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# Analysis of the Potential of Wind Energy Generation at Different Rotor Diameters in the Sudano-Sahelian Zone of Nigeria

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*Abstract:* **This study examines the potential of wind energy generation in the Sudano- Sahelian Zone of Nigeria under different rotor diameters. Data on wind speed, were obtained for 40 years (1973- 2012) from the records of Nigerian Meteorological Agency, Oshodi, Lagos. Mathematical Model was used to compute wind energy potential at 45m, 90m and 126m rotor diameters. The study revealed that about 89% of annual wind speed was found to be above the threshold of 3.0m/s for wind turbine operations. Wind energy potential in the area is high, varying from 704kW in Yelwa to 3,659kW in Kano, at a turbine rotor diameter of 126m. This could generate 512,260kW of electricity with two wind farms of 70 wind turbines each. The study concluded that the Sudano-Sahelian Zone has enormous potential for wind energy generation. It is therefore, recommended that the advantage of wind resources be explored by government through private public partnership initiative to complement existing sources of power generation for rapid socio-economic development in Nigeria.**

*Keywords:* **wind energy, rotor diameters, mathematical model, wind speed, wind turbine, energy potential, wind farm.**

## 1. INTRODUCTION

Wind energy is the kinetic energy derived from air in motion. Wind energy is one of the fastest growing renewable energy which could favorably serve as alternative source of energy to thermal or hydropower source of energy and other non-renewable sources of energy. It is a clean source of energy, environmentally friendly and is generated by converting wind kinetic energy into mechanical and electrical energy using wind turbines. The potential power obtainable from wind is proportional to the cube of wind speed.

According to NIMET, (2009) report, which was centered on the result of using 40 years (1968-2007) available mean wind data from the whole forty-four wind stations across the states of the federation, Nigeria has good wind resources. Ajayi, (2007) reported that the rank of potential for annual wind energy flux density for Nigeria is in the order of North-Central, South–East, South–South and South–West zones, respectively, with the first three political zones of the rank contributing about 86% of the total wind energy in Nigeria as calculated from the findings. Ajayi, et al. (2011) in their study on the assessment of wind power potential and wind electricity generation using WECS in Iseyin and Saki, in south west of Nigeria, also reported that the two sites have potential to generate MWh to GWh of energy at an average cost/kwh of between € (0.025 and 0.049).

Lehmeyer an International Consultants, (2005) reported that wind energy reserve in Nigeria at 10m height shows that some locations have wind regime between 1.0 and 5.1 m/s, hence, the country can be classified under poor/moderate wind regime. However, wind speeds in the country are generally weak in the south except for the coastal regions and offshore areas. The offshore areas from Lagos through Ondo, Delta, Rivers, Bayelsa to Akwa Ibom states were reported to have the capacity to generate wind energy throughout the year. Wind speed is reported strongest in the hilly regions of the North, while the mountainous areas of the middle belt and northern fringes show a high potential of wind energy. However, as a result of varying topography and roughness of the country, large differences may occur within the same area. The values of the wind speed in Nigeria ranges from 1.4 to 3.0 m/s in the southern areas to 4.0–5.12 m/s in the extreme North, at 10m height. Peak wind speed generally occurs between April and August for most locations in the analysis (Ajayi, 2009). Adekoya and Adewale, (1992) analyzed wind speed data of 30 stations in Nigeria, the result shows that the annual mean wind speeds and power flux densities vary from 1.5–4.1 m/s to 5.7–22.5W/$m^2$ respectively, while Fagbenle and Karayiannis (1994) did an analysis of 10-years wind data from 1979–1988, focusing on the surface and upper winds as well as the maximum gusts. Ngala, *et* al., (2007) also did a statistical analysis of wind energy potential in Maiduguri, Borno state, using the Weibull distribution analysis and 10 year (1995–2004) wind data, while Bugaje, (2006) examined the renewable energy usage in Africa using Nigeria, South Africa, Egypt and Mali as case studies. Each of these reported that Nigeria is blessed with wind resource and opportunity for harvesting wind for energy production, especially at the main northern states, mountainous parts of the central and eastern states and also offshore areas where wind is adequately available throughout the year (Ajayi, et al., 2009).

Accurate measurement and assessment is required in the development and ultilization of wind resource for energy generation. There are three important stages in the assessment of wind energy potentials; these are resource assessment, hardware development and installation, and also electricity production and distribution. The first stage, that is, the resource assessment stage, is very important to the other two stages and also to wind energy technology. This stage determines the turbine selection criteria based on the turbine's wind velocity technical rating of cut-in, cut-out and rated wind speeds and also determines the magnitude of wind power that can likely be generated from a location based on the historical wind speed assessment results (Ajayi, et al., 2011b). Similarly, Ajayi, et al., (2012) reported that assessing a location's wind resources for energy generation involves not only profiling the wind power potential but also involves evaluating two important wind speeds that will help in the determination of the wind speed rating of a suitable wind turbine.

In Nigeria, there are relatively sparse researches by Geographer on the computation of wind energy potential in the study area while most of the published works on wind energy potential are done by Engineers. In addition, most of the works have also not discussed wind energy potential under different rotor diameter. Hence, this study attempts to examine the potential of wind energy generation in the Sudano-Sahelian Zone of Nigeria, under different rotor diameters.

## 2. THE STUDY AREA

The Sudano-Sahelian zone in Nigeria is located between longitude $4^o$ and $14^o$E and latitude $10^o$ and $14^o$N and lies immediately to the south of Sahara desert. It is located in the northern part of Nigeria and stretches from the Sokoto plains to the Chad basin (Odekunle, et al, 2008). The zone span roughly through Sokoto, Zamfara, Katsina, Kano, Jigawa,Yobe, and Borno states respectively (Jidauna et al, 2011). The area also includes part of Bauchi.

Figure 1.1 shows the map of the study area. The Sudano-Sahelian zone of Nigeria occupies almost one-third of the total land area of Nigeria (Odekunle, et al, 2008). The zone houses over one-quarter of the Nigeria population (FMEN, 2006). According to the 2006 population census, the total population of the zone is 32,954538. The choice of the study area is based on the vegetation characteristics and climatic condition of the zone. The zone is predominantly savannah area with grasses and short trees which have little impact or effect on wind speed and direction. In term of climate, wind speed is relatively high in the area because of its closeness to the Sahara desert.

The climate of Sudano-Sahelian zone of Nigeria is dominated by the influence of three major meteorological features; namely, the tropical maritime (mT) air mass, the tropical continental (cT) air mass, and the equatorial easterlies (Ileoje, 1981). The first two air masses (mT and cT) meet along a slanting surface called the Inter-Tropical Discontinuity (ITD). The equatorial easterlies are rather erratic and relatively cool air masses from east in the upper troposphere along the ITD. The position of the ITD is a function of the season with considerable short-period fluctuations (Theophilus, et al, 2008). The climate of the area is characterized with alternating wet and dry seasons. The temperature of the zone is high throughout the year with a mean minimum value of about $23^0$C and mean maximum of about $4^0$C (Ojoye, 2008) except during the cold harmattan and rainy season. In the rainy season, temperature is fairly steady because cloudiness and humidity prevent back radiation, thus the diurnal range of temperature is relatively small and it is about $2^0$C (Oyebande, 2000). In the dry season the much back radiation is witnessed in the night and it tends to lower night temperature values. Thus, a high diurnal range of temperature sometimes as high as $12^0$C is observable (Ojoye, 2012). The average temperature in the hot season is about 40.6$^o$C, while the annual rainfall is less than 75cm. The rainy seasons are usually short, which is often within the ranges of four to five months. Owing to seasonal fluctuations, it could even drop to less than four months. Rainfall is marginal in the area. The rainfall in the region is less than 1000mm per annum in only about five months in the year especially between May and October. According to Ayoade, (2006) wind speeds in Nigeria are generally gentle to moderate except at exposed location or at the approach of rainstorms when speed may increase to over 30 knots (55.6 km/hr) particularly in the northern parts of the country. Wind erosion is rampart in the zone. This implies that wind speed is relatively high. In Sokoto state for example, the normal wind velocities range from 1 to 10 knots while some times it may be accompanied by gust of up to 40 knots (Mamman, 2002). Ajayi,et al. (2010) reported that monthly wind speed vary widely in Zamfara State.

