Techno-Economic Assessment of Renewable Electricity for Rural Electrification and IT Applications in Selected Sites Across the Geopolitical Zones of Nigeria

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Abstract

This study presents an energy resource assessment for six sites, one from each geo-political zone of Nigeria. It assessed the feasibility and economic viability of RE resources that can provide sustainable electricity and enhance ICT development for rural communities cut off from the national grid. Hypothetical rural communities made up of 200 homes, a school and health centre was conceived. Specific electrical load profile was developed to suite the rural communities. The required load was analyzed as 358 kWh per day, with 46 kW primary peak load and 20 kW deferrable peak load. The meteorological data utilized were obtained from the Nigeria Meteorological Department spanning 1987-2010. Assessment of the design that will optimally meet the daily load demand with LOLP of 0.01 was carried out by considering standalone PV, Wind and Diesel, and a hybrid design of Wind-PV. The Diesel Standalone system was taken as the basis for comparison. The optimization tool employed after the feasibility analysis with RETScreen[®] software was the HOMER[®] software. The outcome showed that the most economically viable alternative for power generation at most of the sites is the wind standalone system. It proved to be the optimal means of producing renewable electricity in terms of life cycle cost and levelised cost of energy which ranged between $0.129/kWh for Jos and $0.327/kWh for Benin City. This is very much competitive with grid electricity. Renewable technologies could then become the subject of rigorous pursuit for rural electrification and ICT development in local communities around the sites.

Keywords: Photovoltaic Power; Wind power; Solar-Wind Hybrid; Cost per kWh; Clean Energy; Nigeria
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1.0 Introduction

In September 2000, world leaders agreed to the United Nations Millennium Declaration, with the commitment of nations to a novel global partnership that would serve to diminish acute poverty. Part of the agreement includes setting out a sequence of time-bound targets of 2015. These have been christened - the Millennium Development Goals (MDGs). The MDGs also identifies the role that developed countries can play via trade, development aid, debt relief, and technology transfer (UN Documents, 2013; United Nations, 2009; Lankes, 2002). The eight MDG goals include eradication of extreme poverty and hunger, achievement of universal primary education, promotion of gender equality and empower women,

and the reduction of child mortality. It also includes improving maternal health, to combat HIV/AIDS, malaria and other diseases, to ensure environmental sustainability, and to develop a global partnership for development (United Nations, 2009).

As can be observed the MDGs relating to education can be directly linked to goals 2 and 3, whereas goals 4, 5 and 6 will obviously be very much aided in terms of their attainment through the use of information and communication technologies (ICT) when used as a driver in educating the rural populace.

Education can in general be delineated as an act or experience derived from the gradual process of acquiring knowledge that has a constructive effect on the mind, character or physical capacity of an individual (Okebukola, 2002). It is also regarded as the procedure by which society intentionally conveys its amassed knowledge, skills, and values from a generation to another (The voice of the teachers, 2009). Therefore foremost amongst the objectives of education is its functionality and its ability to be utilitarian. Education has also been described as the renovation of society for relevance, sufficiency and competitiveness in the world. (Okebukola, 2002)

However this present millennium has been distinguished by an explosive increase in information, knowledge and understanding acquired via scientific research. Science education has been found to contribute to the overall quality of life via many facets by way of health, nutrition, agriculture, transportation, energy production and industrial development (Jimoh *et al*, 2012). Therefore the conception of a discipline founded on the assimilation of other disciplinary knowledge, into a new whole known as science, technology and mathematics education (STME) (Morrison, 2006). It is an inter-disciplinary approach to learning, where accurate academic theories are connected with real life coaching as students employ STME in a framework that enhance connections between school, community, work and global enterprise, enabling the ability to vie in the new worldwide economy (Tsupros, 2009).

ICT as a tool in driving STME can be deployed through various avenues such as computers, telephones, radio and television. If deployed via radio when not restricted to entertainment alone could serve to enrich basic education, at costs much more modest than those of television or computers. There are also out-of-school models for education of students through online teaching materials on the internet as well as materials in electronic digital devices such as DVDs for both in-school and out-of-school students. There is also the potential of utilizing mass media for public and adult informal education, in areas such as health, citizenship, family planning and agriculture (Kaino, 2013). ICTs can also be of use by teachers and agricultural extension workers as it would likely yield cost advantages over conventional ways of supporting and updating them with latest tools and innovations. This is because ICT channels can transfer information faster without the physical and more expensive means of movements. It has the potential of reducing the isolation of remote communities as well as raises the quality of work undertaken by rural teachers and extension workers.

All these brings us to the inevitable requirement of cheap and easily accessible electricity supply which is the means by which most modern ICT equipment and gadgets operate. Electricity is fundamental to development. It is the means to improved social and economic well-being just as it is vital to industrialization and wealth creation. It is also the gate to employment opportunities to the teeming jobless Nigerian youths. The nation's pursuit of becoming one of the 20 most developed countries in the world by 2020 would be challenging unless it finds the key to significant improvement in power generation (Adenipekun, 2013).

2.0 Potential of renewable energy resources in Nigeria

Many indigenous researchers have considered the prospect of Renewable Energy (RE) resources in Nigeria with a view of demonstrating their practicability in the country. (Onyebuchi, 1989) estimated the technical potential of solar energy in Nigeria using a device with 5% conversion efficiency. The conclusion led to a realization of 15.0×10^{14} kJ of useful energy yearly equating to about 258.62 million

barrels of oil annually (Adekoya *et al*, 1992) and corresponds to 30% of the 876 million barrels of annual crude oil production in the country as of February, 2013. This also sums up to about 4.2×10^5 GWh of annual electricity production, which is about 26 times the recent annual electricity production in the country (Oyedepo, 2012). A work by Chineke and Igwiro, (Chineke *et al*, 2008) reveals that Nigeria receives abundant solar energy that can be profitably harnessed. The annual average daily solar radiation was found to be 5.25 kWh/m^2-day. This varied between 3.5 kW h/m^2-day, around the coastal areas of the south and 7.0 kWh/m^2-day at the northern border. The average duration of sunshine hours all over the country was estimated as 6.5 hours with average annual solar energy intensity being 1,935 kWh per m^2 per year, with an approximation of 1,770 TWh per year of solar energy. This approximately equals a multiple of 120,000 of the total annual average electrical energy generated by the Power Holding Company of Nigeria (PHCN) (UNDP, 2012). Consequently the retrievable solar energy with a 10% unadventurous conversion efficiency yields about 23 times the energy demand projection of the Energy Commission of Nigeria for the year 2030 (Ngala *et al*, 2007). It is thence appropriate to incorporate solar energy in the nation's energy mix.

On the potentials for wind-to-electricity projects in Nigeria, a number of study reports exist. For example Adekoya and Adewale (Adekoya *et al*, 1992) investigated wind speed data of 30 stations in Nigeria and established the annual mean wind speeds and power flux densities to vary between 1.5 - 4.1 m/s and 5.7 - 22.5 W/m^2 respectively. Fagbenle and Karayiannis (Fagbenle *et al*, 1994) in their study on a 10-year wind data from 1979 to 1988 considered surface and higher winds as well as maximum guts. Ngala et al.carried out statistical and cost benefit analyses of the wind energy potential of a site in Maiduguri utilizing Weibull statistics on a 10-year wind data range of 1995 to 2004 (Ngala *et al*, 2007). (Ajayi, 2010) implied that inland, the wind is best in hilly regions of the North, while upland topographies of the middle belt and northern boundaries of the nation have huge potential for huge wind energy production. Mean wind speeds in the north and south were detailed to lie between 4.0 – 7.5 m/s and 3.0 – 3.5 m/s respectively at 10 m height. Most researchers thus concluded that wind energy is particularly of significant abundance at the core northern states, the hilly and mountainous parts of the central and eastern states, and also the country's offshore areas (Adekoya *et al*, 1992; Ajayi, 2010; Fagbenle, *et al*, 2011; Ajayi *et al*, 2011; Ajayi *et al*, 2010). This became a pointer to the fact that, the nation is blessed with enormous natural supply of solar and wind energy, with massive opportunity for electricity production. In spite of this, the energy need of citizens in the rural areas is still hinged on traditional biomass (Ajayi *et al*, 2010). This group of fuels are said to make up more than 50% of total energy usage in Nigeria (National Energy Policy, 2003). Further to this, fuel wood supply/demand imbalance in some parts of the country is becoming a threat to the energy security of the rural communities (Kanase-Patil *et al*, 2010; Rajoriya, 2010; Setiawan *et al*, 2009; Akella *et al*, 2007; Promoting Renewable Energy, 2007) as a result of the extent to which deforestation has taken place. Hence with a very low annual per capita consumption of electricity estimated between 100 kWh and 135 kWh (Ajayi and Ajayi, 2013) and an understanding that over 100 local governments areas of Nigeria remain unconnected to the national electricity grid (Ajayi, 2010), a variegation of the nation's energy mix is therefore necessary for the country to reach the target of energy security by the year 2020. This is given that RE resources has the benefit of being employed for standalone facility in addition to grid connectivity.

3.0 Present work

In Nigeria very few research studies exist that have appraised the potential of hybrid RE system for power generation (Nwosu *et al*, 2012; Mbakwe *et al*, 2011; Abatcha *et al*, 2011; Agajelu *et al*, 2013). Notwithstanding this, the existing results focused on small scale generation for remote telecom applications and also for individual buildings. Research reports on design and economic feasibility of hybrid systems that can provide sustainable power for rural communities are rare. This study is therefore focused on the techno-economic assessment of hybrid RE for rural electrification in selected sites across the geopolitical zones of Nigeria. The six sites are spread across the country. Rural communities made up of 200 homes, a school and health centre was conceived for each site.

