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Evaluation of Wind Energy Potentials in the Nigerian Onshore and Offshore Locations

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Abstract

The wind velocity, direction and characteristics in four (4) different locations of shallow and deep water offshore of Nigeria have been studied. The work evaluates wind energy potential in the vast Nigerian onshore and offshore with respect to power and annual energy output and capacity factor for most common existing state-of-the-art industry turbines. Wind measurements were taken at 10meter above sea level. Based on the monthly mean wind speed computations, the annual mean power densities are presented for the four (4) locations. The computations were made with the aid of Matlab, Excel and Labplot software. Following the parameters obtained from the computations, seven (7) wind turbine models are evaluated for electricity generation.The minimum required designparameters for wind turbine viability for electricity generation in each location are also examined.It is observed that wind power resources increases with distance from shore to offshore similar to the rest of the world. It is however noted that the value of the wind resource is relatively less in Nigeria offshore to warrant the use of floating systems with the attendant operational cost as it is presently the case in Europe, America and Asia. The work identified POLARIS 62-100 as a preferred turbine model over other models with greater wind potential in BongathanAsabo followed byBonny and Forcados (onshore).

Keywords: Mean wind speed, Wind power density, West African offshore, Energy potential, energy synchronization.

Nomenclature

Symbol	Interpretation
C	Weibull scale parameter
G	Gravity
K	Dimensionless shape parameter
T	Time
V	Mean wind speed
Z	Depth
Σ	Standard deviation
Ρ	Density of air
Γ	Design tip

Introduction

The growing globalenergy demand and the possible depletion of fossil fuel reserves and the environmental problems associatedwith the use of fossil fuel necessitate that green and sustainable source of energy be sought for.This workinvestigatespower and annual energy output and capacity factor for most common existing state-of-the-art industry turbinesonshore (near shore to shallow water of less than 50m) to offshore (water depth of over 1000m) in Nigeria. The overall intention is to consider a possibility of proposing the use of already existing technologies on energy generation from wind in areas near water to shallow and deepwater offshore Nigeria.

In Europe and America, wind as a renewable energy has stood out as themost valuable and promising choice of alternative potential green energy source (Sambo, 2006). Figure 1 shows a growing trend and interest in sourcing wind energy from the land, near shore to deep water in developed European countries of Norway, Denmark, Sweden, Netherlandse.t.c.

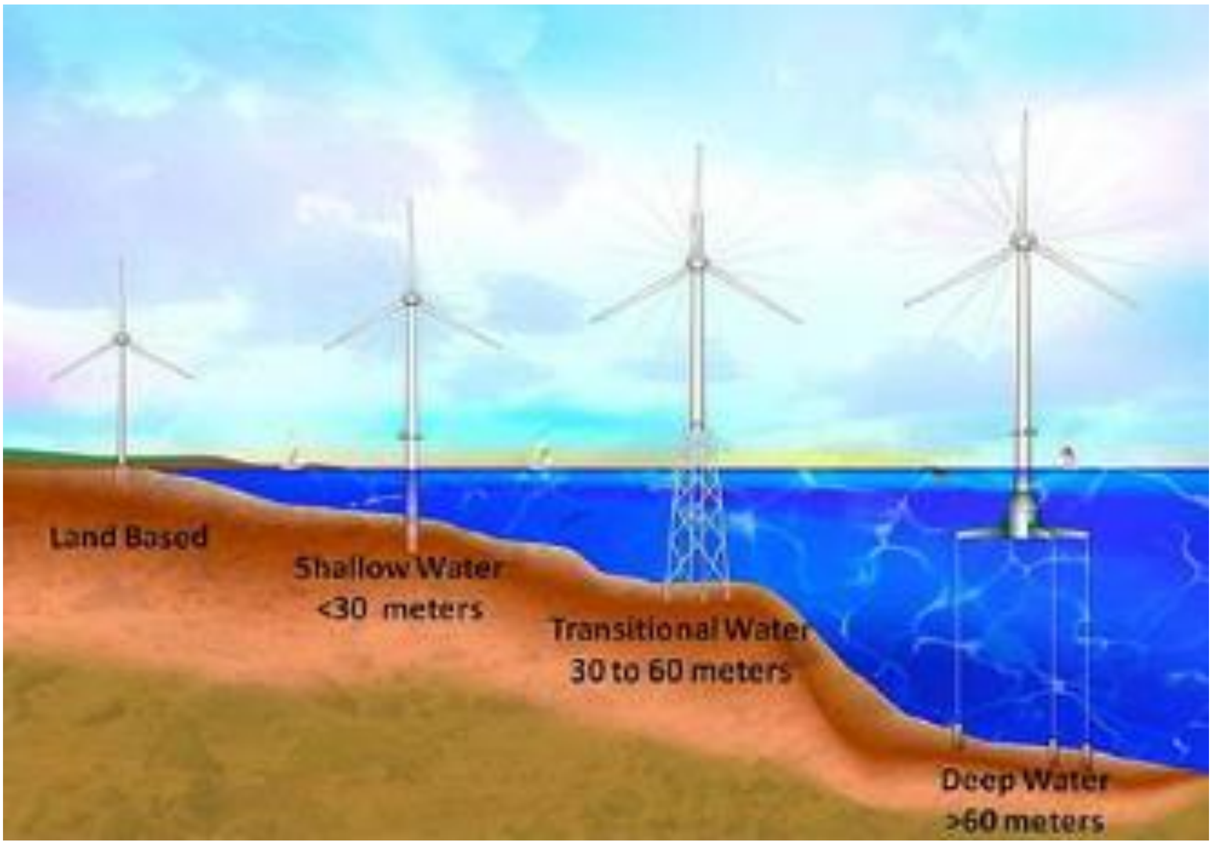

Figure 1: The trend of Wind Energy source in Europe (source:Sambo, 2006.)

