Innovative Systems Design and Engineering
ISSN 2222-1727 (Paper) ISSN 2222-2871 (Online)
Vol.8, No.8, 2017

Potential Study for Hofa Farm Development

Ashraf Samarah*

samarah@bau.edu.jo

Hussein Al Ofeishat*

Qatada Damra**

Omayma Bani Salman*

Ghadeer Al Shabaan*

*College of Engineering, Al-Balqa Applied University

** Jordan University of Science and Technology

Abstract

This paper presents a technical assessment of the wind power potential for Hofa area using statistical analysis of measured wind data and power generation data from the current wind farm, and using the characteristics and financial and technical analysis of modern wind turbines characteristics to determine the best alternative for the site development project. Rayleigh distribution is used to model the monthly average data and to simulate the wind power from the turbines. To validate the model we ran the simulation for the current turbines and the results were compared to the actual power data collected from the farm.

Energy calculations, capacity factors and cost of wind energy production were determined for the location with wind machines of different sizes ranging between 1 MW to 3.6 MW. The quantitative estimates of the technical and economic potential are presented graphically. Rayleigh parameter is adjusted to the hub height to estimate the power output of the machine. The energy cost analyses show that all selected sites have high economic potential with unit cost less than $0.035/kWh of electricity. Finally, the results of this study reveal that Hofa site has high potential wind energy and its environmental and energy policy targets can be met by exploitation of wind energy.

Keywords: Hofa Wind Farm, Wind Turbine, Economical Cost, Wind Farm Development,Probability distribution, Power and Energy Curves.

1. Introduction

Life is a continuous process of energy conversion and transformation. The accomplishments of civilization have largely been achieved through the increasingly efficient and extensive harnessing of various forms of energy to extend human capabilities and ingenuity. Energy is similarly indispensable for continued human development and economic growth. Providing adequate, affordable energy is essential for eradicating poverty, improving human welfare, and raising living standards world-wide. And without economic growth, it will be difficult to address environmental challenges, especially those associated with poverty.

Renewable energy is derived from natural processes that are replenished constantly. In its various forms, it derives directly from the sun, or from heat generated deep within the earth. Included in the definition is electricity and heat generated from solar, wind, ocean, hydropower, biomass, geothermal resources, biofuels and hydrogen derived from renewable resources.

As fossil fuel resources have depleted and environmental concern has increased, renewable energy has become a very important engineering sector. It is undoubtable that in the future a large proportion of energy used by humans will be derived from a diverse range of renewable sources.

Wind energy is a source of renewable power which comes from air current flowing across the earth's surface. Wind turbines harvest this kinetic energy and convert it into usable power which can provide electricity for home, farms, schools or business applications on small (residential), medium (community), or large (utility) scales.Wind power has been used for irrigation pumping and milling grain for centuries. In the 20th century small windmills started to be used for electricity production, especially in remote, rural areas. The modern wind power industry took off in the late 1970's when companies, mainly in Denmark, started serial production of wind turbines. These early wind turbines were small by today's standards, but their size and power output increased rapidly.

Wind energy is one of the fastest growing energy sources. Since 2000, around one third of all installed electricity generating capacity in the EU has been wind power. The share of wind power in total electricity production in Europe was 4.3% in 2010EXPLAINED [1], but with huge differences among the Member States: Germany and Spain together account for more than half of the total installed capacity in Europe. In Denmark, wind energy contributes more than 28%of the total electricity production of the country[2].

1.1 Wind Energy in Jordan

Hofa wind farm is located on the hills of the Irbid province, 80 km to the north of Jordan's capital, Amman. It consists of five pitch-regulated Vestas, 225 kW wind turbines, which were put in operation in June, 1996. The wind turbines were erected in one row on an area of complex terrain and different ground levels.

Wind atlas of Jordan indicates that large areas have average annual wind speeds in excess of 6-6.5 m/s; some more limited areas have an average wind speed above 7 m/s. Two wind farm pilot plants have been commissioned in Jordan. The first one is at Al Ibrahimya which consists of four wind turbines each one is 80 KW with a rated wind farm power of 320 kW established in 1988 with annual energy production of about 750 MWh and the second one is at Hofa which consists of five wind turbines each one is 225 KW with a rated wind farm power of 1,125 kW established in 1996 with annual energy production of 2.4 GWh. There are many other wind energy water pumping stations especially in the remote areas using multi blade mechanical wind pumping systems[3].

Our study on Hofa was based on monthly average wind speed and electricity generated data from 1996 to 2006.We used this data to build a statistical model based on Rayleigh distribution. We used this model to simulate the power output of different proposed wind turbines including the one that has been running on the farm so far to validate the model by comparing the simulated data with the collected data. For the detailed study we used the daily average wind speed data from the year 1998 to build a more detailed and sophisticated Weibull distribution. And we estimated the power from the winner turbine that the first model referred to.

2. Literature review

M. A. Alghoul, M.Y.Sulaiman, B.Z.Azmi and M. Abd. Wahab (2007) have made a study entitled "Wind Energy Potential of Jordan"[4], the purpose of this study is to investigate the wind energy potential in different location in Jordan, the researchers have analyzed data over a period of nine years (1989-1997) and the data was fitted to the Weibull distribution function, the researchers chose five different locations in Jordan (Ras.Monief, Aqaba, Amman, Irbid and Der Alla), the main result of the study is as following: The annual mean values of the wind speed of the observed and theoretical distributions are 6.10 ms^{-1} and 6.26 ms^{-1} for Ras.Monief, 4.79 ms^{-1} and4.77 ms-1 for Aqaba, 3.07ms^{-1} and 3.15ms^{-1} for Amman and 3.09 ms^{-1} and 3.13ms^{-1} for Irbid and 2.34ms^{-1} and 2.40ms^{-1} for Der Alla.

Based on the annual wind speed, wind resource for Ras.Monief, Aqaba, Amman, Irbid and Der Alla are varied from very good to poor. The annual mean power density of Ras.Monief, Aqaba, Amman, Irbid and Der Alla are 261.76 Wm^{-2}, 118.95 Wm^{-2}, 57.45 Wm^{-2}, 40.95 Wm^{-2}, and 24.97 Wm^{-2} respectively. Values of the power density obtained from the manufacturer's power distribution curve of a 300MW wind turbine at a hub height of 10 meters are also given for comparison. The result of the analysis showed that only Ras.Monief and Aqaba have good wind energy potential[5].

