World Academy of Science, Engineering and Technology
International Journal of Environmental, Chemical, Ecological, Geological and Geophysical Engineering Vol:10, No:5, 2016

Wind Power Mapping and NPV of Embedded Generation Systems in Nigeria

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***Abstract*—**The study assessed the potential and economic viability of stand-alone wind systems for embedded generation, taking into account its benefits to small off-grid rural communities at 40 meteorological sites in Nigeria. A specific electric load profile was developed to accommodate communities consisting of 200 homes, a school and a community health centre. This load profile was incorporated within the distributed generation analysis producing energy in the MW range, while optimally meeting daily load demand for the rural communities. Twenty-four years (1987 to 2010) of wind speed data at a height of 10m utilized for the study were sourced from the Nigeria Meteorological Department, Oshodi. The HOMER® software optimizing tool was engaged for the feasibility study and design. Each site was suited to 3MW wind turbines in sets of five, thus 15MW was designed for each site. This design configuration was adopted in order to easily compare the distributed generation system amongst the sites to determine their relative economic viability in terms of life cycle cost, as well as levelised cost of producing energy. A net present value was estimated in terms of life cycle cost for 25 of the 40 meteorological sites. On the other hand, the remaining sites yielded a net present cost; meaning the installations at these locations were not economically viable when utilizing the present tariff regime for embedded generation in Nigeria.

***Keywords*—**Wind speed, wind power, distributed generation, cost per kilowatt-hour, clean energy, Nigeria.

International Science Index, Energy and Power Engineering Vol:10, No:5, 2016 waset.org/Publication/10004296

I. INTRODUCTION

NIGERIA presently lies at a cross-road due to the inability of government to aggressively impact on accelerated growth in the energy sector. This has led to sluggishness in economic development, the result of inadequate generation of power to drive industrial and economic growth. As of 2012, Nigeria's primary consumption was recorded to be approximately 23 Million Tons of Oil Equivalent (Mtoe) or 267.49 TWh. However, a huge chunk of these volumes are produced by traditional biomass and waste (see Fig. 1), yielding 80% of the nation's total primary consumption. Additionally, Nigeria also consumed a minor 35,000 tons of coal in 2012. Fossil fuels cover 16%, while renewable energy in the form of hydropower only meets 1% of primary consumption [1], [2]. It is noteworthy that access to energy is a key to socio-economic development and advancement, especially for the rural populace. Presently, a number of remote rural communities are still unconnected to the central national grid system. Consequent upon this, is a surge in rural-urban migration with its attendant risk of food insecurity and an over stretch of basic infrastructures in city centers. On the other hand, those that remain in rural areas contribute to an unsustainable depletion of the nation's forest, due to the unwholesome acts of tree felling, as they depend on fuel wood to meet their energy demands. It is reported that Nigeria consumes over 50 million metric tons of fuel wood per annum [3]. This alarming rate of consumption far outweighs the rate of replenishment. Studies show that the rate of deforestation in Nigeria is approximately 350,000 hectares per annum, corresponding to 3.6% of current forests and woodlands. Furthermore, the rate of reforestation only measures a tenth of the deforestation rate. This has led to a major increase in desertification in the arid states and erosion in the southern states of the country. [3] Therefore, the objective of this study is to assess the potential and viability of harnessing wind energy resource in every region across the geographical divide of Nigeria. The research focuses on the feasibility of generating clean energy from a freely available and non-deleterious source of energy - wind energy. The idea is to introduce an energy mix that will aid the development of remote communities, while increasing the total energy delivered to distribution networks in each region, by generating wind power in the MW range. This concept is a step towards realising the Federal Government of Nigeria's policy on embedded generation, with positive feed-in tariffs available for renewable energy contribution from consumers.

A. Energy Situation in Nigeria

In December 2014, it was reported that Nigeria's total installed power generation capacity was 7445 MW. However, the nation's available capacity at the time, stood at 4949 MW, while average generation peaked below 3900 MW [4]. As at August 2015, Nigeria's Ministry of Power estimated a new generation peak hovering around 4600 MW. However, this value is approximately eight times lower than South Africa's, which in a quirk of fate, has only a third of Nigeria’s population [5].

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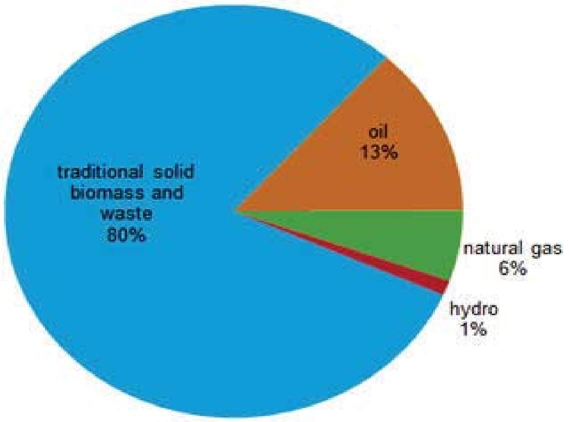

Fig. 1 Nigeria's total primary energy consumption, 2012 [1]

Considering per capita electricity consumption, Nigeria is in a very dire state. In comparison to other countries with similar demography's, such as Pakistan and Brazil, Nigeria's per capita consumption is 3 and 16 times less than these countries, respectively [6]. Energy poverty in Nigeria can be regarded as prevailing and extremely severe, as only 47% of the population have access to erratic electricity supply and approximately 10% of the populace are isolated from the national grid. Further to this, the majority of rural dwellers are largely on the receiving end of energy poverty. They have therefore resorted to the unwholesome use of traditional biomass to meet their energy needs.

Trying to close Nigeria’s energy deficit is going to be a tall order, especially with an approach that predominantly focuses on fossil-based technologies. These technologies are known to require huge capital investments, coupled with very high operation and maintenance costs. Therefore, the fastest route out of this quagmire is for Nigeria to look in the direction of non-depleting, environmentally-friendly energy sources, which are freely abundant across the country. Although, renewable energy tends to have high initial capital costs, the cost of operation and maintenance is low. Fig. 2 presents the total electricity net generation and consumption in Nigeria over a 10-year period, spanning 2002 to 2011.