Though wind as a source of energy varies from one location to another, it is noted that wind energy by natureis clean, abundant, affordable, inexhaustible and environmentally sustainable. Due to these advantages, it has become the fastest growing renewablesource of energy in both developed and some developing countries. Figure 3 shows the world wind energy use as described by Muyiwa et al. (2012)

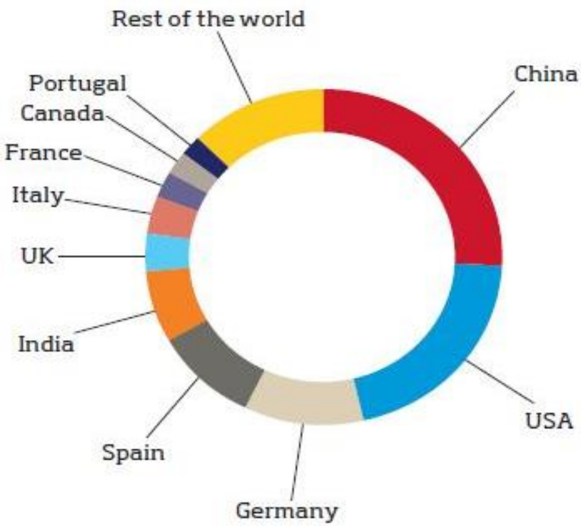

Figure 2. Pie chart representation of the world wind energy usage as (source:Muyiwa et al., 2012)

Interestingly, global cumulative installed wind power capacity from 2001 to 2017 (in megawattsshowsan increase from 24 322 MW as at 2001 to 540,000 MW in 2017. (Statista, 2017). Figure 3 shows an exponential increase of the wind energy source.

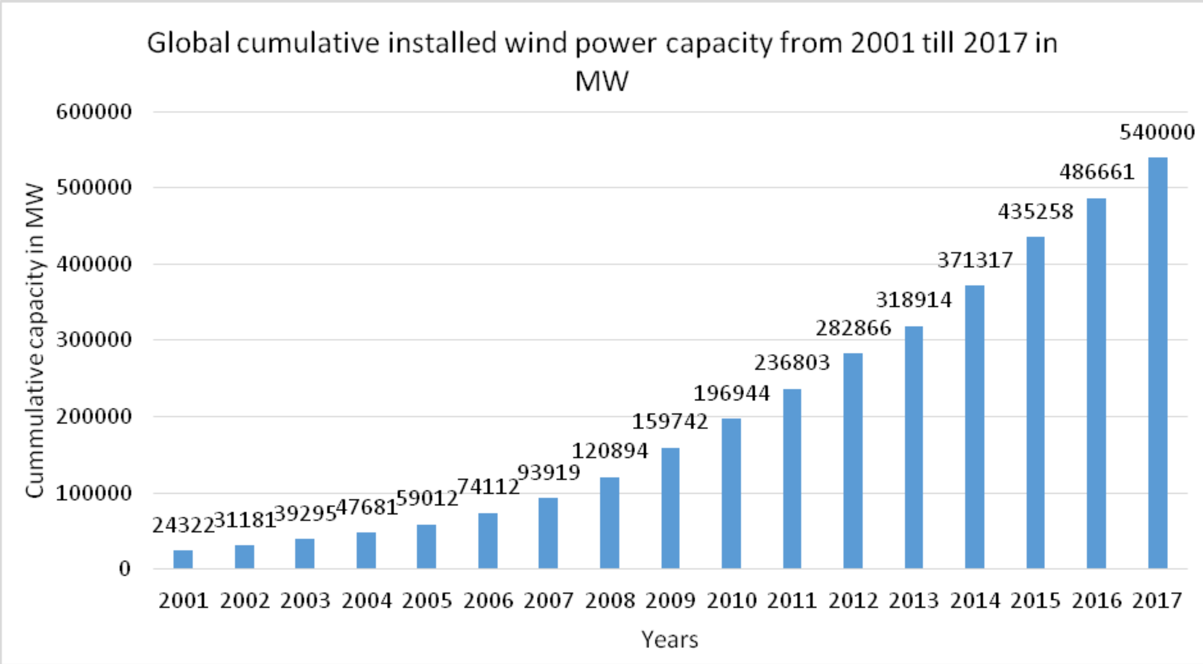

Figure 3: Global cumulative installed wind power capacity from 2001 till 2017 in MW (Source: Statista, 2017)

In Africa,Egypt,Morocco and Tunisia are the leading countries with installedcapacities of 550MW, 291MW and 114MW respectivelyas at the end of 2011(Muyiwa et al., 2012).Wind potential has been studied in Nigeria, especially in the Northern part of the country and it has shown some prospects. Harnessing the wind energy has been done mainly for the purpose of pumping water from open wells for irrigation and drinking in many Secondary Schools of old Sokoto and Kano States as well as in Katsina, Bauchi and Plateau States all in Northern Nigeria (Azad, 2014). However it is noted by Azad (2014) that the wind energy generation from wind in this Northern part of Nigeria is in small scale due to low velocities of wind in the region.

Other pervious works include the 1998, 5kW wind electricity conversion system for village electrification that was installed at SayyanGidanGada, in Sokoto State (Slootweg et al., 2001). It was reported by Agbele (2009) that offshore areas from Lagos State through Ondo, Delta, Rivers, Bayelsa to AkwaIbom States have potentials for harvesting strong wind energy throughout the year. But all these propositions have not been verified with statistical measurements and model tests with existing state-of-the-art wind turbines for the purpose of quantifying the derivable wind power available. It is noted that the wind power could be less available on land when compared with offshore. This is because of the presence of some structures and features that retard the movement of air on land.