The vegetation of the Sudano-Sahelian zone is the Savanna type consisting of Sudan and Sahel with the density of trees and other plants decreasing as one move northwards (Abaje, 2007). It is characterised by abundant short grasses of 1.5-2m and few stunted trees hardly above 15m (on line Nigeria, 2002). The Sahel savanna on the other hand, is the last vegetation belt to the north of Nigeria with proximity to the fringes of the fast-encroaching Sahara desert. It is characterised by very short grasses of not more than one metre high located in-between sand dunes. The area is dominated by several varieties of the acacia and date- palms.

The Sudano-Sahelian zone consists of highlands and plains (Chad and Sokoto Plains). Some of the highland in the zone includes Biu plateau, Mandara mountain, Shara hill and Bamgi hill. According to Ogezi, (2002) the zone lies within the areas with mountain, plateau, hills, ridges, volcanic cones and inselbergs. Ologe, (2002) reported that the Chad plains is an extensive relief made up of recent deposits of sand and clay with an elevation of about 500m. Generally, the topography of the zone is mainly flat and mostly lies between 200 and 400m in elevation. Several isolated plateau and mountain ranges rise from the Sahel, but are designated as separate eco-regions because their flora and fauna are distinct from the surrounding lowland (World Wildlife Fund, 2001).

The zone is characterized with a predominantly rural and peasant population. These are people whose primary occupation is mainly rain-fed farming (with few exceptional areas where irrigation is practised) and animal rearing (Dabi and Jidaunna, 2010). The major agricultural activity in the zone is pastoral farming. The zone supports about 90% of the cattle population, about two-third of the goats and sheep and almost all the donkeys, camels, and horses found in the country. Cereals, cowpeas, groundnut and cotton are the main crops grown in the region (FMEN, 2006).

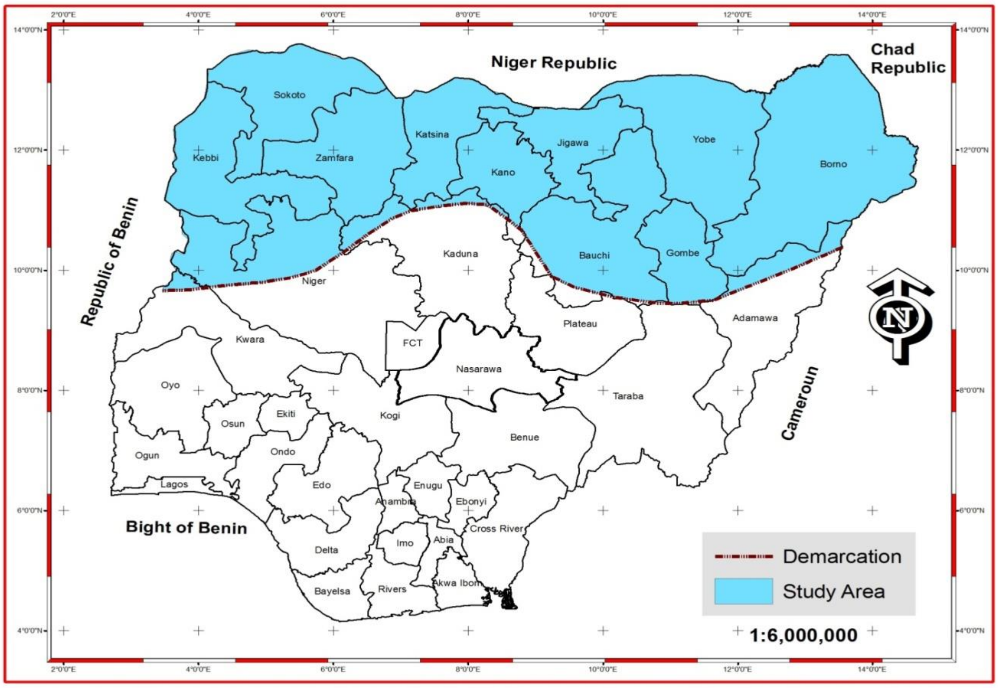


**Figure 1.1 Map of Nigeria showing the study area, Sudano-Sahelian Zone (Extracted from Iloeje, 1982)**

## 3. MATERIALS AND METHOD

There are two main parameters that are used in wind observations. These parameters are wind speed and wind direction. However, for this study, wind speed was used in the analysis of the potential of wind energy generation. Monthly mean wind speed data at 10m meteorological height were collected from eight locations where meteorological station are located in the Sudano-Sahelian Zone, Nigeria, for a period of 40 years (1973-2012). These locations are, Gusau, Kano, Katsina, Yelwa, Sokoto, Nguru, Maiduguri, and Bauchi. The wind speed data were collected from Nigeria Meteorological Agency, Lagos.

### 3.1 Data Analysis:

A mathematical model was used to compute wind energy potential at 45m, 90m and 126m rotor diameters. The choice of these rotor diameters was based on the fact that the medium scales turbine ranges from 12m to 45m. Also, the world largest wind turbine rotor blade diameter is 126m (REUK, 2013). Different rotor blade diameters were used in order to show variations in the wind energy output in relation to the turbine blade diameter.

Wind powers in the area were therefore, computed using the equation:

$$P = \frac{1}{2}\rho A V^3 C_P \quad \text{.............................. eq. 1}$$

where

P = available wind power ($W/m^2$)

ρ = air density ($1.225kg/m^3$) at sea level

A = Swept Area of Blades ($m^2$)

V = wind speed (m/s)

$C_p$ = Power Coefficient (0.40)

Since no wind turbine can operate at the theoretical maximum power coefficient of 0.59%, the average of Betz values of 0.35-0.45 was used as the value for the theoretical power coefficient.

### 3.2 Results and Discussion:

#### *3.2.1 Frequency of Wind Speed in the Sudano-Sahelian Zone of Nigeria (1973-2012):*

The frequency in the occurrence of monthly wind speed is presented in Table 1. In Yelwa, 57.9% (278) of the wind speed falls between 3.0 and 5.9m/s while in Sokoto 54.6% (262) falls between 6.0 and 11.9m/s. The highest percentage of wind speed record in Gusau, (48.1%) falls between 3.0 and 5.9m/s while in Katsina the highest percentage (45%) between 6.0 and 8.9m/s. Bauchi, Nguru and Maiduguri have their highest percentage of wind speed 48.5%, 47.7% and 54.8% respectively between 3.0 and 5.9m/s while that of Kano, (45.5%) falls between 6.0 and 8.9m/s. Generally, in all the stations, greater percentage of wind speed were above 3.0m/s. Figure 2 shows the frequency of the occurrence of wind speed