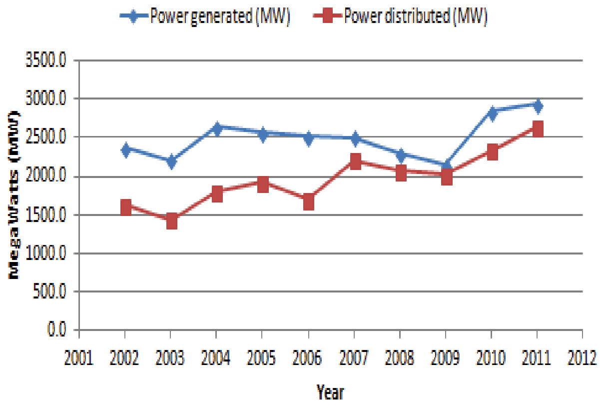

Fig. 2 Total power generation and distribution 2002 - 2011 [7]

B. Wind Resource Assessment in Nigeria

A number of researches have brought to light the huge potential of generating electricity on a massive scale from renewable energy resources in Nigeria. Medugu and Malgwi [8] studied and estimated the wind energy potential of Mubi, Adamawa State, Nigeria. The monthly average wind speed was found to be 3.44m/s with an estimated power density of 16.34Wm^{-2}. The researchers then suggested that harnessing wind energy for power generation could sufficiently cater for the 2.2 MW power deficit in the town, while providing environmentally-friendly energy. Ajayi et al. [9] statistically analysed the feasibility of generating wind power in Jos, North-central Nigeria. They employed a historical monthly mean wind speed dataset spanning 21 years, while carrying out monthly, annual and seasonal analysis of wind energy potentials at the site. They discovered a very favourable wind speed profile suitable for wind farm projects in the MW generation range. The average wind speed of the site ranged between 6.7 and 11.8 m/s across different seasons and years. Aidan and Ododo [10] fitted the wind speeds of eight cities in Northern Nigeria to four distribution functions, the gamma distribution was found to be the best fit for four of the cities, while the Weibull distribution was the best fit for the others. Furthermore, it was discovered that utility-scale wind power production at an 80m hub height was suitable for Zaria, Maiduguri, Gusau and Kaduna.

Ajayi et al. [11] researched the wind profile characteristics and econometrics analysis of wind power generation of a site in Sokoto State, Nigeria. Their study revealed that wind speeds ranged from 2.4 to 12.1 m/s, with modal wind speeds ranging from 6.9 to 9.0 m/s. They also found that 98% of the wind speed data were greater than 3.0 m/s. Subsequently, the outcome proved that electricity generation from wind energy was very viable, with a potential to generate between 60.0 MWh and 1.5 GWh per month, and between 2.1 and 10.8 GWh per annum.

Onyemechi et al. [12] investigated the merits of offshore wind farms being tapped in the Nigerian offshore environment in comparison with what is presently taking place in European nations. Cost evaluation of wind energy exploitation were then compared with conventional generation by Power Holdings Corporation in Nigeria, using data from Danish Utilities. The outcome proved that harnessing Nigeria's offshore wind energy potential is quite competitive in comparison to the present cost of energy generation by Nigeria’s Power Holdings Plc.

Oyedepo et al. [13] analysed the wind speed data and wind energy potential of three sites in south-eastern Nigeria. Annual mean wind speeds at a height of 10 m for Enugu, Owerri and Onitsha were found to be 5.42, 3.36 and 3.59 m/s, respectively, with corresponding annual mean power densities of 96.98, 23.23 and 28.34 W/m^2, respectively. The study then suggested the most feasible option for electricity generation in each location. Dikko and Yahaya [14] carried out an evaluation of the wind power density in Gombe, Yola and Maiduguri; all in North-Eastern, Nigeria. The outcome revealed that the northeastern region of Nigeria is suitable for wind power generation. The highest power density amongst the sites was 377 W/m^2 at Gombe.

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C. Wind Power Generation

From the above studies, it is evident that the nation is vastly blessed with a favourable wind profile across the geo-political regions of Nigeria. However, most of the studies on wind energy statistically analysed average wind speeds and power densities. Furthermore, these researches were focused on individual sites or select sites within a geo-political region. Therefore, this research is centred on presenting a holistic record of wind energy generation potentials of all forty meteorological sites across the six regions in Nigeria. This study presents a mapping of all sites, while revealing the profitability or otherwise of generating wind power at each site via utility-scale wind turbine installations, by taking advantage of Nigeria's renewable energy drives [15]-[17], which has culminated in a favourable feed-in tariff [18] for independent renewable energy producers. An excess of 1 MW generated can be fed into a nearby distribution network, in a form of generation termed embedded generation. The research approach involves generating free electricity through wind energy for rural communities with erratic or non-existent power supply, while selling the energy in excess of 1MW to a nearby distribution grid. The communities consist 200 homes, a school and community health centre.

The paper recommends the incorporation of this approach lead through a private sector drive in the renewable energy sector, where socially responsible entities can provide energy for the rural populace and in the process secure profits. This will enhance, boost and accelerate the growth of per capita electricity consumption and help develop the lethargic nature of the nation's rural electrification programmes.

II. RESEARCH METHODOLOGY

The location parameters and location of the selected sites are as shown in Table I and Fig. 3. Cumulative 3MW Enercon (E-101) wind turbines of 15 MW were utilized for all locations.

A. Data Collection

The daily wind speeds spanning 24 years (1987-2010) that were employed for this study were sourced from the Nigeria Meteorological agency (NIMET), Oshodi, Lagos, Nigeria.

B. Load Calculation

Electricity consumption among rural communities in developing nations has been determined to be relatively low, in the range of an average of 1 kWh/day per home [19], [20]. Therefore, this study assumed an energy demand requirement of 1.4 kWh/day for each home in the assessed rural communities, which is supported by individual power rating of the proposed appliances utilized in each home. Tables II and III [21]-[23] present the mode of analysis; while Fig. 4 reveals the 24-hour hourly load profile used in optimizing the RE system for each community. However, this load profile was directly captured in the 15 MW wind turbine design arrangement for each site, while running the analysis in HOMER® software. Subsequently, the remaining unconsumed energy was supplied to a distribution grid in form of distributed generation.

III. DATA ANALYSIS

Amongst the numerous varieties of statistical distributions helpful in describing and analysing wind speed data, Weibull distribution has been found to yield the most satisfactory results [24]-[26]. The Weibull shape factor, k, is a parameter that specifies the wideness / narrowness of a distribution of wind speeds. The HOMER® software simulation fits a Weibull distribution to the historical wind speed data, for which the k value indicates the shape of that distribution [27]:

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

$f\,(v)$ is the probability of having a wind speed of magnitude v. The matching Weibull Cumulative Distribution Function (CDF) is given as:

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

where c and k are the scale and shape parameters of the Weibull distribution respectively. $F\,(v)$ is used in establishing the CDF of observing wind speed v.

Equation (3) and (4) evaluates the Weibull mean wind speed and standard deviation:

$$\mathrm{v_m} = \mathrm{c}\Gamma\left(1 + \frac{1}{\mathrm{k}}\right) \tag{3}$$

Γ is the gamma function of ( )

$$\sigma = \sqrt{c^2\left\{\Gamma\left(1 + \frac{2}{k}\right) - \left[\Gamma\left(1 + \frac{1}{k}\right)\right]^2\right\}} \tag{4}$$

A. Estimation of Wind Power Density

The wind power density for each site is calculated in (5) using the Weibull parameters as:

$$p(v) = \frac{1}{2}\,\rho c^3\left(1 + \frac{3}{k}\right) \tag{5}$$

$p\,(v)$ = wind power density (W/m^2) and ρ = air density at the site.