4.0 Methodology and data collection

4.1 Data Collection

The twenty-four years (1987 – 2010) daily global solar radiation, daily wind speed data, sunshine hours, minimum and maximum air temperature, and minimum and maximum relative humidity that were employed for this study were sourced from the Nigeria Meteorological agency (NIMET), Oshodi, Lagos, Nigeria. The solar radiation data utilized for some of the sites were also derived from the model proposed by (Ajayi *et al*, 2014) due to insufficient data for some sites. The study focused on designing for rural communities in Nigeria, with 200 homes, having a school and community health centre. The location parameters of the selected sites are as shown in Table 1. Wind turbines ranging from two to four 25 kW turbines, with single 3MW turbines for embedded generation, cumulative solar panels ranging between 105 kW & 190 kW with 7.5MW – 10.5 MW for embedded generation, and a diesel generator of 35 kW were employed for the study as standalone or hybrid power systems. The econometric analysis of the diesel system for comparison is presented in Table 2.

RETScreen® software was used as a feasibility tool and the average air temperature and relative humidity were included in the RETScreen® analysis due to the reliance of PV module efficiency on nearby air temperature and relative humidity. The efficiency of photovoltaic cells has been found to vary with their operating temperature (RETScreen 4 Software, 2013; Omubo-Pepple *et al*, 2013; Skoplaki *et al*, 2009; Fesharaki, 2011). Most cell types exhibit a decline in efficiency as their temperature ascends, while it was also found that increased relative humidity acts to reduce the quantity of visible solar radiation recoverable (Hedzlin *et al*, 2009; Ettah *et al*, 2012; Hussein *et al*, 2013). Also relative humidity together with enormity of wind speed acts as cooling agents that improve the output of a PV module by dropping the module temperature (Hedzlin *et al*, 2009).

Table 1: Location parameter of the studied sites

S/N	Geopolitical Zone	State	Sites	Latitude (° N)	Longitude (° E)
1	North West (NW)	Kano	Kano	12.0031	8.5288
2	North East (NE)	Borno	Maiduguri	11.8333	13.1500
3	North Central (NC)	Plateau	Jos	9.9167	8.9000
4	South West (SW)	Oyo	Iseyin	7.9667	3.6000
5	South East (SE)	Enugu	Enugu	6.4500	7.5000
6	South-South (SS)	Edo	Benin City	6.3176	5.6145

Table 2: Diesel System econometrics for Nigeria

All Sites	Total NPC ($)	Total NPC (NGN)	Initial Capital ($)	Initial Capital (NGN)	LCOE ($)	LCOE (NGN)
Diesel Generator	1,033,203	160,146,465	$12,250	1,898,750	$0.619	95.95
Diesel With Battery	781,259	121,095,145	$31,000	4,805,000	$0.469	72.70

4.2 Load calculation

The load profile of rural communities is not easily presumed, but can be well thought-out to be very low in comparison to urban communities. It is detailed that typically an average of 1 kWh/day per home can be linked with rural community homes (Clean Energy Project, 2005; Lambert *et al*, 2006). Though, for the purpose of this study, the energy demand requirement of the rural communities were assumed to be based on the individual power rating of the appliances employed in each home as shown in Table 3 and 4 (General Wattage Chart, 2013; How much electricity, 2013; RETScreen 4 Software, 2013). The average electricity consumption per home, based on the analysis of Tables 3 and 4, is estimated as 1.4kWh/day with a primary peak load of 46 kW. Fig. 1 presents the 24 hours hourly load profile for the communities.

Table 3: 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)

Table 4: 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
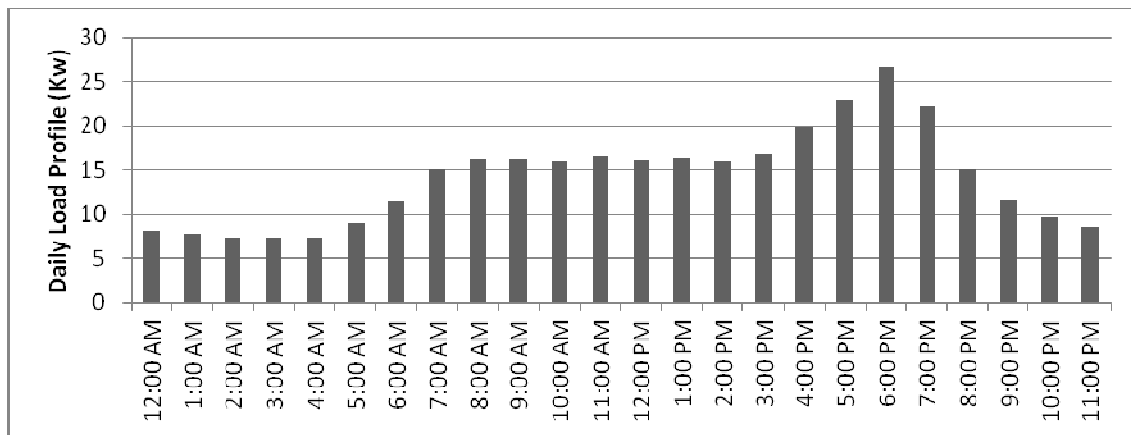
Fig 1: Daily load profile used for design of hybrid energy systems in rural areas of North-West Nigeria

4.3 Modeling the Photovoltaic (PV) project

4.3.1 Description of the solar radiation algorithm

The solar radiation algorithm used can be depicted as a sequence of three basic steps (see Figure 2):
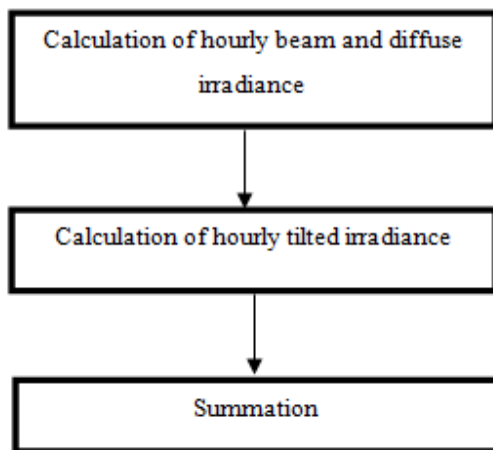

Figure 2: Flowchart for tilted Irradiance Calculation

4.3.2 Calculation of hourly global and diffuse irradiance

Solar radiation is divided into two parts: beam radiation, and diffuse radiation. The tilting algorithm used therefore requires the knowledge of beam and diffuse radiation for every hour of an average day.

Firstly, the monthly average daily diffuse radiation $\bar{H}_d$ is calculated from monthly average daily global radiation $\bar{H}$ using the Erbs *et al.* correlation (Duffie *et al*, 1991). When the sunset hour angle for the average day of the month is less than 81.4° it is:

$$\frac{\bar{H}_d}{\bar{H}} = 1.391\text{-}3.560\bar{K}_T + 4.189\bar{K}_T^2 - 2.137\bar{K}_T^3 \qquad\qquad 1$$

And when the sunset hour angle is greater than 81.4° it is:

$$\frac{H_d}{H} = 1.311 - 3.022\bar{K}_T + 3.427\bar{K}_T^2 - 1.821\bar{K}_T^3 \qquad\qquad 2$$

The monthly average clearness index, $\bar{K}_T$ is calculated with equation 5.

4.3.3 Necessary Solar Equations

Declination (δ)

The angular position of the sun at solar noon, with respect to the plane of the equator is derived from Cooper's equation (Clean Energy Project, 2005):

$$\delta = 23.45 \sin(2\pi \frac{284+n}{365}) \qquad\qquad 3$$

where *n* is the day of year.

Solar hour angle and sunset hour angle

The sunset hour angle ω_s is the solar hour angle corresponding to the time when the sun sets, and given by:

$$\cos \omega_s = -\tan \psi \tan \delta \qquad\qquad 4$$

where ψ is the latitude of the site under consideration.

Clearness Index

This is given as:

$$\bar{K}_T = \frac{H}{H_0} \qquad\qquad 5$$

Where H is the monthly average daily solar radiation on a horizontal surface and $\bar{H}_o$ is the monthly average extraterrestrial daily solar radiation on a horizontal surface.

4.3.4 Tilted Irradiance Calculation

Radiation in the plane of the PV array was calculated using a method comparable to the Klein and Theilacker algorithm (Duffie *et al*, 1991), though the algorithm was extended to tracking surfaces. Therefore to calculate the hourly values of radiation from the average daily values, the Collares-Pereira and Rabl formulae for global irradiance was used (Clean Energy Project, 2005):

$$r_t = \frac{\pi}{24}(a + b \cos \omega \frac{\cos\omega - \cos\omega_s}{\sin\omega_s - \omega_s \cos\omega_s}) \qquad\qquad 6$$

$$a = 0.409 + 0.5016 \sin (\omega_s - \frac{\pi}{3}) \qquad\qquad 7$$

$$b = 0.6609 + 0.4767 \sin (\omega_s - \frac{\pi}{3}) \qquad\qquad 8$$

where r_t is the ratio of hourly total to daily total global radiation, ω the solar hour angle for the midpoint of the hour for which the calculation is made, also expressed in radians. The hour angle is the angular displacement of the sun east or west of the local meridian due to rotation of the earth on its axis at 15^0 per hour, morning negative, afternoon positive.

The formula by Liu and Jordan was used to determine the diffuse irradiance as (Clean Energy Project, 2005):

$$r_d = \frac{\pi}{24}\left(\frac{\cos\omega - \cos\omega_s}{\sin\omega_s - \omega_s\cos\omega_s}\right)$$

$$9$$

where, r_d is the ratio of hourly total to daily total diffuse radiation.