**Table 1: Frequency of wind Speed (1973-2012)**

| | 0.0 – 2.9 (m/s) | | 3.0 – 5.9 (m/s) | | 6.0 – 8.9 (m/s) | | 9.0 – 11.9 (m/s) | | 12.0 – 14.9 (m/s) | | 15.0 – 17.9 (m/s) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Stations | **Freq.** | **%** | **Freq.** | **%** | **Freq.** | **%** | **Freq.** | **%** | **Freq.** | **%** | **Freq.** | **%** |
| 1. Yelwa | 131 | 27.3 | 278 | 57.9 | 70 | 14.6 | 1 | 0.2 | 0 | 0.0 | 0 | 0.0 |
| 2. Sokoto | 4 | 0.8 | 105 | 21.9 | 262 | 54.6 | 102 | 21.3 | 7 | 1.5 | 0 | 0.0 |
| 3. Gusau | 20 | 4.2 | 231 | 48.1 | 207 | 43.1 | 21 | 4.4 | 0 | 0.0 | 1 | 0.2 |
| 4. Katsina | 9 | 1.9 | 181 | 37.7 | 219 | 45.6 | 55 | 11.5 | 15 | 3.1 | 1 | 0.2 |
| 5. Kano | 3 | 0.6 | 89 | 18.5 | 223 | 46.5 | 143 | 29.8 | 21 | 4.4 | 1 | 0.2 |
| 6. Bauchi | 111 | 23.1 | 233 | 48.5 | 113 | 23.5 | 23 | 4.8 | 0 | 0.0 | 0 | 0.0 |
| 7. Nguru | 126 | 26.3 | 229 | 47.7 | 114 | 23.8 | 11 | 2.3 | 0 | 0.0 | 0 | 0.0 |
| 8. Maiduguri | 28 | 5.8 | 263 | 54.8 | 187 | 39.0 | 2 | 0.2 | 0 | 0.0 | 0 | 0.0 |
| Total | **432** | **11.3** | **1609** | **41.9** | **1395** | **36.3** | **358** | **9.3** | **43** | **1.1** | **3** | **0.1** |

*Source: Author's Field work, (2015)*

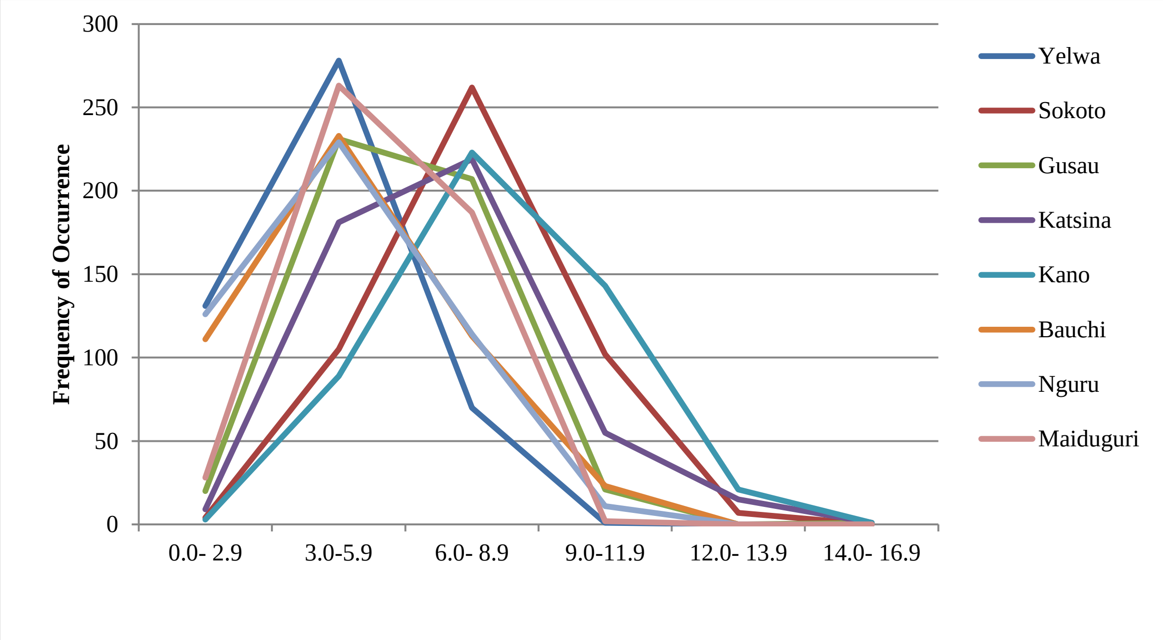


**Figure 2: Frequency of Wind Speed in Sudano-Sahelian Zone of Nigeria Geographical Pattern of Wind Energy Potential in kW in the SSZ, Nigeria (1973-2012)**

**i. Yelwa:**

Table 2 shows the amount of wind energy potential in Yelwa from 1973-2012 for different turbine rotor diameter. From the table with 45m rotor diameter, 90kW of energy can be generated in 2008 while 11kW of energy can be produced in 1982, 1984 and 1995. Similarly, 90m rotor diameter is capable of producing 259kW of energy in 2008 and 45kW in 1982 and 1984 while 126m rotor diameter can generate 704kW in 2008 and 88kW in 1982, and 1984. The table reveals that the more the rotor diameter the more energy produced. Generally, there is variation in the amount of wind energy that can be produced in the area. The results revealed that there is high potential of generating wind energy in Yelwa.

**Table 2: Wind Energy Potential in Yelwa from 1973-2012 (kW)**

| S/N | Year | 45 m blade | 90 m blade | 126 m blade | S/N | Year | 45 m blade | 90 m blade | 126 m blade |
|---|---|---|---|---|---|---|---|---|---|
| 1. | **1973** | 20 | 81 | 159 | **21.** | **1993** | 34 | 136 | 266 |
| 2. | **1974** | 13 | 50 | 98 | **22.** | **1994** | 17 | 67 | 132 |
| 3. | **1975** | 22 | 87 | 170 | **23** | **1995** | 11 | 46 | 89 |
| 4. | **1976** | 39 | 155 | 303 | **24.** | **1996** | 8 | 31 | 61 |
| 5. | **1977** | 39 | 155 | 303 | **25.** | **1997** | 12 | 47 | 92 |
| 6. | **1978** | 40 | 160 | 313 | **26.** | **1998** | 13 | 52 | 101 |
| 7. | **1979** | 34 | 136 | 266 | **27.** | **1999** | 15 | 59 | 116 |
| 8. | **1980** | 28 | 111 | 218 | **28.** | **2000** | 3 | 13 | 26 |
| 9. | **1981** | 12 | 46 | 91 | **29.** | **2001** | 8 | 32 | 62 |
| 10. | **1982** | 11 | 45 | 88 | **30.** | **2002** | 78 | 314 | 614 |
| 11. | **1983** | 12 | 47 | 92 | **31.** | **2003** | 49 | 197 | 386 |
| 12. | **1984** | 11 | 45 | 88 | **32** | **2004** | 38 | 153 | 299 |
| 13. | **1985** | 24 | 98 | 191 | **33.** | **2005** | 66 | 262 | 514 |
| 14. | **1986** | 27 | 110 | 215 | **34.** | **2006** | 73 | 293 | 575 |
| 15. | **1987** | 28 | 114 | 223 | **35.** | **2007** | 63 | 254 | 497 |
| 16. | **1988** | 24 | 95 | 185 | **36.** | **2008** | 90 | 359 | 704 |
| 17. | **1989** | 14 | 57 | 112 | **37.** | **2009** | 65 | 261 | 511 |
| 18. | **1990** | 23 | 92 | 181 | **38.** | **2010** | 73 | 292 | 572 |
| 19. | **1991** | 30 | 121 | 238 | **39.** | **2011** | 20 | 81 | 159 |
| 20. | **1992** | 34 | 136 | 266 | **40.** | **2012** | 13 | 50 | 96 |

*Source: Author's Field work, (2015)*

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**ii. Sokoto:**

Table 3 the highest wind output that can be produced with 45m turbine rotor diameter is 346kW in 1984 and the smallest is 72 kW in 1975 and 1993. For 90m and 126m rotor diameter, the highest energy that can be produced was 1383kW and 2711kW in 1984 respectively. The table also reveals that there is variation in the wind energy output in the station. Ajayi et al. (2011) using 21 years monthly wind speed, also reported that Sokoto has the potential of generating between 2.1 and 10.8GWh per annum. The outcome of the findings showed that Sokoto has a great potential for generating wind energy.