Ababneh, Mohammad. et.al (2009), have made a study entitled " Investigation of Wind Energy in Jordan" , the purpose of this study is to investigates the status of wind energy in Jordan and illustrates the number and the type of the operating wind farms and its share in the total generated power and to investigate the advantages and disadvantages of using wind energy in electrical power generation, the main result of the study is as following: The advantages of wind energy are flawed mainly by the high initial cost and high generation cost, where the generation costs from wind farms almost over twice that of conventional fossil generation, there are eight main wind farms are used for electricity generation in Hoffa, Al-Ibrahimyya, RasMuneef, Shammakh, Safawey, Umari, Twaneh, and AlJafr.

The total electricity generated using wind energy is 3 GWh, which forms less than 0.04% of the total electricity generated in year 2007 only two wind farms are connected to the grid al–Ibrahimyya and Hoffa. There is a big push to move the wind energy program forward, According to the National Energy Strategy; Jordan should be able to generate 600 megawatts of wind and 600 megawatts of solar energy, 10 percent of the country's energy consumption by 2020[5].

Badran, Omar andAbdulhadi, Emad (2009) have conducted a study entitled "Evaluation of FactorsAffecting Wind Power Generation in Jordan" , the main purposes of this study are; the first part utilizes fuzzy logic methodology to assess wind sites in Jordan and to decide which sites should be given the highest priority with respect to their benefits and costs, and to predict the annual generation for different turbines in the best sites, In the second part, to study the parameters that affect the power generation by wind turbines. The results show that Al Harir site in Al Tafila city is found to be the best choice and should be given the highest priority. It is followed by Al-Fujeij in Al-Shawbak then Al-Kamsha in Zarqa[6].

Mohsen, Mousa (2010) have made a study entitled "Potential for Wind-Powered Desalination Systems in Jordan", the main purpose of this study is to seek to address the enhancement of the overall quantity of freshwater available in Jordan, by exploring the potential for integrating wind power and desalination technologies to increase water supplies, the researchers have summarized desalination and wind technologies including growth trends, costs, and emerging technological advancements. These descriptions provide snapshots of the current status of these technologies and their markets, as both independent and integrated technologies. Meteorological data is then used to generate a map of Jordan wind-powered desalination potential "hot spots", the main result of the study is as following: the integration of these two technologies will become an attractive option for increasing regional water supplies by producing freshwater from brackish and seawater, According to the analysis, Jordan has few potential "hotspots" for the implementation of wind-powered desalination, these areas include Hofa, Kamsha, Aqaba, Tafila, Al-Reesheh and Al – Harir; all average wind speed is above 7 m/s. The water produced is 1690 m^3/day, 1744 m^3/day, 1635 m^3/day, 2660 m^3/day, 1537 m^3/day, and 3074 m^3/day for Hofa, Kamsha, Aqaba, Tafila, Al-Reesheh and Al-Harir, respectively. The study recommended the use of advanced technology such as geographical information systems (GIS) to identify wind-powered desalination hotspots because it allows the user to perform analyses based on spatial reference data[7].

M.H. Abderrazzaq, and O. Aloquili (2008), have conducted a study Entitled "Evaluating the impact of electrical grid connection on the wind turbine performance for Hofa wind farm scheme in Jordan", the main purpose of this study is to evaluate wind farm records and proposes a number of methods to overcome the obstacles associated with the design of large wind turbines. Wind turbine performance at Hofa wind farm scheme in Jordan is taken as a case study. Several cases of grid abnormality such as sudden feeder interruption due to the short circuit, network disconnection, voltage variation and circuit breaker opening affecting wind turbines operation and availability are classified and presented. The weight of such an impact is determined for each type of disturbance associated with electronic problems in the wind turbine[8].

Bataineh, Khaled and Dalalah, Doraid, (2013)conducted a study entitled "Assessment of wind energy potential for selected areas in Jordan". The main purpose of this study is to presents a technical assessment of wind power potential for seven locations in Jordan using statistical analysis to determine the wind characteristic based on the measured wind data. The energy cost analyses show that all selected sites have high economic potential with unit cost less than $0.04/kWh of electricity. The lowest unit cost per kWh is obtained by using GE 2.5 MW at Tafila. Finally, the results of this study reveal that Jordan has high potential wind energy and its environmental and energy policy targets can be met by exploitation of wind energy[9].

M.A. Alsaad, (2013), conducted a study entitled "Wind energy potential in selected areas in Jordan", the main purpose of this study is to set up promising wind farms that are able to feed electricity to the Jordanian distribution authority with excellent percentage of clean energy. Four of these promising locations are investigated in this paper for the possibility of building and investing 100 MW wind turbine in each of these four locations. This study reveals that the total rated wind power that can be generated from the four selected wind farms is 136 MW. On the other hand, the expected total energy that can be produced from the four selected wind farms is $18.9 * 10^3$ GWh[10].

M.A. Abderrazzaqa, and B. Hahn. (2006) conducted a study entitled "Analysis of the Turbine Standstill for a Grid Connected Wind Farm (case study)". The main purpose of this study is to analyze the causes of turbines shutdown in a grid-connected wind farm. Although the average availability of the considered wind farm exceeds 96%, the individual availability of some turbines does not exceed 92%. The result shows that the calm hours in summer are 60% less than the average calm time for the considered wind farm. The distribution of inoperative hours reveals a 300% difference between the original and weighed times of downtime. Also, the frequency distribution of the faults has shown that 42% of turbine shutdowns are caused by network disturbances, 70% of them are attributed to grid disconnections. Finally, the time distribution of the network faults is investigated to illustrate their impact on the turbine standstill[11].

3. Site Selection

Jordan is located in the Middle East. Situated between the longitudes 35^{o} and 39^{o} E and between the latitudes 29^{o} and 33^{o} N with a total area of 92,300 km2. 90% of this area is classified as desert. "Considering the past ten years, i.e. 2000-2009, the population has increased from 4,900,000 up to 5,980,000 with an average annual growth rate of approximately 2.5%"[12].

Jordan is classified by the World Bank as a "lower middle income country". The nominal Gross Domestic Product (GDP) for 2009 was $22.929 billion ($3,828 per capita) achieving an annual growth rate of 3.2%. According to the Department of Statistics, almost 13% of the economically active Jordanian population residing in Jordan was unemployed in 2008. The currency has been stable with an exchange rate fixed to the U.S. dollar since 1995 at JD 0.708 to the dollar[12].

