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Evaluating Solar and Wind Power Systems Real-Time Capacity Utilization and Electricity Generation Cost in Nigeria

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ABSTRACT

The performance of grid connected solar/wind power systems were evaluated in terms of the real-time capacity utilization (CU) of the installed plants. Estimation of feed-in-tariff based on assumed CU factor is misleading. This paper estimated the CU and electricity generation costs in Nigeria using hourly normalised power output. Though moderate, and lower than the industry regulator's assumption, the CU factor is higher in the northern region with northwest having the highest wind CU and northeast having the highest solar CU. The estimated real-time electricity generation costs of wind and solar power systemsare expected to be 100% and 23%, respectively higher than the regulator's estimated cost if the other input data were same.

Keywords: *Capacity utilization; Levelised Cost of Electricity;Normalised power output;Solar/wind energy.*

INTRODUCTION

One of the performance metrics in power plant project is the utilization of the installed capacity of the generator(s). Capacity utilization (CU) is the ratio of plant actual energy generation over a period of time, to its potential energy generation if it were possible for it to operate at full nameplate capacity over same period (Jacot, 2011; Mussa and Saleh, 2012). CU is a key determinant of the cost of electricity generation because it's a significant pointer to the quantity and duration a given power plant is producing energy into the grid. High CU is attractive to utilities when investing in power plants project because the capital costs of a power plant that is highly utilized is spread over more energy (kWh), thus reducing the cost required to recover the capital costs. Similarly for the consumers and government, this will reduce tariff and improved assess to power.CU as a concept refers to the extent to which a nation or a utility actually uses its installed production capacity, and its miscalculation will affect the estimation of the cost of electricity generation (Boccard, 2008; Jacot, 2011). Electricity generation cost is highly sensitive to the investment cost and the capacity utilization factor (Eni, 2006).

Generation must match with demand in real time for a balanced grid system. For sustaining reliable electricity supply, at each moment in time and at each network node, generation and demand should be kept in balance. Consequently, depending on the electricity demand in time, generation plants are synchronously operated to automatically supply the actual demand of electricity from a generation-follows-demand perspective (Eid et al., 2016). The CU of any utility scale solar/wind power project will depend on its instantaneous power generation at the location.CU is affected by the availability of the fuel resources, plant equipment, transmission and distribution line capacity, and consumers' demand. Equipment failures or routine maintenance accounts for most of the unused capacity of base load power plants. Curtailed generation caused as a result of reduced energy demand and/or electricity price accounts for most of the unused capacity of peaking power plants. The issue of real-time resource availability is prevalent with variable renewable energy sources (V-RES). The plant equipment is available for generating electricity but its "fuel" (wind, solar irradiance or water) may not be available. Wind farms and solar PV generation outputs are intermittent due to the natural variability of the wind and solar energy resources (Garver, 1966; Milligan, 2011). The production quantity and cost of energy from wind and solar PV power technology depends on CU of the plant, which is mostly determined by the availability of extractable energy in the wind and solar radiation for power generation.

The contribution of solar/wind energy to reliably meet electricity demand in real-time is an important issue for power system planners. The integration of renewable energy promises more substantial impacts on mitigating the energy crisis in Nigeria through improved access to green electricity (FMP, 2015; IPCC, 2011). The government proposed targets of renewable energy share in the Nigerian Electricity Supply Industry (NESI) for the year 2020 and 2030 (excluding medium and large hydro) were 2785 and 9100 MW respectively. The national renewable energy master plan proposed solar would generate 170 and 1600 MW while wind 800 and 5000 MW into the grid by 2020 and 2030, respectively (ICREEE, 2016). Investments in the development and implementation of renewable energy technologies for power production are major priority of the Nigerian governments and the electricity industry.

Estimating the solar/wind electricity real-time fuel resource potential for grid power generation at any given location depends on the accurate determination of the instantaneous extractable energy in the wind and solar radiation intensity in that location. Wind and solar powered generations are top players in the renewable energy resources and key investors and policy makers can only benefit from more information regarding some of its characteristics. Solar radiation and wind speed are intermittent, hence the solar/wind power system cannot generate electricity at a constant rate and the power produced at any instant is a function of weather factors. Very little has been published regarding the real-time CU and generation cost at the national level in Nigeria. The renewable energy feed in tariff for 2016 as established by the Nigerian Electricity Regulatory Commission was based on assumed CU factor of 19 and 32% for wind and solar energy, respectively (NERC, 2016). The Department of Energy and Climate Change estimated the CU factor for wind and solar PV in UK grid to be 33.7% and 11.8% respectively (DUKES, 2016). For high penetration and utilities adoption of solar/wind energy sources, attention must be given to strategies on how to optimally utilize these energy sources.

