tag{6}$$

The most probable wind speed

The most probable wind speed V_{mp} is a significative wind speed that requires to be estimated within the evaluating of wind energy. The importance of this speed is indicated in determining the most frequent wind speed for a given wind probability distribution and it can be calculated using the following equation [30]:

$$V_{mp} = c\left(1-\frac{1}{k}\right)^{\frac{1}{k}}\ (m/s) \tag{7}$$

Wind Speed Carrying Maximum Energy

Wind speed that contains the maximum amount of energy $V_{max,E}$ is also considered as a meaningful speed that needs to be evaluated. It represents the maximum possible energy at a particular site, and it can be calculated using the following equation [30]:

$$V_{max,E} = c\left(1+\frac{2}{k}\right)^{\frac{1}{k}}\ (m/s) \tag{8}$$

RESULTS AND DISCUSSION

Wind speed data for the capital city of Jordan, Amman over duration of seven-year (2010-2016) were analyzed. Depending on these data, the analysis of the wind speeds was carried out by using the method of two-parameter to estimate the Weibull distribution. Calculations were also made to determine the two-parameter of the Weibull k and c. The assessment of wind potential of the site was also made by evaluating the wind power density and wind energy density.

Monthly Wind Speed Variations

The values of the monthly mean wind speeds $\overline{v}$ and the Weibull parameter *c* and *k* at 10 m elevation are shown in Table 1 for the capital city of Jordan, Amman. The monthly variations in mean wind speed are shown in Figure 3. It is observed that the values of the monthly average wind speed during the period of the study (seven years), don't vary too much and it was almost in the range of 1.5 m/s to 3.5 m/s. July 2014 showed the most elevated mean wind speed with a value of 4.555 m/s, November 2010 showed the lowest mean wind speed with a value of 1.0 m/s. It is also noticed that the entire year wind speed has the lowest value in October and the highest value in June ranges from 1.555 m/s to 4.388 m/s. The high wind speed in June is due to the hot dry air that comes from the desert under the low pressure which produces a strong wind. The peak load in Jordan occurs in summer season, exactly, from the beginning of June until the end of September due to the extra usage of air conditioners as a result of dry climate, elevated temperatures and holiday season for many Jordanian expatriates[31], which suggests the advantage of adopting the wind energy as an alternative source of energy.On the other hand, the ranges of the shape parameter

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Table 1: Monthly average wind speed and Weibull parameters (k,c) for Amman

Month	Parameters	2010	2011	2012	2013	2014	2015	2016
Jan	$\bar{v}$	2.389	2.055	2.611	2.555	1.861	3.00	2.833
	k	1.283	1.190	1.341	1.327	1.132	1.438	1.397
	c	2.579	2.180	2.844	2.778	1.946	3.304	3.108
Feb	$\bar{v}$	2.750	2.750	2.889	2.305	2.166	3.833	2.222
	k	1.376	1.376	1.411	1.260	1.222	1.625	1.237
	c	3.009	3.009	3.173	2.480	2.314	4.281	2.380
Mar	$\bar{v}$	3.028	2.111	2.667	2.889	2.972	3.472	3.250
	k	1.348	1.334	1.157	1.341	1.383	1.671	1.229
	c	3.337	2.247	2.910	3.173	3.272	3.860	3.599
Apr	$\bar{v}$	2.639	2.583	1.944	2.611	2.778	4.055	2.194
	k	1.411	1.320	1.397	1.283	1.503	1.565	1.464
	c	2.877	2.811	2.047	2.844	3.042	4.540	2.347
May	$\bar{v}$	2.889	2.528	2.833	2.389	3.278	3.556	3.111
	k	1.411	1.320	1.3978	1.283	1.503	1.565	1.464
	c	3.173	2.745	3.108	2.579	3.632	3.957	3.435
Jun	$\bar{v}$	3.556	2.917	2.694	3.2778	3.722	4.389	3.000
	k	1.565	1.417	1.362	1.502	1.601	1.739	1.437
	c	3.957	3.206	2.943	3.632	4.152	4.926	3.305
Jul	$\bar{v}$	3.194	2.389	2.889	3.167	4.555	3.250	3.250
	k	1.483	1.283	1.411	1.477	1.771	1.496	1.496
	c	3.534	2.579	3.173	3.501	5.118	3.599	3.599
Aug	$\bar{v}$	2.389	2.722	2.917	2.805	3.778	2.639	3.250
	k	1.283	1.369	1.417	1.390	1.613	1.348	1.496
	c	2.579	2.976	3.206	3.075	4.217	2.877	3.599
Sep	$\bar{v}$	2.111	1.916	1.861	2.472	3.694	1.444	2.833
	k	1.206	1.149	1.132	1.305	1.595	0.997	1.397
	c	2.247	2.013	1.946	2.679	4.119	1.443	3.108
Oct	$\bar{v}$	1.778	1.667	1.639	1.861	2.750	1.556	1.805
	k	1.107	1.071	1.062	1.132	1.376	1.035	1.115
	c	1.846	1.712	1.678	1.946	3.009	1.577	1.879
Nov	$\bar{v}$	1.000	1.500	1.694	1.472	2.778	2.167	2.361
	k	0.83	1.016	1.080	1.007	1.383	1.222	1.275
	c	0.905	1.510	1.745	1.476	3.042	2.314	2.546
Dec	$\bar{v}$	1.778	1.500	2.167	2.639	1.805	1.830	2.861
	k	1.107	1.016	1.222	1.348	1.115	1.124	1.404
	c	1.846	1.510	2.314	2.877	1.879	1.913	3.140