B. Simulating the Electrical Power Output from a Wind Turbine Model

Equation (6) presents a combination that can be used in simulating the electrical power yield of diverse wind turbine models.

$$P_e = \begin{cases} 0 & (v < v_c) \\ P_{eR}\,\dfrac{v^k - v_c^k}{v_R^k - v_c^k} & v_c \le v \le v_R \\ P_{eR} & v_R \le v \le v_f \\ 0 & v > v_f \end{cases} \tag{6}$$

C. Wind Energy Production Simulation

The average power output ($P_{e,ave}$) of a wind turbine is presented in (7). ($P_{e,ave}$) is connected to the total energy produced in addition to the total revenue/cost analysis [28]:

$$P_{e,ave} = P_{eR} \left\{ \frac{e^{-\left(\frac{v_C}{c}\right)^k} - e^{-\left(\frac{v_R}{c}\right)^k}}{\left(\frac{v_R}{c}\right)^k - \left(\frac{v_C}{c}\right)^k} - e^{-\left(\frac{v_F}{c}\right)^k} \right\} \tag{7}$$

Equation (8) presents the capacity factor (CF) of a wind turbine, identified as the average power output of the wind turbine(s) divided by the total capacity of the wind turbine(s) [28], [29]:

$$CF = \left\{ \frac{e^{-\left(\frac{v_C}{c}\right)^k} - e^{-\left(\frac{v_R}{c}\right)^k}}{\left(\frac{v_R}{c}\right)^k - \left(\frac{v_C}{c}\right)^k} - e^{-\left(\frac{v_F}{c}\right)^k} \right\} \tag{8}$$

One turbine model was employed for the embedded generation analysis. This is the E-101 (of Enercon). The technical details of the turbines are presented in Table IV [30], [31]. The power curve for the turbine is presented in Fig. 5. Cumulative E-101 turbines were utilized for embedded generation at each meteorological station. The wind energy embedded generation systems were suited to connect to a 15 MVA distribution injection substation. The feed-in tariff for wind energy in Nigeria's Electricity Regulatory Commission, Multi-Year Tariff Order for year 2015 is \$0.158/kWh [18]. Table V presents the assumptions used in simulating connection to distribution networks in each region. Table V contains a grid purchase capacity, because the renewable energy supply to the rural communities was designed to operate at a 10% maximum annual capacity shortage. Therefore, there remains a possibility of purchasing power from the grid at sites that do not generate consistently through all the hours of a year.

D. Cost Benefit Analysis

Since, conventional and non-conventional energy sources are known to present extremely diverse cost characteristics, a suitable economic optimization model is usually decisive in selecting renewable and non-renewable energy sources, either singly or in combination [32]. Renewable sources of energy have a tendency towards high initial capital costs and low operating costs, while carbon-based sources are contrariwise. Hence, in effect, the HOMER optimization model employed in this study, simulates the design set-up towards a declining life-cycle cost or total net present cost (NPC).

All costs incurred during the Renewable Energy (RE) system lifetime are captured in the life cycle analysis. These costs include; the initial costs of construction, maintenance, component replacements, fuel costs (if applicable), and cost of buying power from the grid (where applicable), plus revenue yields from energy sales to a distribution network (grid), in addition to any salvage value determined at the end of the RE system life cycle. It is noteworthy that in estimating life cycle costs in this study, costs are regarded as negative and revenues as positive.

The salvage value of all components of at the end of the project life cycle is:

$$S = C_{rep} \frac{R_{rem}}{R_{comp}} \tag{9}$$

where: S is the salvage value, C_{rep} is the component replacement cost, R_{rem} is the remaining life of the component, and R_{comp} represents the component lifetime.

The cost of the wind energy system used in simulating the RE system set-up is presented in Table VI [33]-[36]. A 25-year project life cycle was utilized in carrying out the techno-economic simulation of the wind energy system.

Equation (10) is used in determining the total net present cost, after the total annualized cost of the system is derived from the annualized cost for each component. The total annualized cost is vital in estimating the value of two fundamental economic indicators for the system, which are the total net present cost and the levelized cost of energy (LCOE).

$$C_{NPC} = \frac{C_{ann,tot}}{CRF(i, R_{proj})} \tag{10}$$

where: $C_{ann,tot}$ is the total annualized cost, i represents the annual real interest rate (the discount rate), R_{proj} is the project lifetime, and CRF(•) is the capital recovery factor, which is presented in (16):

$$CRF(i, N) = \frac{i(1+i)^N}{(1+i)^N - 1} \tag{11}$$

i is the annual real interest rate, while N = the number of years.

The annualized capital cost for each component is:

$$C_{acap} = C_{cap} \,.\, CRF(i, R_{proj}) \tag{12}$$

where: C_{cap} = the initial capital cost of the component

The annualized replacement cost for each component of the system is represented by (13):

$$C_{arep} = C_{rep} . f_{rep} . SFF(i, R_{comp}) - S.SFF(i, R_{comp}) \tag{13}$$

f_{rep} represents a factor necessitated on the fact that a component lifespan may be different from the system lifespan:

$$f_{rep} = \begin{cases} CRF(i, R_{proj})/CRF(i, R_{rep}), & R_{rep} > 0 \\ 0, & R_{rep} = 0 \end{cases} \tag{14}$$

R_{rep}, = the replacement cost duration:

$$R_{rep} = R_{comp} . INT\left(\frac{R_{proj}}{R_{comp}}\right) \tag{15}$$

INT ( ) is an integer function that returns the integer portion of a real value.

The salvage value (S) of each component is assumed to be proportional to its remaining life at the end of the project life cycle:

$$S = C_{rep} . \frac{R_{rem}}{R_{comp}} \tag{16}$$

TABLE I
LOCATION PARAMETER OF THE STUDIED SITES

Geopolitical Zone	Site	State	Latitude (° N)	Longitude (° E)
North-West	Sokoto	Sokoto	13.0833	5.2500
	Yelwa	Kebbi	10.8331	4.7387
	Gusau	Zamfara	12.1667	6.6667
	Kaduna	Kaduna	10.5167	7.4333
	Katsina	Katsina	12.9833	7.6000
	Zaria	Kaduna	11.0667	7.7000
	Kano	Kano	12.0031	8.5288
North-East	Maiduguri	Borno	11.8333	13.1500
	Bauchi	Bauchi	10.5000	10.0000
	Potiskum	Yobe	11.7333	11.1500
	Nguru	Yobe	12.8750	10.4550
	Yola	Adamawa	9.2300	12.4600
	Ibi	Taraba	8.1850	9.7450
North-Central	Jos	Plateau	9.9167	8.9000
	Ilorin	Kwara	8.5000	4.5500
	Bida	Niger	9.0833	6.0167
	Abuja	FCT	9.0667	7.4833
	Lokoja	Kogi	7.8167	6.7500
	Makurdi	Benue	7.7333	8.5333
	Minna	Niger	9.6167	6.5500
South-West	Iseyin	Oyo	7.9667	3.6000
	Ikeja	Lagos	6.5833	3.3333
	Oshodi-Lagos	Lagos	6.4500	3.3833
	Ijebu-ode	Ogun	6.8208	3.9208
	Abeokuta	Ogun	7.1500	3.3500
	Oshogbo	Osun	7.7667	4.5667
	Ondo	Ondo	7.1667	5.0833
	Akure	Ondo	7.2500	5.1950
	Shaki	Oyo	8.6667	3.3999
	Ibadan	Oyo	7.3907	3.8923
South-East	Onitsha	Anambra	6.1667	6.7833
	Enugu	Enugu	6.4500	7.5000
	Owerri	Imo	5.4833	7.0333
South-South	Calabar	Cross-Rivers	4.9500	8.3250
	Port-Harcourt	Rivers	4.7833	7.0000
	Ikom	Cross-Rivers	6.0833	8.6167
	Ogoja	Cross-Rivers	6.6667	8.8000
	Warri	Delta	5.5167	5.7500
	Uyo	Akwa-Ibom	5.0500	7.9333
	Benin City	Edo	6.3176	5.6145