Jordan has experienced an average growth rate of primary energy demands of 5.1% per year over the past ten years. The consumption has risen from 5114 up to 7739 million Ton Oil Equivalent (TOE) according to the data available from the Ministry of Energy and Mineral Resources[13].

Most of the final energy (39%) is consumed by the transportation sector while the industrial and residential sectors equally consume 22%. The rest of final energy is consumed by commercial buildings and public services such as water pumping and street lighting[13].

The most serious challenge of development in Jordan is the lack of water and energy resources. In 2012, Jordan covered 96% of the energy demands by crude oil (CO) and natural gas (NG) while renewable energy resources supplied 2% of the total primary energy, and a very high percentage (96%) of the energy resources (mainly CO and NG) are imported. Energy is produced locally, but in very minimal quantities which make these resources very limited and yields an unsolicited burden on the general budget[13].

There are two wind farms connected to the grid in the northern part of the country; one with a capacity of 320 kW in Ibrahimya, consisting of four stalls regulated by the Tellus wind turbines of 80 kW each, established in 1988 in co-operation with a Danish firm and considered as a pilot project[14]. The other most recent one, has a capacity of 1125 kW in Hofa, consisting of 5 pitch regulated by the Vestas wind turbines of 225 kW each, established in 1996 in co-operation with the German Government under the so-called ELDORADO program [14].

Wind energy is considered one of the most feasible and the most reliable among the renewable energy technologies after hydropower. The utilization of wind energy as a clean natural resource can contribute to reducing environmental pollution and to meet the national plan for having about 6% renewable from the national energy mix. Figure (1) shows the national energy mix as described in the National Energy Strategy[15].

The wind atlas for Jordan in Figure (2)[15], below provides the annual average wind speed all over the country. This atlas was established in 1987 using satellite measurements and has not been updated since. Generally, the most energetic wind is found at a distance of almost 400 km along the western border. At the same time, the lowest wind potential is found at the east, middle and south east of Jordan. However, there are some areas in the northwest, middle, and southwest that have the best wind speed[14].

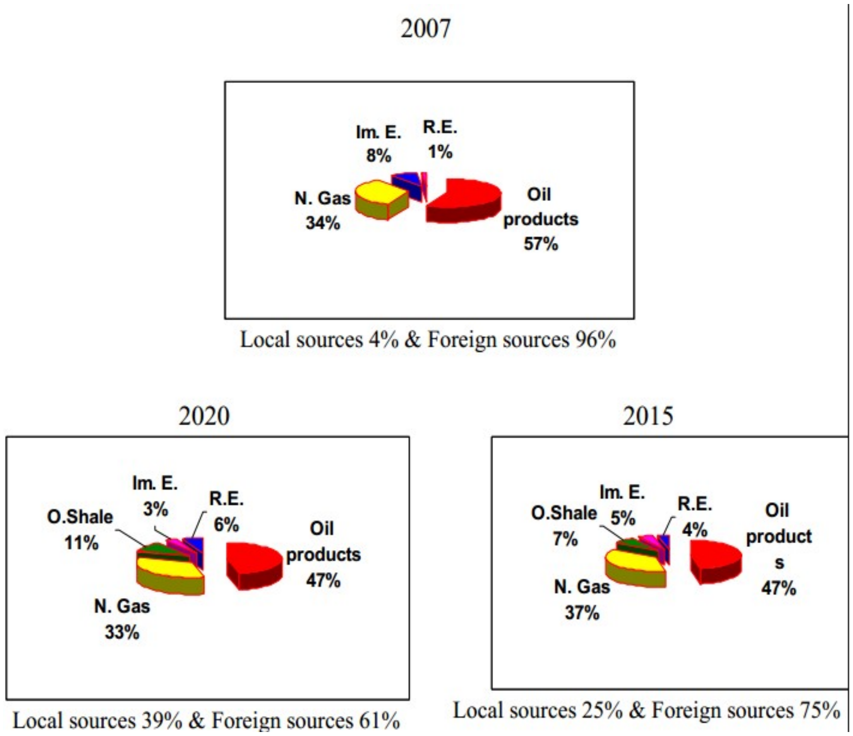

Figure (1): National energy mix as described in the National Energy Strategy[15].

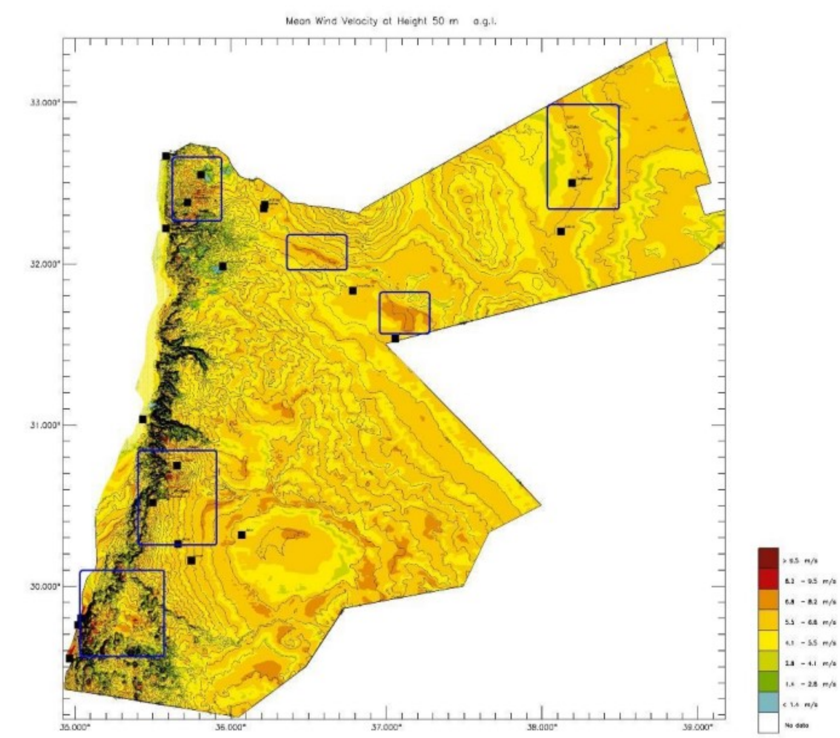

Figure (2): The wind atlas for Jordan[3].

3.1 Reasons for studying Hofa site

A. Data Availability

The site that has been chosen for the study is Hofa and that was for many reasons. One of most important, is the data availability of this site.