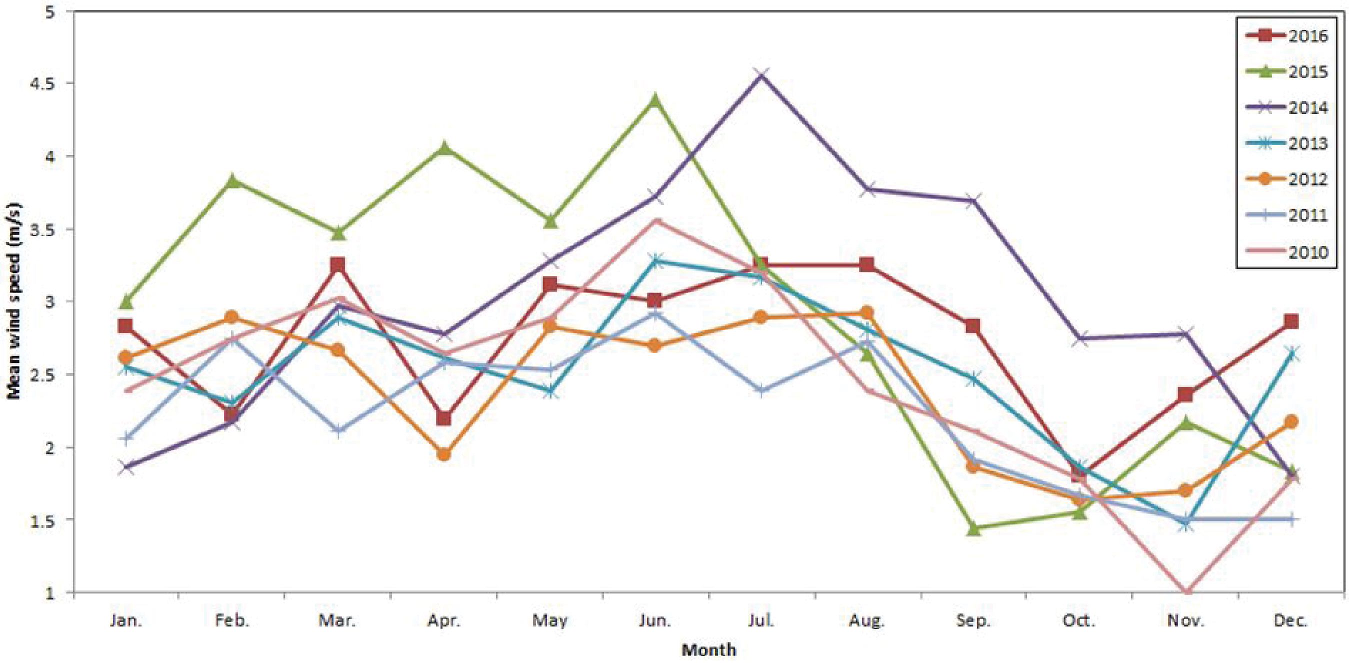

Figure 3: Monthly mean wind speeds for Amman city (2010–2016)