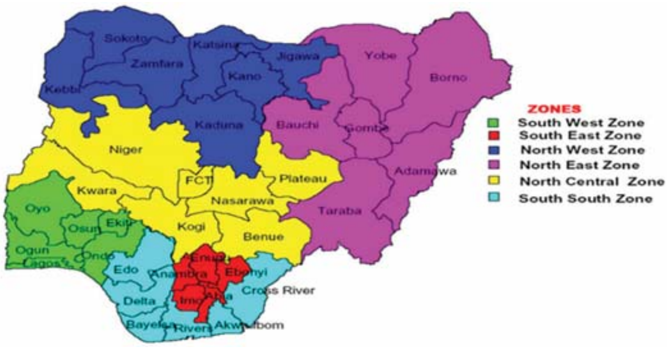

Fig. 3 Map of Nigeria highlighting the six geo-political zones [37]

TABLE II
GENERAL WATTAGE CHART FOR SOME HOUSEHOLD APPLIANCES

Power rating	Household Appliance
24 watts	42" ceiling fan (low speed)
55-90 watts	19" CRT television
150-340 watts	Desktop Computer & 17" CRT monitor
60 watts	60-watt light bulb (incandescent)
18 watts	CFL light bulb (60-watt equivalent)

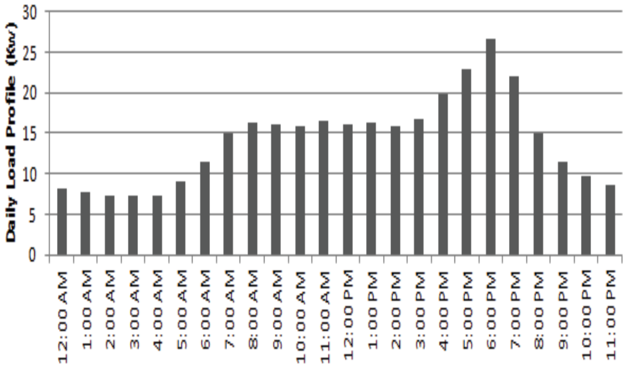

Fig 4 Daily load profile used for design of wind energy systems in rural areas of Nigeria

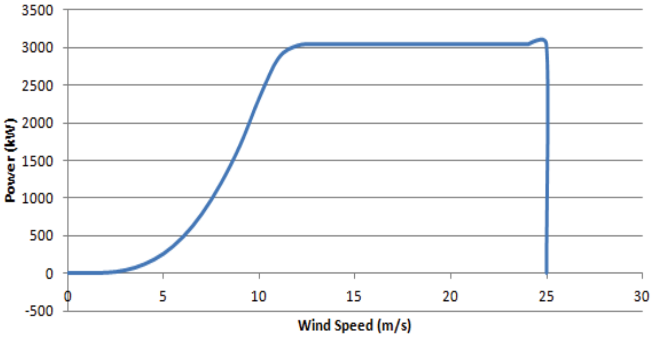

Fig. 5 Power curve for E-101

R_{rem} yields the remaining life of the component at the end of project lifetime:

$$R_{rem} = R_{comp} - \left(R_{proj} - R_{rep}\right) \tag{17}$$

where, C_{rep} represents the replacement cost of the component, R_{comp} = lifetime of the component.

The sinking fund factor is a ratio used in estimating the future value of a sequence of equal annual cash flows. Equation (18) captures the sinking fund factor:

$$SFF(i,N) = \frac{i}{(1+i)^{N}-1} \tag{18}$$

SFF ( ) is the sinking fund factor

The total operation and maintenance (O&M) cost (the sum of the system fixed O&M cost, plus penalty for capacity shortage).

The total annual O&M cost is:

$$C_{om,total} = C_{om,fixed} + C_{cs} + C_{emissions} \tag{19}$$

where: $C_{om,fixed}$= system fixed O&M cost ($/yr), C_{cs}= penalty for capacity shortage ($/yr), $C_{emissions}$= penalty for emissions ($/yr)

Equation (20) calculates penalty for capacity shortage:

$$C_{cs} = c_{cs}.E_{cs} \tag{20}$$

where: c_{cs}= capacity shortage penalty ($/kWh), E_{cs}= total capacity shortage (kWh/yr)

Consequently, the total annualized cost is:

$$C_{ann,tot} = C_{acap,total} + C_{arep,total} + C_{om,total} + R_{ann,proj} \tag{21}$$

where, $R_{ann,proj}$ = annual project revenue ($/yr). Therefore, the levelised cost of energy (LCOE) is:

$$LCOE = \frac{C_{ann,tot}}{E_{load\ served,total} + E_{grid,sales}} \tag{22}$$

where, $C_{ann,tot}$ covers the total annualized cost, E_{prim} and E_{def} is the total amounts of primary and deferrable load served annually by the system respectively, summed up as $E_{load\ served,total}$ (total load served), while $E_{grid,sales}$ is the amount of energy sold to the grid per annum. In this analysis, in computing LCOE values, energy served is regarded as negative and grid sales (revenue) is regarded as positive. Therefore, (22) is only valid when $E_{load\ served,total} \neq E_{grid,sales}$

It is worth mentioning that in circumstances where incurred costs outweigh revenues from grid sales (or any other revenue), (22) will yield a total annualized cost (negative value), and by extension, a negative LCOE value. This is termed levelised value of energy (LVOE) [38]. This output provides a measure of determining the viability of generating electricity from renewable energy sources at a point in which revenues plus other government incentives exceeds all cost incurred per kWh. Since the NPC has yielded a positive value, i.e. net present value (NPV), it explains that the projected earnings generated by the investment (in present dollars) exceeds the anticipated costs (also in present dollars). In general, an investment with a positive NPV is known to be a profitable one. Hence, it is significant from an investors' standpoint in determining the degree of profitability in generating energy amongst different technologies, and in this case, it determines the level of viability of wind energy production amongst the meteorological sites in Nigeria. Equation (23) represents the LVOE of the system.