**Table 3: Wind Energy Potential in Sokoto from 1973-2012 (kW)**

| S/N | Year | 45 m blade | 90 m blade | 126 m blade | S/N | Year | 45 m blade | 90 m blade | 126 m blade |
|---|---|---|---|---|---|---|---|---|---|
| 1. | **1973** | 121 | 486 | 952 | **21.** | **1993** | 72 | 287 | 563 |
| 2. | **1974** | 135 | 542 | 1061 | **22.** | **1994** | 134 | 535 | 1048 |
| 3. | **1975** | 72 | 289 | 566 | **23.** | **1995** | 225 | 900 | 1766 |
| 4. | **1976** | 97 | 390 | 764 | **24.** | **1996** | 184 | 737 | 1444 |
| 5. | **1977** | 85 | 342 | 670 | **25.** | **1997** | 179 | 717 | 1406 |
| 6. | **1978** | 95 | 379 | 742 | **26.** | **1998** | 189 | 756 | 1483 |
| 7. | **1979** | 186 | 745 | 1461 | **27.** | **1999** | 123 | 492 | 965 |
| 8. | **1980** | 218 | 872 | 1709 | **28.** | **2000** | 154 | 616 | 1208 |
| 9. | **1981** | 294 | 1174 | 2302 | **29.** | **2001** | 165 | 660 | 1294 |
| 10. | **1982** | 214 | 856 | 1678 | **30.** | **2002** | 153 | 614 | 1203 |
| 11. | **1983** | 328 | 1311 | 2570 | **31.** | **2003** | 129 | 516 | 1012 |
| 12. | **1984** | 346 | 1383 | 2711 | **32.** | **2004** | 211 | 847 | 1660 |
| 13. | **1985** | 232 | 927 | 1817 | **33.** | **2005** | 200 | 801 | 1570 |
| 14. | **1986** | 189 | 757 | 1483 | **34.** | **2006** | 101 | 405 | 793 |
| 15. | **1987** | 250 | 998 | 1957 | **35.** | **2007** | 109 | 438 | 858 |
| 16. | **1988** | 212 | 847 | 1660 | **36.** | **2008** | 117 | 469 | 919 |
| 17. | **1989** | 241 | 964 | 1889 | **37.** | **2009** | 129 | 516 | 1012 |
| 18. | **1990** | 198 | 792 | 1552 | **38.** | **2010** | 170 | 682 | 1336 |
| 19. | **1991** | 119 | 473 | 931 | **39.** | **2011** | 129 | 516 | 1012 |
| 20. | **1992** | 80 | 322 | 631 | **40.** | **2012** | 203 | 813 | 1594 |

*Source: Author's Field work, (2015)*

**iii. Gusau:**

Table 4 shows the amount of potential wind energy in Gusau from 1973-2012 for 45m, 90m and 126m turbine rotor diameters. From the table with 45m rotor diameter, 206kW of energy can be generated in 1988 while 35kW of energy can be produced in 2008. Similarly, 90m rotor diameter is capable of producing 138kW of energy in 2008 while 126m rotor diameter can generate 1612kW in 1988 and 271kW in 2008. The table shows that the more the rotor diameter the more energy produced. Generally, there is variation in the amount of wind energy that can be produced in the area. The outcome of the findings showed that Gusau has a great potential for generating wind energy. Ajayi et al. (2011) also reported that Gusau is a suitable site for generating wind power.

**Table 4: Wind Energy Potential in Gusau from 1973-2012 (kW)**

| S/N | Year | 45 m blade | 90 m blade | 126 m blade | S/N | Year | 45 m blade | 90 m blade | 126 m blade |
|---|---|---|---|---|---|---|---|---|---|
| 1. | **1973** | 71 | 286 | 560 | **21.** | **1993** | 77 | 308 | 605 |
| 2. | **1974** | 63 | 255 | 500 | **22.** | **1994** | 73 | 294 | 575 |
| 3. | **1975** | 61 | 245 | 481 | **23.** | **1995** | 84 | 337 | 660 |
| 4. | **1976** | 54 | 217 | 425 | **24.** | **1996** | 103 | 412 | 808 |
| 5. | **1977** | 46 | 186 | 364 | **25.** | **1997** | 119 | 477 | 935 |
| 6. | **1978** | 49 | 197 | 386 | **26.** | **1998** | 85 | 340 | 667 |
| 7. | **1979** | 84 | 337 | 660 | **27.** | **1999** | 87 | 347 | 680 |
| 8. | **1980** | 44 | 176 | 344 | **28.** | **2000** | 76 | 304 | 596 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 9. | **1981** | 54 | 214 | 420 | **29.** | **2001** | 124 | 494 | 969 |
| 10. | **1982** | 117 | 467 | 915 | **30.** | **2002** | 96 | 382 | 749 |
| 11. | **1983** | 82 | 328 | 643 | **31.** | **2003** | 56 | 223 | 437 |
| 12. | **1984** | 88 | 350 | 687 | **32.** | **2004** | 74 | 296 | 581 |
| 13. | **1985** | 66 | 264 | 517 | **33.** | **2005** | 61 | 243 | 476 |
| 14. | **1986** | 82 | 327 | 640 | **34.** | **2006** | 41 | 164 | 321 |
| 15. | **1987** | 179 | 714 | 1400 | **35.** | **2007** | 45 | 180 | 353 |
| 16. | **1988** | 206 | 822 | 1612 | **36.** | **2008** | 35 | 138 | 271 |
| 17. | **1989** | 157 | 629 | 1233 | **37.** | **2009** | 63 | 252 | 495 |
| 18. | **1990** | 147 | 587 | 1150 | **38.** | **2010** | 51 | 204 | 400 |
| 19. | **1991** | 93 | 371 | 728 | **39.** | **2011** | 49 | 197 | 386 |
| 20. | **1992** | 82 | 328 | 644 | **40.** | **2012** | 84 | 337 | 660 |

*Source: Author's Field work, (2015)*

**iv. Katsina:**

Table 5 shows the power converted from the wind into rotational energy in the turbine of different rotor blades diameter in Katsina from 1974-2012. The highest wind energy that can be produced in the station was 374kW, 1494kW and 2928kW for 45m, 90m, and 126m rotor blade diameters respectively. On the other hand the lowest wind energy that can be produced in the station with rotor blade diameters 45m, 90m, and 126m is 27Kw, 108kW and 212kW respectively. This implies that Katsina is a good site for generating wind energy. Variation exists in the wind energy output in the station in the years under review. A distinct increase occurred in the amount of potential energy generated from 1984 to 1997.