Table 2: annually ($\bar{v}$,k,c,V_{mp},$V_{max,E}$,P/A ,E/A) at 10 m height

Parameter	2010	2011	2012	2013	2014	2015	2016
$\bar{v}$	2.458	2.220	2.400	2.537	3.012	2.933	2.747
k	1.301	1.237	1.286	1.322	1.440	1.421	1.376
c	2.662	2.377	2.593	2.756	3.318	3.225	3.006
V_{mp} (m/s)	0.865	0.624	0.805	0.947	1.457	1.371	1.170
$V_{max,E}$(m/s)	5.444	5.176	5.379	5.533	6.073	5.983	5.772
P/A (W/m^2)	31.185	25.232	29.664	33.335	48.378	45.626	39.562
E/A (KWh/m^2)	273.182	221.037	259.855	292.016	423.790	399.689	346.562

are varying from 1.2 to 1.5, with some having higher or lower values than the ranges. Whereas the range of the scale parameter is between 2 m/s and 3.5 m/s with some values less than 2 m/s or more than 3.5 m/s.

Annual Wind Speed Variations

The annual mean wind speeds can be calculated by averaging the available wind data during the whole year for Amman. The average value for each year from 2010 to 2016 is listed in Table 2. The averaged results show that most of wind speeds are lower than 3.1 m/s with a range between 2.2 m/s to 3.02 m/s. The most elevated mean wind speed is 3.012 and it appears in 2014 whereas the lowest mean wind speed appears in 2011 with a value of 2.220 m/s. Overall, Amman city is a promising site for utilization wind energy and it will be more suitable for small-scale wind turbine farms with the current mean wind speeds, as illustrated in the classification system of the Pacific Northwest National Laboratory [1].

Wind power and energy density

As mentioned before, wind energy and wind power density are very important indicators in estimating the potential of wind energy in any particular site. For that, both of them are evaluated using Equation 5 and 6, respectively. The calculated results are shown in Table 2, Figure 4 and Figure 5. In the year 2014, the wind power density was the highest during the studied period with a value 48.378 W/m^2, whereas the lowest value was 25.232 W/m^2 in the year 2011. The values of the yearly energy density were ranging from 221 KWh/m^2 to 424 KWh/m^2. Moreover, the maximum wind energy density between the years 2010-2016 was in June whereas the minimum was in October as illustrated in Figure 5. Further, the wind speeds which carrying the maximum energy and the most probable wind also listed in table 2. The highest values for both speeds were 6.073 m/s and 1.457 m/s, respectively, in the year 2014.

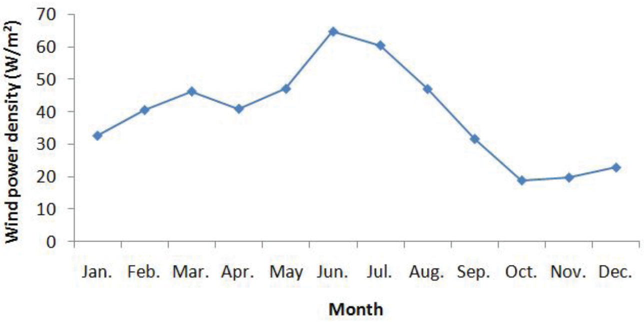

Figure 4: Monthly variation of the wind power density for whole years (2010-2016) in Amman