For each hour of the average day, global horizontal irradiance H having diffuse and beam components H_d and H_b are specified as (Clean Energy Project, 2005):

$$H = r_t \bar{H}$$

$$10$$

$$H_d = r_d \bar{H}_d$$

$$11$$

$$H_b = H - H_d \tag{12}$$

Calculation of hourly irradiance in the plane of the PV array

Evaluation of hourly irradiance in the plane of the PV array, H_t, was done using a simple model, described in (Duffie *et al*, 1991):

$$H_t = H_b R_b + H_d \left(\frac{1+\cos\beta}{2}\right) + H\rho\left(\frac{1-\cos\beta}{2}\right) \tag{13}$$

where ρ represents the diffuse reflectance of the ground (also called ground albedo) and β represents the slope of the PV array. Ground albedo was set to 0.2 if the average monthly temperature is greater than 0°C, R_b is the ratio of beam radiation on the PV array to that on the horizontal, which can be expressed as:

$$R_b = \frac{\cos\theta}{\cos\theta_z} \tag{14}$$

Where θ is the incidence angle of beam irradiance on the array and θ_z is the zenith angle of the sun. The above algorithm can be used with tracking arrays. For tracking surfaces, the slope β of the array and the incidence angle θ for every hour are resolved by equations of Braun and Mitchell (Braun *et al*, 1983).

Summation

Once tilted irradiance for all hours of the day was computed, the daily total $\bar{H}_t$ was obtained by summing individual hours.

4.3.5 PV Array Model

The PV array model is based on work by Evans (Evans, 1981).

Calculation of average efficiency

The array is characterized by its average efficiency, η_p which is a function of average module temperature T_c:

$$\eta_p = \eta_r \left[1 - \beta_p \left(T_c - T_r\right)\right]$$
15

where η_r is the PV module efficiency at reference temperature T_r (= 25°C), and β_p is the temperature coefficient for module efficiency, T_c is related to the mean monthly ambient temperature T_a through Evans' formula (Evans, 1981):

$$T_c - T_a = \left(219 + 832 \bar{K}_t\right) \frac{NOCT - 20}{800}$$
16

where NOCT is the Nominal Operating Cell Temperature and $\bar{K}_T$ the monthly clearness index; η_r, NOCT and β_p depend on the type of PV module considered.

4.4 Modeling the wind speed distribution

4.4.1 Wind Energy Model

Wind speed profile characterization and analysis for the site was carried out using the Weibull probability density function. This is because the Weibull probability density function has been found to match considerably with the experimental long-term distribution for various sites (Ajayi *et al*, 2011).

4.5 Cost benefit analysis

Economics is vital in the selection of energy resources, as renewable and non-renewable energy sources usually have very diverse cost characteristics. Renewable sources tend towards having high initial capital costs and low operating costs, while conventional non-renewable sources usually tend to have low capital and high operating costs. The life-cycle cost (or NPC) analysis comprises the costs of initial construction, component replacements, maintenance, fuel, cost of buying power from the grid, and miscellaneous costs such as fines ensuing from pollutant emissions. Revenues take into account income from selling power to the grid, plus any salvage value that occurs at the end of the project lifetime. As for the NPC estimation, costs are seen as positive and revenues are negative. A negative NPC value typifies a net present value (NPV).

For each component, the capital, replacement, maintenance, and fuel costs, along with the salvage value and other costs or revenues, make up the component's annualized cost. The annualized costs are therefore totaled for each component, together with any miscellaneous costs, so as to find the total annualized cost of the system. The total net present cost is:

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

17

where: $C_{ann,tot}$ = total annualized cost, R_{proj} the project lifetime, and CRF(•) is the capital recovery factor, given by the equation:

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

18

where, i, is the annual real interest rate (the discount rate) and N is the number of years.

The annualized capital cost of each component is calculated using the following equation:

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

19

where:

C_{cap} = initial capital cost of the component

The annualized replacement cost of a system component is the annualized value of all the replacement costs occurring throughout the lifetime of the project, minus the salvage value at the end of the project lifetime. It must be noted that the annualized replacement cost can be negative because it includes the annualized salvage value.

The following equation was used in calculating each component's annualized replacement cost:

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

20

f_{rep}, is a factor arising due to the fact that the component lifetime can be different from the project lifetime, as given by:

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

21

R_{rep}, the replacement cost duration, is given by:

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

22

Where, INT ( ) is the integer function, returning the integer portion of a real value. The integer function does not round up but only returns the integer portion of the number.

The salvage value of each component at the end of the project lifetime was assumed proportional to its remaining life. Therefore the salvage value S is given by:

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

23

Where R_{rem}, the remaining life of the component at the end of the project lifetime, and it is given by:

$$R_{rem} = R_{comp} - (R_{proj} - R_{rep})$$

24

C_{rep} = replacement cost of the component.

SFF ( ) = sinking fund factor

R_{comp} = lifetime of the component

The sinking fund factor is a ratio used to calculate the future value of a series of equal annual cash flows, (the future value being the equivalent value at some designated future date of a sequence of cash flows, taking into account the time value of money). The equation for the sinking fund factor is:

$$SFF(i, N) = \frac{i}{(1+i)^N - 1}$$
<div align="right">25</div>

The total O&M cost is the sum of: the system fixed O&M cost, the penalty for capacity shortage and penalty for emissions (if any).

The following equation is used in calculating the total annual O&M cost:

$$C_{om,total} = C_{om,fixed} + C_{cs} + C_{emissions}$$
<div align="right">26</div>

where:

$C_{om,fixed}$ = system fixed O&M cost ($/yr)

C_{cs} = the penalty for capacity shortage ($/yr)

$C_{emissions}$ = the penalty for emissions ($/yr)

The following equation is used to calculate the penalty for capacity shortage:

$$C_{cs} = c_{cs} \cdot E_{cs}$$
<div align="right">27</div>

where:

c_{cs} = capacity shortage penalty ($/kWh)

E_{cs} = total capacity shortage (kWh/yr)

Therefore, the total annualized cost is:

$$C_{ann,tot} = C_{acap,total} + C_{arep,total} + C_{om,total} + R_{ann,proj}$$
<div align="right">28</div>

Where, $R_{ann,proj}$ = annual project revenue ($/yr)

The levelised cost of energy (LCOE) is therefore:

$$LCOE = \frac{C_{ann,tot}}{E_{prim} + E_{def} + E_{grid,sales}}$$

<div align="center">29</div>

Where, $C_{ann,tot}$ is the total annualized cost, E_{prim} and E_{def} are the total amounts of primary and deferrable load, respectively, that the system serves per year, and $E_{grid,sales}$ is the amount of energy sold to the grid per year.

4.6 Specifications of Wind Turbines and Solar Panel used in this study

PGE turbines (HOMER Software, 2013) were cumulatively employed for this study for wind standalone application (WSS), each with the specification indicated in Table 6. The Enercon turbine is for embedded generation.

Table 6: Turbine specification

Wind Machine	V_c (m/s)	V_{Fi} (m/s)	V_{Fo} (m/s)	V_R (m/s)	P_{eR} (kW)	Available Hub Height (m)	Rotor Diameter (m)
PGE 20/25	3.5	1.7	25	9	25	24/30/36	20
Enercon	3	2	25	12	3000	120/135	101

V_c = cut-in wind 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.

The specification of the solar panel with a collector area of 5.1 m^2 rated at 1 kW by Sunpower (Skoplaki *et al*, 2009) used in this research is presented in Table 7. Therefore in order to suite the load demand, the solar collector area increases while other parameters in Table 7 remained constant (RETScreen 4 Software, 2013). Table 8 reveals components' cost as used in designing the Hybrid Energy Systems (HES) with the installation costs embedded within each component cost.

Table 7: PV system specification

PV Technology	Power capacity	Efficiency	NOCT	Temperature coefficient	Solar collector area	Miscellaneous losses	Array slope angle
mono-Si	1 kW	19.60%	45°C	0.40% / ^{o}C	5.1m^2	10%	Location latitude

Table 8: Cost of Components used in the design of HES (installation cost embedded in component cost)

Component	Interest Rate (%)	Project Life time	Cost ($/kW)	O & M ($)	Replacement Cost ($/kW)
Wind turbine	6	20 years	1800	400/yr	1800
Solar panel	6	25 years	3000	0/yr	1500
Battery	6	10 years (float)	100	20/yr	100
Converter	6	12 years	500	80/yr	500
Diesel generator	6	15,000 hrs	350	0.050/hr	300

5.0 Results and Discussion

Fig. 2 presents the average monthly solar radiation profiles covering the period between 1987 and 2010. The figure shows that the 24 years monthly average solar radiation ranged between 2.93 (kWh/m²/d) in August for Iseyin (SW) and 6.468 (kWh/m²/d) in April for Maiduguri (NE). Fig. 2 also shows that the period between July and August experiences the least solar radiation across the sites/states. Maiduguri and Kano appears to be the sites/states with the better solar profiles than the other regions.
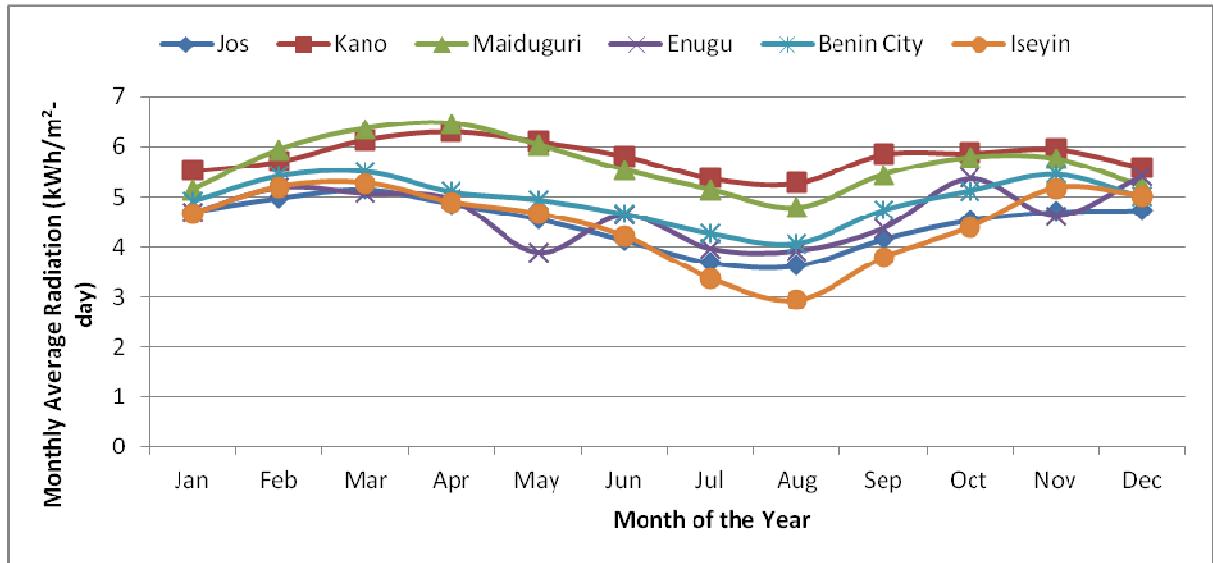
Fig 2: 24- Year Monthly Average Radiation (kWh/m²-day) for sites in Nigeria