Several performance evaluation studies on solar PV and wind power systems in Nigeria has be carried out based on either daily, monthly or yearly average solar radiation and wind speed respectively. The annual average of total solar radiation varies from about 12.6 MJ/m^2-day in the coastal latitudes to about 25.2 MJ/m^2-day in the far North. The annual average wind speed at 50m heights varies from about 2 m/s in the coastal areas to about 8 m/s in the far north (Sambo and Doyle, 1986; ECN, 2003; National Technical Working Group on Energy, 2009).These studies confirmed the possibilities of converting solar/wind energy to utility scale power generation in Nigeria. Also, Adegoke and Olatona (2015) assessed the solar and wind power resource for the deployment of solar photovoltaic and wind power technology applications in Osogbo, Nigeria using mean-monthly daily solar-radiation and daily wind speeds by estimating the sunshine-hours and annual-mean wind speed. However, studies on the instantaneousreal-time hourly variation in wind speed and solar radiation, and the resulting power output variation were not studied. A number of experts did point out that the existing survey of the wind energy resource (LAMEA map) has insufficient data points and that the study of specific sites merits more attention, in particular given the high prospects of cost reductions in wind technology. The potential of solar and wind energy for Nigeria is yet to be researched (The Nigerian Economic Summit Group 2017).

Solar and wind power generation are emerging technologies in Nigeria and real time energy resource data is limited. The real-time power output from solar/wind power systems are essentials for efficient and reliable utilization of the wind/solar energy potential for grid connected electricity generation. This study estimates the normalised power output from a wind energy conversion system with a view to providing insight on the real-time hourly electricity generation variations from the wind power technology into the electricity grid. The real-time hourly solar radiation in w/m^2, which is equivalent to the quantity of hourly electricity that can be generated in one square meter area in a particular location, was analysed using standard statistical values. In order to quantify these resources, the wind and solar energy resources were estimated by evaluating the real time capacity utilization (CU) of the plant in different locations. This allows for comparing which renewable energy generation technology is the most viable at specific locations in Nigeria. The calculated CU serves as input parameter in electricity generation cost analysis.

METHODS AND THEORY

The analysis of the utilized capacity of installed solar/wind power plant for electricity generation was based on the extractable energy from solar and wind energy sources which is proportional to solar radiation in w/m^2 and the cube of the wind speed in m/s, respectively. Hence, hourly wind speed and solar radiation data for the years 2013 - 2015 from metrological sites at the six geopolitical zones of Nigeria were collected. Wind speed measured in nautical miles per hour (knots) were collected from Sokoto in Northwest, Yola in Northeast, Port-Harcourt in South-south, Enugu in Southeast, Ilorin in North central, and Ikeja in Southwest, Nigeria. All anemometers at the various metrological sites were installed at different elevation from the ground. Solar radiation data were obtained from Kaduna in Northwest, Yola in Northeast, Warri in South-south, Enugu in South east, Ilorin in North central, and Ibadan in South west.

The wind speed values in knots were converted to meter per second and adjusted to a wind turbine hub height of 50 m. The wind power curve, a relationship between wind speed and power output, was used to estimate the wind turbine power output at different wind speed. The advantage of using a power curve was that it included the wind turbines efficiency for all wind speeds of operation. The power curve of a 2MW Enercon E-82 wind turbine power system was used for this study (Enercon 2015). The cut-in speed of 3m/s, rated speed of 13m/s, cut-out speed of 25m/s and maximum power output of 2MW were used for estimating the hourly normalized power output and CU. When wind speed is below the cut-in-speed, the power output is zero, and when wind speed is between the cut-in speed and the rated speed, the output of the wind power plant is proportional to the cube of the wind speed as mathematically represented in equation 1. At wind speed between the rated and cut-out speed, the power output is proportional to the cube of the rated speed.

$$P = k\rho AV^3 \qquad (1)$$

where, P is the wind turbine power output, k is a constant, ρ is the density of air, A is the area swept out by the turbine rotor blade and V is the wind speed. The normalised power output was estimated using wind power and wind speed relationship. The CU of the wind energy conversion system (WECS), which is the ratio of actual wind electricity production to the maximum theoretical wind electricity production, was estimated for each location for the study period.

Solar light intensity, temperature and relative humidity are factors that affect the output performance of solar photovoltaic system (Omubo-Pepple et al., 2009; Skoplaki and Palyvos, 2008). Analysis of the fluctuation in power output of a PV power system with climatic factors also revealed that there is direct proportionality between the power output of the system and the climatic factors. The CU is strongly positive correlation with solar radiation and moderately positive correlation with ambient air temperature and PV module temperature. The Relative humidity is negatively correlated with CU (Chaudhari et al., 2016). Therefore, the CU of a standard solar panel of 1000 watt/square meter for the different locations was estimated by calculating the ratio of the sum of the year 2013, 2014 and 2015 daily average solar radiation to the sum of the daily maximum theoretical solar radiation. The unique 24 hours on/off cycle of the hourly solar radiation that gives a natural and enforced pause each day formed the basis for assessing the solar electric energy potential and estimation of the CU of a solar PV system in this study. For each study location, the hourly solar radiations for the study period were analysed into standard statistical values: minimum, maximum, mean, median and standard deviation.