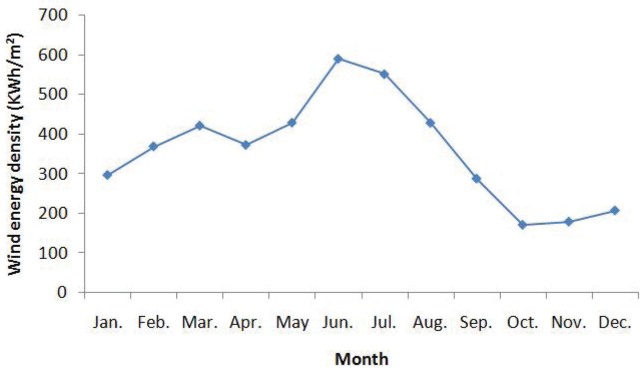

Figure 5: Monthly variation of the wind energy density for whole years (2010-2016) in Amman

Weibull Distribution

Shape parameter k and scale parameter c of the Weibull distribution are evaluated using equation 2 and equation 3, respectively, and listed in table 2. The monthly range of the shape parameter values is between 1 and 1.5, while the monthly range of the scale parameter is in the range of (1.5-3.5) m/s. The maximum values of the annually shape parameter and scale parameter were 1.421 and 3.318 m/s in 2014, respectively. Whereas, the minimum values were 1.237 and 2.377 m/s in the year 2011, respectively.The high values of the shape parameter indicate high stability of wind speeds at the studied site, whereas the high values of the scale parameter denote the site is windy.

The frequencies of the Weibull distribution for the years 2010, 2013, 2016 are shown in figure 6. These frequencies can foresee the energy that can be generated from the conversion system in the site. It was observed that the three selected years had shown the same frequency pattern. Moreover, the most frequent speed was between 2 m/s and 3 m/s during all studied years.

Wind direction

Proper identification of wind direction is also critical along with other parameters while evaluating wind potential of a particular site. In figures (7-9) polar diagram for Amman cityduring three years (2010, 2013, 2016) are shown. Wind directions are shown monthly with the percentage of the most prevalent.It was noticed that the prevailing wind direction varied from month to month as well as from year to year.In 2010, 2013, the most frequent wind direction was predominantly by west and southwestern wind, whereas in 2013, 68% of the wind was in the direction of west and northwestern.Overall, most of the wind was blowing in the direction between the southwest and the northwest although they don't have the same magnitude. Moreover, there is a monthly variation in the direction of the wind. In January 2016, for example, 54% of the wind was blowing in the west direction, whereas in November 2016, only 19% of the wind was in the west direction.

CONCLUSIONS

Meteorological records constitute a reliable data for assessing the potential of wind energy in any particular site. In this study, wind speed, wind direction and wind energy potential for the capital city of Jordan, Amman were investigated, using meteorological records over seven years (2010-2016). The wind energy potential of the city has been studied based on the Weibull distribution method (two-parameter function).The main findings and conclusions of this study are presented below:

1. The monthly mean wind speed was varying between 1.5 m/s and 3.02 m/s, whereas the yearly wind speed was ranging from 2.2 m/s to 3.02 m/s.
2. The highest monthly wind speed takes place in June; due to the hot dry air that comes from the desert under low pressure.
3. The shape parameter *k* values were between 1 and 1.5. The highest scale parameter *c* was found in July with a value of 5.118 m/s, whereas the lowest value was 0.905 m/s in November.
4. The maximum value of the wind power density is 48.378 w/m^2 in 2014, whereas the minimum is 25.232 w/m^2 in 2011.
5. The most probable wind speed is 1.457 m/s, whereas the wind speed that carrying the maximum energy is 6.073 m/s which founds in the year 2014.
6. The data also showed that most of the wind was blowing in the direction between the southwest and the northwest although they don't have the same magnitude.
7. The capital city of Jordan, Amman is more suitable for small-scale wind farms due to the specific range of wind speeds.