Considering the hours equaled or exceeded for a series of mean measured solar radiation (Fig. 3) across the studied period revealed that the power generated for each site from the designed PV array is between 4313 hours for Iseyin (SW) and 4472 hours for Jos (NC) out of the 8760 hours in a year. This corresponds to about 49.2% - 51.1% of the hourly duration in a whole year. This however is because solar radiation, unlike wind speed, is in occurrence only during the daytime with Iseyin having a twenty four year average sunshine daily duration of about 5.46 hours, while Jos has 7.33 hours. Fig. 3 which presents the average yearly solar radiation profiles covering the period between 1987 and 2010 shows Maiduguri (NE) had the highest yearly average radiation in 1997, and Enugu (SE) had the lowest in 2004. More variability however was found to be associated with the monthly solar data than yearly solar radiation data. Fig. 4 shows that the solar radiation profiles for all sites in Nigeria can be grouped broadly in two, Northern Nigeria and Southern Nigeria, with very similar characteristics. The similarity in characteristics is a result of similar weather and climatic conditions within the same geographical region.
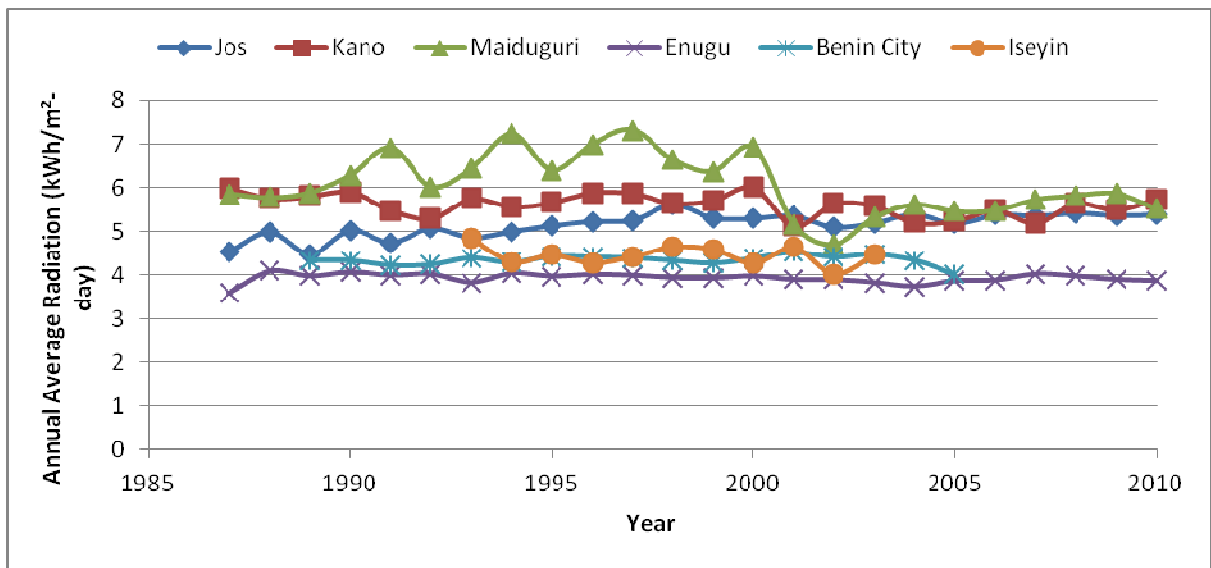
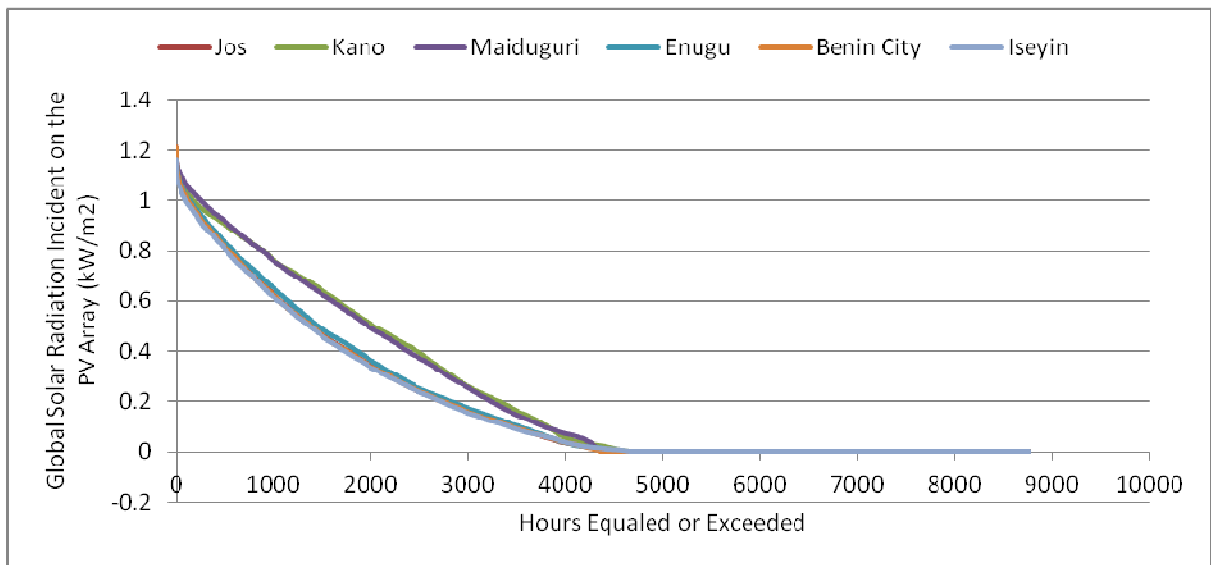Fig 3: 24- Year Yearly Average Radiation (kWh/m²-day) for sites in Nigeria

Fig. 4: Plot of 24 Years' Annual Average Hours Equaled or Exceeded for Nigeria

The correlation of the annual average solar radiation and PV module size for the 6 sites is presented in Fig. 5. It demonstrates that a good correlation exist between the incident irradiation and the PV size. An inverse proportionality exists between the two quantities, with the PV requirement increasing with reduction in solar radiation intensity. This is due to the overriding influence of daily global solar radiation on the sizing of photovoltaic systems. It also shows that the 24 years annual average solar radiation ranged between 4.4498 (kWh/m².day) for Iseyin (SW) and 6.0684 (kWh/m².day) in Kano (NE) with a corresponding PV rating of 155 kW and 115 kW respectively.
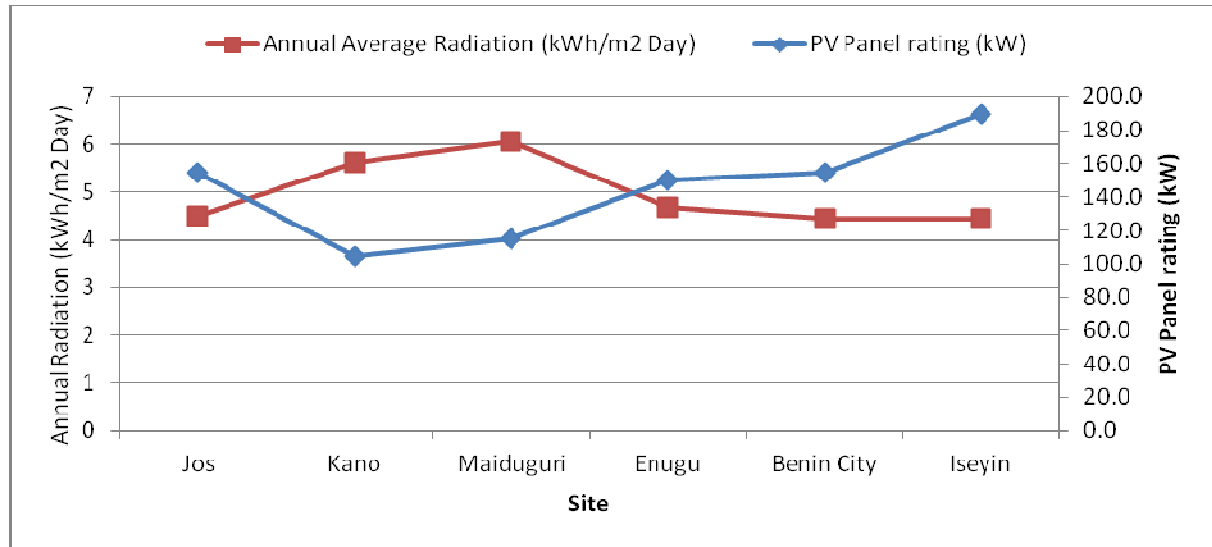
Fig 5: Correlation between the monthly average solar radiation and solar panel size for Nigeria

From Table 9, it is observed that the most cost effective system design for the PV standalone systems having a Loss of Load Probability (LOLP) of 0.01(Hontoria *et al*, 2005; Shen, 2009; Khatib *et al*, 2013), gave an average excess electricity equivalent to 26.3% of annual generation for Nigeria. However, this is due to days within the rainy season periods in which the average sunshine duration were between 3 and 4 hours in the north and 1 to 2 hours in the south. Thus a design that will serve a load profile of 200 rural homes including the requirement for battery charging will of necessity take into consideration the days of limited solar radiations. The battery days of autonomy therefore ranged between 48.7 hours for NW and 68.9 hours for SS at an initial state of charge of 50% (to extend battery life (Hund *et al*, 2010; Hund, 2009; Hunt, 2009; Overview of the NERC regulations, 2012; Multi-Year Tariff Order, 2011; Branker *et al*, 2011; Lorenz *et al*, 2008). Thence, with a design covering an entire year, it gives rise to an excess in energy generated annually when the period of higher sunshine duration is balanced with those of lower duration. The excess may be utilized in the form of embedded generation. Embedded generation in this case is defined as a form of generation where excess renewable energy generated by a consumer ranging between 1 MW to 5 MW is sold to a nearby distribution network (Overview of the NERC regulations, 2012; Multi-Year Tariff Order, 2011). The sales to the grid have the benefit of a reduction in the LCOE, as indicated by equation 4. The excess though may not always be sold to the grid as it will be wasted when less than 1 MW, if optimum battery capacity by design could not take care of this excess. Table 9 also presents the battery specification employed in the study. It shows the optimized rated capacity (or nominal capacity) of the battery, which is the amount of energy that could be pulled out from it at a particular constant current, starting from a fully charged state.

