Wind Characteristics & Wind Energy Potential in Libya : the case study in Derna

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Abstract

In this paper the wind characteristics of seven sites in the windy regions in Libya have been analyzed, wind speed and wind direction were measured every 10 min at multiple levels for one year and half. The annual energy yield and wind direction were evaluated using the Weibull and Excel datasheet function, considering wind turbines ranging between 1500 W and 2000 W. Values of production of almost all turbines used are apparently good enough to think in three sites (Tarhuna, Derna and Al-Magrun) as a feasible site to develop a wind farm project in terms of economic parameters, in addition for approximately 2400 EqH as a reasonable value, Misalatha and Asaaba are suitable sites for a wind farm project in terms of economic parameters. On the other hand the values of EqH production is in general apparently not enough to think in Azizyah and Goterria towns, as a feasible value**.**

Keywords: wind energy ; wind turbines; wind speed; wind direction

1. INTRODUCTION

Libya's electricity demand is growing at a rapid rate in last year's, this requires significant additional capacity in the coming years as a result of rapidly increasing population and the improvement of individuals' life quality, without taking into account in the rationalization of electricity consumption.

Libya has a total installed power generation capacity of 6,300 MW and total electricity production was 30,374 GWh in 2010.

The electric energy production in Libya is provided by gas-turbine, steam-turbine and combined cycle power plants, which use heavy oil, light oil and natural gas. Gas turbine and combined cycle power plants have a share of 50% in total installed power capacity, the share of steam power plants is 50% in total. Furthermore, some small diesel power plants are also used to contribute to the energy supply, especially in remote areas.

Libya is one of the leading oil exporting countries and it has a great potential of renewable energy resources. So it will be a main objective to increase the production of electricity in future from renewable energy sources which can reach 10 % . Therefore, in order to reduce the deficit and the ongoing balancing in energy demand with the amount of generation of available capacity it is necessary to study all electrical systems and the most important of which are solar and wind energy projects to meet a significant part of

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this demand, and to reduce, as much as possible, the carbon dioxide emissions. The motivation behind this is to significantly reduce the costs of the national electricity production [1].

The aim of this study is to assess the potential wind energy on seven towns in Libya, as shown in "Fig. 1"and "Fig. 2".

Figure 1. Location of five towns in Libya

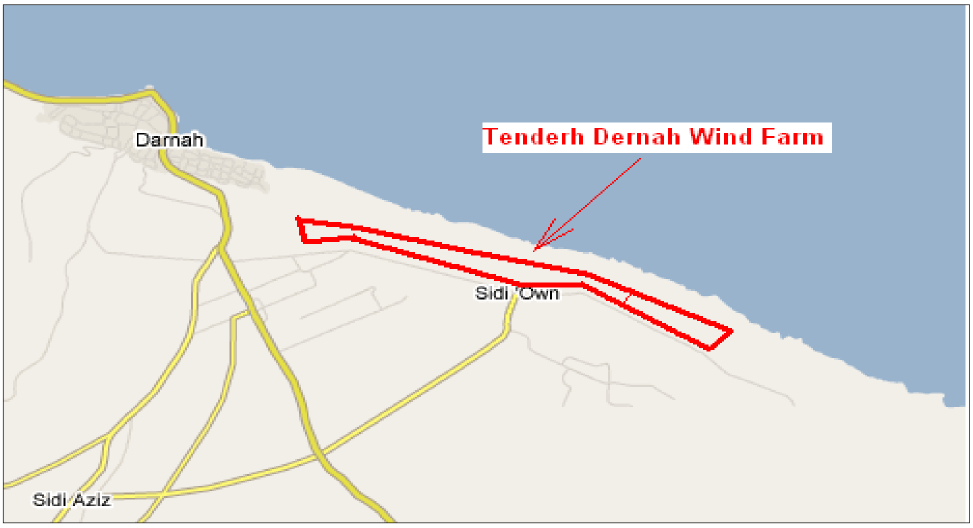

Figure 2. Location of Derna town in libya

2. DATA AND METHODS

2.1 Data collection

Details weather data concerning atmospheric pressure, temperature, humidity, and wind speed as well as the wind direction was measured in seven towns by using a meteorological mast.

The analyzed period contains data since in all towns as follows:

- Tarhuna (Period from : 01-11-2007 to 31-10-2007)
- Misalatha (Period from : 01-08-2007 to 31-07-2008)
- Goterria (Period from : 01-10-2007 to 30-09-2008)
- Assaba (Period from : 01-02-2007 to 31-01-2008)

- Azizyah (Period from : 01-06-2007 to 31-05-2008)
- EL-Magrun (Period from: 01-10-2007 to 30-09-2008)
- Derna (Period from : 30/10/2002 to 13/05/2004)

The data were recorded each 10 minutes from seven levels beginning from 3.5 m to 40 m , see "Fig. 3" [2].