In this paper, it is intended to investigate the wind characteristics in the Nigerian vast areas of near shore and offshore waters using wind data acquired from four (4) distinct different locations. This paper has discussed the topic explicit by carrying out calculations putting into consideration the different turbine models to estimate wind power output that could be expected at different fields.

Methodology

The potentials in wind becomes more appreciable when the wind power is determined using the available wind speed (preferably mean speed) at the height of interest to see if it has meet the required demand to rotate a turbine to a useful output rotation speed and torquerequirement.

Several mathematical models such as normal and lognormal can be used for wind data analysis. However the approach used in this work is Weibull and Rayleigh distribution models which stands to be the best for West African analysis.Simply because it gives abetter fit for measured monthly probability density distributionsthan other statistical functions. Inaddition, the Weibull parameters at known height can be used to estimate wind parameters at another height (Udo et al., 2017)
The parameters needed for this analysis can be calculated as shown in the equations below;

The Weibull probability density function $\boldsymbol{f(v)}$ is a function of a continuous random variable whose integral across an interval gives the probability that the variable lies within the same interval.According to Slootweg et al., 2001, it is given as:

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

Where;

k = *dimensionless shape parameter*

c = *Weibull scale parameter*

v = *monthly wind velocity*

And the cumulative distribution $\boldsymbol{F(V)}$ is a function whose value is the probability that a corresponding continuous random variable has a value less than or equal to the argument of the function. According to Bhola et al. (2009), it is simply the integral of the probability density function expressed as;

$$F(V) = 1 - e^{-(\frac{v}{c})^k} \qquad \text{Eqn. 2}$$

The dimensionless Weibull parameter $(\boldsymbol{k})$ is very important in normalizing the Weibull distribution. According to the work of Sambo (2009), it is expressed as:

$$k = \frac{\sigma}{V_m}^{-1.086} \qquad \text{Eqn.3}$$

Where σ = standard deviation and v_m is mean wind speed

The Weibull scale parameter $(\boldsymbol{c})$ measured in meter per second is given by the 2005 report on Nigerian Wind Power Mapping Project as.

$$c = \frac{V_m k^{2.6674}}{0.184 + 0.816 k^{2.74}} \qquad \text{Eqn.4}$$

The monthly variation of this speed characteristics which include mean power density and mean energy density as well as the annual values of these parameters at a height of 10 m have been determined using the work of Mutlu (2010);

$$V_f = C(\frac{k-1}{k})^{\frac{1}{k}} \qquad \text{Eqn.5}$$

$$V_E = C(\frac{k+2}{k})^{\frac{1}{k}} \qquad \text{Eqn.6}$$

v_f=Most probable wind speed;

v_f=Wind speed carrying maximum energy

From power law one can determine wind speed at different altitude provided the speed at a particular level have been measured. This can be achieved by using the formulation:

$$v(z) = V\left(\frac{d_z}{d_o}\right)^{\frac{1}{\alpha}} \quad \text{Eqn.7}$$

$v(z)$is the velocity at a given height z

Roughness coefficient (α)is assumed to be 0.143 (or 1/7) in this case as suggested byOmotosho and Abiodun(2007). However, the surface roughness coefficient can be determined from the expressiongiven by Ojosu et al.(1990).

$$\alpha = [0.37 - 0.088 lnV_0]/[1 - 0.088\ln\left(\frac{h_0}{10}\right)] \quad \text{Eqn.8}$$

Following the power law relationship a shape parameter C_o(Cwas obtained for this analysisusing the 2005 report on Nigerian Wind power mapping Project

$$C_h = C_0\left(\frac{h}{h_0}\right)^n \quad \text{Eqn.9}$$

The scale parameter (K_0)

$$K(n) = K_0\left[1 - 0.088\ln\left(\frac{h_0}{10}\right)\right] / \left[1 - 0.088\ln\left(\frac{h}{10}\right)\right]$$

Where $n = [0.37 - 0.088\ln(lo)]/[1 - 0.088\ln\left(\frac{h}{10}\right)]$

2.1 Mean wind power density

The mean wind power density which is measured in watts per square meter, indicates how much energy is available at a site for conversion by wind turbine. Thus, it is a very useful way to evaluate the wind resource available at a potential site. It can be estimated by usingthe knownequation:

$$P_D = \frac{1}{2}\rho {V_m}^3 \quad \text{Eqn.10}$$

ρ = Density of air (1.225kg/m^3)

2.2 Energy density

The mean energy density (E_D) over a period of time is the product of the mean power density and the time (T), and it is expressed as:

$$E_D = \frac{1}{2}\rho C^3 \gamma (1 - \frac{3}{k}) \quad \text{Eqn.11}$$

Where; ρ = air density,

C = the Weibull scale parameter (in meter per second)

γ = design tip

k =dimensionless shape parameter.

3.0 Data

The data used in this work is sourced from SHELL Nigeria. The company with its partners have worked on West African Swell Project and acquired these data. The data collected transcends from shallow water to deep water offshore sites. The description of the sites and data are given in 3.1 to 3.4.

3.1 Forcados Terminal (Onshore)

The mean wind speed and direction measured at Nigeria Forcados platform e-block (onshore) latitude: 5.3605 and longitude: 5.349 with the use of an instrument named S2000 mechanical met station which was deployed by Hunting Surveys Limited on the 3rd of January in 1980 to September 1982. Using the continuous chart recordings method, the sample duration was 60 seconds, the recording interval was 60 seconds and sensor height was 6.5 meter but corrected to 10 meter above mean sea level.