Table 9: Technical requirements employed for the PV standalone system design

Site	PV Panel rating (kW)	PV hours of Operation (hrs/yr)	Battery Nominal Capacity (kWh)	Battery Usable Capacity (kWh)	Battery Autonomy (hours)	Excess Electricity (% of Production)
Jos (NC)	155.0	4,472	1469	1,028	68.9	19.3
Kano (NW)	105.0	4,466	$0.127	1,037	48.7	17.9
Maiduguri (NE)	115.0	4,357	1,102	771	51.7	23.0
Enugu (SE)	150.0	4,457	1,274	892	59.8	28.6
Benin (SS)	155.0	4,353	1,469	1,028	68.9	28.0
Iseyin (SW)	190.0	4,313	1382	968	64.9	41.1

The NPC (Fig. 6) represents the life cycle cost, which captures all the cost throughout the operational life (25 years) of the system. The study first employed a project life of 25 years because of the life span of solar panels. However, the inclusion of the replacement cost for each component in the analysis, whereby the design goes beyond the required twenty five years' lifespan of the module makes the design set up cheaper for higher operational life cycle periods. Also, since each component cost is expected to reduce over the years, the LCOE is projected to further decline. The analysis reveals that the effect of solar panel on the total NPC is averagely about 52% for the Kano site, 73.4% for Maiduguri, 51% for Enugu, 54% for Benin, 75% for Iseyin, and 53% for Jos. The remaining is borne by the battery and converter's initial, maintenance and replacement costs. This shows that with the present rate of decline in prices of solar panels (Branker *et al*, 2011; Lorenz *et al*, 2008; Renewable Power Generation Costs, 2012), the effect on life cycle cost will progressively decline, which will make PV systems much more competitive with grid electricity. Fig. 6 also makes a comparison between total NPC and initial capital cost and reveals that both costs follow the same pattern. The reason is due to the fact that all sites use the same technology, though the initial costs are less than NPC for each site.
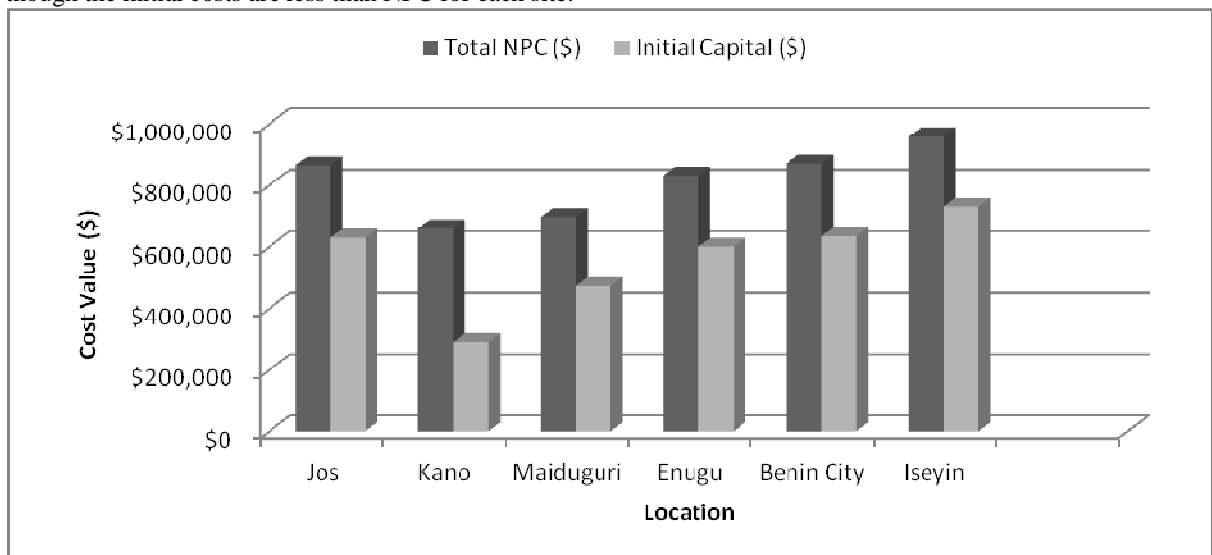

Fig 6: Comparison between Net Present Cost (NPC) and Initial Capital for PV standalone system

Table 10 presents an econometric ranking by total NPC for the sites. It reveals that the LCOE is directly proportional to total NPC for all sites. Therefore Fig. 7 presents the best location in Nigeria by LCOE. It shows Iseyin as the poorest in terms of LCOE at $0.579/kWh and Kano as the best with $0.398/kWh. This equates to 7.1% and 56% savings respectively on an equivalent DSS that will serve the same load for this communities, with the additional savings in 279 tons of CO_2 green house gas emissions (GHG).
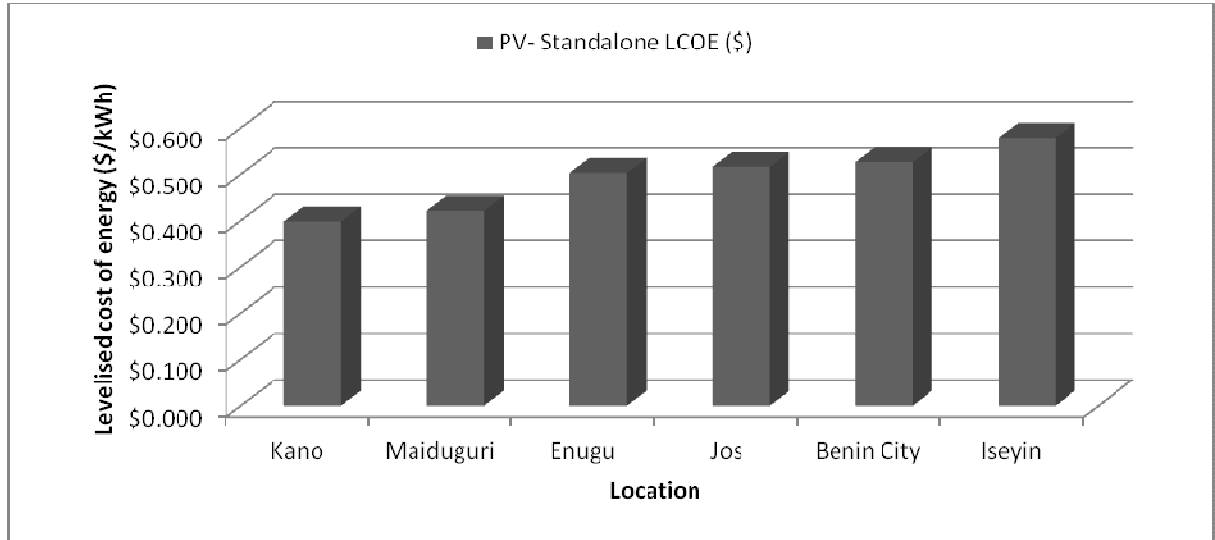

Fig 7: LCOE for PV standalone system

Table 10: Total NPC and LCOE values for the PV standalone system design

Site	Total NPC ($)	LCOE ($/kWh)
Kano	$660,209	$0.398
Maiduguri	$697,700	$0.421
Enugu	$832,253	$0.503
Jos	$865,771	$0.516
Benin	$870,270	$0.526
Iseyin	$958,655	$0.579