$$(-\mathrm{LCOE}) = \frac{-\mathrm{C_{ann,tot}}}{\mathrm{E_{prim}+E_{def}+E_{grid,sales}}} = \text{LVOE (a positive value)} \tag{23}$$

TABLE III
ELECTRICITY CONSUMPTION ANALYSIS FOR A RURAL COMMUNITY OF 200 HOMES

Description	AC/DC	Intermittent resource-load correlation	Base case load/home (watt)	No. of appliance per home(watt)	Hours of use per day (hr/day)	Days of use per week	Base case load for community (watt)
TV	AC	Negative	90	1	6	7	18000
Bulb	AC	Negative	18	6	7	7	21600
Fan	AC	Zero	24	3	8	7	14400
Water Pump	AC	Positive	Community based	Community based	3	3	20000
Radio	DC	Zero	6	1	5	7	1200
Clinic equipment	AC	Positive	Community based	Community based	5	5	2000
School electronics	AC	Positive	Community based	Community based	5	5	2400
Electricity - daily – AC (KWh)					Electricity - daily - AC (KWh)		357.256571

TABLE IV
TURBINE SPECIFICATION

Wind Machine	V_c (m/s)	V_{Fi} (m/s)	V_{Fo} (m/s)	V_R (m/s)	P_{eR} (kW)	Hub Height (m)	Rotor Diameter (m)
Enercon	3	2	25	12	3000	124	101

V_c = cut-in wind speed, V_F = wind cut-out speed, V_{Fi} = low wind cut-out speed, V_{Fo} = high wind cut-out speed, V_R = rated wind speed, P_{eR} = rated power at rated wind speed.

TABLE V
GRID CONNECTION SPECIFICATION

Description	$	kW	$/kWh
Interconnection charge	5000	-	-
Standby charge	1000/yr	-	-
Grid sale capacity	-	15000	-
Purchase capacity	-	100	-
Grid power price	-	-	0.150
Feed-in tariff	-	-	0.158

TABLE VI
COST OF COMPONENTS USED IN THE DESIGN OF WIND DISTRIBUTED GENERATION SYSTEM (INSTALLATION COST EMBEDDED IN COMPONENT COST)

Component	Interest Rate (%)	Life time	Cost ($/kW)	O & M ($/kW)	Replacement Cost ($/kW)
Wind turbine	6, 10, 15, 20, 25	15 years	2000	60/yr	1400

IV. RESULTS AND DISCUSSION

A. Econometrics of Embedded Generation

The results of wind profile analysis at the top sites in each region are as shown in Figs. 6 and 7. The figures show that the 24 years' monthly average wind speeds ranged between 3.9 m/s in November for Calabar and 10.1 m/s in December for Jos. The annual average ranged between 1.8 m/s in 1999 for Iseyin and 11.8 m/s in 2002 for Jos. Considering that the cut-in wind speed for modern turbines is 3 m/s, the monthly average values evidence that most of the sites are well-matched with modern wind turbines for power generation throughout the year.

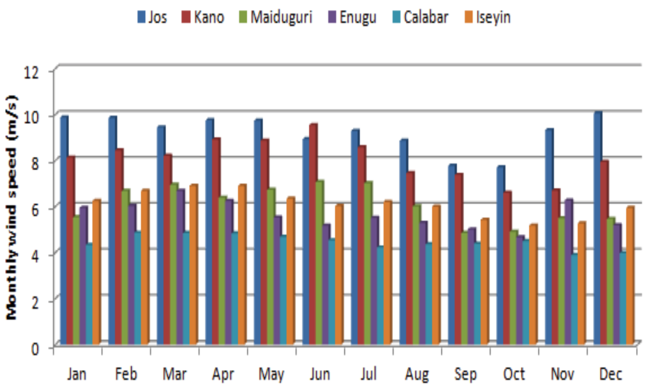

Fig. 6 Average annual monthly mean wind speed for top sites in each region during the entire period

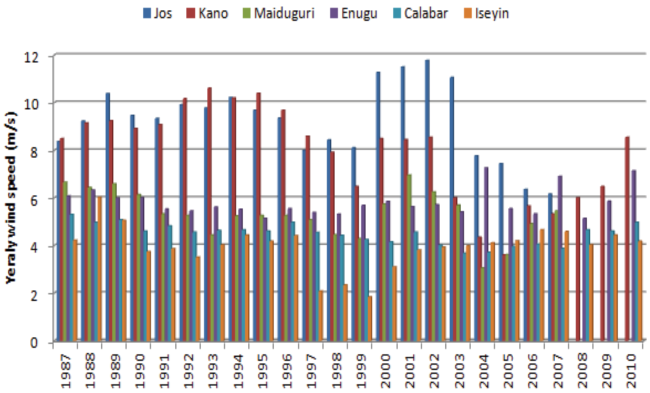

Fig. 7 Average annual mean wind speed for top sites in each region during the entire period

B. Wind Energy Classification for Nigeria

Table VII presents the ranking of the 40 sites based on the same Enercon wind turbine rated at 3 MW in series of five for each site. The result of the techno-econometric ranking is based on life cycle costs -- a Net Present Value (NPV) and Levelised Value of Producing Energy, (LVOE) analysis. Table VII is divided into three categories; Excellent, Good and Infeasible. During the research, sensitivity analysis, using different project Interest Rate (IR) was carried out to determine the viability of the RE project at different IR. Six IR were utilized in the sensitivity analysis; 6%, 10%, 15%, 20% and 25%. All sites within the excellent range yielded a positive NPV at ≤15% IR, while those in the good category yielded positive NPV at ≤6% IR. Furthermore, those sites in the infeasible category could not yield a positive NPV at the least IR of 6%. A total of sixteen sites were estimated in the excellent range, while nine were estimated in the good range. It was discovered that fifteen sites were not feasible for utility scale wind energy generation from a business perspective.

From Table VII, it is observed that the northern regions lead in rank for wind embedded generation, though with little incursion into the top 16 from sites in the south (Iseyin, Ibadan, Oshodi-Lagos, Enugu and Ikeja). In furtherance to this, the NW was observed to be the best region as it has the highest number of sites (6) from a region in the excellent category. The NW is followed in rank by the NC and NE. However, Jos -- a site in NC is the most viable location in Nigeria to set up a utility scale wind farm. Jos, together with eight (8) other sites all yielded a positive NPV at a high IR of 25% (see Fig. 9). Also, the sites in southern Nigeria could be said to perform fairly well with a reasonable portion of the sites, (8) being economically viable. Fig. 8 presents the same results in the form of wind power mapping for embedded generation in Nigeria. Figs. 9-11 present the NPV values against each IR utilized in the sensitivity analysis for the different ranking categories, while Figs. 12-14 present the net grid sales in kWh per annum for each category. The results of net grid sales at each site as shown in Figs. 12-14 show that the annual sales in kWh/yr ranged between 38,745,584 for Ilorin and 86,124,784 for Jos (excellent category). For the good category, it ranged between 24,350,758 for Abuja and 37,339,708 for Makurdi, while that of the infeasible category ranged between 3,185,119 for Ondo and 22,703,484 for Onitsha.