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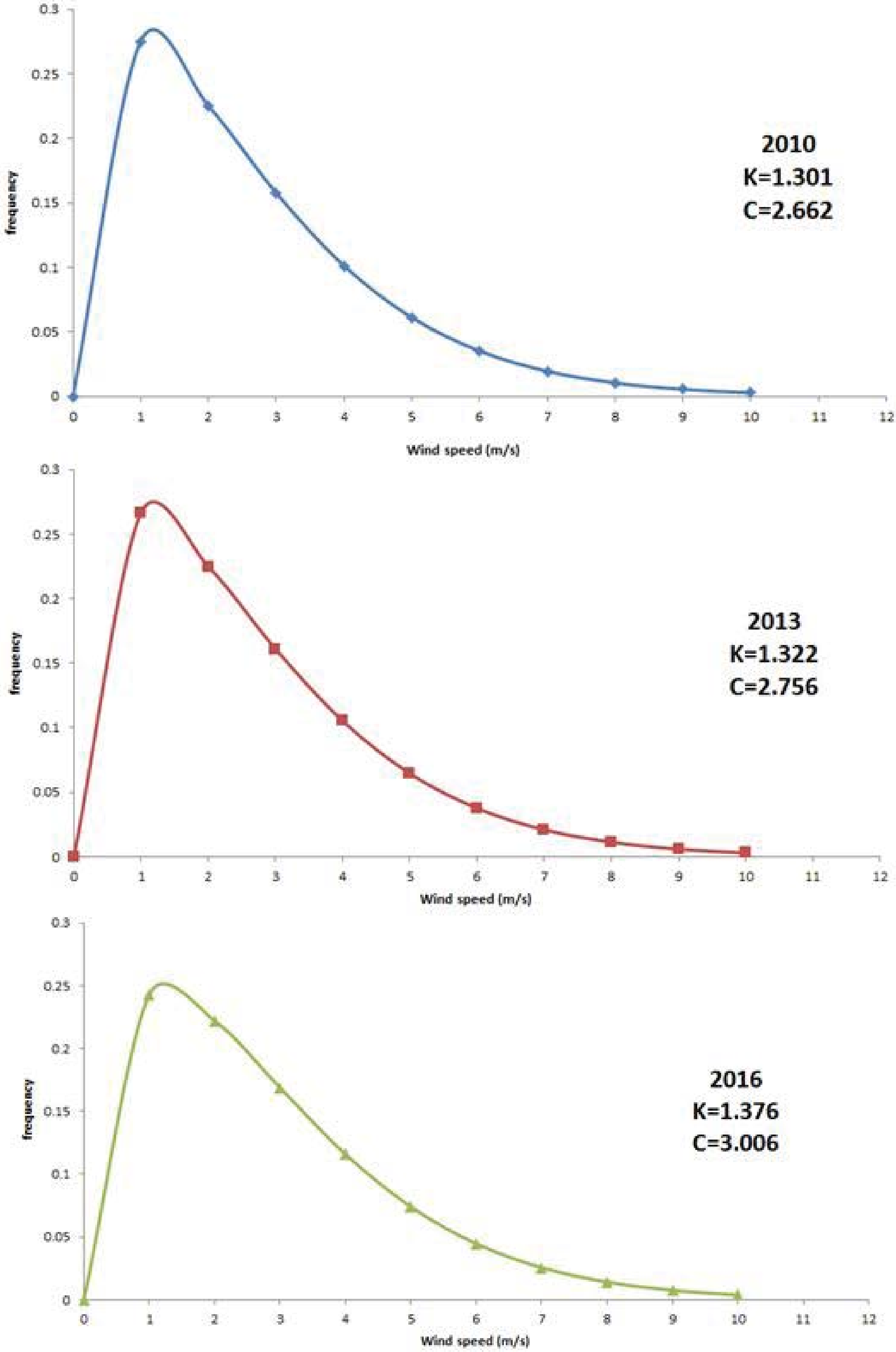