**Table 5: Wind Energy Potential in Katsina from 1973-2012 (kW)**

| S/N | Year | 45 m blade | 90 m blade | 126 m blade | S/N | Year | 45 m blade | 90 m blade | 126 m blade |
|---|---|---|---|---|---|---|---|---|---|
| 1. | **1973** | 46 | 183 | 359 | **21.** | **1993** | 145 | 581 | 1140 |
| 2. | **1974** | 27 | 108 | 212 | **22.** | **1994** | 145 | 579 | 1136 |
| 3. | **1975** | 62 | 249 | 489 | **23.** | **1995** | 207 | 828 | 1623 |
| 4. | **1976** | 51 | 205 | 400 | **24.** | **1996** | 230 | 921 | 1804 |
| 5. | **1977** | 111 | 444 | 870 | **25.** | **1997** | 163 | 652 | 1278 |
| 6. | **1978** | 91 | 364 | 714 | **26.** | **1998** | 53 | 212 | 415 |
| 7. | **1979** | 74 | 295 | 578 | **27.** | **1999** | 44 | 176 | 344 |
| 8. | **1980** | 78 | 310 | 608 | **28.** | **2000** | 59 | 236 | 463 |
| 9. | **1981** | 77 | 307 | 602 | **29.** | **2001** | 114 | 454 | 890 |
| 10. | **1982** | 99 | 395 | 775 | **30.** | **2002** | 119 | 475 | 931 |
| 11. | **1983** | 90 | 361 | 707 | **31.** | **2003** | 97 | 390 | 764 |
| 12. | **1984** | 225 | 901 | 1766 | **32.** | **2004** | 135 | 539 | 1057 |
| 13. | **1985** | 260 | 1041 | 2040 | **33.** | **2005** | 109 | 438 | 858 |
| 14. | **1986** | 259 | 1037 | 2033 | **34.** | **2006** | 68 | 271 | 531 |
| 15. | **1987** | 374 | 1494 | 2928 | **35.** | **2007** | 54 | 218 | 427 |
| 16. | **1988** | 300 | 1201 | 2356 | **36.** | **2008** | 73 | 290 | 569 |
| 17. | **1989** | 310 | 1241 | 2434 | **37.** | **2009** | 59 | 237 | 465 |
| 18 | **1990** | 271 | 1084 | 2125 | **38.** | **2010** | 44 | 176 | 344 |
| 19. | **1991** | 274 | 1095 | 2146 | **39.** | **2011** | 73 | 290 | 569 |
| 20 | **1992** | 236 | 943 | 1850 | **40.** | **2012** | 259 | 1037 | 2033 |

*Source: Author's Field work, (2015)*

**v. Kano:**

According to table 6 the highest potential wind energy in Kano with turbine of 45m rotor diameter is 467kW in 1993 and the smallest was 36kW in 2003. For 90m and 126m rotor diameter, the highest energy that can be produce was 1867kW and 3659kW in 1993 respectively. The implication of this is that Kano has great potential for generating wind energy. The table reveals that there is variation in the wind energy output in the area within the years under review.

**Table 6: Wind Energy Potential in Kano from 1973-2012 (kW)**

| S/N | Year | 45 m blade | 90 m blade | 126 m blade | S/N | Year | 45 m blade | 90 m blade | 126 m blade |
|---|---|---|---|---|---|---|---|---|---|
| 1. | **1973** | 71 | 284 | 557 | **21.** | **1993** | 467 | 1867 | 3659 |
| 2. | **1974** | 59 | 236 | 463 | **22.** | **1994** | 415 | 1659 | 3251 |
| 3. | **1975** | 71 | 284 | 557 | **23.** | **1995** | 438 | 1753 | 3436 |
| 4. | **1976** | 95 | 381 | 746 | **24.** | **1996** | 353 | 1414 | 2770 |
| 5. | **1977** | 71 | 284 | 557 | **25.** | **1997** | 248 | 991 | 1943 |
| 6. | **1978** | 103 | 412 | 808 | **26.** | **1998** | 194 | 777 | 1523 |
| 7. | **1979** | 164 | 658 | 1289 | **27.** | **1999** | 106 | 424 | 831 |
| 8. | **1980** | 233 | 930 | 1824 | **28.** | **2000** | 238 | 954 | 1869 |
| 9. | **1981** | 187 | 748 | 1467 | **29.** | **2001** | 235 | 940 | 1843 |
| 10 | **1982** | 272 | 1088 | 2132 | **30.** | **2002** | 244 | 974 | 1909 |
| 11. | **1983** | 352 | 1409 | 2762 | **31.** | **2003** | 36 | 145 | 284 |
| 12. | **1984** | 300 | 1202 | 2356 | **32.** | **2004** | 85 | 340 | 666 |
| 13. | **1985** | 300 | 1202 | 2356 | **33.** | **2005** | 79 | 317 | 621 |
| 14. | **1986** | 246 | 984 | 1930 | **34.** | **2006** | 58 | 232 | 455 |
| 15. | **1987** | 239 | 957 | 1876 | **35.** | **2007** | 75 | 301 | 590 |
| 16. | **1988** | 298 | 1194 | 2340 | **36.** | **2008** | 91 | 368 | 721 |
| 17. | **1989** | 308 | 1234 | 2418 | **37.** | **2009** | 82 | 328 | 643 |
| 18. | **1990** | 293 | 1171 | 2295 | **38.** | **2010** | 85 | 338 | 663 |
| 19. | **1991** | 293 | 1171 | 2295 | **39.** | **2011** | 238 | 954 | 1869 |
| 20. | **1992** | 411 | 1644 | 3223 | **40.** | **2012** | 235 | 940 | 1843 |

*Source: Author's Field work, (2015)*

**vi. Bauchi:**

Table 7 shows the wind energy output in Bauchi from 1973-2012 for 45m, 90m and 126m turbine rotor diameters. From the table with 45m rotor diameter, 198kW of energy can be generated in 1975 while 5kW of energy can be produced in 2002, 2003, and 2011. Similarly, 90m rotor diameter is capable of producing 792kW of energy in 1975 and 19kW in 2002 while 126m rotor diameter can generate 1552kW in 1975 and 37kW in 2002. This implies that Bauchi is a good site for generating wind energy. The table shows that potential wind energy varies from one year to another. Generally, there is variation in the wind energy potential in Bauchi.

**Table 7: Wind Energy Potential in Bauchi from 1973-2012 (kW)**

| S/N | Year | 45 m blade | 90 m blade | 126 m blade | S/N | Year | 45 m blade | 90 m blade | 126 m blade |
|---|---|---|---|---|---|---|---|---|---|
| 1. | **1973** | 138 | 553 | 1084 | **21.** | **1993** | 6 | 25 | 48 |
| 2. | **1974** | 159 | 634 | 1242 | **22.** | **1994** | 39 | 155 | 303 |
| 3. | **1975** | 198 | 792 | 1552 | **23.** | **1995** | 21 | 83 | 162 |
| 4. | **1976** | 148 | 594 | 1164 | **24.** | **1996** | 26 | 106 | 207 |
| 5. | **1977** | 98 | 391 | 768 | **25.** | **1997** | 32 | 127 | 248 |
| 6. | **1978** | 70 | 280 | 548 | **26.** | **1998** | 29 | 118 | 231 |
| 7. | **1979** | 70 | 278 | 545 | **27.** | **1999** | 34 | 136 | 267 |
| 8. | **1980** | 64 | 256 | 503 | **28.** | **2000** | 36 | 145 | 284 |
| 9. | **1981** | 72 | 289 | 566 | **29.** | **2001** | 67 | 269 | 528 |
| 10. | **1982** | 69 | 277 | 542 | **30.** | **2002** | 5 | 19 | 37 |
| 11. | **1983** | 55 | 219 | 430 | **31.** | **2003** | 5 | 20 | 39 |
| 12. | **1984** | 92 | 370 | 725 | **32.** | **2004** | 23 | 90 | 177 |
| 13. | **1985** | 66 | 264 | 516 | **33.** | **2005** | 66 | 265 | 519 |
| 14. | **1986** | 43 | 171 | 336 | **34.** | **2006** | 55 | 220 | 432 |
| 15. | **1987** | 26 | 106 | 207 | **35.** | **2007** | 108 | 430 | 843 |
| 16. | **1988** | 28 | 114 | 223 | **36.** | **2008** | 68 | 272 | 531 |
| 17. | **1989** | 21 | 85 | 166 | **37.** | **2009** | 43 | 173 | 340 |
| 18. | **1990** | 13 | 50 | 98 | **38.** | **2010** | 77 | 309 | 605 |
| 19. | **1991** | 26 | 104 | 204 | **39.** | **2011** | 5 | 20 | 39 |
| 20. | **1992** | 9 | 36 | 70 | **40.** | **2012** | 23 | 90 | 177 |

*Source: Author's Field work, (2015)*

### vii. Nguru:

According to table 8 the wind energy potential in Nguru with turbine of 45m rotor diameter is 167kW in 2006 and 2kW in 2004. For 90m and 126m rotor diameter, the highest energy that can be produce is 668kW and 1310kW in 2006 respectively. The outcome of the results shows that Nguru has the potential for generating wind energy. The table reveals that there is variation in the wind energy output in the area within the years under review.