B.Located near the populated areas and the main electrical distribution line

Hofais located in the northern part of Jordan around 70 km north of Amman, the capital city of Jordan and on the south part of Irbid as Figure (3) shows Hofa is very close to Irbid city This is located very close to large cities such as Ajloun andJarash, and there are many small villages and towns in that area.According to the Department of Statistics, the population of Irbid is 1,064,400 around 17.8% of the overall population of Jordan. Also, the population of Ajloun is 137,500 around 2.3% of the overall population and the population of Jarash is 179,400 which is around 3% of population. Those statistics explain that Hofais located in a high population density area and it is important to understand the noise effects in case of installing large wind farms in the future [16].

C. Wind speed Indicators

Before building this wind farm, a broad scan of the country was made. The results showed that Jordan is classified into three wind regions according to prevailing wind speed: less than 4 m/s, between 4 and 6 m/s and more than 6 m/s for low, medium and high regions, respectively. But high wind regime is limited to certain districts: most attractive sites are Hofa, in the northwestern corner and Fjeij, near Showbak, and WadiAraba in the south.

D. Topography and Geographical location

Hofa wind farm is located on the hills of the Irbid province,80 km to the north of Amman, Jordan's capital. It consists of 5 pitch-controlled, Vestas 225 kW wind turbine, which were installed and put in operation in June, 1996. They are connected with the medium voltage feeders via step-up transformers. The wind turbines were erected in one row on an area of complex terrain and different ground levels. The Figure 3 below shows a 3D map of Hofa terrains.Notice the valleys that receive the wind coming from the Mediterranean over "MarjBanyAmer", which gets amplified by this natural venturi.

Figure (3): The Hofa wind farm 3D Terrain

Figure (4):(A) The Hofa wind farm, (B): Tree clipping by wind near Hofa wind farm, (C): Rock Exposed Layers, (D) Tree Carpeting.

3.1.3.2 Ecological Indicators

The surface of the earth itself will be shaped by persistent strong winds, with the results called eolian features or eolian landforms. The effects are most pronounced where the climate is most severe and the winds are the strongest. An important use of eolian features will be to pinpoint the very best wind energy sites, as based on very long term data. Figure (4.C) shows how wind exposed the rock layers of the hill where the wind farm is located above.

Other Ecological indicators are the biological indicators. Living plants will indicate the effects of strong winds as well as eolian features on the earth itself. As we can see from Figures 4.B and 4.D show trees that suffer from clipping and even carpeting up the hills.

3.1.3.3 Wind Data Measurements

National Center for Research and development\ERP-Energy Research Program is conducting wind measuring campaign in the promising sites in Jordan as a first stage based on the availability of wind measuring systems at different heights (10,30, 40, 50,60) meters above ground level (a.g.l). The geographic location together with this topographic properties justify why Hofa was one of the first locations to install a wind speed measuring station, three stations at least were installed and dismantled at the site on different intervals, the full data are available from the national energy research center.

The data collected shows that Hofa has a wind average speed of nearly 7.16 m/s which is the most important reason to select Hofa area as a very proper site for energy generation using wind power[9].

3.1.4 Potential Investment Opportunity

The Jordanian government has announced through Jordan Investment Board that it will receive offers from investors to develop and operate Hofa wind farm and Al Ibrahimiya wind farm on IPPs bases. The announcement state that Hofa and Al Ibrahimiya sites are two possibilities for wind power generation projects that could accommodate a minimum [30] MW each at estimated capital cost of [US$800 to US$1,000] / kW (Total Cost JD 17+ million) and eventually expand to 100 MW[17].

4. Wind characteristic analysis

The wind speed data usually presented by the frequency distribution of the wind speeds. And the available wind data for Hofa area is the daily average wind data for one year (1998) and monthly average from 1996 to 2006.

Table (1): frequency distribution of the wind velocity

Frequency distribution of wind velocity			
Velocity	Main V	Days	Cumulative
0-1	0.00	0	0
1-2	1.78	2	2
2-3	2.57	13	15
3-4	3.49	37	52
4-5	4.45	68	120
5-6	5.47	46	166
6-7	6.38	42	208
7-8	7.48	49	257
8-9	8.48	29	286
9-10	9.38	26	312
10-11	10.27	15	327
11-12	11.36	5	332
12-13	12.50	1	333
13-14	13.40	2	335
22-23	22.00	1	336

