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Incorporating Solar and Wind Energy Technologies in the Power Mix of a Proposed Power Structure

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ABSTRACT
In this work, the possibility of utilizing solar energy and wind energy for electricity generation in a proposed new power structure in Nigeria was examined. The wind and solar energy potentials of all the 36 states and the federal capital territory of Nigeria for electricity generation were assessed using data in the open literatures about selected locations in each state, usually, the state capitals. Using the levelized cost of electricity (LCOE) and the net present value (NPV) methods, the economic viability of the usage of both energy systems (solar photovoltaic (PV) system for solar energy conversion and wind turbines for wind energy conversion) were presented. Project life of 20 years at 9% discount rate together with electricity price of ₦55 per kW-hr ($0.1339 per kW-hr) was used for the analysis. While it is not economically viable to operate wind energy system in several states in the southern part due to low wind speeds, the reverse is the case in few other states such as Anambra and Enugu states. It is economically viable to operate solar PV system on commercial scale in several states in the southern part, but in the northern part, solar PV systems can be operated on commercial scale profitably in all the states, with Yobe state having the lowest LCOE. The LCOE as a function of the wind speed and the solar irradiation were obtained in this work. These relations can aid quick assessment of the economic viability of operating either energy system in any location..

KEYWORDS: Levelized cost of electricity, Net present value, Solar energy, Solar photovoltaic, Wind Energy, Wind turbine.

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1. INTRODUCTION
The power sector of Nigeria is dominated by gas turbine power plants located mainly in the south-south geopolitical zone of the country, followed by hydropower power plants in the Northern region of the country (Saturday, 2021). There is inadequate power supply in Nigeria. This is not totally due to the low amount of installed power in the country which is less than 15 GW today (the electrical energy demand value as projected by different researchers ranges from some 17 GW to 50 GW using different economic growth scenarios (Ibrahim and Gokhan, 2018; Ezennaya *et al.*, 2014; Sambo, 2008). In the existing structure, power generation comes from power plants owned by the federal government, state governments and private individuals. Power transmission is solely in the hands of the federal government through the transmission company of Nigeria (TCN), while power distribution is achieved through eleven (11) electricity distribution companies (DISCOS) which are privately owned (Saturday, 2021; FGN, 2017). The inability of the DISCOS to improve their infrastructures and distribute all the power generated and transmitted to their ends is a major problem in the existing structure. Power is in recurrent list in the Nigerian constitution, but the federal government plays major role in the power sector while some state governments has little or no contribution to the growth of the sector. A new structure was thus proposed to address these problems (Saturday, 2021). Details of both the existing structure and the proposed structure are provided in next section of this paper.

There has been clamour for injecting renewable energy-based power generation systems to the power mix. Much attention has been paid to wind energy and solar photovoltaic (PV) systems for power generation in Nigeria. As solar energy can come in small units, several homes have embraced it amidst the high installation cost complains. Also, several private organizations and state governments have gone into different solar energy projects for power production in Nigeria (REA, 2021; FGN, 2021; FGN, 2018). Wind energy has not enjoyed much usage as solar energy in Nigeria. This is because wind energy conversion systems do not come in little packages that could be easily purchased and installed by individuals.

1.1 Aim and Objectives of the study

The aim of this work is to incorporate solar and wind energy technologies in the power mix of a proposed power structure in Nigeria and ascertain the locations with high potentials for their utilizations. The objectives of this study include:

i. To examine the existing power structure and the proposed power structure in Nigeria,

ii. To determine the power demand of the various states in Nigeria,

iii. To assess the wind and solar energy potentials of selected locations in the various states, and

iv. To determine the different locations with viable wind energy or solar energy potentials for electricity generation via the results of economic analysis.

1.2 The Nigerian Power Structure and a Proposed Structure

The existing power structure of Nigeria is shown in Figure 1.

The existing structure consists of the power generators, the transmission company of Nigeria and the DISCOS in one hand which is basically concerned with grid-connected power and the Interconnected Mini Grids and Isolated Mini Grids which are driven by the Rural Electrification Agency. The federal government plays several roles through the federal ministry of power with its agency, the Nigerian Electricity Regulatory Commission, playing regulatory role in the sector. The Nigerian Bulk Electricity Trading company is also of the federal government charged with the responsibility of buying electricity from the power generators and selling same to the DISCOS.

In the proposed structure, each state will have power generating plants jointly owned with private organizations that will oversee the running of the plants. The Power plants owned by the federal government (partly sold today) that are connected to the national grid should sell power to those states with insufficient power generation while the federal government maintains the TCN. States with excess power production can sell power to other states through the national grid. Each state will have not less than two electricity distribution companies jointly owned by the state and private partners who will equally have shares in the power generating companies. The federal government will merely be an observer, supporter, and tax collector in the new structure. For areas far from grid-connected power, the various state governments should exploit mini-grids using basically solar and wind energy systems in such areas if the potentials of these energy resources are appreciable in those areas. The move towards renewable energy utilization for power production should start from those areas.