**Table 8: Wind Energy Potential in Nguru from 1973-2012 (kW)**

| S/N | Year | 45 m blade | 90 m blade | 126 m blade | S/N | Year | 45 m blade | 90 m blade | 126 m blade |
|---|---|---|---|---|---|---|---|---|---|
| 1. | **1973** | 5 | 20 | 39 | **21.** | **1993** | 25 | 100 | 196 |
| 2. | **1974** | 45 | 181 | 355 | **22.** | **1994** | 31 | 123 | 241 |
| 3. | **1975** | 50 | 202 | 396 | **23.** | **1995** | 27 | 107 | 211 |
| 4. | **1976** | 106 | 422 | 827 | **24.** | **1996** | 26 | 102 | 200 |
| 5. | **1977** | 96 | 382 | 749 | **25.** | **1997** | 35 | 140 | 275 |
| 6. | **1978** | 120 | 479 | 940 | **26.** | **1998** | 135 | 542 | 1061 |
| 7. | **1979** | 135 | 542 | 1061 | **27.** | **1999** | 26 | 104 | 204 |
| 8. | **1980** | 37 | 147 | 288 | **28.** | **2000** | 50 | 202 | 396 |
| 9. | **1981** | 58 | 232 | 455 | **29.** | **2001** | 1 | 6 | 11 |
| 10. | **1982** | 63 | 252 | 495 | **30.** | **2002** | 0.4 | 2 | 3 |
| 11. | **1983** | 41 | 165 | 323 | **31.** | **2003** | 0.1 | 0.5 | 1 |
| 12. | **1984** | 13 | 51 | 100 | **32.** | **2004** | 2 | 8 | 16 |
| 13. | **1985** | 13 | 51 | 100 | **33.** | **2005** | 84 | 337 | 660 |
| 14. | **1986** | 14 | 55 | 108 | **34.** | **2006** | 167 | 668 | 1310 |
| 15. | **1987** | 15 | 61 | 119 | **35.** | **2007** | 19 | 75 | 147 |
| 16. | **1988** | 13 | 58 | 113 | **36.** | **2008** | 70 | 281 | 551 |
| 17. | **1989** | 15 | 60 | 118 | **37.** | **2009** | 105 | 418 | 820 |
| 18. | **1990** | 14 | 54 | 106 | **38.** | **2010** | 127 | 508 | 995 |
| 19. | **1991** | 16 | 66 | 129 | **39.** | **2011** | 27 | 107 | 211 |
| 20. | **1992** | 20 | 81 | 159 | **40.** | **2012** | 26 | 102 | 200 |

*Source: Author's Field work, (2015)*

### viii. Maiduguri:

Table 9 shows the wind energy output in Maiduguri from 1973-2012 for different turbine rotor diameter. From the table with 45m rotor diameter, 104kW of energy can be generated in 1976 while 11kW of energy can be produced in 2004. Similarly, 90m rotor diameter is capable of producing 416kW of energy in 1976 and 44kW in 2004 while 126m rotor diameter can generate 87kW in 2004 and 816kW in 1976. Generally, the result revealed that Maiduguri has a high potential for generating wind energy. Table 8.8 also reveals that wind energy potential varies with turbine rotor blade diameter. The wider the rotor diameter the more the energy produced. Generally, there is variation in the amount of wind energy that can be produced in Maiduguri.

**Table 9: Wind Energy Potential in Maiduguri from 1973-2012 (kW)**

| S/N | Year | 45 m blade | 90 m blade | 126 m blade | S/N | Year | 45 m blade | 90 m blade | 126 m blade |
|---|---|---|---|---|---|---|---|---|---|
| 1. | **1973** | 47 | 187 | 366 | **21.** | **1993** | 34 | 137 | 269 |
| 2. | **1974** | 63 | 254 | 497 | **22.** | **1994** | 57 | 227 | 445 |
| 3. | **1975** | 94 | 377 | 739 | **23.** | **1995** | 57 | 228 | 447 |
| 4. | **1976** | 104 | 416 | 816 | **24.** | **1996** | 57 | 228 | 447 |
| 5. | **1977** | 85 | 342 | 670 | **25.** | **1997** | 51 | 206 | 403 |
| 6. | **1978** | 129 | 514 | 1008 | **26.** | **1998** | 35 | 138 | 271 |
| 7. | **1979** | 108 | 434 | 851 | **27.** | **1999** | 31 | 124 | 243 |
| 8. | **1980** | 95 | 379 | 742 | **28.** | **2000** | 74 | 295 | 578 |
| 9. | **1981** | 65 | 259 | 508 | **29.** | **2001** | 132 | 528 | 1034 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 10. | **1982** | 27 | 107 | 209 | **30.** | **2002** | 95 | 381 | 746 |
| 11. | **1983** | 23 | 94 | 184 | **31.** | **2003** | 72 | 289 | 566 |
| 12. | **1984** | 41 | 164 | 321 | **32.** | **2004** | 11 | 44 | 87 |
| 13. | **1985** | 78 | 312 | 612 | **33.** | **2005** | 56 | 224 | 440 |
| 14. | **1986** | 126 | 505 | 991 | **34.** | **2006** | 54 | 217 | 425 |
| 15. | **1987** | 116 | 463 | 907 | **35.** | **2007** | 80 | 322 | 631 |
| 16. | **1988** | 104 | 416 | 816 | **36.** | **2008** | 73 | 293 | 575 |
| 17. | **1989** | 112 | 448 | 878 | **37.** | **2009** | 85 | 342 | 670 |
| 18. | **1990** | 90 | 361 | 707 | **38.** | **2010** | 8 | 30 | 59 |
| 19. | **1991** | 59 | 236 | 462 | **39.** | **2011** | 72 | 289 | 566 |
| 20. | **1992** | 57 | 228 | 447 | **40.** | **2012** | 56 | 224 | 440 |