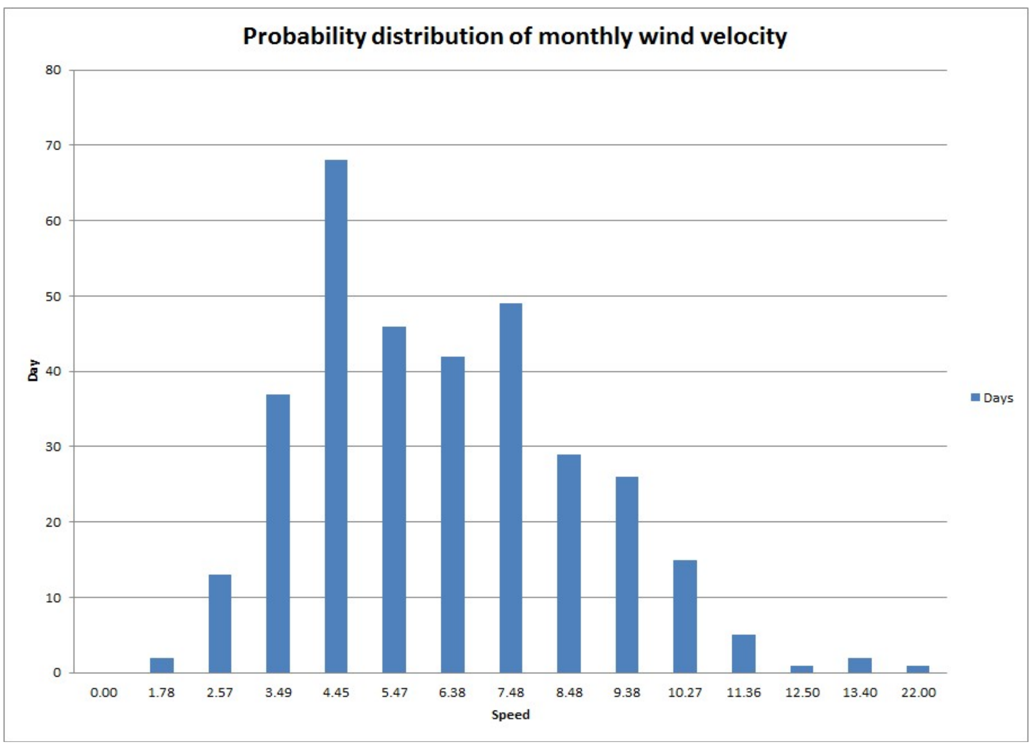

Figure (5):Probability distribution of monthly wind velocity

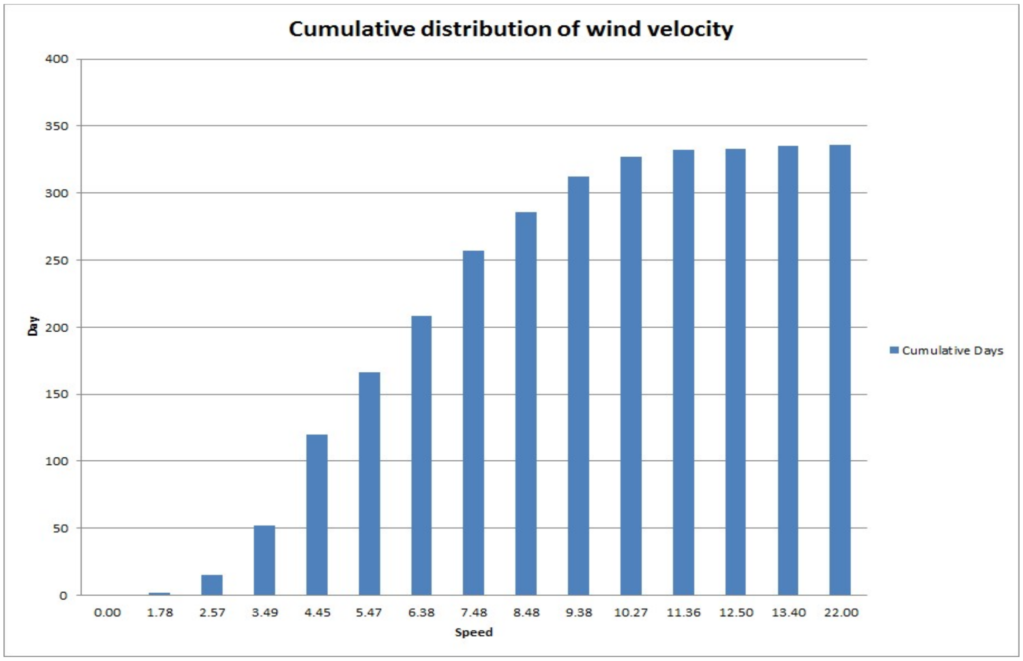

Figure (6): Cumulative distribution of wind velocity

Table (2) : Monthly Average Speed

Monthly Average Speed		
Month	Av. Speed	Av. Genration
Jan	6.12	210,727.00
Feb	6.37	208,217.00
Mar	6.27	217,925.00
Apr	6.05	176,254.00
May	6.09	196,357.00
Jon	6.48	238,070.00
Jul	7.78	294,841.00
Aug	7.06	250,268.00
Sep	5.62	164,855.00
Oct	4.85	100,746.00
Nov	5.21	131,910.00
Dec	5.78	174,437.00

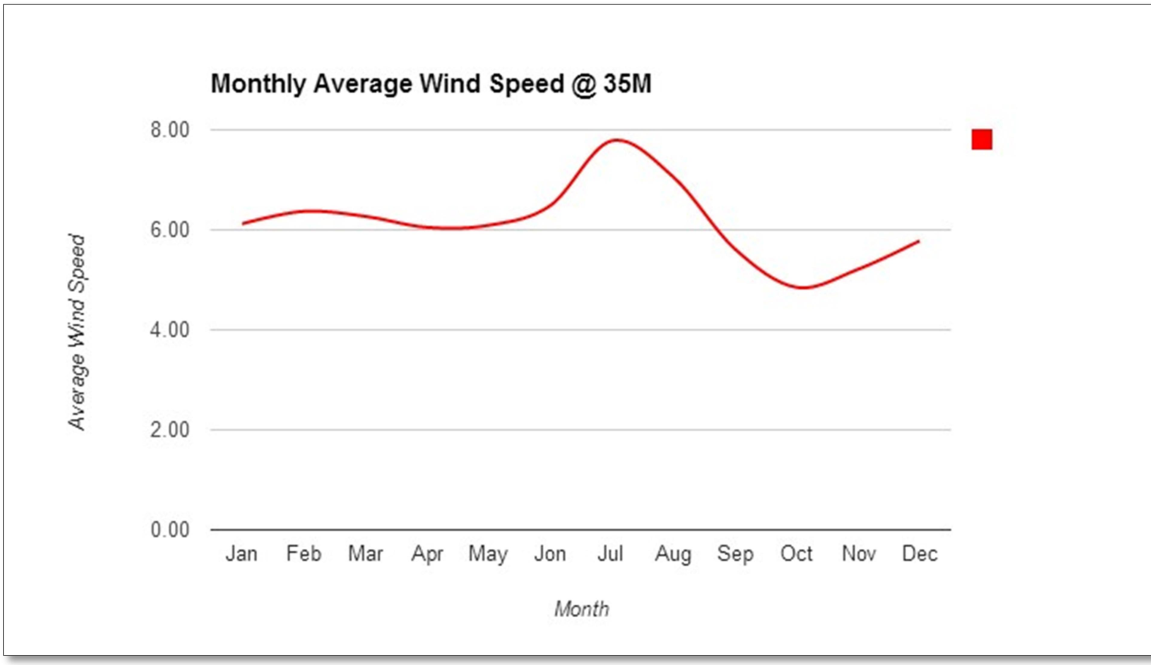

Figure (7): Monthly Average Wind speed @35m.