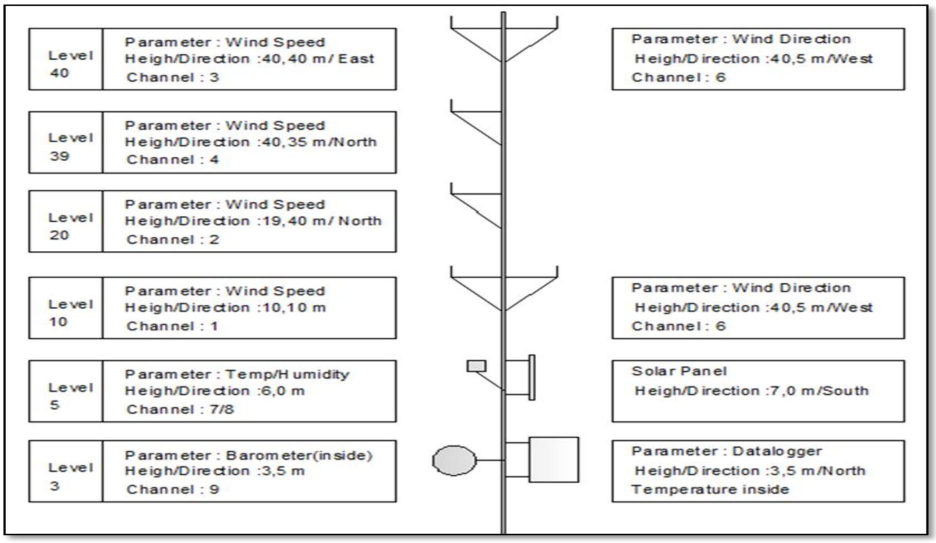

Figure 3. Meteorological Mast in the all towns

2.2 Methodology

All the statistical analysis of wind data and resource estimation were performed by using Weibull distribution, Excel work sheet .

The Excel work sheet has been generated in order to allow comparisons at different heights:

- Histograms of wind speed at 80m, 40m and 10m.
- Estimated wind speed variation with height up to 80m.
- Estimation of Weibull parameters.
- Estimate of Power production using a Weibull distribution
- Evaluated the annual energy yield for seven towns, considering wind turbines from1.5 MW- 2MW using Ahwide's Approach, in the same manner used in the previous research published and submitted by Ahwide and Spena [3].

2.2.1 Wind speed variation with height

In this study the annual behavior of the wind speed, averages of ten minute values of wind speed were used to get yearly mean values for an all towns. The case study in Derna used in order to indicate the variation in the importance of changes. The variation in wind speed with elevation influences both the assessment of wind resources and the design of wind turbines. First, the assessment of wind resources over the study area was measured by the anemometer data. Hence, a metrological mast was established to obtain data concerning the direction and speed of winds at different elevations, starting from 10 m, 20 m, to 40 m. While, the data direction and wind speed with heights up to 80 meters, were estimated in the same manner used in the previous research published and submitted by Ahwide and Spena [3] and Shata and Hanitsch [4].

2.2.2 Weibull distribution

The Weibull distribution technique is widely accepted and used in the wind energy industry as the preferred method for describing wind speed variations at a given site; some claim the Weibull distribution as the best fit for describing wind speed variations at a given site .

In Weibull distribution, the variation in wind velocity are characterized by the two function; (1) The probability density function and (2) The cumulative distribution function. The probability density function indicates the fraction of time (or probability) for which the wind is at a given velocity (V). The cumulative distribution function of the velocity (V) gives us the fraction of time (or probability) that the wind velocity is equal or lower than (V). Thus the cumulative distribution is the integral of the probability density function. The equations used in this section were calculated in the same manner used in the previous research published and submitted by Ahwide F. and Spena, A. [5].

For analyzing a wind regime following the Weibull distribution, we have to estimate the Weibull parameters k and c. The method used for determining k and c was Graphical method. In the graphical method, we transform the cumulative distribution function in to a linear from, adopting logarithmic scales. The expression for the cumulative distribution of wind velocity can be rewritten as:

$$1 - F(V) = e^{-(V/c)^k} \tag{1}$$

Taking the logarithm twice, we get:

$$\ln(-\ln[1 - F(V)]) = k\ln(V_i) - k\ln c \tag{2}$$

Plotting the above relationship with ln (V_i) along the X axis and $\ln(-\ln[1 - F(V)])$ along the Y axis, we get nearly a straight line. From "Eq. (2)", k gives the slop of this line and –equation for the plotted line using any standard spread sheets or statistical packages and compare it with "Eq. (2)", we can find out the values of k and c.