Since, each site utilized the same wind turbine model and similar assumptions were used in simulating the wind energy generation systems, it can be clearly deduced that the annual net sales in kWh correlates with the 24-year average annual wind speeds for each site (see Figs. 15-17). This reveals that the magnitude of electric energy retrievable from a site is overwhelmingly dependent on the magnitude of wind resource at that site.

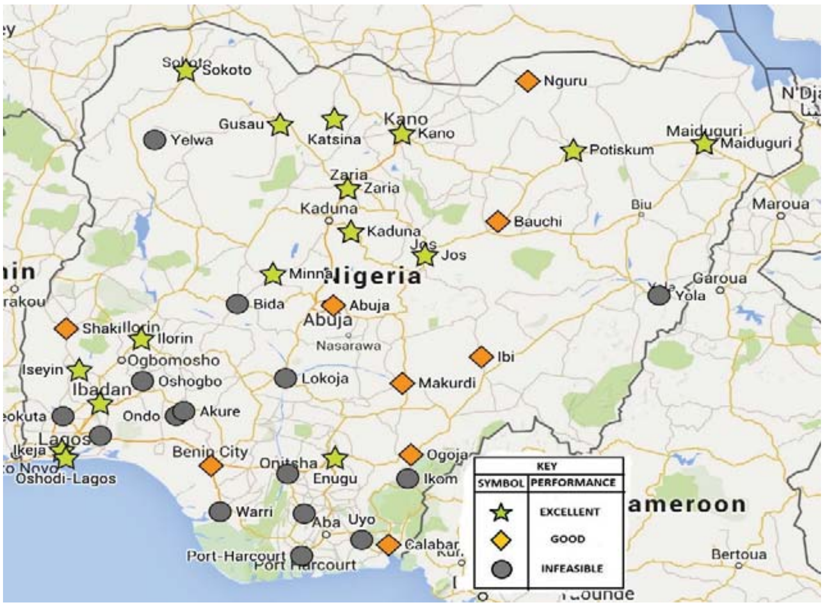

Fig. 8 Wind power mapping for embedded generation in Nigeria

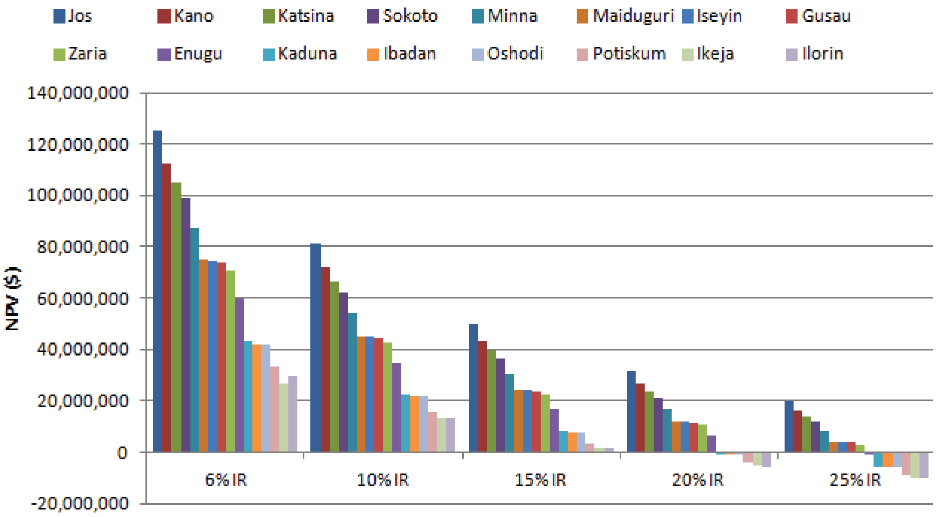

Fig. 9 NPV values versus IR for the excellent category

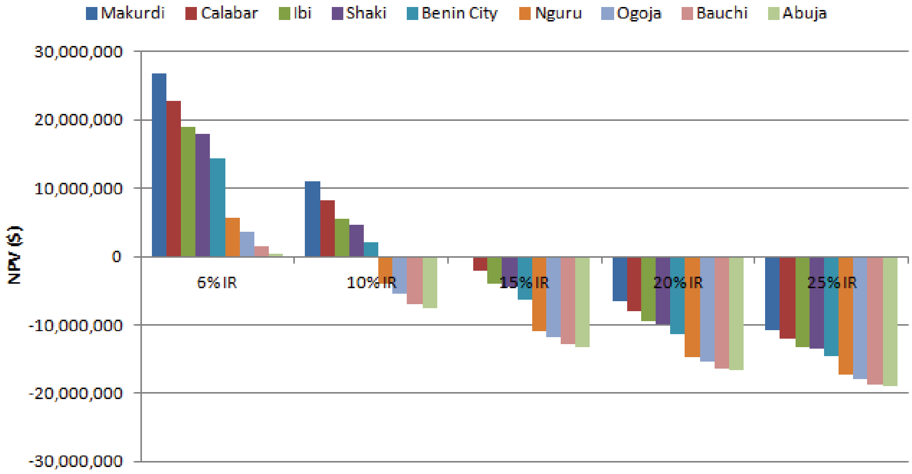

Fig. 10 NPV values versus IR for the good category

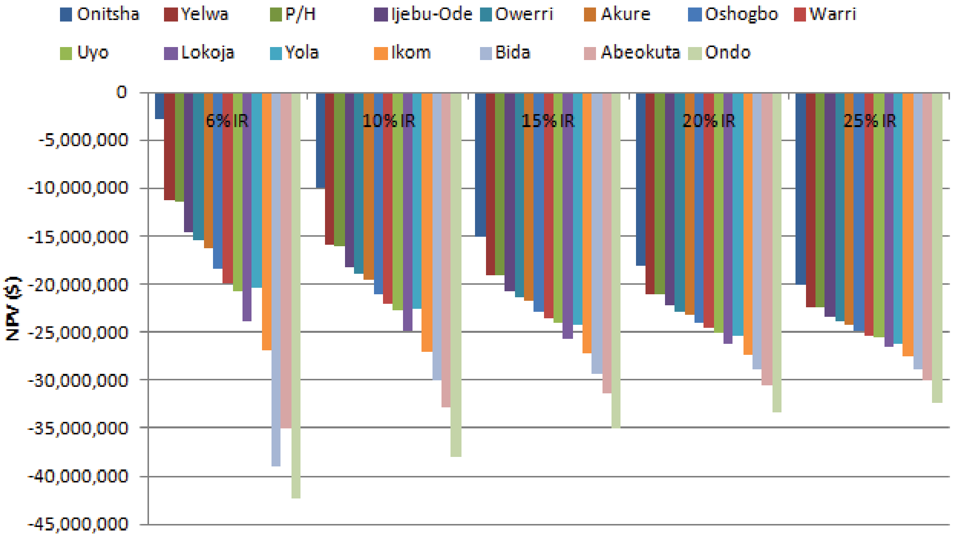

Fig. 11 NPV values versus IR for the infeasible category

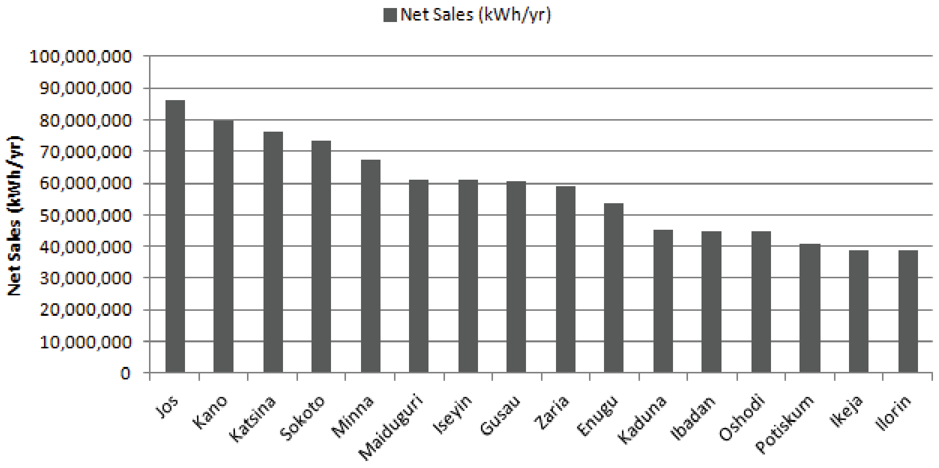

Fig. 12 Net sales values versus IR for the excellent category

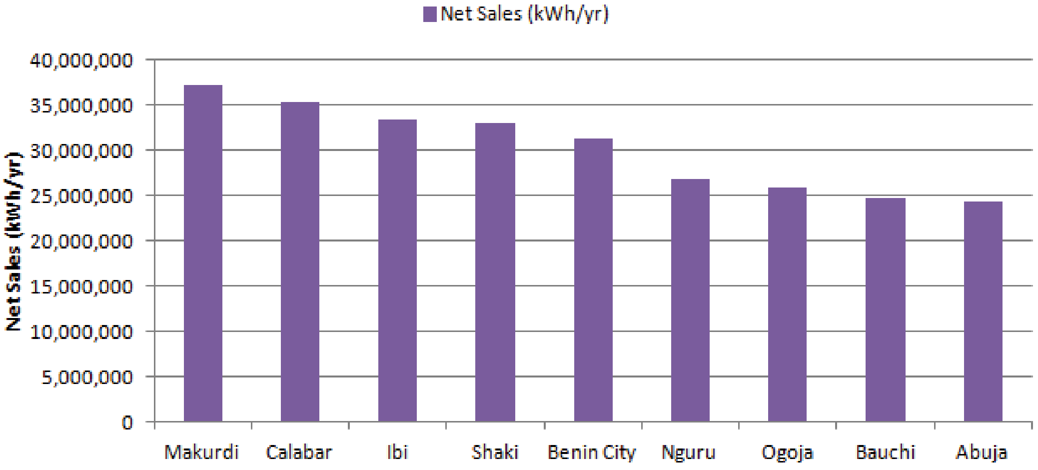

Fig. 13 Net sales values versus IR for the good category

TABLE VII
WIND POWER CLASSIFICATION FOR NIGERIA

s/n	Site	LVOE ($/kWh) at 6% IR	NPV ($) at 6% IR	NPV ($) at 10% IR	NPV ($) at 15% IR	NPV ($) at 20% IR	NPV ($) at 25% IR	Net Sales (kWh/yr)	Remark
1	Jos	74.988	125,260,288	80,923,112	49,740,248	31,551,312	19,897,664	86,124,784	Excellent
2	Kano	67.484	112,725,392	72,022,504	43,401,740	26,699,886	15,990,226	79,918,688	
3	Katsina	63.069	105,350,376	66,785,748	39,672,424	23,845,510	13,691,252	76,276,280	
4	Sokoto	59.275	99,013,656	62,286,252	36,468,136	21,392,986	11,715,939	73,129,936	
5	Minna	52.362	87,465,464	54,086,264	30,628,574	16,923,450	8,116,083	67,412,352	
6	Maiduguri	44.782	74,803,616	45,095,500	24,225,868	12,022,889	4,169,070	61,143,404	
7	Iseyin	44.666	74,610,648	44,958,480	24,128,290	11,948,205	4,108,918	61,047,864	
8	Gusau	44.092	73,651,984	44,277,768	23,643,526	11,577,171	3,810,080	60,573,224	
9	Zaria	42.441	70,893,976	42,319,396	22,248,886	10,509,729	2,950,340	59,207,708	
10	Enugu	35.951	60,053,140	34,621,676	16,767,009	6,313,963	-429,017	53,840,356	
11	Kaduna	25.847	43,174,964	22,637,038	8,232,232	-218,458	-5,690,361	45,483,876	
12	Ibadan	25.24	42,161,720	21,917,566	7,719,865	-610,619	-6,006,216	44,982,208	
13	Oshodi	25.218	42,124,584	21,891,196	7,701,086	-624,992	-6,017,792	44,963,824	