The Levelised Cost of Electricity (LCOE) model, which is an engineering economy method, was used for estimating the real-time electricity generation cost from solar PV and wind power technologies. LCOE is the implied price ($/kilowatt hour) of energy generated by the power plants. It is the minimum breakeven tariff expressed in US$/MWh for each plant by location, based on a set of assumptions and discount rate chosen (weighted average cost of capital). This is an assessment of the economic lifetime energy cost and lifetime energy production and it is applied to all energy technology. The estimation of cost of electricity using the LCOE method made it possible to compare power plants of different generation and cost structures with each other. This method is an abstraction from reality, but with the goal of making different sorts of generation plants comparable. In order to give a broad perspective of the costs variation of different power technology manufacturers, four cost scenarios were used for the estimating the LCOE for the different power generation technologies. They are:

- Low capital and low fixed operation and maintenance costs (LL Scenario),
- Low capital and high fixed operation and maintenance costs (LH Scenario),
- High capital and low fixed operation and maintenance costs (HL Scenario), and
- High capital and high fixed operation and maintenance costs (HH Scenario)

Speed Height Correction

The wind speed values in knots were converted to meter per second by multiplying each with 0.514 and adjusted to the desired wind turbine hub height of 50m by applying the one-seventh law of wind speed height correction as shown in equation 2.

$$\frac{V(Z_2)}{V(Z_2)} = \left(\frac{Z_2}{Z_2}\right)^{\alpha} \qquad (2)$$

Where $V(Z_2)$ is the wind speed at the desired height of Z_2, $V(Z_1)$ is the wind speed measured at the height of Z_1 above the ground. Wind shear exponent, α. of 0.1429 was used in the estimation of the wind speed height correction (Bartlett, 2003; Burton, 2001).

Normalised Power Output

With other factor affecting CU of a WECS kept constant, the effect of the "fuel" availability and variability of the wind resources at any given hour can be estimated using the hourly Normalised Power Output (N_P), which is the ratio of the expected power output at a specific time (hour) to the maximum rated power output of a WECS. Equation 3 illustrates the relationship between N_P and wind speed (V), which is based on the proportionality relationship. From the equation, maximum normalised power, $N_{P\ max}$, is 1. This is the same as the maximum theoretical capacity factor (i.e. 100%).

$$N_p = \frac{P_t}{P_{max}} \propto \frac{V_{w\ t}^3}{13^3} \qquad (3)$$

Where;

N_p = normalised power output

P_t = power output at time t_1

P_{max} = maximum theoretical power output

$V_{w\ t}$ = wind speed at time t

The CU of the WECS was estimated using the ratio of the summation of the hourly normalised power, $N_{P,}$ to the summation of the maximum theoretical normalised power, N_{Pmax}, (Khambalkar, et al. 2006). Equations 4 - 6 show the mathematical relationship.

$$CU = \frac{E_{Actual}}{E_{Max}} \qquad (4)$$

$$\frac{E_{Actual}}{E_{Max}} \propto \frac{\sum_{t=1}^{n} N_p}{\sum_{t=1}^{n} N_{p\ max}} \qquad (5)$$

$$CU = \frac{\sum_{t=1}^{n} N_p}{\sum_{t=1}^{n} N_{p\ max}} \qquad (6)$$

Where;

E_{Actual} = actual energy produced

E_{max} = maximum theoretical energy produced

N_p = normalised power output = hourly capacity factor

$N_{p\ max}$ = maximum theoretical hourly capacity factor

Where, $\sum N_{p\ max}$ = 8760 for a year and 8784 for a leap year

Levelised Cost of Electricity (LCOE)

The levelised cost electricity (LCOE) is broken down into the contribution from capital costs, fixed operating costs, fuel and carbon costs and non-fuel operating costs. For calculating the LCOE for new plants, the formula below was applied (Konstantin, 2009; Jason 2011). The levelised cost of electricity ($/kWh) for technology k in location j can be described as follows:

$$LCOE_{k,j} = \frac{I_0 + P_{C+O}^{k,j}}{P_G^{k,j}} \quad (7)$$

$$P_{c+o}^{k,j} = \sum_{i=1}^{n} \frac{AT_i^{k,j}}{(1+r^{k,j})^i} \quad (8)$$

$$P_G^{k,j} = \sum_{i=1}^{n} \frac{G_i^{k,j}}{(1+r^{k,j})^i} \quad (9)$$

Where;

I_0 = Investment expenditures in $

n = Economic operational lifetime in years

i = Year of lifetime (1, 2, ...n)

AT = the annual total capital, operating, fuel and emissions cost for technology k in location j

r = the weighted average cost of capital for technology k in location j, and

G = the generated quantity of electricity in the respective year in kWh for technology k in location j.