Prospect of standalone wind-to-electricity project in the sites

The results of wind profile analysis at the site are as shown in Figs. 8 and 9. The figures demonstrate that the 24 years monthly average wind speeds ranged between 3.476 m/s in November for Benin and 10.062 m/s in December for Jos. The yearly average ranged between 1.842 m/s in 1999 for Iseyin and 11.783 m/s in 1993 for Jos. Moreover, the hours equaled or exceeded for a range of mean measured wind speeds (Fig. 10) across the period revealed that 67.2% of the data spread are values above 3.0 m/s for the poorest site in terms of wind profile, and 91.9% for the best wind profile in Jos. Thus this values proof that most of the sites are compatible with modern wind turbines for power generation throughout the year with corresponding higher returns on investment.
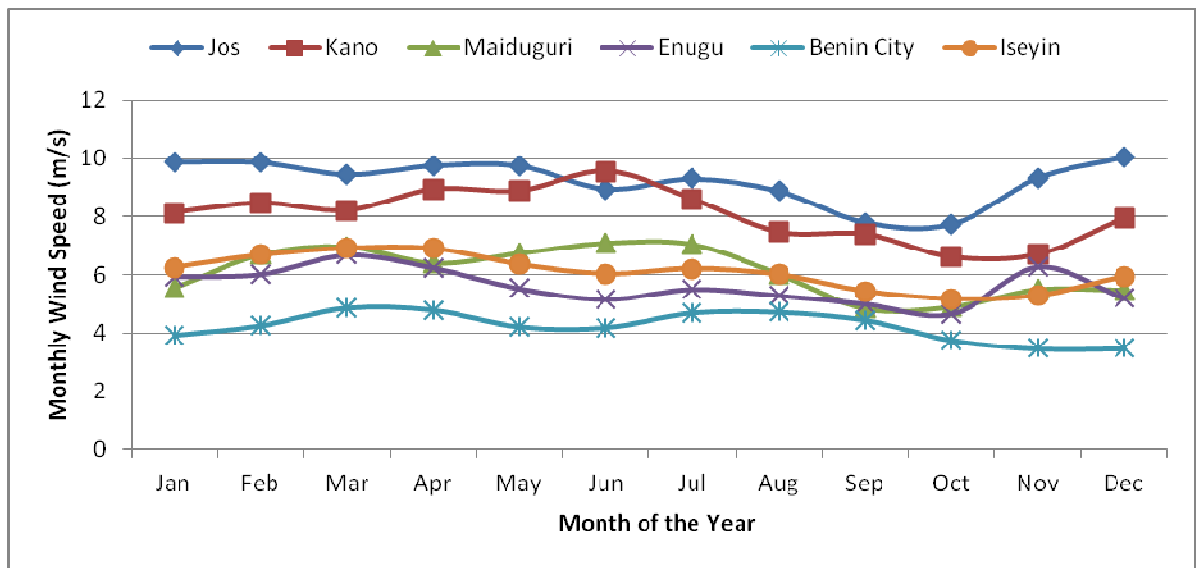
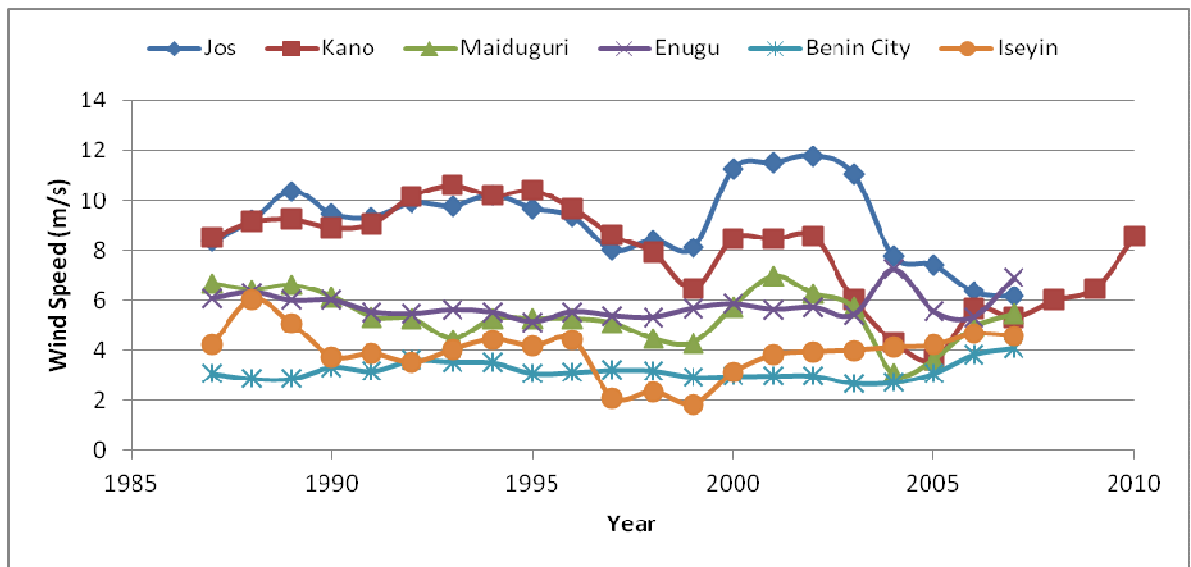Fig. 8: Plot of 24 Years' Monthly Average Wind Speeds

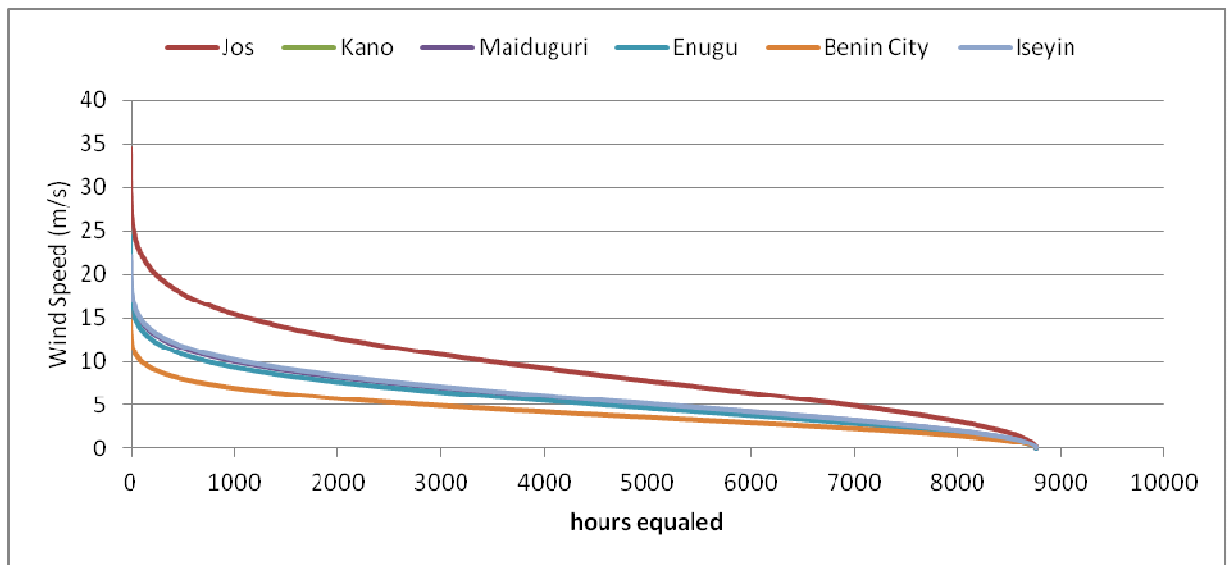Fig. 9: Plot of 24 Years' Annual Average Wind Speeds

Fig. 10: Plot of 24 Years' Annual Average Hours Equaled or Exceeded for different wind speeds
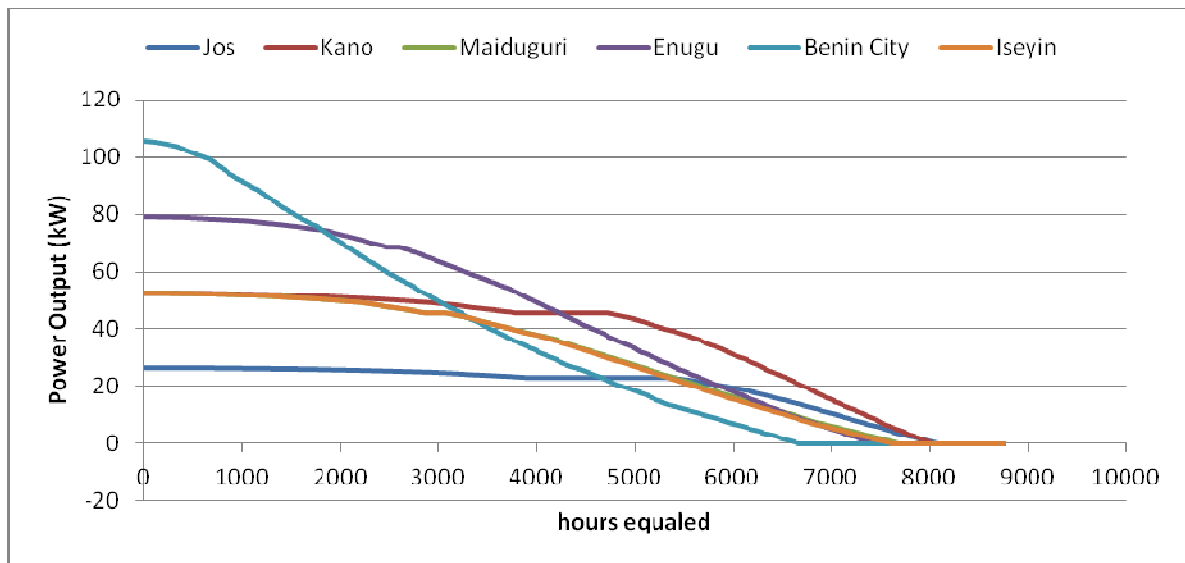
Fig. 11: Plot of 24 Years' Annual Average PGE 2025 Power Output Duration Curve (kW)

Fig. 11 presents the hours equaled for power generated for each site from the respective turbine sizing based on their respective wind speed profiles. It shows that SS requires the highest of 100 kW, and as such generates more excess power than any other site but for a very short period. It does not generate for more than about 68% of the time while a site like Kano in the NW though sized to 50 kW because of a very favorable wind profile consistently generates 90% of the hourly duration in a year. Based on this,

Table 11 shows that Benin has the highest battery capacity requirement, which is to compensate for about a third of the duration of the year without turbine production.

Table 11: Technical requirements and correlation of electricity consumed as a percentage of wind standalone production

Site	Wind Turbine rating (kW)	Wind hours of Operation (hrs/yr)	Battery Nominal Capacity (kWh)	Battery Usable Capacity (kWh)	Battery Autonomy (hours)	Excess Electricity (% of Production)
Jos	50.0	8,089	302	212	14.2	59.0
Kano	50.0	8,025	367	257	17.2	56.6
Enugu	75.0	7,444	691	484	32.4	60.4
Benin	100.0	6,679	1,123	786	52.7	54.1
Maiduguri	50.0	7,701	583	408	27.4	45.9
Iseyin	50.0	7,619	821	575	38.5	45.3

Table 11 reveals an average excess electricity equivalent to 54% of annual generation. This is because wind power is averagely generated for about 80% of the time generally within the studied sites in Nigeria (see Fig. 10 & Table 11). Therefore since the sites have the ability of generation for over two-thirds of every hour of the day, an average optimal battery size of 30.8 hours of autonomy can be employed. Also since the rated speed for the PGE 20/25 turbines used in the design is 9 m/s, Fig. 10 shows that averagely for about 24% of annual hourly duration, the turbines can produce at the rated capacity. This therefore gives good returns on investment and an opportunity for embedded generation (Overview of the NERC regulations, 2012; Multi-Year Tariff Order, 2011). Table 12 reveals that the Wind Standalone System (WSS) is generally more cost effective due to an average savings of 80% of both rated capacity and usable capacity of the battery requirement as compared to that of the PV Standalone System (PSS). The average usable capacity for Nigeria for wind standalone system is 70% of its nominal capacity. Also, the average expected life of the battery is 10 years from the design, as specified by the manufacturer. This is because the wear cost losses are very low as the batteries are hardly cycled below 90% of their energy capacity. This makes the WSS more cost effective as there are fewer replacements for batteries than that of PSS with an average expected life of 8.63 years.

