An Assessment of wind energy potential of the Amatole district in the Eastern Cape Province of South Africa

P Masukume[1], G Makaka[1] and D Tinarwo[2]
[1]University of Fort Hare, Department of Physics, P. Bag X1314, Alice 5700'
[2]University of Venda, Department of Physics, P. Bag X5050, Thohoyando,0950

E-mail:pmasukume@gmail.com

Abstract: South Africa is heavily depended on fossil fuels for its energy needs and is the highest emitter of greenhouse gasses in Africa and 18th in the world. It is therefore imperative to shift to renewable energy sources for power production to mitigate the carbon emissions. The purpose of this paper is to investigate wind energy potential in the Amatole District in the Eastern Cape Province of South Africa. The Weibull density function was used to estimate the wind energy potential in this location. The Weibull parameters, k(shape parameter) and c(scale parameter) varied from 1.651 to 2.026 and 3.093 to 4.310 respectively. The study shows that the area has moderate wind energy potential for decentralized wind energy systems, exploitable at 10m or more for low speed wind turbines. It therefore follows that it is not suitable for large scale wind energy production.

1 . Introduction

South Africa's energy intensive economy depends greatly on fossil fuels for its energy needs, with almost 90% coal based electricity generation and is the highest emitter of green house gasses in Africa and 18th in the whole world (Olivier et al, 2012). However, South Africa is endowed with abundant un-exploitable renewable energy resources. Wind energy is one of the least exploited renewable energy sources. The use of wind energy can significantly reduce the combustion of fossil fuels and consequent Carbon dioxide (CO_2), a principal cause of enhanced green house effect.

For any power plant to generate electricity, it needs fuel, for a wind power plant, that fuel is wind. It is therefore imperative to have a through wind resource assessment to establish the wind energy potentiality of the site for successful planning and implementation(Anyanwu and Iwuagu, 1995, Celik et al, 2010, Islam et al, 2011). Estimates of wind resources are expressed in wind power classes ranging from 1 to 7, with each class representing a range of mean wind power density or equivalent mean wind speed at specified heights above the ground. A wind class table is shown in Table 1.

Measurements of wind speed distribution or frequency distribution are used for calculating the output of the wind energy in a particular site if available. Similarly, probability density functions (PDF) are also used to predict the wind power density of a site. One of these functions is the Weibull distribution function (named after the Swedish physicist Weibull, who applied it when studying material strength in tension and fatigue in the 1930s) (Ulgen and Hepbasli, 2002). Several researchers have used the Weibull distribution in wind energy potential assessment(Lun and Lam, 2000, Seguro and Lambart, 2000, Weisser,2003 and Zhou et al, 2006). This analytical distribution for fitting wind speed data is generally accepted as the standard approach.(Bansal et al,2002, Persaud et al, 1999). This approach has been adopted in this paper. This paper presents a wind energy potential assessment of the Amatole District in the Eastern Cape province using the Weibull distribution function.

Table 1. Classes of wind power density

	10m		50 m	
Wind power class	Wind power density (W/m^2)	Mean wind speed (m/s)	Wind power Density (m/s)	Mean wind speed (m/s)
1	<100	<4.4	<200	<5.6
2	100-150	4.4-5.1	200-300	5.6-6.4
3	150-200	5.1-5.6	300-400	6.4-7.0
4	200-250	5.6-6.0	400-500	7.0-7.5
5	250-300	6.0-6.4	500-600	7.5-8.0
6	300-400	6.4-7.0	600-800	8.0-8.8
7	>400	>7.0	>800	>8.8

(Source: Wind power generation and wind turbine design, Wit press,2010)

2.0 Methodology.

2.1 Site and data collection

The wind assessment was done in the Amatole district in the Eastern Cape province of South Africa. The wind speed data in hourly time series format over a period of 3 years (2010-2012) was supplied by the South African Weather Service(SAWS). The data was measured at a meteorological weather station at Fort Beaufort. The measurements were taken at a standard height of 10 m above the ground. Table 2. Summarizes the station location.

Table 2. Location of Fort Beaufort.