*Source: Author's Field work, (2015)*

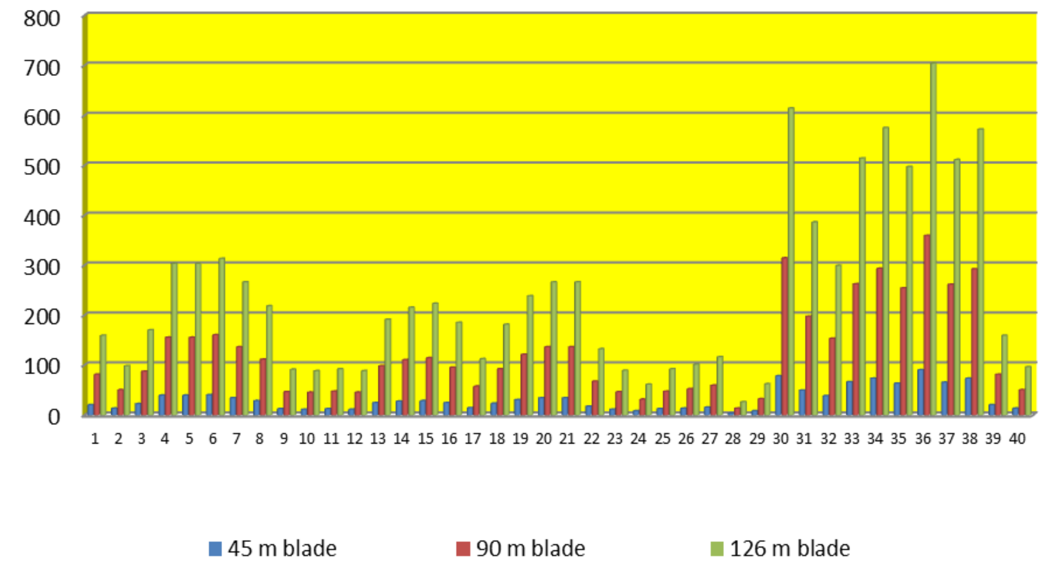
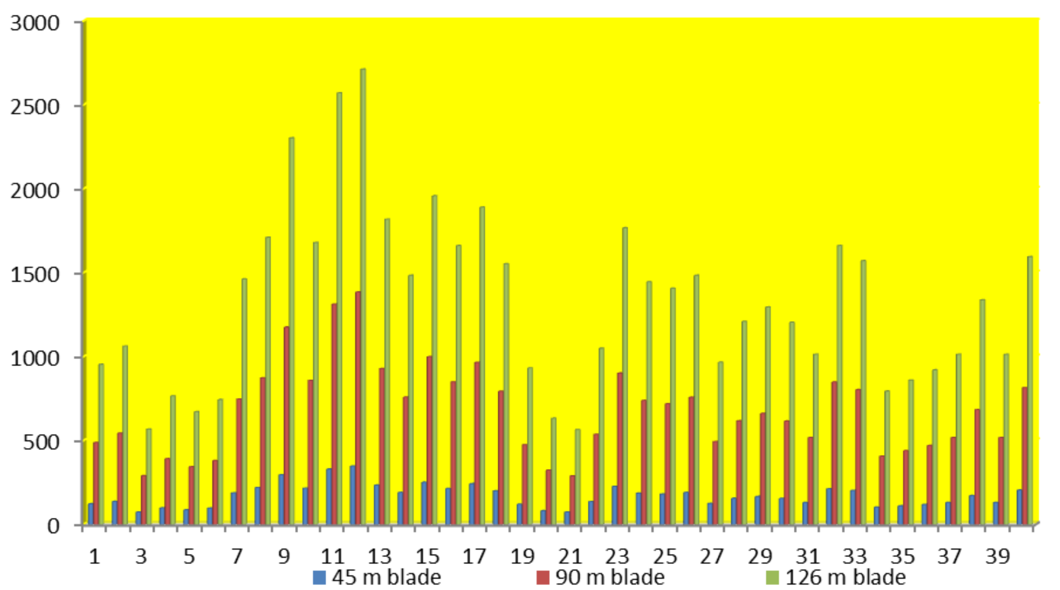



**Figure (a): Yelwa**




**(b): Sokoto**

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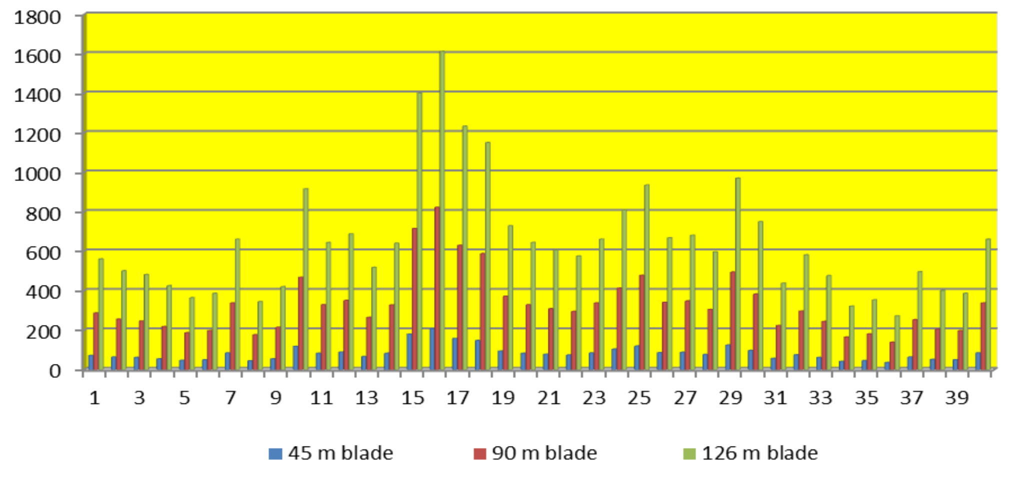
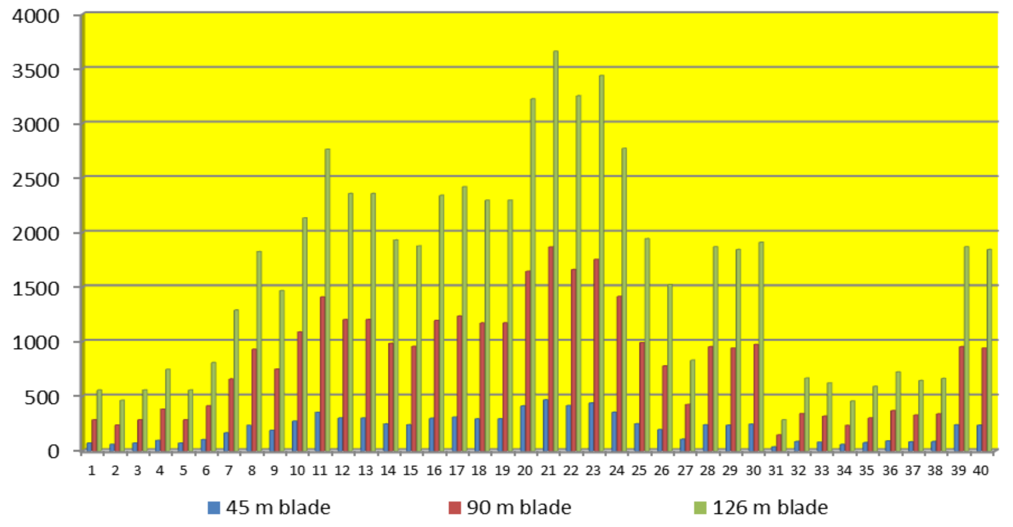
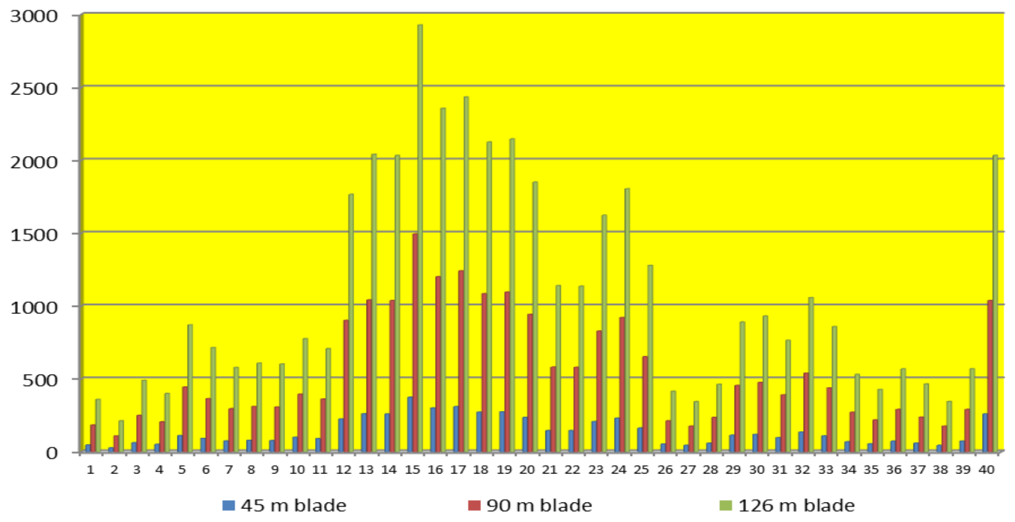