2.2.3 power curve

For an 82 m diameter wind turbine, these curves feature have three key wind speed:

a) Cut- in wind speed: This is the wind speed at which the wind turbine will start generating power- typical cut- in wind speeds are 3 to 5m/s.

b) Numinal wind speed: This is the lowest speed at which the wind turbine reaches its numenal power output. Above this speed, higher power outputs are possible, but the rotor is controlled to maintain a constant power to limit loads and stresses on the blades.

c) Cut-out wind speed: This is the highest wind speed which the turbine will operate at. Above this speed, the turbine is stopped to prevent damage to the blades [7].

2.2.4 Estimate of Power production using a Weibull distribution

In this study Weibull distribution statistics has been used that was by compensation in the equation (3) to calculate the average wind machine power [7].

$$\overline{P}_W = \sum_{j=1}^{N_B}\left\{\exp\left[-(\frac{V}{C})^k\right] - \exp\left[-(\frac{V_j}{C})^k\right]\right\}P_W\left[\frac{V+V_j}{2}\right] \tag{3}$$

2.2.5 Annual energy generation and equivalent house

Wind speed variation during long period can be converted to annual energy production (kWh) using Ahwide's Approach, through integration the power values in a series of small periods of time during the time period specified. This can be accomplished by knowing the characteristics of power curve of the wind turbine with the cumulative distribution of wind speed. So that should be taken into consideration the variations of wind speed with height t, which represents the wind speed at the height of the turbine tower. Wind turbines used in this paper was mostly on the rising 80 m from the surface.

The power curve combined with the annual wind speed distribution can be used estimated how much energy a wind turbine could generate in typical year. This is then summed to get the annual energy generated. All calculations used in this section were evaluated in the same manner used in the previous research published and submitted by F. Ahwide, and A. Ismail. [8]

3. RESULTS AND DISCUSSION

This section covers the long term annual and diurnal variation of average of each ten minute values of wind speed; the wind availability in terms of frequency distribution, power production using a Weibull distribution, energy yield using a Ahwide's Approach, considering wind turbines ranging between 1.5 MW - 2 MW of different rated powers and its variation with wind machine size and hub height.

3.1 Long term Wind speed variation with height

The long term yearly variation of wind speed provides an understanding of the long term pattern of wind speed and also confidence to an investor on the availability of wind power in coming years. In order to study the annual behavior of the wind speed, values of wind speed of each ten minute values were used to get yearly mean values.

The mean wind speed at 10 m, 40 m and 80 m above the ground for different towns is shown in table 1. This table shows that the mean wind speed with height in Derna town equal to 10 m, 40 m and 80 m height, and respectively 6.52 m/s, 8.09 m/s, and 9.25 m/s.

Table 1: Average Wind Speed With Height

Town	Average wind speed with height (m/s)			
	80 m	*40m*	*20m*	*10m*
Derna	9.25	8.09	7.15	6.52
Tarhuna	8.5	7.14	6.79	6.53
Misalata	7.12	6.68	6.19	5.85
Goterria	5.97	5.56	5.21	4.83
Assaba	7.73	7.35	7.01	6.64
Azizyah	6.66	6.35	6.09	5.78
ELMagrun	7.22	6.82	6.08	5.37

The percent histogram frequency distribution of average wind speed at different hub heights is shown in "Fig. 4", "Fig. 5" and "Fig. 6", the case study in Derna used in order to indicate the variation in the importance of changes in height . Figure 4, indicates that the wind speed at 10 m height remained between 0 and 4m/s for almost24% of the times during the entire period of data collection. It is also clear from this figure that the wind remained between 4.0 and 15.0 m/s for almost 74% of the times. About 2% of the times, it remained above 15.0 m/s. While figure 6, indicates that the wind speed at 80 m height remained between 0 and 4m/s for almost 15% of the times during the entire period of data collection. It is also clear from this figure that the wind remained between 4.0 and 15.0 m/s for almost 80% of the times. About 5% of the times, it remained above 15.0 m/s. Since most modern wind turbines usually start producing energy above 3 m/s, the 80%

availability of wind speed above the cut-in-speed of wind turbines is a good indication of Derna being a potential site for wind farm development.