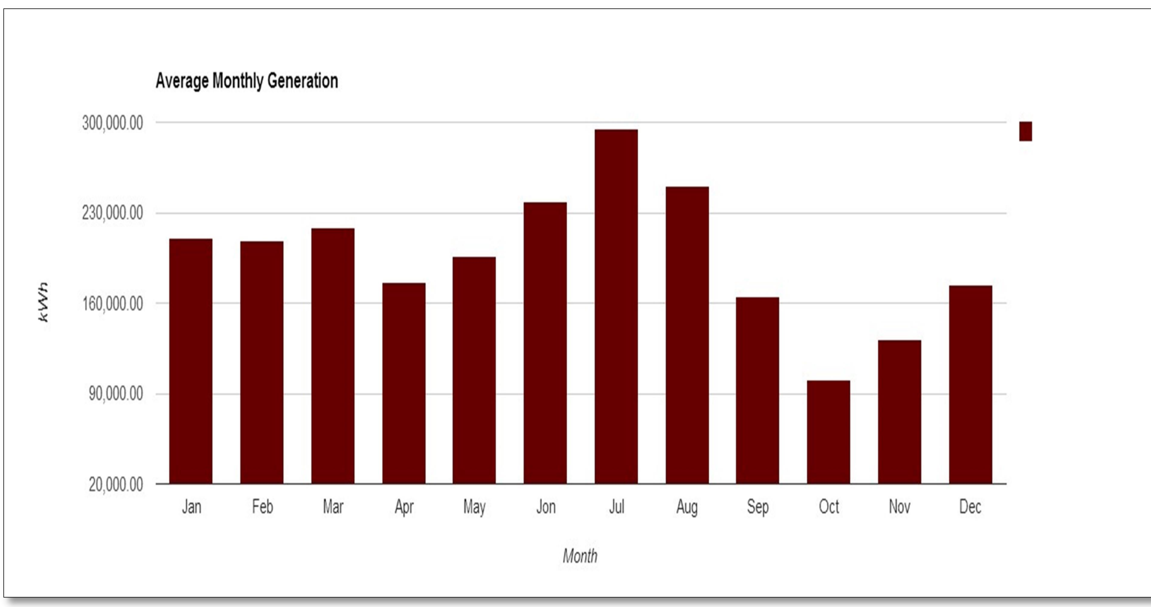

Figure (8): Average monthly generation.

Calculating the output of a wind machine at a particular site requires knowledge of the distribution of the wind speed. Weibull distribution was found to be one of the best functions to fit wind speed experimental data .This distribution is characterized by two parameters: a dimensionless shape parameter k and a scale parameter c (m/s). The probability density function of theWeibull distribution is expressed mathematically as depicted in [18]:

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

And the cumulative density function is given by[18]:

$$F(V) = 1 - \exp\left[-\frac{v}{c}\right]^{k} \quad (2)$$

The Weibull parameters can be estimated using different methods, the method that use in this study is the graphical method and the Standard deviation method and Maximum Likelihood method, and the result was as shown in Table (3)[18].

Table (3): different methods for estimating Weibull parameters.

	Method		
Parameter	graphical	Standard deviation method	Maximum Likelihood method
K	2.7000	3.0260	2.64
C (m/s)	6.4261	8.1084	6.90

The method that have used in the calculation is the Maximum Likelihood method because the error was estimated to be 0.08%, and that consist with the result found in literature.

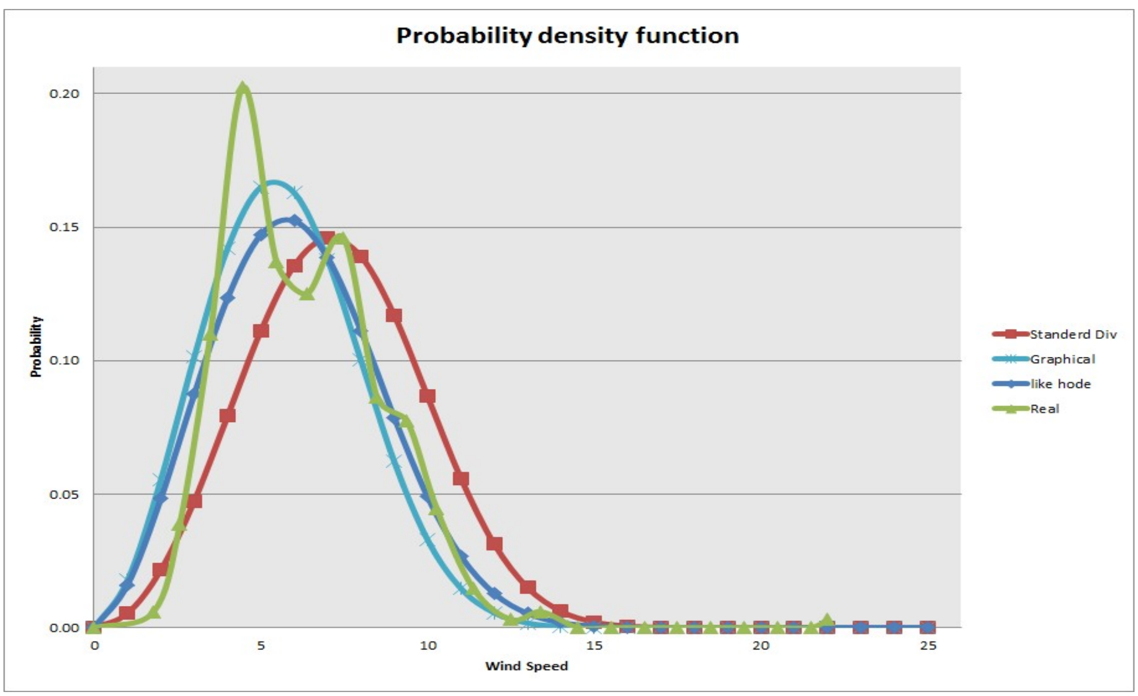

Figure (9): Probability density function to presented the frequency distribution of the wind speeds