2. MATERAILS AND METHODS

2.1 Power Plants in Nigeria and Total Power Installations in Various States

There are several power plants in Nigeria, and they are spread across the country. While the southern part of the country has basically gas turbine-based power stations, the northern part has a number of hydro power plants connected to

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the national grid. Before estimating the electrical energy demand of each state, it is necessary to know the total installed power capacity of power plants located in each state. Table 1 provides this information

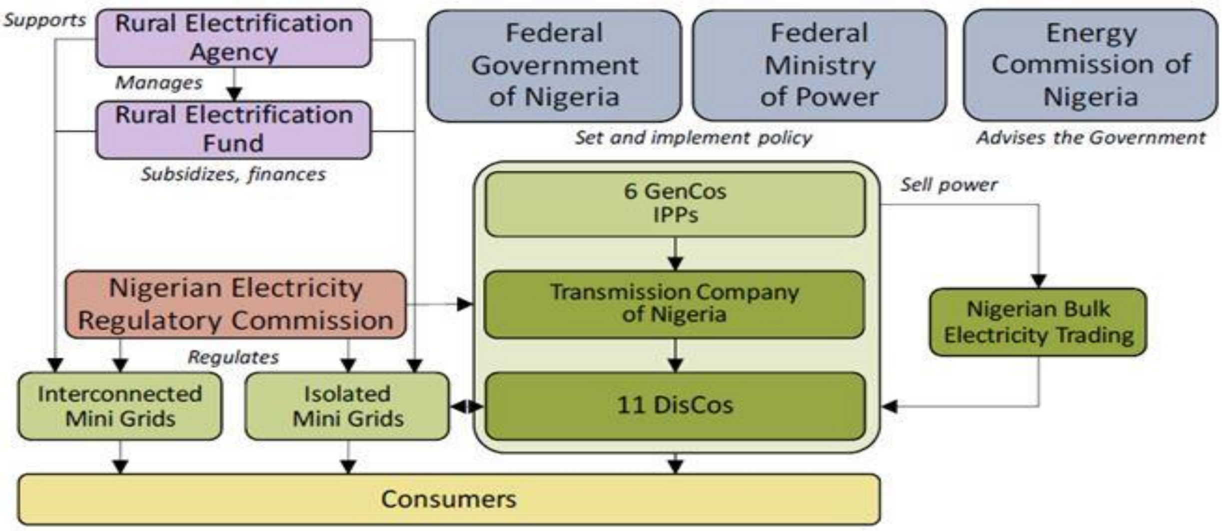

Fig. 1 The power sector structure of Nigeria (World Bank, 2017)

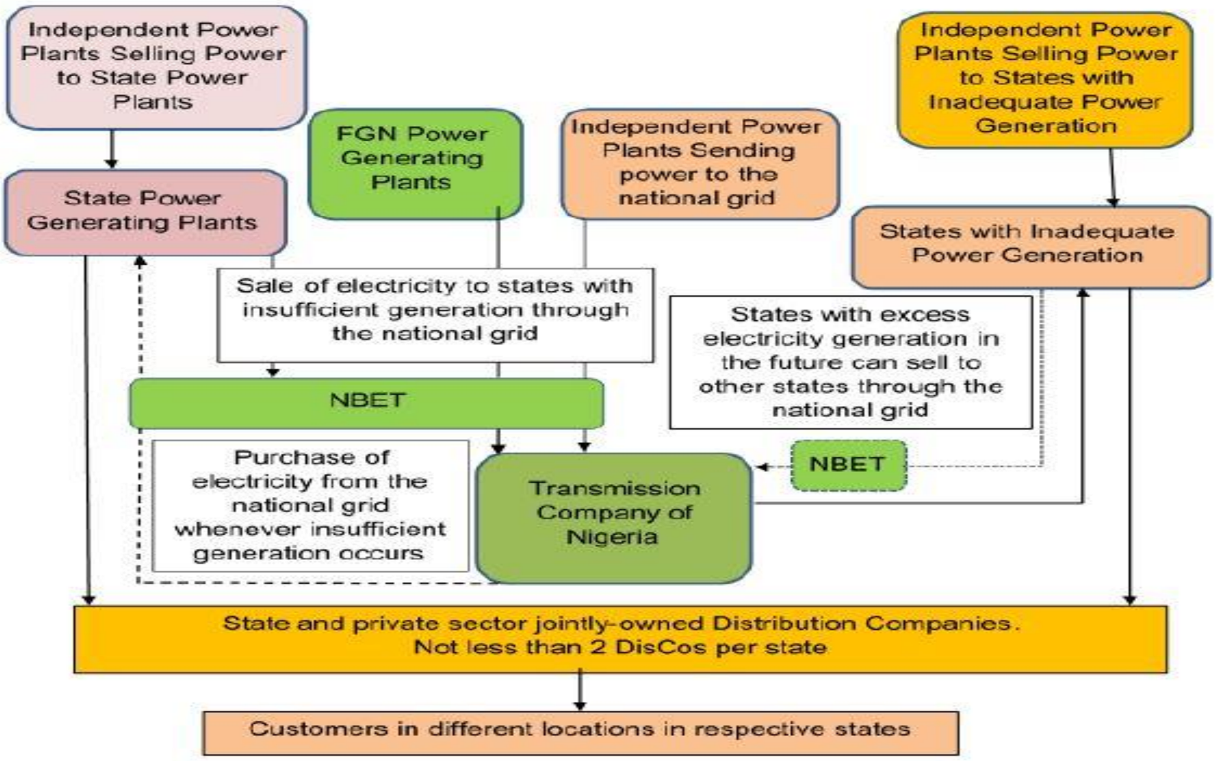

Fig. 2 Proposed structure of the power sector (Saturday, 2021)