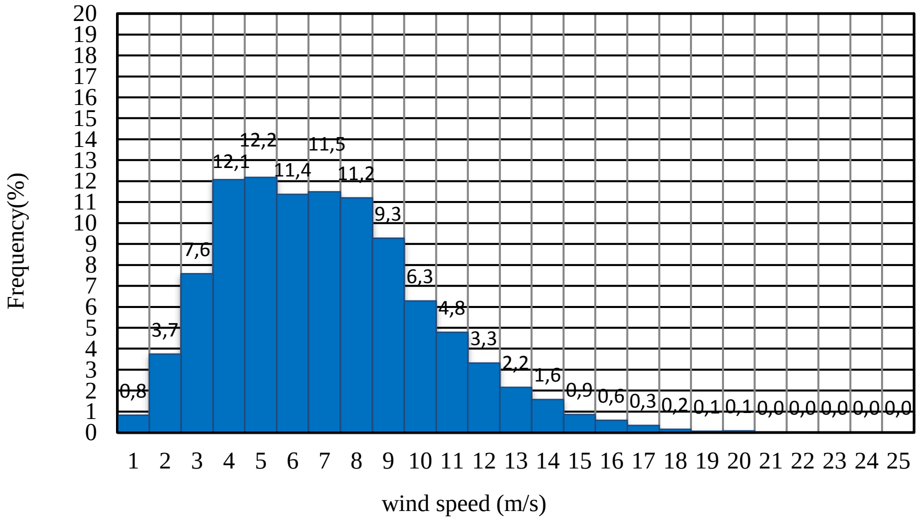

Figure 4. Histogram of of frequency distribution of average wind speed at 10 m height

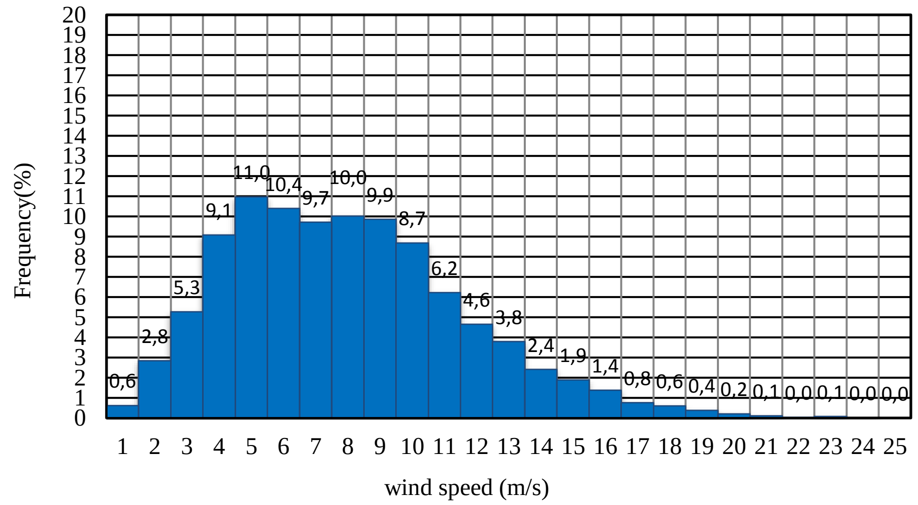

Figure 5. Histogram of frequency distribution of average wind speed at 40 m height

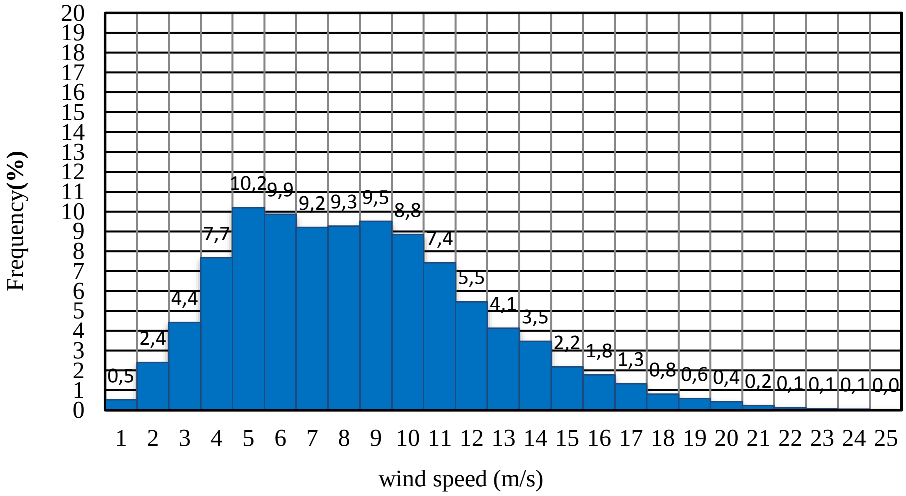

Figure 6. Histogram of frequency distribution of average wind speed at 80 m height

3.2 Weibull distribution

To determine Weibull frequency distribution and Weibull cumulative distribution, it is necessary to determine first the scle parameter (C) and the shape parameter (k). Figure 7 shows the technique that used to determine these parameters for Derna town, at 80m height, period from : 30/10/2002 to 13/05/2004,[6].