3.2 Bonny Terminal (Onshore)

Bonny wind data was collected between 6thJune 1979 and 4th October, 1982 at Nigeria Bonny platform site 1 (k-block) located latitude 4.4036 and longitude 7.1366. The instrument used was S2000 Mechanical Met Station. The sample duration used was 60 second, the recording interval was 60 second and sensor height was 10 meter above mean sea level.

3.3 Asabo Offshore:

Asabo wind data was collected between 7th April 1981 and 1st September, 1983 at an Asabo offshore platform located latitude 4.1166 and longitude 7.8. The Asabo offshore in Nigeria is characterised by water depth of 43 m. The instrument used was Continuous Observation of Embedded Multicore Systems (COEMS). The sample duration used was 1 second, the recording interval was 60 second and sensor height was 30 meter but corrected to 10 meter above mean sea level.

3.4 Bonga Offshore

Bonga wind data was collected between 8thMarch 2001 and 6th April, 2001 at Nigeria bonga site located latitude 4.5386 and longitude 4.8163. The Bonga offshore in Nigeria is characterised by water depth of 1050 m. The instrument used is Impeller Anemometer/Direction vane. The sample duration used was 10 second, the recording interval was 60 second and sensor height was 3 meter but corrected to 10 meter above mean sea level. The monthly mean of the wind data across the different sites are computed and presented.

Table 1: Tabular presentation of monthly wind speed at Bonga platform in 1980.

Month	Mean Monthly Wind Speed (m/s)	Mean Monthly Wind Direction (deg)
January	6.5268	230
February	6.8376	218
March	5.9052	190
April	5.2836	211
May	6.993	245
June	7.9254	225
July	7.6146	220
August	6.216	234
September	5.7498	226
October	6.6822	219
November	9.4794	301
December	4.5066	207

Table 2: Monthly wind speed at Forcados platform in 1982.

Month	Mean Monthly Wind Speed (m/s)	Mean Monthly Wind Direction (deg)
January	1.2	235
February	4.2	240
March	6.1	238
April	5.3	215
May	3.9	223
June	5.4	217
July	5.1	231
August	2.5	214
September	2.1	220
October	4.1	205
November	1.8	211
December	2.3	196

Table 3: Tabular presentation of monthly wind speed at Bonny platform in 1980

Month	Mean Monthly Wind Speed (m/s)	Mean Monthly Wind Direction (deg)
January	3.6	241
February	4.3	232
March	3.8	238
April	3.2	250
May	3.5	247
June	4.7	2263
July	5.4	212
August	4.5	239
September	4.1	245
October	3.5	197
November	3.9	208
December	4.7	227

Table 4: Tabular presentation of monthly wind speed at Asabo platform in 1982

Month	Mean Monthly Wind Speed (m/s)	Mean Monthly Wind Direction (deg)
January	3.7	221
February	4.1	229
March	4.6	207
April	4.2	190
May	4.8	223
June	6.4	234
July	5.7	222
August	7.1	225
September	5.6	219
October	6.2	231
November	4.4	210
December	3.7	230

4.0 Results

Tables 1 to 4 indicate the monthly mean values of the wind speed of the different locations. The mean monthly wind directions. Tables 1 to 4 descriptions were used in the computations of energy potentials of the sites and other related parameters as documented in Tables 5 to 8.

Table 5: Forcadosfield energy analysisusing 1982 wind data for case study.

MONTHS	V_m (m/s)	K	c (m/s)	V_F (m/s)	V_E (m/s)	P_D(W/m^2)	E_D(kWh/m^2)
January	1.2	2.6	1.6	1.3	3.4	1.0584	25.4016
February	4.2	5.7	5.7	4.4	7.5	45.3789	1089.094
March	6.1	6.5	6.3	6	10	139.0258625	3336.621
April	5.3	6	5.44	5.3	6.6	91.1871625	2188.492
May	3.9	4.91	4.31	3.7	5.4	36.3328875	871.9893
June	5.4	6.2	5.7	5.1	8	96.4467	2314.721
July	5.1	6.1	5.9	5	6.4	81.2487375	1949.97
August	2.5	3.6	2.8	3.1	4.8	9.5703125	229.6875
September	2.1	3.3	2.4	4	5	5.6723625	136.1367

October	4.1	5.1	4.5	4.1	5.3	42.2141125	1013.139
November	1.8	2.5	1	2.3	3.88	3.5721	85.7304
December	2.3	2.8	2.6	3.1	4.4	7.4522875	178.8549
TOTAL	44	55.37	48.25	47.4	70.72	559.159825	13419.84
Annual Mean	**3.67**	**4.61**	**4.02**	**3.95**	**5.89**	**46.59665208**	**1118.32**

Mean wind speed (V_m); dimensionless Weibull shape parameter (k); Weibull scale parameter (c); most probable wind speed (V_F); wind speed carrying maximum energy (V_E); wind power density (P_D); mean energy density (E_D).

Table 6: Bonny field energy analysis using 1980 wind data for the case study.

MONTHS	V_m (m/s)	K	c (m/s)	V_F (m/s)	V_E (m/s)	P_D(W/m^2)	E_D(kWh/m^2)
January	3.6	3.2	3	2.9	5	28.5768	685.8432
February	4.3	4.6	5.3	4.4	6	48.69804	1168.753
March	3.8	4.2	6	6	8	33.6091	806.6184
April	3.2	4.5	5.98	5	7	20.0704	481.6896
May	3.5	4.62	4.86	4.6	5.4	26.26094	630.2625
June	4.7	4.2	5.2	5.3	8	63.59159	1526.198
July	5.4	5.1	5.7	5	7	96.4467	2314.721
August	4.5	4.3	3.8	5.3	6	55.81406	1339.538
September	4.1	4.7	2.9	4	5	42.21411	1013.139
October	3.5	3.8	4.6	4.2	5.6	26.26094	630.2625
November	3.9	2.5	2.8	3.6	4	36.33289	871.9893
December	4.7	2.8	3.4	3.9	3	63.59159	1526.198
TOTAL	49.2	48.52	53.54	54.2	70	541.4672	12995.21
Annual Mean	**4.1**	**4.043333**	**4.46166**	**4.516667**	**5.83333**	**45.1222**	**1082.934**

Mean wind speed (V_m); dimensionless Weibull shape parameter (k); Weibull scale parameter (c); most probable wind speed (V_F); wind speed carrying maximum energy (V_E); wind power density (P_D); mean energy density (E_D).