14	Potiskum	20.178	33,705,648	15,913,190	3,443,892	-3,883,401	-8,642,181	40,795,564	
15	Ikeja	17.739	26,630,992	13,019,910	1,383,464	-5,460,430	-9,912,353	38,778,168	
16	Ilorin	17.699	29,565,166	12,973,168	1,350,176	-5,485,907	-9,932,873	38,745,584	
17	Makurdi	16	26,725,618	10,956,899	-85,695	-6,584,907	-10,818,030	37,339,708	Good
18	Calabar	13.696	22,878,536	8,225,214	-2,031,045	-8,073,856	-12,017,261	35,434,992	
19	Ibi	11.37	18,991,744	5,465,331	-3,996,476	-9,578,175	-13,228,870	33,510,626	
20	Shaki	10.761	17,988,852	4,753,210	-4,503,608	-9,966,328	-13,541,496	33,014,084	
21	Benin City	8.63	14,415,417	2,215,833	-6,310,583	-11,349,367	-14,655,424	31,244,856	
22	Nguru	3.453	5,767,790	-3,924,563	-10,863,421	-14,696,288	-17,351,104	26,963,364	
23	Ogoja	2.21	3,690,961	-5,399,248	-11,733,608	-15,500,089	-17,998,502	25,935,116	
24	Bauchi	0.862	1,440,716	-6,997,073	-12,871,487	-16,371,009	-18,699,958	24,821,010	
25	Abuja	0.294	490,916	-7,671,494	-13,351,772	-16,738,614	-18,996,036	24,350,758	
26	Onitsha	-1.698	-2,836,196	-10,033,966	-15,034,189	-18,026,318	-20,033,178	22,703,484	Infeasible
27	Yelwa	-6.796	-11,351,279	-15,933,944	-19,074,700	-21,006,830	-22,363,824	19,244,236	
28	P/H	-6.885	-11,501,272	-16,040,450	-19,150,548	-21,064,882	-22,410,584	19,169,972	
29	Ijebu-Ode	-8.745	-14,607,235	-18,245,892	-20,721,136	-22,266,992	-23,378,788	17,632,196	
30	Owerri	-9.183	-15,399,194	-18,911,932	-21,356,570	-22,865,398	-23,930,672	16,513,179	
31	Akure	-9.721	-16,237,234	-19,549,602	-21,810,680	-23,212,968	-24,210,614	16,068,554	
32	Oshogbo	-10.987	-18,352,640	-21,051,682	-22,880,376	-24,031,702	-24,870,038	15,021,203	
33	Warri	-11.886	-19,855,016	-22,118,470	-23,640,082	-24,613,172	-25,338,366	14,277,369	
34	Uyo	-12.451	-20,798,720	-22,788,562	-24,117,282	-24,978,416	-25,632,542	13,810,136	
35	Lokoja	-14.277	-23,848,142	-24,953,858	-25,659,280	-26,158,646	-26,583,122	12,300,349	
36	Yola	-16.104	-20,437,752	-22,515,352	-24,250,106	-25,406,016	-26,211,098	11,955,975	
37	Ikom	-16.11	-26,909,330	-27,127,506	-27,207,230	-27,343,430	-27,537,372	10,748,736	
38	Bida	-18.594	-39,059,370	-30,074,314	-29,305,776	-28,949,634	-28,831,042	8,730,027	
39	Abeokuta	-20.931	-34,962,444	-32,845,758	-31,279,440	-30,460,254	-30,047,726	6,797,593	
40	Ondo	-25.299	-42,258,816	-38,026,668	-34,968,988	-33,284,190	-32,322,184	3,185,119	