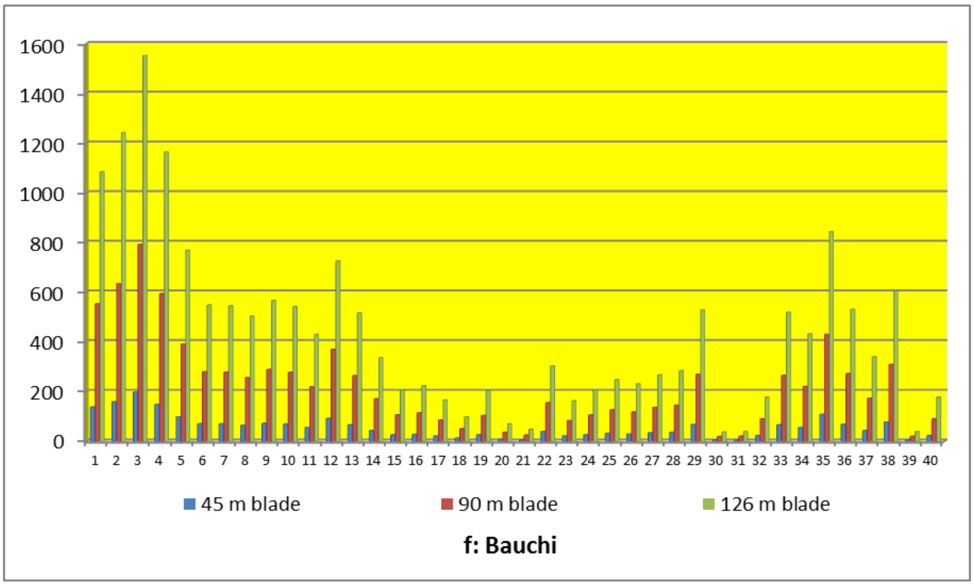

**(C) Gusua**

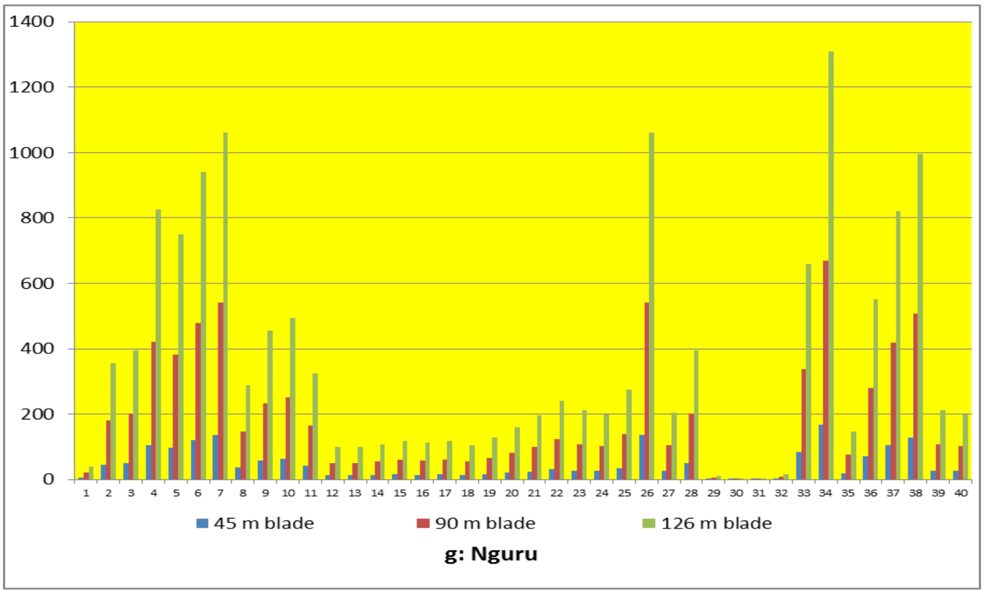


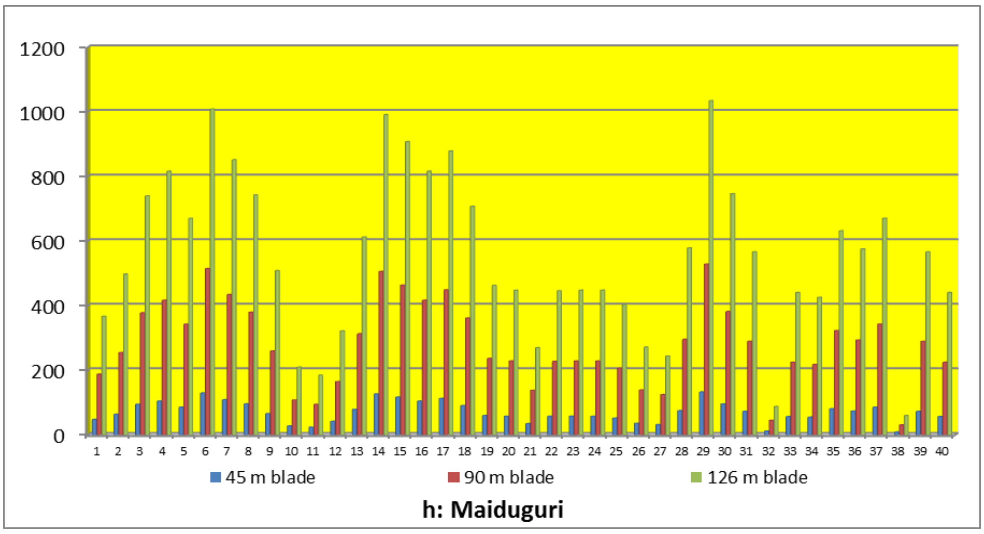

**(d) Kano**




**(e): Katsina**




**Figures (a-h): Geographical Pattern of Potential Wind Energy Estimates for Different Rotor Diameter in the Sudano-Sahelinan Zone of Nigeria**

### 3.2.2 *Implication for Energy Generation:*

The result of the analysis revealed that the eight stations in this study have annual wind regime between 2.0m/s and 10.2m/s and monthly wind regime between 0.68m/s and 15.7m/s. Average annual wind speed in the zone over the 40year was 5.83m/s. This paper concluded that the eight stations that make up the zone are potential wind farm areas. This is because most wind turbines start generating electricity at wind speed of around 3-4m/s (www.bwea.com). In addition, with 45m 90m and 126m rotor diameters, an average of 100.57kW, 402.41kW and 788.74kW of electricity can be generated in the zone respectively. This implies that a wind farm of about 60 turbines can produce an average of 6.03MW, 24.1MW, and 47.3MW respectively. These values show that the Sudano-Sahelian Zone of Nigeria has a strong wind energy potential of generating electricity especially when 126m rotor diameter is used.

## 4. CONCLUSION

The potential of wind energy generation has been examined in this research work. The results revealed that wind energy potential in the area is high if larger rotor diameter and efficient wind turbines are used. Eight-nine percent of annual wind speed was found to be above the threshold unit of 3.0m/s for wind turbine operations. About 512,260 kW of electricity can be generated in the area. Therefore, both the government and the private sector should take the advantage of the abundant wind resource in the area for energy generation. In the light of the findings of this study, it is therefore recommended that Government and private establishment should invest in wind energy in the area to complement the energy supplied to the Nigeria National grid.

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