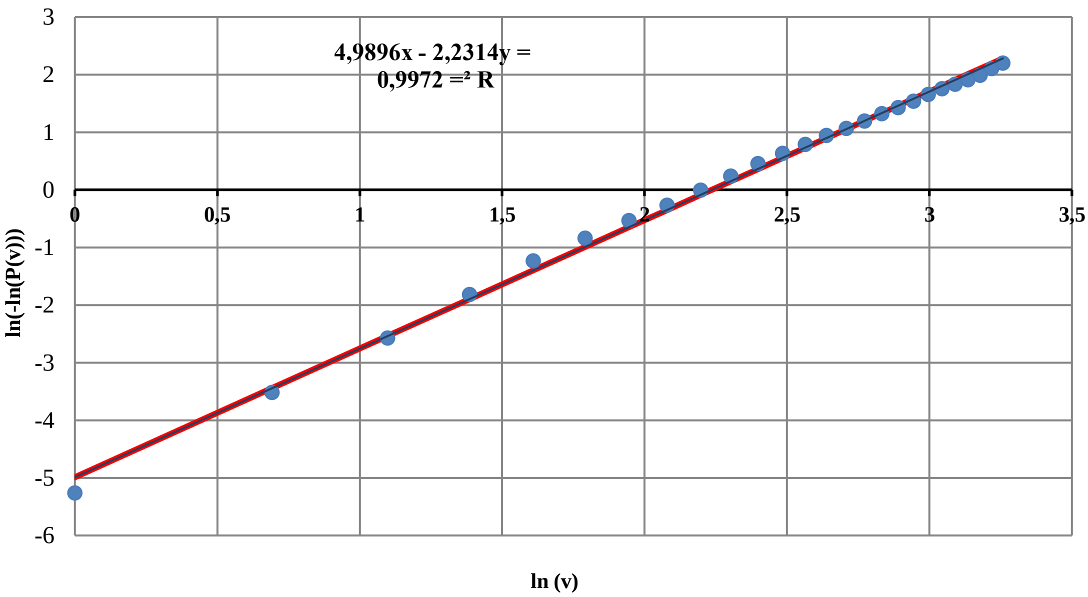

Figure 7. Graphical method to estimate Weibull k and c

Figures 8 and 9 show The probability of wind speed which drawn by using the values of scale and shape parameters and Weibull cumulative distribution functions of a wind regime, following the Weibull distribution for Derna town, at 80m height, period from : 30/10/2002 to 13/05/2004.

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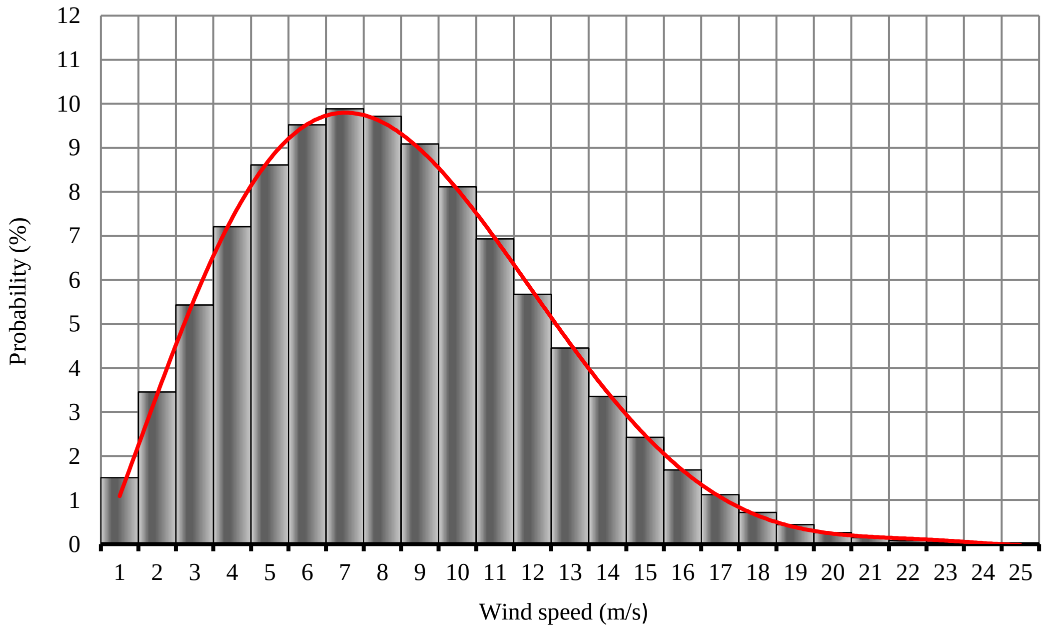

Figure 8. Weibull probability distribution for Derna at 80m.