The annual total costs comprise of fixed and variable costs for the operation of the plant, maintenance, service, repairs and insurance payments. Equation 10 is the formula for calculating the annual total costs used in the estimation of the LCOE.

$$AT = F_{(OC)} + V_{(OC)} + R_{(V)} \quad (10)$$

Where;

AT = Annual total costs

$F_{(oc)}$ = Fixed operating costs

$V_{(oc)}$ = Variable operating costs

$R_{(v)}$ = Residual value/disposal of the plant

Results and Discussion

Wind Energy Resources Potential

The estimated hourly wind speed at a corrected turbine hub height of 50m elevation from the ground is shown in Table 1. This shows that more than 50% of the hourly wind speed data in Yola, Ikeja and Port-Harcourt were less than the cut-in-speed of 3 m/s while at Sokoto, Ilorin and Enugu, wind speed lesser than 3m/s occurred 26.14%, 36.86% and 35.61%, respectively of the total hourly wind speed. This represents the percentage of the plants lifetime that will be incapability of generating electricity due to low wind speed below the cut-in-speed. This implies that the WECS installed at Yola, Ikeja and Port-Harcourt will only be able to generate electricity to the utility grid at less than half of the plant lifetime while in Sokoto, Ilorin and Enugu, power production durations will be more than half of the plants lifetime. Also, the percentage occurrences of the hourly wind speed within the rated and cut-out speed were less than 1% for all the locations. This implies that the WECS can only generate at full load capacity at these location in less than 1% of the plants lifetime. For the studied locations, wind speed in the ranges of 0 - 2.99m/s and 3 - 3.99m/s has the highest percentage of the hourly occurrence. Sokoto has the highest occurrence (30.17%) at speed of 3-3.99m/s while Yola, Ilorin, Enugu, Ikeja and Port-Harcourt have their highest hourly occurrence at speed of 0-2.99m/s. This indicates that Sokoto may have the best hourly wind energy potential than the other locations.

Normalised Power Output of Wind Energy Conversion System

The normalized power output, N_p, which represents the hourly variations of the power output of the WECs installed at the various locations, is shown in Table 2. The hourly N_p of 0, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 and 1 for the WECS in Sokoto occurred at 26.17%, 1.17%, 0.98%, 0.73%, 0.23%, 1.1%, 0.51% and 0.88% of the study period, respectively. For a WECS located at Ikeja, the hourly $N_p$of 0, 0.1, 0.2 and 0.3 occurred at 56.5%, 28.8%, 6.1% and 4.98% of the study period respectively while N_p higher than 0.3 occurred for 3.65% of the study period only. Yola has estimated N_p of 0, 0.1, 0.2 and 0.3 for 57.8%, 26.9%, 10.9% and 1.97% of the study period respectively while N_p higher than 0.3 occurred for 2.5% of the study period only. Likewise, Port Harcourt has N_p of 0, 0.1, 0.2 and 0.3 for 71.29%, 23.34%, 3.76% and 0.44% of the study period respectively while N_p higher than 0.3 occurred for 1.16% of the study period only.For Ilorin site, the N_p was 0, 0.1, 0.2 and 0.3 for 36.8%, 56.81%, 3.65% and 1.48% of the study period respectively while N_p higher than 0.3 occurred for 1.26% of the study period only. Enugu has estimated N_p of 0, 0.1, 0.2 and 0.3 for 35.57%, 49.54%, 10.18% and 1.68% of the study period respectively while N_p higher than 0.3 was for 3.03% of the study period only. All the WEC system sited at the various locations has N_p of 1 at less than 1% of the study duration. WECS in Sokoto will operates at full nameplate capacity for 0.81% of the plants lifetime while Ikeja, Yola, Port-Harcourt, Enugu and Ilorin will operates at full nameplate capacity for 0.04%, 0.4%, 0.16%, 0.11% and 0.25%, of the plants lifetime, respectively.

Table1. *Hourly Wind Speed Data at a Corrected Turbine Hub Height of 50m Elevation from the Ground.*

	Sokoto		Yola		Ilorin		Enugu		Ikeja		Port-Harcourt	
Wind Speed (m/s)	No. of Hours	Percentage (%)	No. of Hours	Percentage (%)	No. of Hours	Percentage (%)	No. of Hours	Percentage (%)	No. of Hours	Percentage (%)	No. of Hours	Percentage (%)
0-2.99	6877	26.14	15209	57.82	9696	36.86	9367	35.61	14984	56.96	18764	71.34
3-3.99	7935	30.17	3691	14.03	7366	28.00	6250	23.76	4160	15.82	3730	14.18
4-4.99	941	3.58	2612	9.93	4524	17.20	3627	13.79	2602	9.89	1100	4.18
5-5.99	4027	15.31	756	2.87	3037	11.55	3143	11.95	692	2.63	1298	4.93
6-6.99	3710	14.10	2119	8.06	366	1.39	2232	8.49	1604	6.10	396	1.51
7-7.99	1029	3.91	990	3.76	752	2.86	548	2.08	698	2.65	594	2.26
8-8.99	332	1.26	286	1.09	358	1.36	600	2.28	611	2.32	207	0.79
9-9.99	535	2.03	196	0.75	56	0.21	200	0.76	575	2.19	50	0.19
10-10.99	242	0.92	168	0.64	59	0.22	156	0.59	156	0.59	33	0.13
11-11.99	329	1.25	122	0.46	53	0.20	84	0.32	116	0.44	80	0.30
12-12.99	134	0.51	50	0.19	7	0.03	30	0.11	46	0.17	11	0.04
≥13	213	0.81	105	0.40	30	0.11	67	0.25	60	0.23	41	0.16