Table 12: Econometrics Analysis for wind standalone system

Site	Total NPC ($)	Total NPC	Initial Capital ($)	Initial Capital	LCOE ($)	LCOE
Jos	$214,644	33,269,820	$130,740	20,264,700	0.129	NGN 20.00
Kano	$238,263	NGN 36,930,765	$141,720	NGN 21,966,600	0.144	NGN 22.32
Maiduguri	$279,356	NGN 43,300,180	$158,820	NGN 24,617,100	0.168	NGN 26.04
Iseyin	$358,700	NGN 55,598,500	$192,080	NGN 29,772,400	0.217	NGN 33.64
Enugu	$385,754	NGN 59,791,870	$222,870	NGN 34,544,850	0.233	NGN 36.12
Benin	$541,558	NGN 83,941,490	$310,820	NGN 48,177,100	0.327	NGN 50.69

Table 12 presents the NPC of employing only wind standalone system for power generation at each of the communities. Comparing the NPC for all sites reveals differences. This is due to the fact that all sites have different wind speed profiles as the wind energy resource at some locations are very close to the turbines rated speed while others are a bit far off. Therefore those with close value to turbine rated speed enabled production at its power rating up to 47 % of the time for Jos site. This was why a lower capacity rating of 50 kW was required for Jos as compared to 100 kW for Benin for the wind turbines. The total NPC was found to be averagely 142% less for the WSS than the total NPC for the PSS when all sites were considered. It was also observed that the greatest differential of NPC by cost type is with the capital cost.
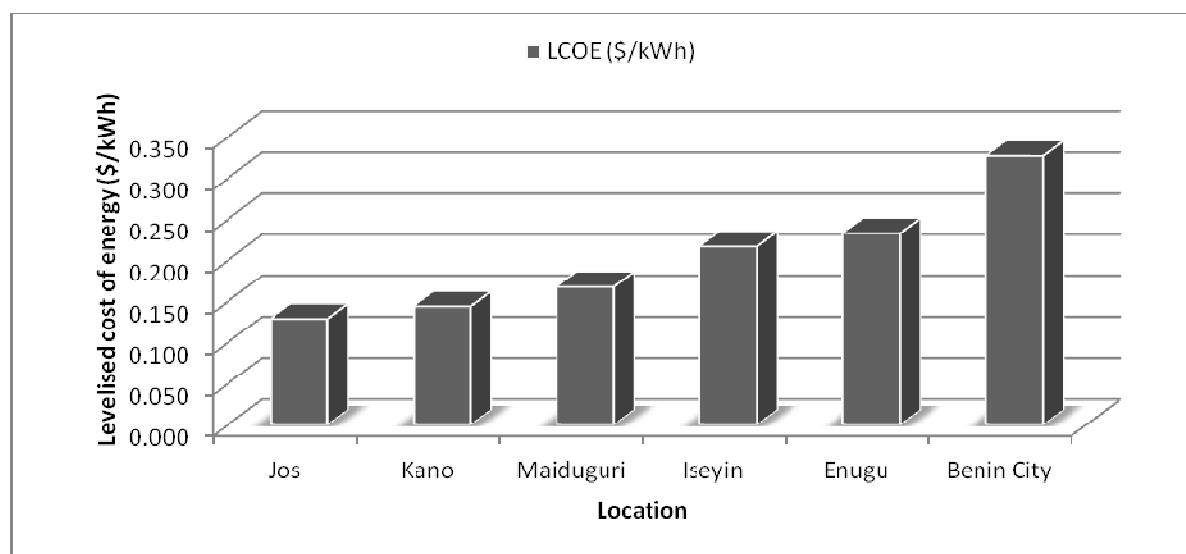

Fig 12: Net Present Cost (NPC) summary - comparison between wind standalone systems

Table 12 also presents an econometric ranking by total NPC for the sites and it reveals that the LCOE correlates for all sites with the NPC values. Therefore Fig. 12 presents the comparative rank of the sites by LCOE, with Benin being the poorest at $0.327/kWh and Jos the best with $0.129/kWh. This equates to 89.6% and 380% savings respectively on an equivalent DSS that will serve the same load for this communities. It also comes with additional savings in 279 tons of CO_2 greenhouse gas (GHG) emissions which is equivalent to an addition of 25 hectares of forest for CO_2 absorption.

Evaluation of the potential of solar-wind hybrid system

The benefit which hybridizing renewable energy resources present over their respective facilities is in the fact that the base load can be covered by the most abundant and firmly available renewable source, thereby reducing the technical requirements and the cost of the storage batteries. Tables 13-15 and Fig. 13 present the economic cost of utilizing standalone wind and solar systems for power generation whether individually or as hybrid systems.

Table 13: Results of econometrics analysis for the deployment of solar-wind hybrid technology (Ranking by Total NPC)

Site	Total NPC ($)	Total NPC (NGN)	Initial Capital ($)	Initial Capital	LCOE ($)	LCOE
Kano	$253,550	NGN 39,300,250	$157,460	NGN 24,406,300	0.153	NGN 23.72
Jos	$286,688	NGN 44,436,640	$168,700	NGN 26,148,500	0.172	NGN 26.66
Maiduguri	$421,231	NGN 65,290,805	$252,580	NGN 39,149,900	0.252	NGN 39.06
Iseyin	$492,543	NGN 76,344,165	$335,940	NGN 52,070,700	0.295	NGN 45.73
Enugu	$507,056	NGN 78,593,680	$324,860	NGN 50,353,300	0.304	NGN 47.12
Benin	$594,877	NGN 92,205,935	$391,020	NGN 60,608,100	0.356	NGN 55.18

Tables 13 and 15 present the total NPC and LCOE for solar-wind hybrid in the selected sites from each region in Nigeria. For all of the 6 sites there was no considerable improvement in terms of LCOE for the hybrid system over the WSS but it had an improvement over the PSS for all sites. Therefore for all the sites, the WSS proves to be the best renewable energy generation system that can adequately cater for the energy needs of the rural poor.

Table 14: Technical requirements and electricity consumed as a percentage of wind-PV hybrid production

Site	Wind Turbine rating (kW)	PV Panel rating (kW)	Battery Nominal Capacity (kWh)	Battery Autonomy (hours)	Excess Electricity (% of Production)	Optimum Ratio % (WIND:PV)
Jos	50.0	5	432	20.3	59.6	98%-2%
Kano	50.0	5	400	18.8	57.4	97%-3%
Maiduguri	50.0	10	821	38.5	49.3	94%-6%
Enugu	50.0	40	994	46.6	51.7	82%-18%
Benin City	75.0	45	1,015	47.6	51.5	81%-19%
Iseyin	50.0	50	734	34.5	56.9	81%-19%

Table 14 reveals the optimum combination of the hybrid systems for this study. It demonstrates that together with the WSS and PSS, the wind-solar hybrid contributes 100% renewable energy. These points to an environmental savings of 279 tons of CO_2 greenhouse gas emission (GHG) annually. It also demonstrates the immense advantage of producing energy from RE, beyond just the cost implication alone, but also the possibility of having a cleaner and safer environment.

Table 15: LCOE for different energy systems in Nigeria (Ranked by Hybrid System)

Site	PV LCOE ($/kWh)	PV LCOE (NGN/kWh)	WIND LCOE ($/kWh)	WIND LCOE (NGN/kWh)	HYBRID LCOE ($/kWh)	HYBRID LCOE (NGN/kWh)
Maiduguri	$0.398	NGN 61.69	0.144	NGN 22.32	0.153	NGN 23.72
Jos	$0.516	NGN 79.98	0.129	NGN 20.00	0.172	NGN 26.66
Kano	$0.421	NGN 65.26	0.168	NGN 26.04	0.252	NGN 39.06
Iseyin	$0.579	NGN 89.75	0.217	NGN 33.64	0.295	NGN 45.73
Enugu	$0.503	NGN 77.97	0.233	NGN 36.12	0.304	NGN 47.12
Benin	$0.526	NGN 81.53	0.327	NGN 50.69	0.356	NGN 55.18