Table 7: Bonga platform energy analysis 1980

MONTHS	V_m (m/s)	K	c (m/s)	V_F (m/s)	V_E (m/s)	P_D(W/m^2)	E_D(kWh/m^2)
January	6.5268	4.05	4.4	4.31	8.01	170.297	4087.128
February	6.8376	4.31	4.56	4.42	7.04	195.802	4699.248
March	5.9052	3.76	4.03	4	10	126.1275	3027.061
April	5.2836	3.31	3.78	3.65	9.68	90.34329	2168.239
May	6.993	4.47	4.63	4.42	12	209.4579	5026.989
June	7.9254	4.95	5.51	4.97	8.11	304.9086	7317.806
July	7.6146	4.83	4.95	4.93	7.9	270.4253	6490.208
August	6.216	3.96	4.35	4.26	6.3	147.109	3530.615
September	5.7498	3.63	3.96	3.82	6.01	116.4298	2794.316
October	6.6822	4.22	4.47	4.41	7.31	182.753	4386.072
November	9.4794	5.72	8.01	7.07	15.01	521.7334	12521.6
December	4.5066	3.13	4.08	3.83	4.4	56.06	1345.44
TOTAL	79.7202	50.34	56.73	54.09	101.79	2391.447	57394.72
Annual Mean	**6.64335**	**4.195**	**4.73**	**4.51**	**8.48**	**199.2872**	**4782.894**

Mean wind speed (V_m); dimensionless Weibull shape parameter (k); Weibull scale parameter (c);most probable wind speed (V_F); wind speed carrying maximum energy (V_E); wind power density (P_D); mean energy density (E_D).

Table 8: Asabo field energy analysis 1982

MONTHS	V_m (m/s)	K	c (m/s)	V_F (m/s)	V_E (m/s)	P_D(W/m^2)	E_D(kWh/m^2)
January	3.7	3.23	3.53	3.62	4.1	31.0249625	744.5991
February	4.9	3.49	4.13	4.21	4.5	42.2141125	1013.139
March	4.6	4.78	4.71	4.65	5.2	69.6183	1430.839
April	4.5	4.24	3.99	4.32	4.8	45.3789	1089.094
May	4.8	3.53	4.82	4.84	5.4	77.7376	1625.702
June	6.4	3.01	6.32	5.08	7.7	160.5632	3853.517

July	5.7	4.52	5.62	5.82	6.5	113.4307125	2722.337
August	7.1	3.07	7.04	6.89	8.2	219.2204875	5261.292
September	5.8	4.93	5.43	5.72	6.4	107.5648	2581.555
October	6.2	4.41	6.14	5.67	7.5	145.9759	3503.422
November	4.4	3.65	4.39	4.53	5.8	52.1752	1252.205
December	3.9	3.11	3.74	4	4.6	31.0249625	744.5991
TOTAL	60.5	45.97	59.86	64.43	71.3	1075.929138	25822.3
Annual Mean	**5.14**	**3.83**	**4.99**	**5.37**	**5.94**	**95.66076146**	**2151.858**

Mean wind speed (V_m); dimensionless Weibull shape parameter (k); Weibull scale parameter (c); most probable wind speed (V_F); wind speed carrying maximum energy (V_E); wind power density (P_D); mean energy density (E_D).

5.0 Discussion

Figures5to 9 are plots of mean wind directions computed from daily measurements taken in the four (4) different locations. It can be seen that majority of the wind came in the SSW direction thereby favouring the utilization of wind turbine since the wind is arriving almost from same direction through out the year.

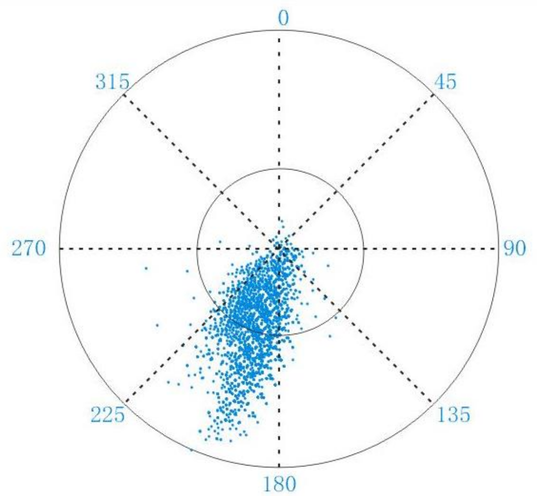

Figure 4: Weekly mean wind direction in 1982 at Asabo platform.

The mean wind speed experienced at Asabo platform in 1982 reached a monthly mean speed of 7.1m/s in the month of August with a maximum wind speed of 12m/s at an instant during the month.