Table2. *Normalized Wind Power Output*

	Sokoto		Ikeja		Yola		Port Harcourt		Ilorin		Enugu	
Normalized Power Output.	No. of Hours	Percentage (%)	No. of Hours	Percentage (%)	No. of Hours	Percentage (%)	No. of Hours	Percentage (%)	No. of Hours	Percentage (%)	No. of Hours	Percentage (%)
0	6885	26.17	14851	56.46	15200	57.79	18752	71.29	9680	36.8	9356	35.57
0.1	12895	49.02	7583	28.83	7068	26.87	6140	23.34	14943	56.81	13031	49.54
0.2	4100	15.59	1604	6.1	2876	10.93	990	3.76	959	3.65	2677	10.18
0.3	971	3.69	1309	4.98	519	1.97	117	0.44	390	1.48	441	1.68
0.4	308	1.17	273	1.04	83	0.32	95	0.36	183	0.7	297	1.13
0.5	257	0.98	304	1.16	173	0.66	45	0.17	9	0.03	165	0.63
0.6	192	0.73	155	0.59	108	0.41	33	0.13	50	0.19	156	0.59
0.7	60	0.23	83	0.32	101	0.38	63	0.24	17	0.06	49	0.19
0.8	289	1.1	33	0.13	21	0.08	17	0.06	36	0.14	35	0.13
0.9	134	0.51	46	0.17	50	0.19	11	0.04	7	0.03	30	0.11
1	213	0.81	63	0.24	105	0.4	41	0.16	30	0.11	67	0.25
Total	26304	100	26304	100	26304	100	26304	100	26304	100	26304	100

This reveals that, most of the hourly power generation from the WECS in these locations will be 0.1 of the plants installed capacity. Thus the power generation from the WECS to the grid will be relative low compared to the installed capacity. For matching generation with demand, the implication of these changes in the power output from the WECS is that the dispatchable generating technologies in the system will have to fill in the generation gap by exhibiting their operational flexibility. The N_p of the WECS represents the power output profile and the variation pattern that has to be balanced by the dispatchable generation technologies through ramp-up and ramp-down at the same but opposite pattern to the WECS power output. Figure 1 is an illustration of a typical wind power output variation using the estimated N_p of Sokoto for the first six weeks of 2014. This revealed that wind power outputs fluctuate with time, and the output for this case study varies over 80% of its maximum generation output.

Capacity Utilisation of Wind Energy Conversion System

The sum of the hourly normalised of the WECS power output in each of the studied locations and their corresponding CU for each year within the study period is shown in table 3. The estimated CU of the WECS, which is the average of the capacity utilization for the study period of 2013– 2015, gives a clue to its generated energy in real-time operations relative to its installed capacity. The CU of the WECS in Sokoto, Yola, Enugu, Ikeja, Ilorin and Port-Harcourt were estimated to be 9.26%, 6.97%, 5.50%, 5.50%, 3.38% and 1.88% respectively. The moderate CU is attributed to the high occurrence of hourly wind speeds lower than the cut-in speed of 3m/s (which do no generate electricity), and at speed range of the cut-in speed of 3m/s to 4.99m/s (which produce very little power output) in all the locations. Thus, for most of the plant lifetime, utility wind farm in these locations will not be generating or generating at a reduced power output.

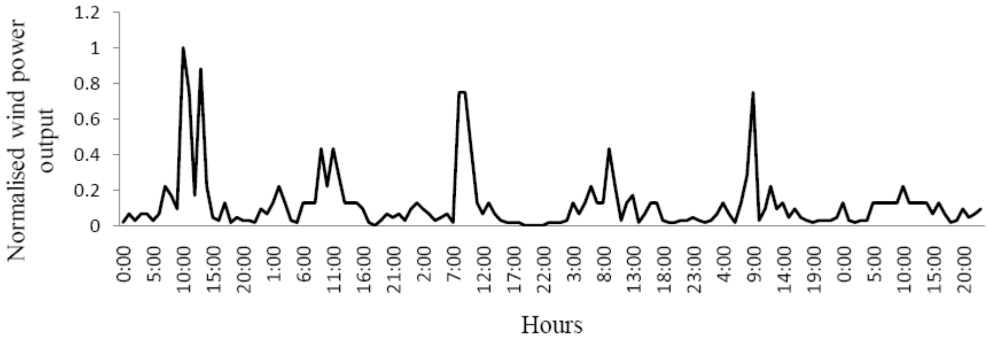

Figure1. *Real time wind power output variation*

Solar Energy Resource Potential

The solar energy resource is off line at sun set and stays that way until sunrise. Figure 2 (a-f) shows the real-time minimum, maximum, mean, median and standard deviation of the hourly solar radiations at the studied locations. The analysis was a statistical synopsis of the 3-year's real time hourly solar radiation for these locations used to reveal the variability of solar electric resource potentials with respect to time. It shows that solar energy can be harnessed as from 0700 – 1800hrs of the day. It also shows that the highest average hourly solar radiations occurred mostly at 1200hrs of the day in all the studied locations. The hourly average and maximum solar radiation of the location are: Yola - 959.26 and 2111W/m^2, Kaduna - 903.42 and 1370W/m^2; Ilorin - 881.52 and 1364W/m^2; Ibadan - 881.19 and 1364W/m^2; Enugu - 806.6526 and 1120 W/m^2; and Warri - 587.99 and 1176W/m^2. The median and standard deviation of the solar radiation at each hour of the day further reveals the dispersion of the solar PV power output from its nameplate capacity.