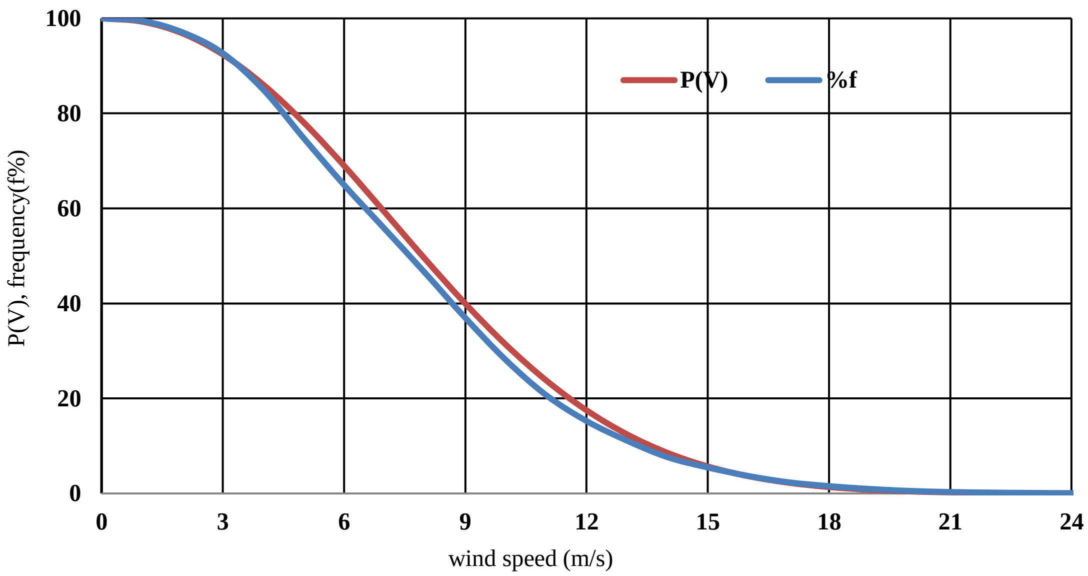

Figure 9. cumulative weibull distribution for Derna at 80m.

3.4 Power Curve analysis

To estimate the energy output from a wind machine must know the technical data of wind machines used of nine different sizes is summarized in Table 2.

Table 2: Main Characteristics of wind turbines used

Turbine	Diameter *m*	Hub height *m*	Cut-in wind speed *m/s*	Rated wind speed *m/s*	Cut-out wind speed *m/s*
Gamesa G90/2000	90	78	3	15	21
Gamesa G80/2000	80	80	4	15	25

Vestas V82/1.65	82	80	3.5	13	20
Vestas V80/2000	80	80	4	15	25
De Wind D8.2	80	80	3.5	13	25
M.Torres 1.65-82	82	71	3.5	13	25
M.Torres 1.65-77	77	71	3	13	25
HW77/1500 kW	77	61.5	3	12	25
GE 77-1.5 MW	77	65	3.5	14	25

Figure 10 indicate the power curves for vestas wind turbine & M.Torres wind turbine 82-1.65 MW for a wind turbine shows the net power output as a function of wind speed. The power output equal to zero at wind speed below 4m/s for most wind turbines , due to the mechanical losses, while for wind speed between 5-13 m/s the power output has increased by increasing wind speed rapidly. As for as, the wind speed equal the cut-out velocity - the wind speed at which the wind turbine is shut down to keep loads and generator power from reaching damaging levels. This applies to most of the wind turbines used with minor differences in the characteristics of each turbine .

Specifically, the power at each wind speed is multiplied by the number of hours per year that the wind blows at that speed to estimated how much energy in generated at each wind speed as shown in "Fig. 4", "Fig. 10" and "Fig. 11".