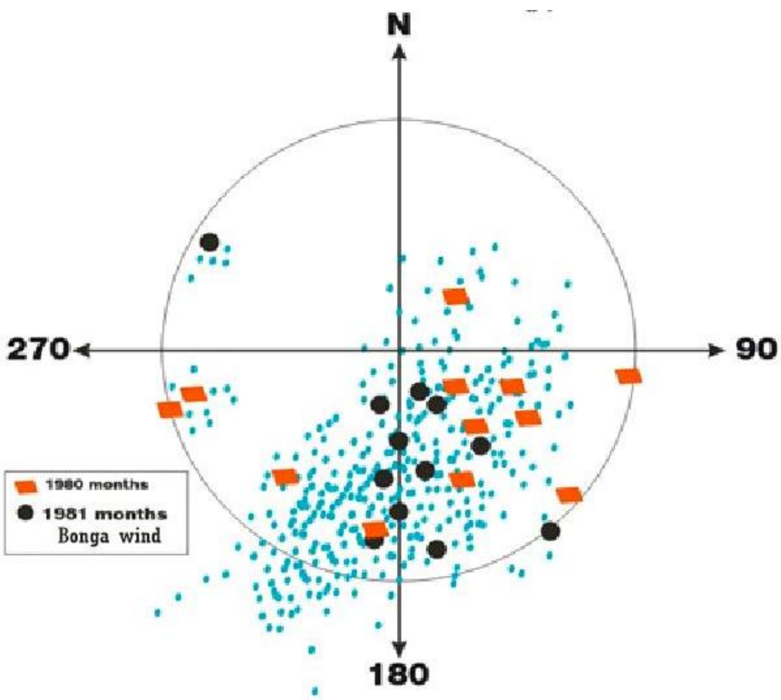

Figure 5: Bonga monthly and weekly wind direction in 1980 and 1981

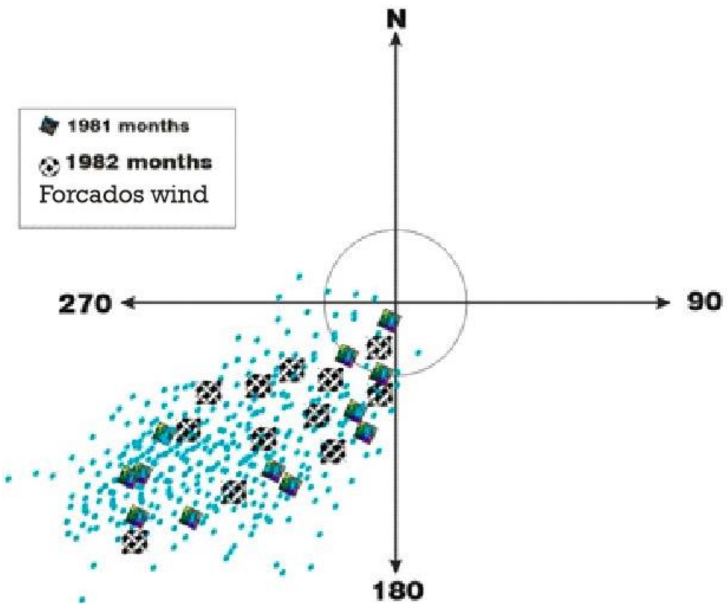

Figure 6: Monthly and weekly wind direction at Forcados

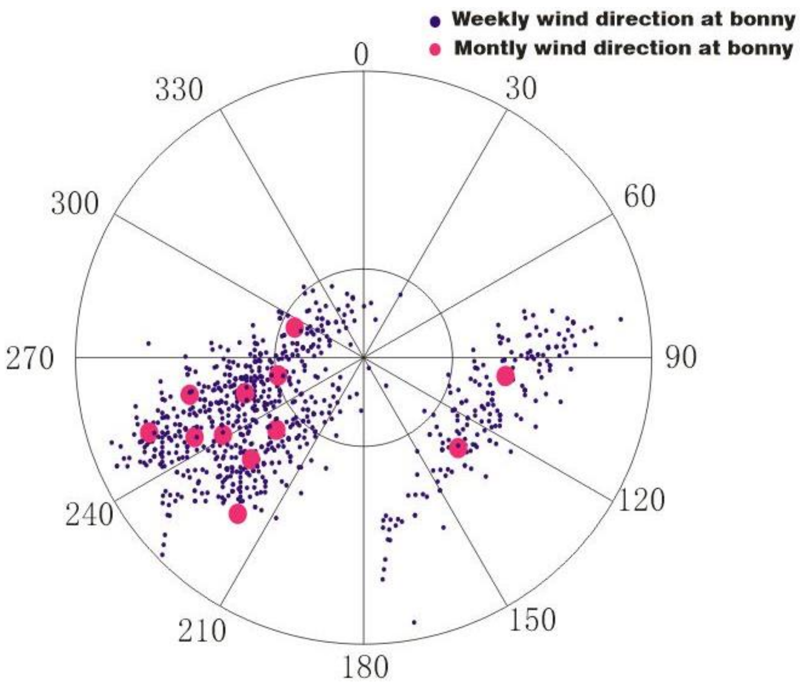

Figure 7: Bonny monthly and weekly wind direction measured in 2006

The least monthly value of the Weibull shape parameter k for Asabo is 3.01 in June and reached the highest value of 4.93in the month of September. Therefore, the wind speed is most uniform in Asabo in September, while it is least uniform in June. The annual shape factors for Forcados, Asabo and Bonga are 4.61, 3.83 and 4.195, respectively.

The least monthly value of Weibull scale parameter c is obtained as 1m/s in the month of November in Forcados, and the highest value is8.01m/s in the month of November in Bonga. This result implies that Bonga offshore (deep water) has more peaking wind and narrower variation than the rest of the fields. This is expected.