Figure 6: Weibull wind speed frequencies of Amman in 2010, 2013, 2016

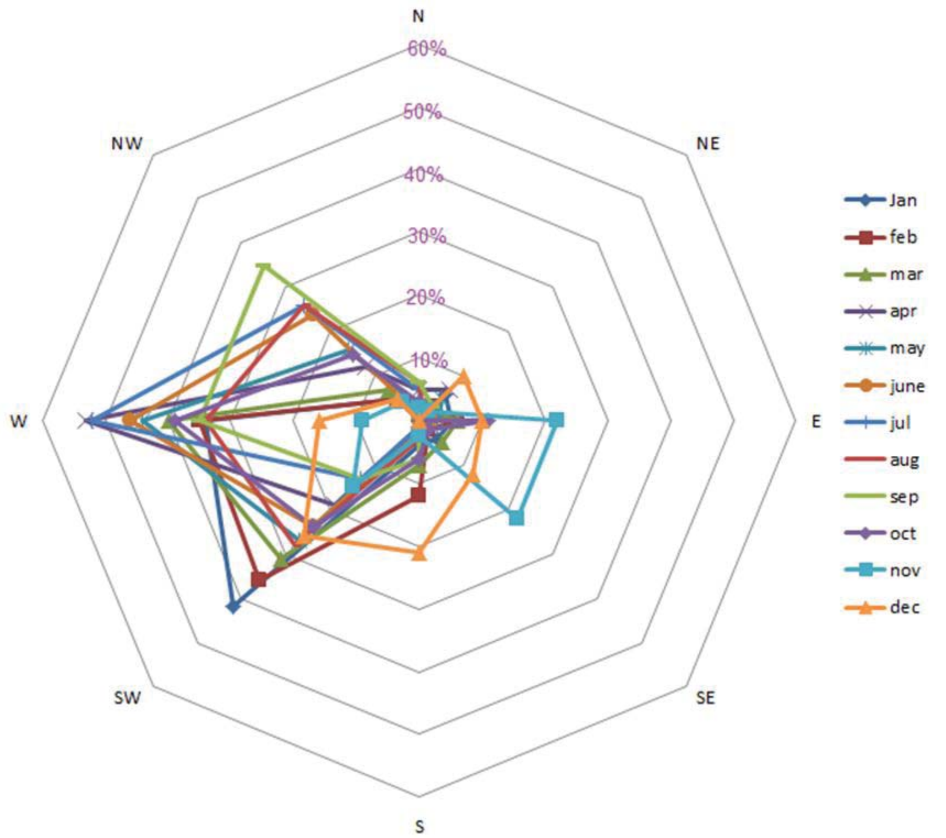

Figure 7: Monthly wind directions for the year 2010

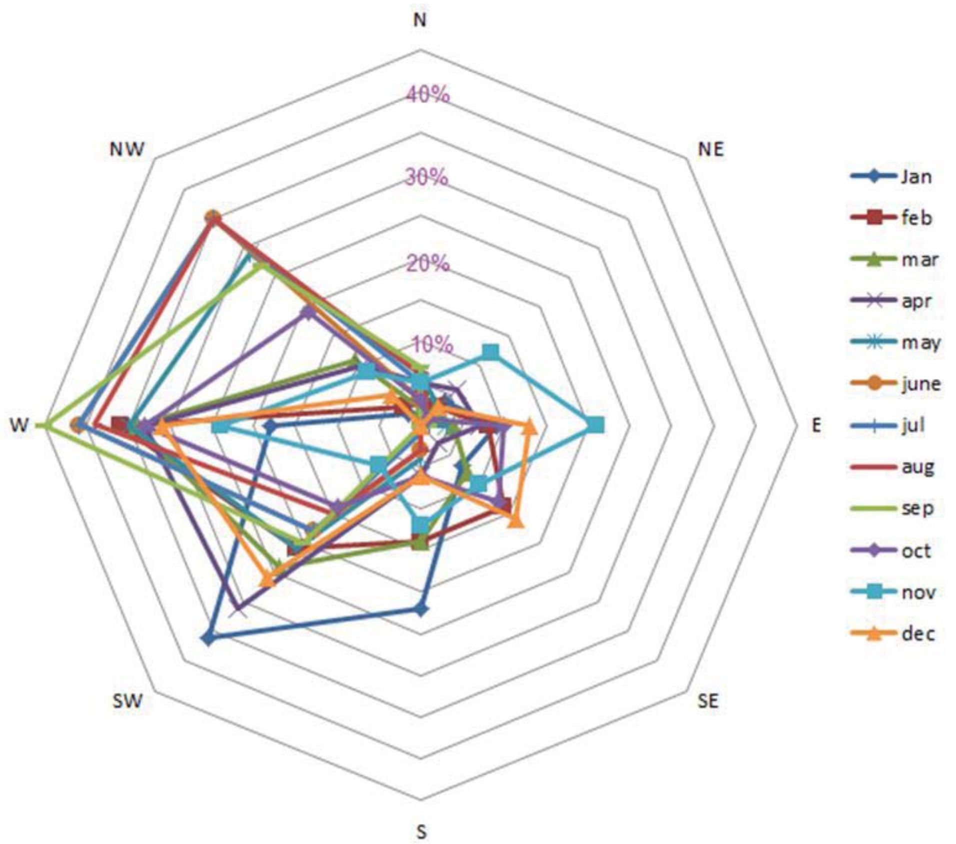