Table 3. *Capacity Utilisation Factor of Wind Farm at Different locations*

Location	Year	$\sum N_p$	Yearly capacity factor(%)	CU (%)
Sokoto	2012	813.16	9.2573	9.2573
	2013	676.17	7.7188	
	2014	779.66	8.9002	
Yola	2012	612.6	6.9737	6.9737
	2013	620.3	7.0811	
	2014	328.96	3.7553	
Ilorin	2012	297.07	3.3819	3.3819
	2013	325.32	3.7137	
	2014	311.05	3.5508	
Enugu	2012	483.29	5.5019	5.5019
	2013	580.1	6.6222	
	2014	303.98	3.4701	
Ikeja	2012	439.79	5.0067	5.0067
	2013	414.23	4.7287	
	2014	448.44	5.1192	
Port-Harcourt	2012	165.45	1.8835	1.8835
	2013	252.03	2.877	
	2014	209.16	2.3877	

Capacity Utilisation of Solar PV System

The estimated CU of solar PV power plant for grid connected electricity generation in the various studied locations is shown in table 4.

The average of the real-time daily energy produce (sum of the hourly solar power output) for the studied duration for solar power plant in Kaduna, Yola, Ilorin, Enugu, Ibadan and Warri were 6.129, 6.332, 6.067, 5.304, 5.929 and 3.943 MWh, respectively while the maximum theoretical real-time energy that can be generated from a standard solar panel of 1000 watt/square meter is 24MWh. Thus, the solar PV power plant CU for Kaduna, Yola, Ilorin, Enugu, Ibadan and Warri were estimated to be 25.53%, 26.38%, 25.28%, 22.10%, 24.71% and 16.43%, respectively. This revealed that capacity of a solar PV power plant will be more utilized in the northern than southern region of Nigeria with the north-eastern part having the highest and the south-southern part the least.

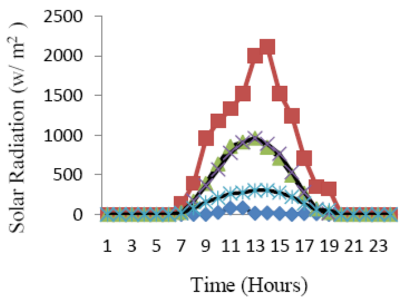

Fig2(a). *Solar Radiation of Yola*

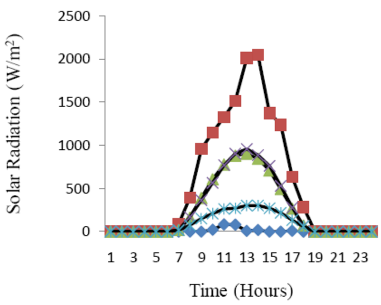

Fig2(b). *Solar Radiation of Kaduna*

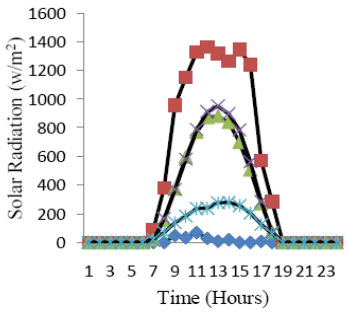

Fig2(c). *Solar Radiation of Ilorin*

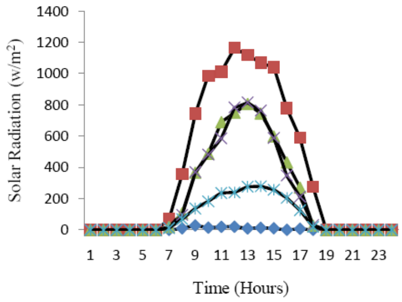

Fig2(d). *Solar Radiation of Enugu*

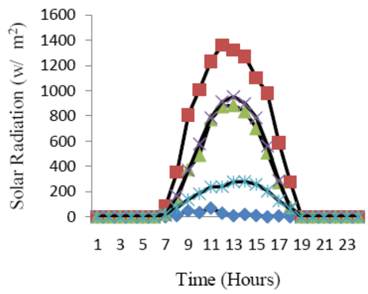

Fig2(e). *Solar Radiation of Ibadan*

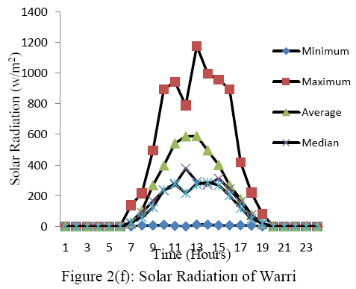

Fig2(f). *Solar Radiation of Warri.*

Table 4. *Estimated Capacity Utilisation Factor of Solar PV power System at selected locations*

Location	Daily Average Energy Generation(MWh)	Daily Maximum Theoretical Energy Generation (MWh)	CUF (%)
Kaduna	6.129	24.00	25.54
Yola	6.332	24.00	26.38
Ilorin	6.067	24.00	25.25
Enugu	5.304	24.00	22.10
Ibadan	5.929	24.00	24.71
Warri	3.943	24.00	16.43