The annual mean power densities for these sites have been computed in Tables 5 to 8. In the case of Bonga (Table 7), the minimum and maximum values of the monthly mean wind speeds are 4.5m/s (in December) and 9.4m/s (in November), respectively. Detailed informationab out the site wind speed characteristics (mean wind speed, most probable wind speed (V_F) and the wind speed carrying maximum energy (V_E) and mean power densityare illustrated in Tables 7. Compare this with Tables 5, 6 and 8 of Forcados, Bonny and Asabo. One clear observations is increase in power from shallow to deep water

Examining the results with the Universal Classification of Table 9, the wind resource in these locations falls into class 3 or less. This is considered as marginal or unsuitable for wind power development. The wind source as found can be used for water pumping and small-scale electricity generation, providing intermittent power requirements for a variety of purposes that need low-energy capacity, slow-running high-torque. It is noted that energy can be enhanced to enter higher class by applying the current technology shown in Figure 9. For a modern wind turbine, the cut-in wind speed required to start generating electricity is generally between 3m/s to 5 m/s. Depending on the size of the turbine, the peak power output can beattained when the wind speed is in the range of 10 m/s to 15 m/s.

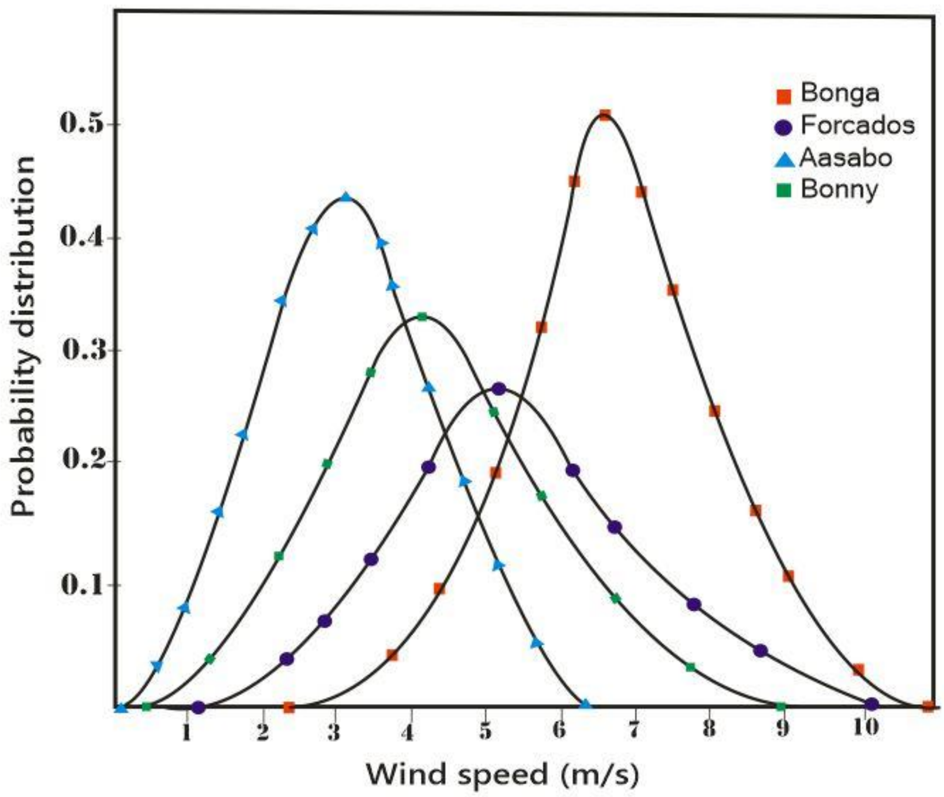

Figure 8: Annual wind speed distribution for Probability density function.

In general, Nigerian offshore exhibits a great variation in the wind speed in daily terms, recording as high as 15m/s at some instance and 0m/s at times. The mean power density is a useful way to evaluate the wind resource available at a potential site as it indicates how much energy is available at the site for conversion by a wind turbine. The classes of wind power density for two standard wind measurement heights are listed in the table below. It is important to know that the wind speed generally increases with height above ground.

Table 9: Classes of Wind Power Density at 10 m and 50 m

-	10 m (33 ft)		50 m (164 ft)	
Wind Power Class	Wind Power Density (W/m^2)	Speed[b] m/s (mph)	Wind Power Density (W/m^2)	Speed[b] m/s (mph)
1	<100	<4.4 (9.8)	<200	<5.6 (12.5)
2	100 - 150	4.4 (9.8) / 5.1 (11.5)	200 - 300	5.6 (12.5) / 6.4 (14.3)
3	150 - 200	5.1 (11.5) / 5.6 (12.5)	300 - 400	6.4 (14.3) / 7.0 (15.7)
4	200 - 250	5.6 (12.5) / 6.0 (13.4)	400 - 500	7.0 (15.7) / 7.5 (16.8)
5	250 - 300	6.0 (13.4) / 6.4 (14.3)	500 - 600	7.5 (16.8) / 8.0 (17.9)
6	300 - 400	6.4 (14.3) / 7.0 (15.7)	600 - 800	8.0 (17.9) / 8.8 (19.7)
7	>400	>7.0 (15.7)	>800	>8.8 (19.7)

Table 9 is the universal wind power classification as extracted from www.bwea.com.

It is evidently observed that as one moves from shallow water (Forcados)through to deep water (Bonga) locations, there is incremental values in wind mean speed.The shallow waters ofForcados,Bonny and Asabo yielded annual wind speed of 3.67m/s, 4.1m/s and 5.14m/s respectively. A deep waterlocation,Bonga produced an annual wind speed of 6.6m/s.Bongafields falls slightly into class 3 following the Universal wind energy association classification described in Table 9.

The computed mean monthly values of wind for Bonga locations were tested on the seven common wind turbine models and the results are indicated in Table 10.

Table 10: Characteristics of selected wind turbines.