Figure 8: Monthly wind directions for the year 2013

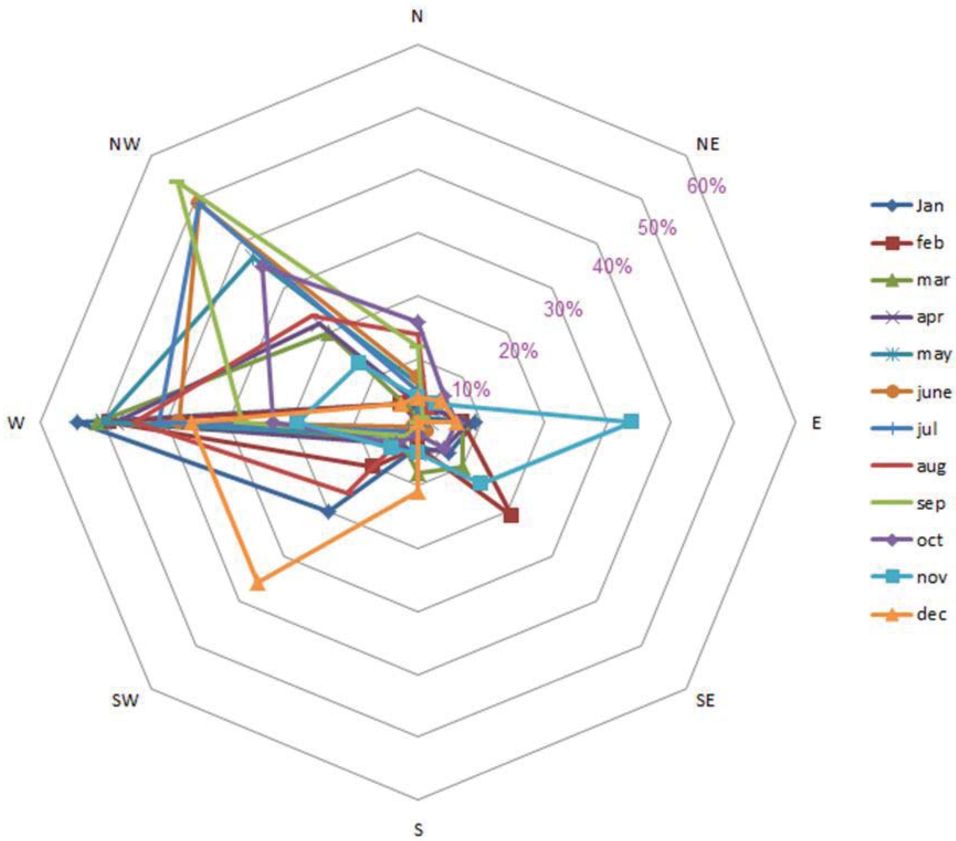

Figure 9: Monthly wind directions for the year 2016

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