Real-Time Electricity Generation Cost

LCOE of Wind Turbine Power System

Cost data collected vary according to manufacturer. Input technical and cost data used for the estimation of the LCOE of a utility scale wind turbine power plant were: net facility power output – 10 MW, construction time – 12 months, facility life – 20 years, low capital cost – 1400 $/kW, high capital cost – 2500 $/kW, low operations and maintenance cost – 35000 $/MW/annum and high operations and maintenance cost – 40000 $/kW. LCOE at 10% discount rate for the wind power system installed in the studied locations is shown in Table 5. Sokoto in North-Western Nigeria has the lowest LCOE for all the research scenarios while Port-Harcourt in South-Southern Nigeria has the highest. Yola, Enugu, Ikeja and Ilorin have LCOE in ascending order. The LCOE analysis for the in LL, LH, HL and HH scenarios shows that electricity generation cost from a wind power system installed at Sokoto will be 247.23 $/MWh, 250.95 $/MWh, 403.42

$/MWh and 409.55 $/MWh while at Port-Harcourt will be 1210.12 $/MWh, 1228.35 $/MWh, 1974.61 $/MWh and 2004.65 $/MWh respectively. This revealed that locations in the North-Western will be the best while those in the South-Southern will be the worst sites in Nigeria for the installation of wind power plants.

In all the research scenarios, total capital cost had the highest percentage share of the LCOE with values of 81.65%, 80.43%, 89.35% and 88.01% in the LL, LH, HL and HH scenarios respectively in all the studied locations. The percentage share of the fixed operation and maintenance cost in the LCOE were 18.65%, 19.57%, 10.65% and 11.99% in the LL, LH, HL and HH scenarios respectively in all the locations. This shows that more than 80% of the LCOE of a wind power system are incurred from the capital costs. This calls for research and development in wind power technology as well as the application of the learning curve in order to reduce the capital cost.

Table 5. *Levelised Cost of Electricity of a Wind Turbine Power System at 10% Discount Factor at Selected Locations in Nigeria for Different Scenarios.*

	LCOE ($/MWh)					
Scenarios	**Sokoto**	**Yola**	**Enugu**	**Ikeja**	**Ilorin**	**Port-Harcourt**
LL	247.23	328.46	418.04	459.84	676.24	1210.12
LH	250.95	333.41	424.34	466.77	686.43	1228.35
HL	403.42	535.97	682.14	750.35	1103.46	1974.61
HH	409.55	544.12	692.52	761.77	1120.25	2004.65

LCOE of Solar PV Power System

The technical and cost input data used in estimating the LCOE of a utility scale solar PV power plant were: net facility power output – 10MW, construction time – 12 months, facility life – 20 years, low capital cost – 2500 $/kW, high capital cost – 6000 $/kW, low operations and maintenance cost – 13000 $/MW/annum and high operations and maintenance cost – 20000 $/kW. Table 6 shows the LCOE at 10% discount rate for the solar power system installed at the studied locations. Yola in North-Eastern Nigeria has the lowest LCOE for all the research scenarios while Warri in South-Southern Nigeria has the highest. Kaduna in North-Western, Ilorin in North-Central, Ibadan in South-Western and Enugu in South-Eastern Nigeria have LCOE in ascending order. The electricity generation cost from a solar PV power system installed in Yola were 132.7 $/MWh, 135.7 $/MWh, 310.6 $/MWh and 313.6 $/MWh while that for Warri were 213.1 $/MWh, 217.9 $/MWh, 498.7 $/MWh and 503.6 $/MWh in LL, LH, HL and HH scenarios respectively. This revealed that locations in the North-Eastern will be the best while those in the South-Southern will be the worst sites in Nigeria for the installation of solar PV power plants.

In all the research scenarios, total capital cost had the highest percentage share of the LCOE with values of 95.76%, 93.62%, 98.19% and 97.24% in the LL, LH, HL and HH scenarios respectively in all the studied locations. The percentage share of the fixed operation and maintenance cost in the LCOE were 4.24%, 6.38%, 1.81% and 2.76% in the LL, LH, HL and HH scenarios respectively in all the locations. This shows that more than 93% of the LCOE of a wind power system are incurred from the capital costs. It also calls for further research and development in solar PV power technology in order to reduce the capital cost.

Table 6. *Levelised Cost of Electricity of a Solar PV Power System at 10% Discount Factor at Selected Locations in Nigeria for Different Scenarios.*

	LCOE ($/MWh)					
Scenarios	**Kaduna**	**Yola**	**Ilorin**	**Enugu**	**Ibadan**	**Warri**
LL	137.064	132.700	138.639	158.399	141.668	213.063
LH	140.193	135.729	141.803	162.015	144.902	217.927
HL	320.820	310.604	324.504	370.757	331.596	498.706
HH	323.949	313.633	327.669	374.373	334.830	503.569

$ = 198 Naira (CBN, 2014)

Sensitivity Analysis of Solar/Wind Power System LCOE to Capacity Utilisation

Investigation on how LCOE changes with change in CU is shown in the sensitivity graph (Figure 3) using the low capital and low fixed operation and maintenance costs (LL) Scenario. The sensitivity graph revealed that LCOE of solar PV and wind turbine power system decrease with increase CU of the installed plant. The LCOE for both power technologies are the highest sensitivity to 1 – 10 % capacity utilization. Above 10% capacity utilization, the LCOE tend to be moderately sensitive.