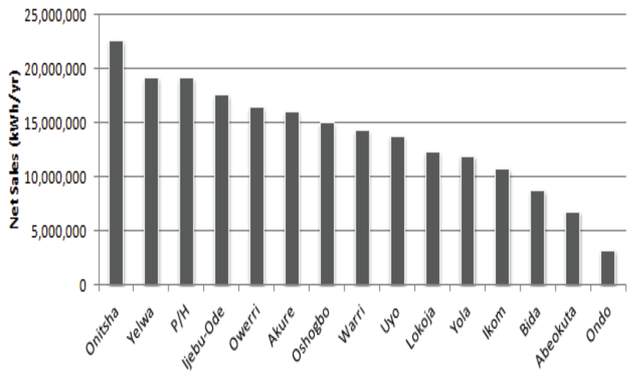

Fig. 14 Net sales values versus IR for the infeasible category

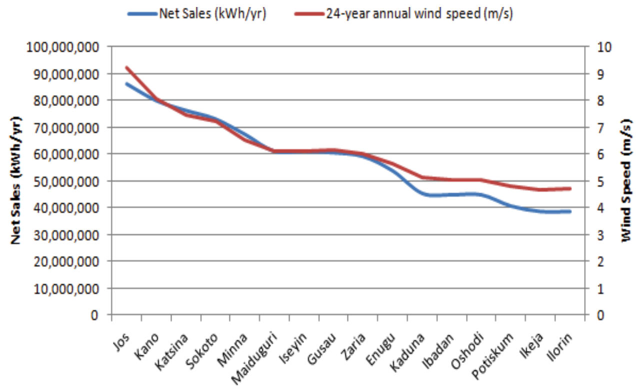

Fig. 15 Correlation of net sales with the 24-year average annual wind speed for the excellent category

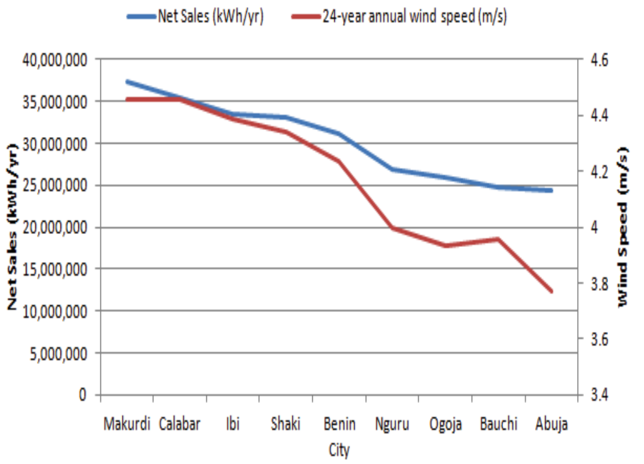

Fig. 16 Correlation of net sales with the 24-year average annual wind speed for the good category

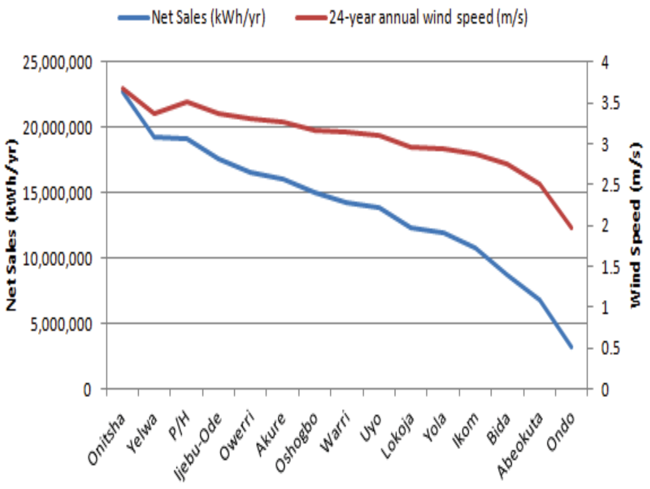

Fig. 17 Correlation of net sales with the 24-year average annual wind speed for the infeasible category

V. CONCLUSION

Based on the results of this study, it can be concluded that 62.5% of the present meteorological stations, cutting across all the geo-political regions of Nigeria are suitable for utility scale wind energy stand-alone systems. The embedded generation systems analysis proof that this form of generation can become effective when engaged by both government and private corporations in providing environmentally-friendly and non-depleting renewable energy, to improve per capita electricity consumption and empower the poor in rural regions of Nigeria. This is also central to attaining the 17 Sustainable Development Goals (SDGs) built on the 8 Millennium Development Goals (MDGs) targeted for achievement by 2015. These new SDGs include; ending poverty and hunger, improving health and education, making cities more sustainable, combating climate change, etc. These goals like the MDGs are also significantly hinged on adequate access to clean energy. Therefore, this paper recommends the incorporation of the approach presented in this study -- a private sector-led drive in the renewable energy sector, where government and socially responsible entities can provide energy for the rural populace and in the process secure profits. This will enhance, boost and accelerate the growth of per capita electricity consumption and help stimulate the lethargic nature of the nation's rural electrification programmes.

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