Station	Duration (yrs)	Latitude	Longitude	Height above sea level (m)
Fort Beaufort	2010-2012	32.7880	26.6290	455

2.2 Weibull distribution function

The Weibull distribution function was used to analyze the wind speed data as alluded to in the previous section. The general form of the two-parameter Weibull probability density function is given by (Keyhani et al, 2010):

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

where f(v), is the probability of observing speed v, k, is the dimensionless Weibull shape parameter and c, is the Weibull scale parameter.

The corresponding cumulative probability function of the Weibull distribution is given as (Akpinar and Akpinar,2004):

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

The Weibull parameters, k and c, characterize the wind potential of the site under study. The scale parameter , c, indicates how "windy" the site under consideration is, where as the shape parameter, k, indicates how peaked the wind distribution is (ie, if the wind speed tend to be very close to a certain value, the distribution will have a high k value and is very peaked)

2.3 Parameter estimation

The Weibull parameters were estimated using the Maximum likelihood method. This method was widely used by other researchers(Dike et al, 2011). The shape parameter k, and scale parameter c, are estimated by the following(Maatallah et al, 2012):

$$k=\left(\frac{\sum_{i=1}^{n} v_i^k \ln(v_i)}{\sum_{i=1}^{n} v_i^k}-\frac{\sum_{i=1}^{n}\ln(v_i)}{n}\right)^{-1} \quad (3)$$

$$c = \left(\frac{\sum_{i=1}^{n} (v_i)^k}{n} \right)^{\frac{1}{k}} \tag{4}$$

Where v_i *and n* are respectively the wind speed and the number of observed non zero wind speeds.

2.4 Meaningful wind speeds

There are basically two meaningful wind speeds for wind energy estimation when using the Weibull distribution function. These are the most probable wind speed, V_{mp}, and the wind speed carrying the maximum energy, V_{maxE}. The most probable wind speed denotes the most frequent wind speed for a given wind probability distribution and is expressed as(Jamil et al,1995):

$$V_{mp} = c\left(\frac{k-1}{k}\right)^{\frac{1}{k}} \tag{5}$$

The wind speed carrying the maximum energy represents the wind speed that carries the maximum amount of energy and is expressed as (Celik, 2004):

$$V_{\max E} = c\left(\frac{k+2}{k}\right)^{\frac{1}{k}} \tag{6}$$

2.5 Wind power density (WPD)

It is well known that the power of the wind that flows at a speed v, through a blade sweep area A increases as the cube of its velocity and is given by:

$$P_{(v)} = \frac{1}{2}\rho A V^3 \tag{7}$$

Wind power density(WPD), expressed in Watt per square metre (W/m^2), takes into account the frequency distribution of the wind speed and also depend on air density and the cube of the wind speed. Therefore WPD is generally considered a better indicator of the resource than wind speed. (Al-Nassar et al, 2005). Monthly or annual wind power density per unit area for a region, based on the Weibull probability density function, can be expressed as follows(Rumbayan and Nagasaka, 2011):

$$P_w = \frac{1}{2}\rho c^3 \Gamma\left(1 + \frac{3}{k}\right) \tag{8}$$

Where Γ, is the gamma function, ρ, is the air density which can be calculated as follows:

$$\rho = \frac{P}{RT} \tag{9}$$

P is the average pressure, T is the average temperature and R is the dry gas constant

2.6 Goodness of fit

The Goodness of fit test were done using the Kilmogrov-Smirnov(KS) test, Anderson-Darling (AD) test and the Chi-squared(CH) test.

3.0 Results and discussion

3.1 Wind characteristics

The wind speed for a period of 3 years from 2010 to 2012 was analysed. Figure 1 shows the mean daily wind speeds values for 2010. It is clear from the diagram that the mean daily wind speed varies from 0.9 m/s to 7.5 m/s between April and September and 1.3 m/s to 5.6 m/s between October and

March. It has been observed that the trend of this variation over the three years is similar. The mean monthly wind speeds vary between 2.3 m/s to 3.45 m/s. It has also been observed that all the months between October to January have mean monthly wind speeds over 3 m/s. The trend is the same for all the years under study. This indicates that this is the windiest time of the year. Figure 2 shows the mean monthly wind speed values for 2010.