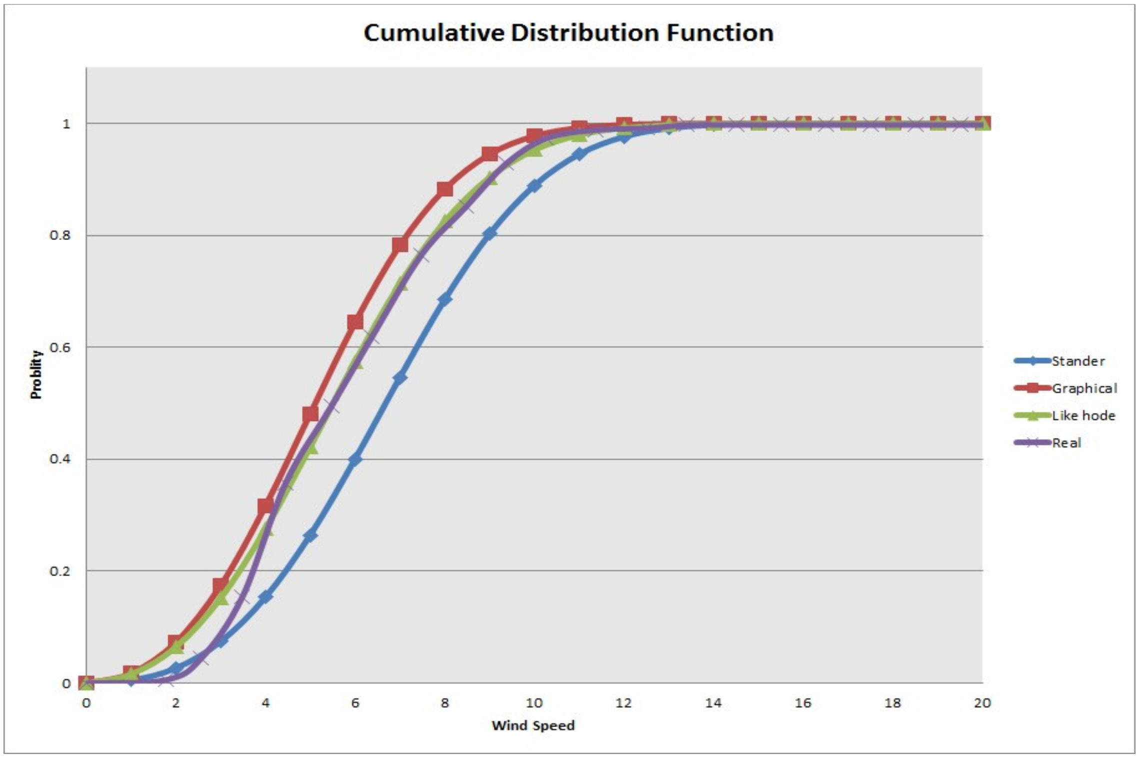

Figure (10): Cumulative distribution function to present the frequency distribution of the wind speeds.

As we can see from figures, the most frequent velocity is 4.45 = m/s, the maximum speed is = 22 m/s. The average Wind speed is 7.16 at 45m and 6.1 at 35. The month with the highest wind potential is July and least is October.

5. Site Wind Power Density Potentials:

Power density curves are shown in the figure below. Figure (11) represents the power curve for Hofa site per unit area, the figure shows the following:

1. Theoretical power available on the wind :

$$P_{A_{theo}} = \frac{1}{2}\rho_a V^3 \quad (W/m^2) \tag{3}$$

where$\rho_a$is the density of airassumed to be constant and equal to 1.225[18].

2. Using Betz limit to find the maximum theoretical power that could be extracted from wind per unit area:

$$P_{A_{Bets}} = \frac{1}{2}\rho_a V^3 \times (16/27) \quad (W/m^2) \tag{4}$$

3. Actual extracted power per unit area, here done by the assumptions of (Erich H., 2006). Considering overall efficiency as 38.61%[19].For estimating actual power/energy generation, it has been considered the losses as a typical value as presented by [19]. Such as: (17) a- Rotor efficiency = 44.00% b- Bearing efficiency = 99.60% c- Gearbox efficiency = 97.20% d- Generator eff. = 96.50% e- Efficiency of Frequency converter = 97.50% f- Reactive power compensation and harmonic filters = 98.30% g-

Transformer and other transmission accessories = 98.00%. Therefore, the estimated total system efficiency would be 38.61% [19].

$$P_{A_{Actual}} = P_{A_{theo}} \times 03861 \quad (W / m^2) \tag{5}$$

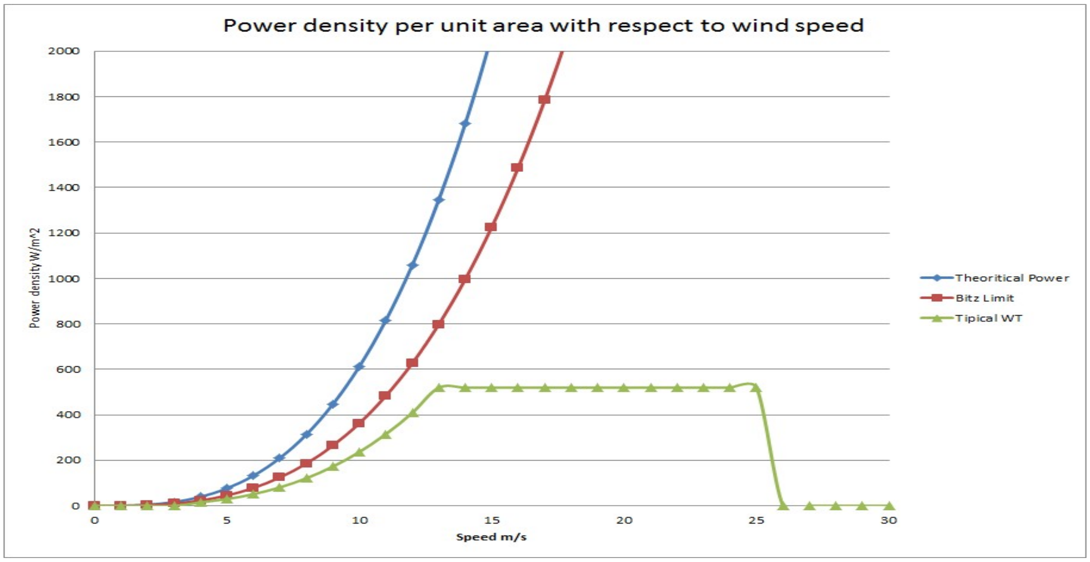

Figure (11) : Power density per unit area with respect to wind peed

Ideally available power density = 219 W/m2, Betz limit power density = 130 W/m2,andExtracted (considering 38.61% system eff.) = 84.6 W/m2

6. Wind Turbine Selection

In this section specifically we will make an assessment of five types of commercially available turbines and make comparisons between them and make a selection to the one that we think will be the best. The comparison will be for major specification in turbine like capacity factor, initial cost, simple payback period and internal rate of return. In this case we has four turbines to study and the fifth one will be our reference because this one (VESTAS V27KW) is the one which already installed at Hofa.

The wind turbine models are chosen in this study, namely; VESTAS V27 225KW, SIEMNS STW 1MW, GE 2.5 MW, VESTAS V90-3MW, SIEMENS STW-3.6MW. Table (4)present the main specification of the five wind turbine[20].