Fig. 13 presents a comparison among the different energy systems of WSS, PSS and hybrid by LCOE of the selected sites, with Benin being the poorest at $0.356/kWh and Kano the best with $0.153/kWh. This equates to 74% and 305% savings respectively on an equivalent DSS that will serve the same load for this communities.
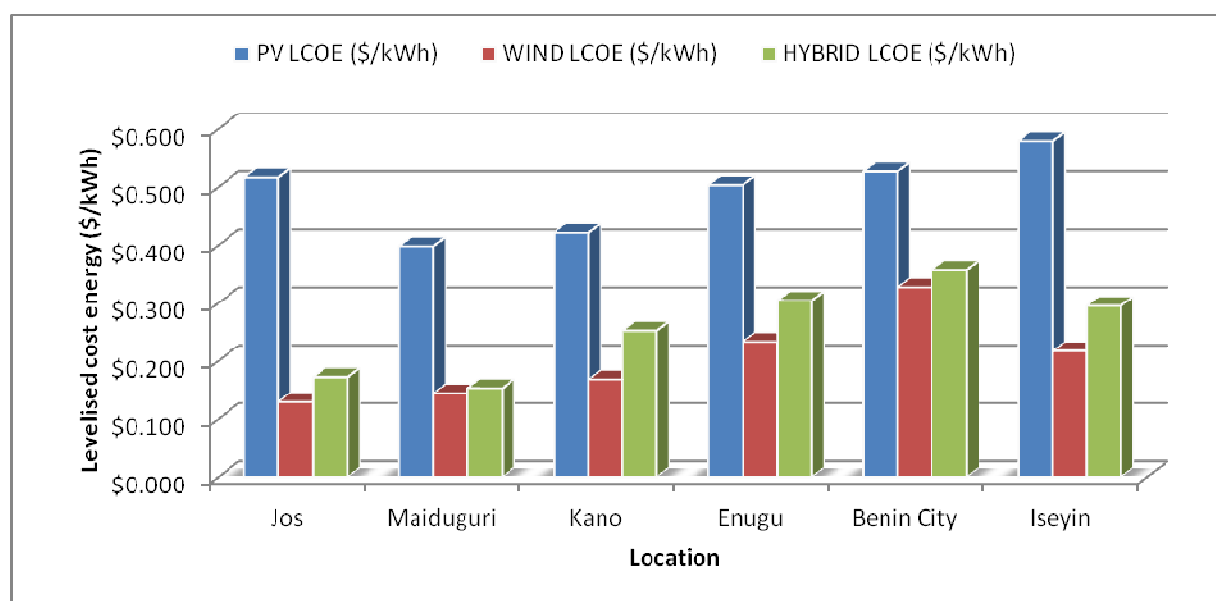

Fig 13: Net Present Cost (NPC) summary - comparison between wind, PV and hybrid systems

Furthermore, Table 15 shows that the solar resource, though very much feasible for all sites falls below the potential of wind energy. However, for all sites, the results show that all renewable technologies fared better than the conventional DSS without batteries. The degree of improvement ranged from 74% to 380% by LCOE. Therefore the best renewable technology that fulfills all the technical requirements, as well as being the most economically viable alternative for power generation at the rural community of 200 homes in Jos (NC), Maiduguri (NE), Kano (NW), Iseyin (SW), Enugu (SE), and Benin City (SS) is the wind standalone system. Consequently with the present reform of electric tariff regime ongoing in

Nigeria by government with grid electricity prices rising [68], and also based on the fact that research is ongoing to lower the price of wind turbine materials and solar panels, the competitiveness of RE generation will be on the increase.

Econometrics of embedded generation

The Federal government has provided the needed conducive environment for the growth of renewable energy (RE) generation by producers and consumers alike (Ajayi, 2010) through embedded generation. The results of econometrics analysis of using the sites RE resources as standalone and embedded generation facilities are presented in Table 16. The design adopted was such that all the sites utilized mono-crystalline solar panel ranging between 7.5 MW and 10.5 MW having the same specification as that in Table 7, while for the wind energy generation, the sites used different rated wind turbines in multiples of 3 MW, with Kano, Jos and Iseyin all using 3 MW, and Maiduguri and Enugu employed 6 MW. Benin City utilized 9 MW so as to meet up with the required excess electricity of ≥ 1 MW monthly average required to activate sale to a distribution network. The analysis was carried out for a five year project lifespan in line with the National Electricity Regulatory Commission's (NERC) 5-year plans (Multi-Year Tariff Order, 2011). As can be observed from Table 16 both technologies (PSS and WSS) yielded profits per year for all the sites showing the immense potentials and opportunities in the renewable energy sector in Nigeria.

Table 16: Investor Profit on Embedded Generation for a 5-year Project Life Span with the present MYTO for Nigeria

Site	Power Technology	Turbine/ PV panel Rating (MW)	Region	Initial Capital ($)	Total NPC	Annualized Cost ($/yr)	LCOE ($/kWh)	PROFIT ($/yr)
Kano	Wind Embedded Generation	3	NW	5,265,580	-9,303,480	-2,272,018	-0.136	2,277,287
	PV Embedded Generation	7.5		25,503,080	-5,434,678	-1,290,165	-0.106	1,294,039
Jos	Wind Embedded Generation	3	NC	5,303,080	-10,050,370	-2,385,552	-0.136	2,363,150
	PV Embedded Generation	8.5		28,753,080	-2,215,464	-525,938	-0.044	581,302
Maiduguri	Wind Embedded Generation	6	NE	10,553,080	-13,124,641	-3,115,001	-0.124	3,090,997
	PV Embedded Generation	7.5		25,503,080	-7,189,541	-1,706,759	-0.129	1,690,652
Iseyin	Wind Embedded Generation	3	SW	5,265,580	-6,455,611	-1,532,079	-0.122	1,510,234
	PV Embedded Generation	10.5		30,003,080	-339,454	-80,569	-0.006	77,299
Enugu	Wind Embedded Generation	6	SE	10,515,580	-11,073,101	-2,626,464	-0.118	4,165,940
	PV Embedded Generation	8.5		28,503,080	-1,162,113	-275,777	-0.025	274,061
Benin City	Wind Embedded Generation	9	SS	15,752,000	-6,607,001	-1,566,501	-0.081	1,560,665
	PV Embedded Generation	9		30,003,080	-306,213	-72,679	-0.006	66,313

The negative NPC indicates Net Present Value (NPV) of the system and the negative LCOE signifies that both systems actually yield profit in $/kWh.

Beforehand, due to the chronic poverty of rural areas in sub-Saharan Africa, the provision of energy to these locations was seen merely as social endeavors as the rural dwellers did not have the economic means to maintain such infrastructure. Consequently, both government and private corporations exercised a lack of enthusiasm in providing energy to the rural poor. However, with the declining prices of renewable energy technology (Branker *et al*, 2011; Lorenz *et al*, 2008; Renewable Power Generation Costs, 2012; A Citizen's Guide to Energy Subsidies in Nigeria, 2012; Mustafa, 2010; Xie *et al*, 2008) as well as the provision for embedded generation by government (Overview of the NERC regulations, 2012; Multi-Year Tariff Order, 2011), it has become essential that RE technologies be employed for electrical purposes as it will provide incentive for socially responsible businesses to make profit as well as transform and improve the life of rural dwellers. It will also enhance the actualization of the education and technology advancement of the millennium development goals. As universal primary education which is tied to goal 2 ensures that by 2015, both male and female children should be able to conclude a full course of schooling, the role of ICT cannot be overemphasized. ICTs could be integrated with more conventional technologies such as books and radios, and be more extensively employed in the training of teachers. This is feasible as a provision for e-learning via the internet together with teleconferencing made available by telecommunications service providers. They will enable easy delivery of lectures from teachers in the cities as well as those from instructors across the globe, thus bridging the knowledge gap between those in the rural and urban areas. All these can happen as a result of adequate access to clean and affordable energy made available via renewable energy.

Government Efforts

A national energy policy was approved by the federal government of Nigeria in 2003 with the overall thrust of optimal exploitation of the nation's energy resources; both conventional and renewable, for sustainable development and with the active involvement of the private sector (National Energy Policy, 2003). There is also the Renewable Energy Master Plan, which aims to improve the use of renewable energy in Nigeria (Renewable Energy Master Plan for Nigeria, 2006; Power Generation, 2011; Promoting Renewable Energy, 2007). The Renewable Energy Master Plan expresses Nigeria's vision for attaining sustainable development. The plan also seeks to move the economy from an undiversified fossil economy to one driven by an increasing share of renewable energy in the national energy mix. This entails the exploitation of renewable energy in quantities and at prices that will support the attainment of equitable and sustainable growth. (Renewable Electricity Policy Guidelines, 2006; Renewable Energy and Conservation Development of renewable energy, 2006)

Requirements for the future

In 2012 a government publication stated that a new peak generation of 4,322 MW had been delivered, which prior to this has been the highest capacity ever generated (Electric Power Investors Forum, 2011). While many Nigerians, especially those dwelling in urban areas would agree that there seems to be a slight improvement in electricity supply, their concern, however, was that the government seems not to be keeping pace with the terms of the Roadmap for Power Sector Reform (Nigeria Vision 20: 2020, 2009).

Tables 17 and 18 presents the current reform of electric tariff regime ongoing in Nigeria by government in terms of growth rates of forecasted electricity prices for 2012-2017 (Multi-Year Tariff Order, 2011).

Table 17: Wholesale Feed-in-Tariff for Land Mounted Wind Power Plant

YEAR	2012	2013	2014	2015	2016
Wholesale contract prices (NGN/MWh)	24,543	26,512	28,641	30,943	33,433

Table 18: Wholesale Feed-in-Tariff for Solar Power Plant

YEAR	2012	2013	2014	2015	2016
Wholesale contract prices (NGN/MWh)	67,917	73,300	79,116	85,401	92,192

Conclusion

An assessment and design of the potential of wind and PV energy resources in the six geo-political regions of Nigeria as standalone and in hybrid format for 6 meteorological sites in these regions has been carried out. The DSS being the only conventional means of generating power for these locations, since they remain grid unconnected, was taken as the basis of comparison. Hence the most economically viable alternative for power generation at these rural communities of 200 homes in Jos (NC), Maiduguri (NE), Kano (NW), Iseyin (SW), Enugu (SE), and Benin City (SS) is the wind standalone system. With grid electricity presently at a cost of about $0.09/kWh (NGN 13.45/kWh), the WSS, PSS and hybrid system is very competitive. The WSS and hybrid system and even the PV set up should then become a priority for both government and private corporations in providing clean and non-depleting renewable energy to the rural poor. This will help meet the millennium development goals. These goals are significantly hinged on adequate access to energy. This endeavor can thus serve as a profitable venture for socially responsible businesses through the provision made by government for embedded generation with profits in the range of $66,313 per year to $2,363,150 per year achievable from a 9MW Solar panel and 3MW wind turbine. Hence the private sector can take advantage of this, while still helping to enlighten and develop the rural populace through the instrumentality of ICT so as to meet up with the MDGs.

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