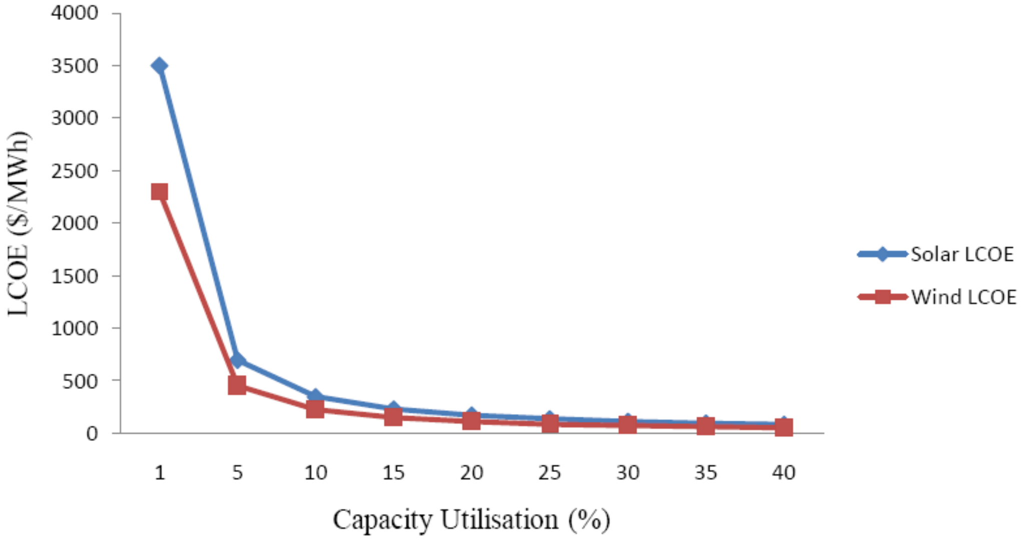

Figure3. *Sensitivity Analysis of LCOE with Capacity Utilisation for a Solar PV and Wind Power Systems*

Conclusion and Policy Recommendations

As the nation seeks to effectively harness solar/wind energy resources and integrates them with other power technology in the electricity grid network, the estimated capacity utilization of the installed plant is a crucial information for decision makers. The reliance on the assumed 19% and 32% CU factor values for estimating the feed in tariff for wind and solar power plants in Nigeria is not without consequences. Moderate CU may prove impediments to the growth, development and penetration of solar/wind power generations. For utility developer and investor, the levelised cost of energy (LCOE) of a wind/solar power plant is proportional to its CU over the 20 years lifetime of the equipment. In Nigeria, a realized real-time CU of 9.3% for wind and 26% for solar energy means that the real-time levelised costs of wind and solar power generators will be 100% and 23%, respectively higher than the published estimated value if the other input data were same.

The wedge between assumed and realized CU implies that utility developer and investors may be victims of a variant of the winner's curse, the discovery after sitting the power plant that the location is not among the best. If the Nigerian Electricity Regulatory Commission (NERC) is to treat investors as rational, then it must be the case that the realized CU must make projects profitable given its subsidies guaranteed, local political support and financial frameworks aimed at stimulating the expansion of the renewable electricity market. The knowledge that the estimated CU is lower than assumed may discourage the development of utility scale solar/wind power generators since the projects in the best promising sites may not attract investment. However, further research may discover higher solar radiation and wind speed sites. Also, technically advanced wind turbine that is more efficient which can run even at lower speed, and are with higher hub height can be developed.

The novel information on solar/wind power provided is of greatest importance for public authorities because the real-time CU at country level exactly determines the avoidable carbon emissions in the electricity sector. The fact that solar/wind power generation seems to be less efficient than assumed is no reason for the government to withdraw support because they remain the unique renewable energy sources able to expand on a large scale at a reasonable cost to tackle the Nigeria's Kyoto commitment. However, other technologies such as biomass and fuel cells are emerging and may become competitive as solar/wind to meet our environmental goals. Tracking the progress (or lack thereof) in each field is thus essential to avoid been trapped someday into a sub-optimal renewable technology. Also, the following policy recommendations may help utility policy makers in attaining sustainable green electricity.

- More solar energy should be integrated into the grid than wind because solar energy has a higher CU and will therefor reduce more carbon emission than wind.
- Develop solar/wind power projects in neighbouring country having higher CU factor with the resulting green electricity being entirely bought by Nigerian customers.
- Promote regional Research and Development on CU factor which will obviously guide policy makers.
- Wind power plants should be installed more in the North West and solar power plant installed in North East geopolitical zones of Nigeria because of therelative high CU in these regions.
- A revised and realistic feed-in-tariff based on accurate CU factor of solar/wind power plant should be used in tariff estimation

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