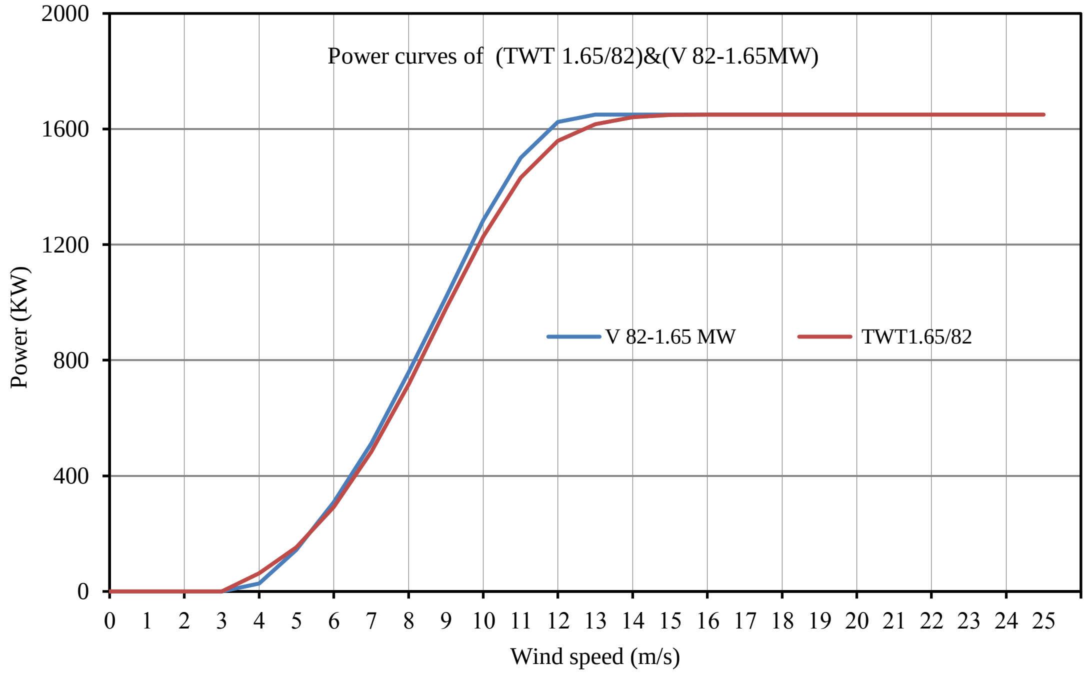

Figure 10. Power curves for vestas & M.Torres 82-1.65MW

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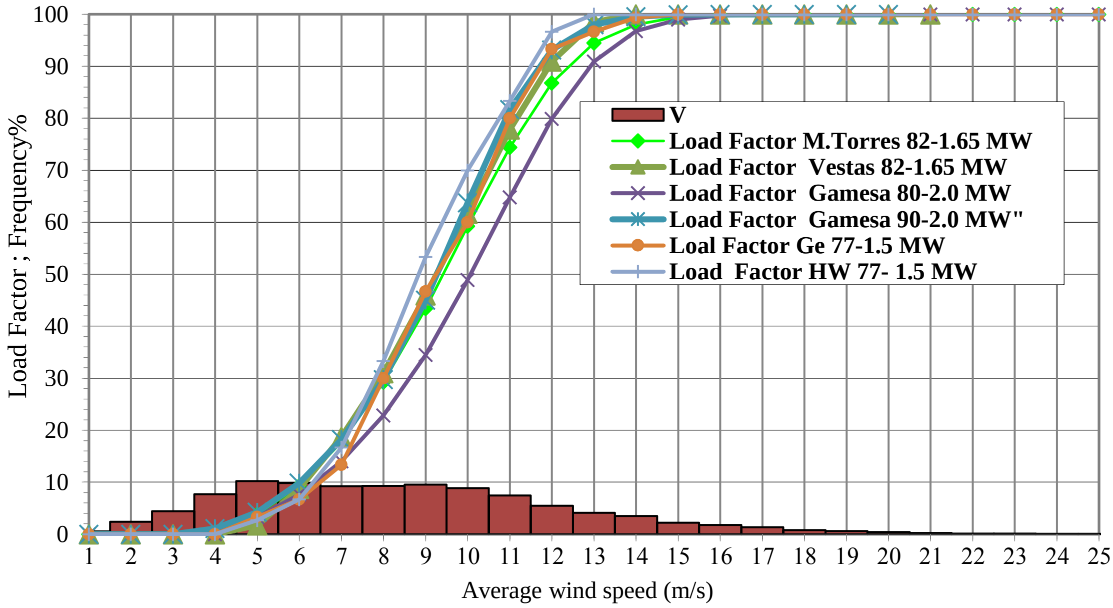

Figure 11: Load Factor of power curves for deiferent turbinens and frequency distribution of average wind speed

3.4 Power production & Wind energy generation analysis

Power production using Weibull distribution and annual energy yield using Ahwide's Approach were evaluated for seven towns (Tarhuna, Derna, Goterria, Assaba, Misalatha, Azizyah, AL-Magrun), considering wind turbines ranging between 1.5 MW - 2 MW . Different turbines were evaluated to assess their wind energy capacity in the study areas. Table 3, 4 show the results of power production and energy yield. In Derna town the wind turbine (vestas 90/2000) and (Gamesa 90/2000) recorded the highest values, equaling 6.72 GWh and 6.51 GWh respectively, while (v1.65-82) and (TWT 1.65-82) equaling 5.42 GWh and 5.29 GWh respectively, compared to the rest of turbines studied. These values encouraged us to take advantage of wind power to achieve economic benefits. As for an estimation of annual energy yield at position of Azizyah meteorological mast has been done,considering a generic wind turbine between 1.5 - 2 MW (power curve considering air density 1.15 Kg/m3), see table 2, the value of EqH production is in general apparently not enough to think in Azizyah as a feasible site to develop a wind farm project in terms of economic parameters, considering approximately (2400 EqH) as a feasible value, but total production (GWh) is lower. Nevertheless, a more detailed study in the area is necessary (longer time of measurements, detailed orography to allow a conceptual design of the wind farm, digital map of the area around the site), to confirm the results of present study. An estimation of annual energy yield at position of Tarhuna meteorological mast has been done, (power curve considering air density 1.12 Kg/m3). At 40 m the estimation is 4.39 GWh or 2195 equivalent hours. At 80 m the estimation is 4.91 GWh or 2454 equivalent hours. It seems a fair value in the context of a possible development of a wind energy project in the area. The annual energy yield at position of Misalatha meteorological was estimated, (power curve considering air density 1.15 Kg/m3). At 40 m the estimation is 3.91 GWh or 1954 equivalent hours. At 80 m the estimation is 4.47 GWh or 2235 equivalent hours. Considering a value of 2400 equivalent hours as the limit to consider a wind warm economically profitable, 2235 Eqh is close to this limit. Anyway, more data and a detailed wind farm study would be necessary to draw conclusions. An estimation of annual energy yield at position of Asaaba meteorological mast has been done, the total produced energy at 80 m is estimated in 5.08 GWh or 2541 equivalent hours, considering a generic wind turbine of 2 MW (Gamesa G80/2000) in position of meteorological mast. Four other turbines have been tested. Table IV shows their characteristics and results obtained. Values of production of two of the proposed turbines are apparently enough to think in Asaaba as a feasible site to develop a wind farm project in terms of economic parameters. M. Torres turbine is close to this limit.