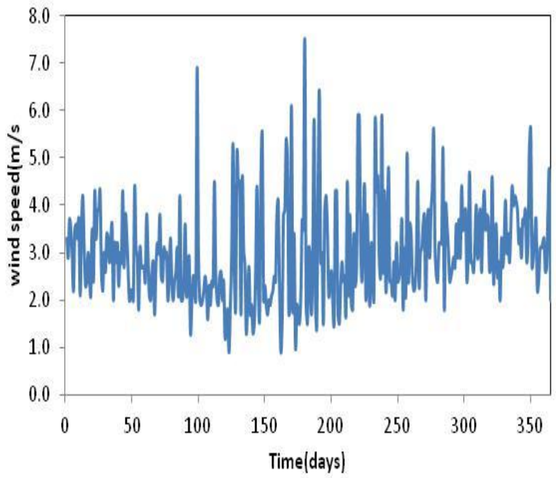

Fig. 1 Mean daily wind speeds(2010)

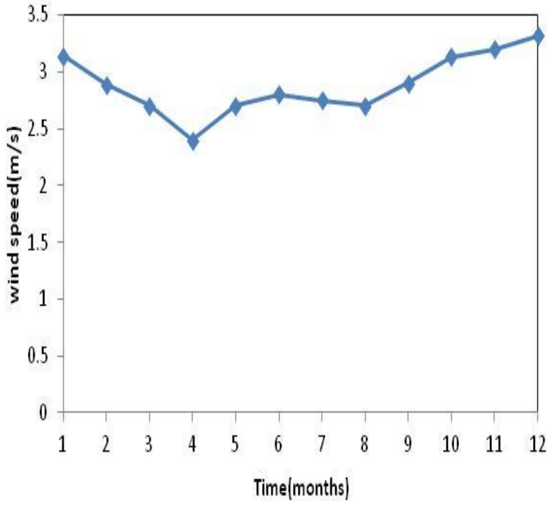

Fig. 2 Mean monthly wind speeds(2010)

It is clear from the diagram that the mean monthly wind speeds between October to January is well over 3 m/s. The month of April has the least mean monthly wind speed of 2.4 m/s in 2010. And the maximum of 3.32 m/s in December. A minimum of 2.22 m/s and 2.39 m/s were observed in March 2011 and 2012 respectively. It can be concluded that the months of March and April have the least wind speeds while December has the maximum wind speed over 3 m/s. The yearly mean wind speed can be obtained by averaging all the available wind speeds in the year. For this site, the yearly mean wind speeds are less than 3 m/s. The yearly mean for 2010 is 2.92m/s while that for 2011 and 2012 is 2.72 m/s and 2.76 m/s respectively. The overall mean wind speed for the site under study is 2.80 m/s.

3.2 Weibull Distribution

The mean monthly Weibull parameters for the site , the scale parameter c and the shape parameter k, are shown in Table 3. The shape parameter k, has a smaller variation than the scale parameter c. k varied from 1.651 to 2.026 while c varied from 3.093 to 4.310 during the same period. K had the least value in December and its highest in March. In the same period c had the least value in March and its the maximum in December. Figure 3 (a) shows a histograms of the variation of the observed and the superimposed Weibull probability density function for the site under study. The graph is skewed to the right. The calculated values for skewness and excess kurtosis in Table 5, agrees with the nature of the graph. The excess kurtosis in the graph indicates that the peak of the graph is sharper than the normal distribution. The corresponding cumulative distribution function for the site is also shown in Figure 3(b). The closeness of the graph to the observed data is a clear indication that the Weibull distribution fit the data. The results of the goodness of fit applied to the data are given in Table 6. All the p-values are above 0.05, indicating that the Weibull distribution fits the data.

Table 3. Descriptive statistics

Period	skewness	Excess kurtosis
2010-2012	0.56	-0.23

Table 4. Goodness of fit tests

Period	KS p-value	AD p-value	CS p-value
2010-2012	0.7311	0.9105	0.2121

Table 5. Descriptive statistics, meaning full velocities, Weibull parameters and wind power density