Table 4: Main characteristics of the selected wind turbines for this study. [15]

	Model				
	VESTAS V27 225KW	SIEMENS STW 1MW	VESTAS V90-3MW	GE 2.5 MW	SIEME SWT-3. W
Rotor diameter	32	54	90	88	12(
Hub height	27	45	65	80	90
Rated	0.225	1	3	2.5	3.(
Cut in speed	4	4	4	3	3
Rate speed (m/s)	15	15	15	12.5	13
Cut out speed	26	25	25	25	30
Swept area	572 m^2	2,307	6,362	6082	900

6.5. SIEMENS STW-3.6MW

For this turbine we made a simulation by using RETScreen programing, the power capacity 3.6 MW. In this turbine simulation the hub height taken 90 m and the rotor diameter is 120 m, the capacity factor is 33.2%, and the annual exported electricity is 10460 MWh.

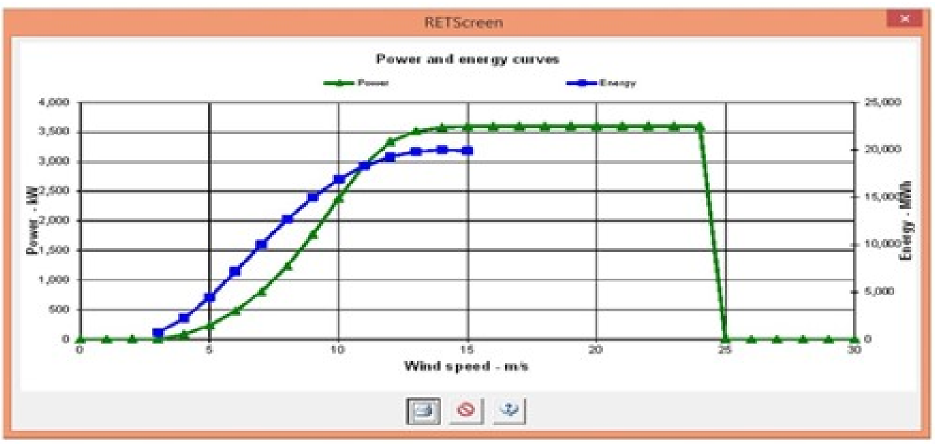

Figure (12): Power curve of SIEMENS SWT-3.6MW.

From the figure above the cut in speed is 3.5 m/s. and the cut of speed is 24 m/s. the rated power speed from(13 – 24) m/s.In Table(5) below a comparison in all parameters done for all types.

TABLE (5): Turbines specifications comparison

Turbine type	VESTAS V27	GE 2.5 MW	VESTAS V90-3MW	**SIEMENS**
Power capacity(MW)	0.225	2.5	3	**3.6**
Hub height (m)	32	85	65	**90**
Rotor diameter (m)	27	88	90	**120**
Capacity factor%	20.8	31.9	30.7	**33.2**
Ann.elc. generatedMWh	410.4	6992	8079	**10460**
Internal rate of return (%)	17.8	14.8	14	**15.7**
Simple payback period	4.9	5.6	5.8	**5.4**
Cumm. Savings	5	17	19.5	**26.6**
Equity pay pack (Yrs)	1.6	2	2.1	**1.9**
Cut in speed (m/s)	4	3.5	3	**3.5**
Cut of speed (m/s)	25	24	24	**24**
rated power speed(m/s)	15-25	12-25	15-25	**13-25**

From the result in the table above for SIEMENS SWT-3.6MW it's readily to figure out this turbine is the best, if our constraint out of limited budget, so this one the selected turbine for our project will be.

References:

[1]. EXPLAINED, E.S. *STATISTICS EXPLAINED*. 2015.
[2]. Denmark, T.O.W.o. *Green Energy*. 2015.
[3]. Laboratory, R.N., et al., *Wind Atlas for Jordan*. 1989.
[4]. Alghoul, M.A., et al., *Wind Energy Potential of Jordan.* International Energy Journal, 2007. **8**: p. 71-78.
[5]. Ababneh, M., et al. *Investigation of Wind Energy in Jordan*. in *International Conference and Exhibition on Green Energy and Sustainability for Arid Regions and Mediterranian Countries* 2009. Amman, Jordan.
[6]. Badran, O. and E. Abdullah. *Evaluation of Factors Affecting Wind Power Generation in Jordan*. in *The seventh Asia-Pacific Conference on Wind Engineering*. 2009. Taipei, Taiwan.
[7]. Mousa, M., *Potential for Wind-Powered DesalinationSystems in Jordan.* Intenational Journal of Thermal and Environmental Engineering, 2010. **1**(2): p. 109-123.
[8]. Abdelrazzaq, M.H. and O. Aloquili, *Evaluating the impact of Electrical Gridd Connection on the Wind Turbine Performance for Hofa Wind Farm Scheme in Jordan.* Energy Conversion and Management, 2008. **49**: p. 3376-3380.
[9]. Bataineh, K. and D. Dalalah, *Assessment of Wind Energy Potential for Selected Areas in Jordan.* Renewable Energy, 2013. **59**: p. 75-81.
[10]. ALsaad, M.A., *Wind Energy Potential in Selected Areas in Jordan.* Energy Conversion and Management, 2013. **65**: p. 704-708.
[11]. Abdulrazzaq, M.H. and B. Hahn, *Analysis of the Turbine Standstill for a Gridd Connected Wind Farm (Case Study).* Renewable Energy, 2006. **31**: p. 89-104.
[12]. Jordan, H.P.C.o., *Statistical Indicators Database*, in *Higher Population Council of Jordan*. 2017, Ministry of Planning and International Cooperation: Jordan.
[13]. Jordan, M.o.E.a.M.R.i. *Energy Statistics in Jordan*. Energy Statistics 2017 2013].
[14]. (NERC), N.E.R.e. *Wind Energy in Jordan*. 2013.
[15]. Resources, M.o.E.a.M. *Wind Energy Statistics*. 2013.
[16]. Jordan, D.o.S.i., *Jordan in Figures* 2009, Ministry of Energy and Minerals Resources.
[17]. Commission, J.I. *Energy Sector*. 23 2013; powered_generationat_hofa.pdf&tabid=93&mid=429&language=en-US.
[18]. MAthew, S. *Wind Energy Fundamentals, Resources Analysis and Economics*. 2006. Malapuram, Kerala, India.
[19]. Erich, H., *Wind Turbines: Fundamentals, Technologies, Applications and Economics*. second edition ed. 2006, Berlin, Germany: Springer-Verlag.
[20]. Models, W.T. *Turbines*. 2014.