Table 3: Power generation & energy yield at 80 m height

Power (W)	Energy yield (kWh)	Energy yield (kWh)	Energy yield (kWh)	Energy yield kWh
	Gamesa G90/2.0MW	Gamesa G80/2.0 MW	Vestas V82/1.65 MW	M.Torres 82/1.65MW
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
2	21	0	0	0
9	671	414	226	509
27	6516	3967	4861	5165
66	28168	17130	24455	23110
133	86282	52373	75756	71605
232	228695	138418	196707	185808
358	513561	311416	418919	402854
502	858047	538078	690161	659547
645	1055047	715074	868305	828942
767	971004	711662	822887	789465
850	827728	635834	701380	687352
883	725890	568431	612778	609436
862	444666	350549	375057	374829
793	333577	263461	281316	281316
690	217339	171732	183279	183279
569	108715	85902	91678	91678
445	62142	49102	52404	52404
330	32999	26074	27828	27828
233	12495	9873	0	10537
157	0	3586	0	3827
100	0	1377	0	1469
61	0	594	0	634
36	0	264	0	282
8751	6513563	4655312	5427996	5291876

Table 4: Characteristics and production of wind turbines

Wind Turbines	Rated power (MW)	Hub altitude (m)	Energy Production (GWh)	Production [Eqh]

Tarhuna town (Period from : 01-11-2007 to 31-10-2008)				
G80/2000	2000	80	4.91	2454
AW82/1500	1500	80	4.41	2941
EC80/1670	1670	80	3.98	2383
G90/2000	2000	78	5.56	2780
TWT 1.65-82	1617	71	4.6	2846
V90/2000	2000	80	5.71	2853
Derna town (Period from : 01-11-2007 to 31-10-2007)				
G90/2000	2000	80	6.51	3255
HW77/1500	1500	61.5	4.65	3100
GE 77/1500	1500	65	4.46	2973
V82/1650	1650	80	5.42	3284
G80/2000	2000	78	4.65	2325
TWT 1.65-82	1650	70	5.29	2846
V90/2000	2000	80	6.72	3206
Goterria town (Period from : 01-10-2007 to 30-09-2008)				
G80/2000	2000	80	3.12	1557
AW82/1500	1500	80	3.01	2007
EC80/1670	1670	80	3.3	1976
G90/2000	2000	78	3.73	1863
TWT 1.65-82	1617	71	3.04	1879
V90/2000	2000	80	3.71	1854
Assaba town (Period from : 01-02-2007 to 31-01-2008)				
G80/2000	2000	80	5.08	2541
AW70/1500	1500	80	3.71	2471
EC62/1300	1300	80	2.74	2109
TWT 1.65-70	1650	71	3.9	2365
V80/2000	2000	78	4.57	2287
Misalatha town (Period from : 01-08-2007 to 31-07-2008)				
G80/2000	2000	80	4.47	2235
AW82/1500	1500	80	4.28	2852
EC80/1670	1670	80	3.62	2169
G90/2000	2000	78	5.34	2671
TWT 1.65-82	1617	71	4.32	2673
V90/2000	2000	80	5.23	2615
Azizyah town (Period from : 01-06-2007 to 31-05-2008)				
G80/2000	2000	80	4.07	2033
AW77/1500	1500	80	3.38	2254
EC74/1670	1670	80	3.05	1826
G87/2000	2000	78	4.48	2236
TWT 1.65-77	1650	71	3.48	2110
V90/1800	1800	80	4.53	2517
AL-Magrun town (Period from : 04/11/2002 to 31/12/2003)				
G90/2000	2000	78	6.05	3023
G80/2000	2000	80	4.36	2180

V82/1.65	1650	80	5.13	3107
V80/2000	2000	80	4.36	2180
TWT1.65-82	1650	71	4.39	2660
TWT1.65-77	1650	71	3.62	2194
De Wind D8.2	2000	80	4.06	2031

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