Month	V_m (m/s)	σ (m/s)	c (m/s)	k	V_{mp} (m/s)	V_{maxE} (m/s)	WPD (W/m^2)
Jan	3.052	1.971	4.130	1.691	2.433	6.553	70.841
Feb	2.770	1.825	3.490	1.863	2.309	5.162	37.543
Mar	2.443	1.614	3.093	2.026	2.211	4.341	23.797
Apr	2.431	1.763	3.097	1.830	2.010	4.636	26.813
May	2.493	1.856	3.103	1.742	1.901	4.813	28.806
Jun	2.951	2.231	3.597	1.656	2.056	5.802	48.281
Jul	2.667	1.864	3.267	1.811	2.096	4.926	31.897
Aug	2.531	2.217	3.630	1.730	2.204	5.660	46.551
Sep	2.913	2.013	3.557	1.780	2.237	5.430	42.108
Oct	3.128	1.962	4.016	1.757	2.487	6.189	61.676
Nov	3.107	1.944	4.216	1.733	2.566	6.565	72.754
Dec	3.114	1.950	4.310	1.651	2.453	6.970	83.469

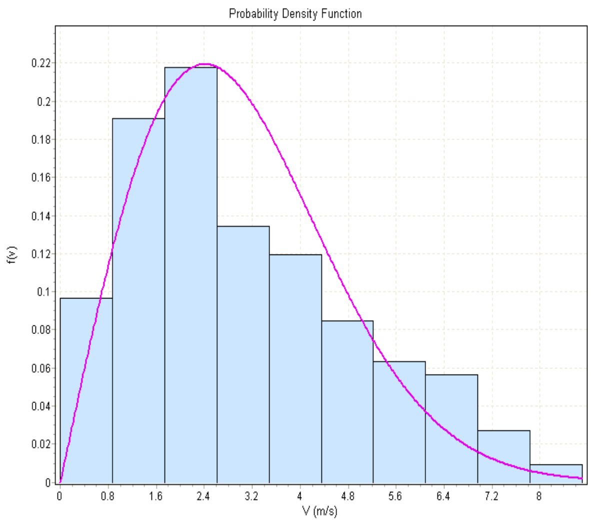

Fig 3. Histogram of observed and Weibull PDF simulation

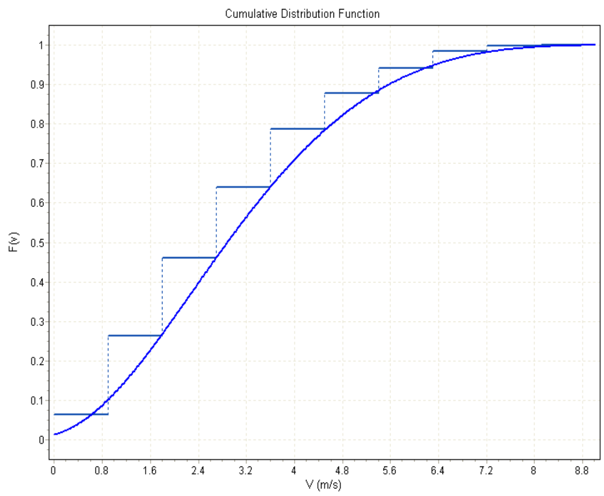

Fig 4. Cumulative probability function for the data

3.3 The Power density

The most probable wind speed V_{mp} , varied from 1.901 m/s to 2.566 m/s. In all cases it is observed that the most probable wind speed is less than the mean monthly wind speed but are quite close. The wind speed carrying the maximum energy varied from 4.341 m/s to 6.970 m/s. Unlike the most probable wind speed, the wind speed carrying the maximum energy is greater than the monthly mean and is almost twice as much. The wind power density varied from 23.797 W/m^2 to 83.469 W/m^2 . The lowest was in March and April. It was 23.797W/m^2 in March and 26.813W/m^2 in April. The period October to January produced the most wind power density, ranging from 61.676 W/m^2 to 83.469 W/m^2. The overall wind power density of the site is 47.878 W/m^2. This value is less than 100 W/m^2, therefore the WPD is in Class 1 according to the classification shown in Table 1.

4.0 Conclusion

This paper assessed the wind energy potentiality of Amatole District. The average wind power density of the site is 47.878 W/m^2. According to the classification shown in Table 1, the wind power density is in Class 1. It is less than 100 W/m^2. Class 1 wind speeds are not suitable for large scale wind energy development. We therefore conclude that Amatole District has moderate wind energy potential for decentralized energy systems, exploitable at 10m or higher for low speed wind turbines. It therefore follows that it is not suitable for large scale wind energy development.

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