Turbine model	Annual wind speed at hub height (m/s)	Rated speed (m/s)	Rotor diameter (m)	Calculated actual wind power (KW)	Hub height (m)
POLARIS P62-1000	8.2	12	62	**601.6**	60
WES30	7.75	12.5	30	**118.9**	36
POLARIS P15-50	7.57	10	15.2	**28.4**	30

POLARIS P19-100	7.57	12	19.1	**44.9**	30
WWD-1-60	8.42	12.5	60	**610**	70
POLARIS P50-500	8.07	12	50	**372.96**	50
BONUS 1000-54	7.96	14	54	**417.5**	45

The Power-velocity curves (Figure 9) for seven wind turbine models is shown below, the plotted point along each path indicates the actual power of the turbine at hub height as computed for Bonga offshore.

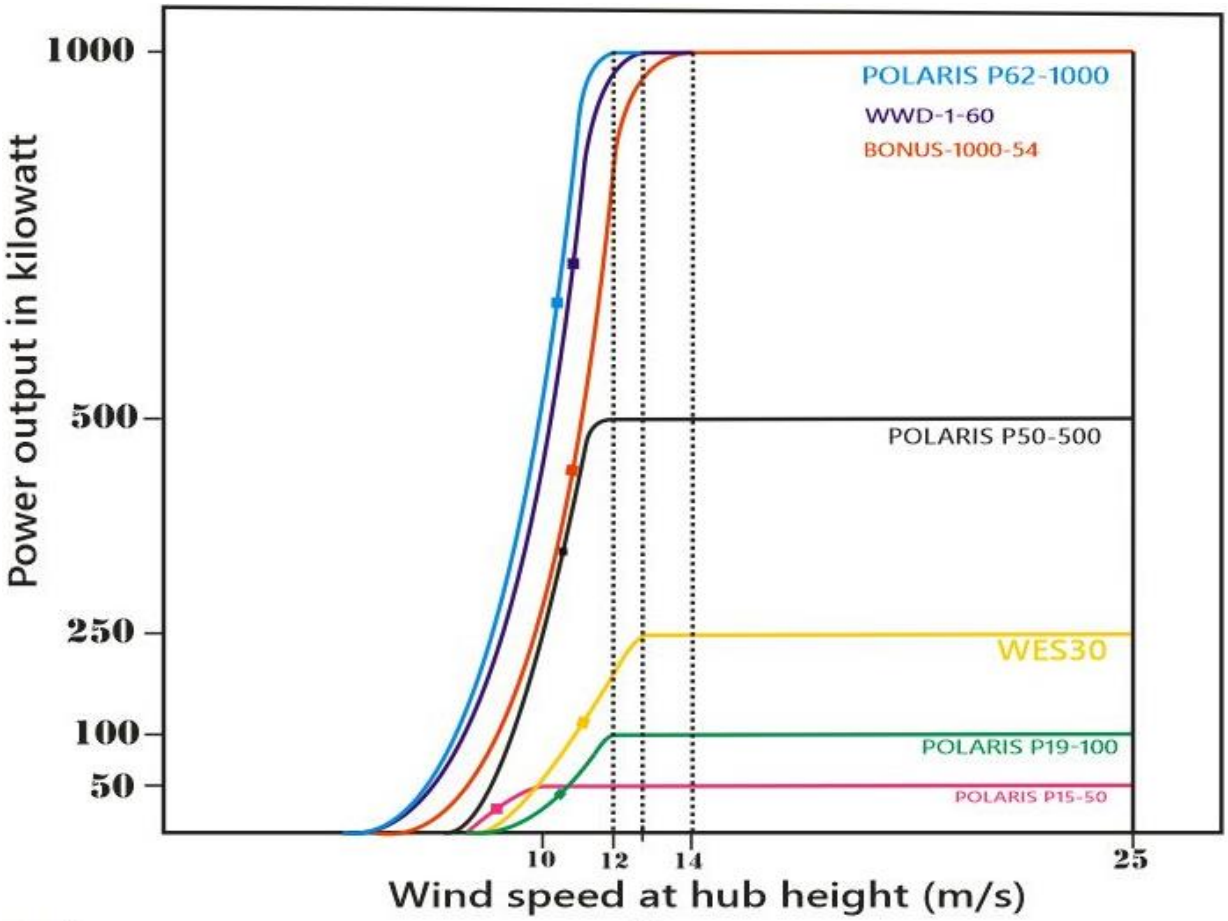

Figure 9: Power-velocity curves of seven existing wind turbines.

6.0 Conclusion

The following conclusions can be drawn from the above study on wind potential in offshore Nigeria.

i. Through calculations on wind data collected for four (4) different locations offshore, the annual speed were obtained 6.64m/s, 5.04m/s, 4.1m/s and 3.73m/s for Bonga field, Asabo offshore, Bonny and Forcados respectively.
ii. The mean annual value of Weibull shape parameter (k)is between 3.83 and 4.61, while the annual value of scale parameter (c) is between 4.02 and 4.99 m/s.
iii. The annual mean power densities are 199.28W/m^2, 89.661W/m^2, 45.122W/$m^2$and 46.5967W/m^2 for Bonga field, Asabo offshore, Bonny and Forcados respectively. The mean energy density are 4782.894Kwh/m^2, 2151.858Kwh/m^2, 1082.934Kwh/$m^2$and 1118.32Kwh/$m^2$for Bonga field, Asabo platform, Bonny and Forcados respectively.
iv. The use of POLARIS 62–1000 is preferred over other models because of its rotor diameter, cut-in speed and hub height advantages.

It is noted that according to the classification,Bonga offshore lies within class 3. It is believed that wind power at deep water will perform excellently when synchronized with ocean current energy technology. As suggested by Agbakwuru J. (2017) and Akinsanya et al. (2017), this is becausecurrent in the area is largelyunidirectional and consistent in availability.

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