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Table 1: Amount of power installations in the various states

Southern Region			Northern Region		
S/N	State	Total installed power capacity [MW]	S/N	State	Total installed power capacity [MW]
1	Akwa Ibom	731	1	Benue	10 MW gas plant planned; 600 MW gas plant proposed.
2	Bayelsa	305	2	Kogi	848
3	Cross River	562	3	Kwara	100 MW plant planned
4	Delta	2851	4	Niger	2638
5	Edo	1951	5	Plateau	No known proposed plant
6	Rivers	2041	6	Nasarawa	100 MW coal-fired plant planned, 20MW Farin-Ruwa hydro plant to be revived
7	Abia	1216	7	Adamawa	35
8	Anambra	2000	8	Gombe	40
9	Imo	338	9	Taraba	3050, under construction
10	Ebonyi	4185 MW power station planned	10	Bauchi	140 MW IPP planned back in 2013.
11	Enugu	Has several proposed coal-fired power stations	11	Borno	50 MW gas-fired power plant by NNPC, planned.
12	Lagos	1590	12	Yobe	No known major plant
13	Ogun	1347	13	Kaduna	245, under construction
14	Ondo	787	14	Kano	100, under construction
15	Osun	13	15	Katsina	10
16	Ekiti	Government involved in building of substations	16	Jigawa	2080, under construction
17	Oyo	IPPs planned	17	Kebbi	100 MW solar power project proposed
			18	Sokoto	38, 55MW plant proposed
			19	Zamfara	100

Table 2: Gross domestic product and population of Nigerian states

Southern Region			Northern Region		
State	Population	GDP ($)	State	population	GDP ($)
Akwa Ibom	5,867,929	10,154,048,645	Abuja (FCT)	4,292,710	5,391,492,820
Bayelsa	2,413,990	4,280,713,142	Benue	6,097,210	5,806,505,574
Cross River	4,097,147	8,201,773,224	Kogi	4,750,116	4,673,085,623
Delta	6,037,668	14,751,472,570	Kwara	3,390,330	$3,742,563,051
Edo	4,470,604	10,696,120,166	Niger	5,947,318	5,658,258,371
Rivers	7,817,865	18,655,004,840	Plateau	4,433,502	4,964,050,182
Abia	3,934,157	7,078,540,953	Nasarawa	2,679,432	3,099,277,879
Anambra	5,846,198	6,036,241,899	Adamawa	4,502,132	3,751,750,590
Imo	5,766,234	13,492,238,667	Gombe	3,472,222	2,336,725,192
Ebonyi	3,046,287	2,888,378,681	Taraba	3,249,971	3,466,950,121
Enugu	4,683,887	4,115,415,401	Bauchi	6,997,318	4,672,296,430

Table 2: Continuation

Southern Region			Northern Region		
State	Population	GDP 9 ($)	State	Population	GDP 9 ($)
Lagos	13,380,099	28,982,026,725	Borno	6,272,546	4,902,895,994
Ogun	5,573,705	12,050,266,752	Yobe	3,532,988	1,604,566,336
Ondo	4,960,576	8,518,451,881	Kaduna	8,762,663	9,257,479,660
Osun	5,016,594	7,319,461,128	Kano	13,969,084	13,611,262,055
Ekiti	3,480,005	2,922,923,727	Katsina	8,315,581	5,337,228,655
Oyo	8,392,589	14,359,592,133	Jigawa	6,176,192	4,240,457,755
			Kebbi	4,724,046	2,684,906,080
			Sokoto	5,307,155	5,090,063,046
			Zamfara	4,813,862	4,024,430,859

Source: Kingmakers (2020)

2.2 Power Demand of Various States in Nigeria

The demand for electrical power or energy of the various states is estimated here. Energy demand depends on the population and the level of economic activities or gross domestic product (GDP) of the locality in question. If the energy demand of one state is known, that of other states can be estimated by exploiting the population and GDP of the states as in (Saturday and Aderibigbe, 2020). In this case, an average electrical energy demand value of 1035 MW (Briggs & Ugorji, 2017) for Rivers State is used to estimate that of the remaining states exploiting Equation (1) (Saturday & Aderibigbe, 2020)

$$ED_s = \frac{GDP_s}{GDP_{rs}} \times \frac{POP_s}{POP_{rs}} \times ED_{rs} \qquad (1)$$

From Equation (1) ED_s , GDP_s and POP_s represent respectively energy demand, GDP, and population of the various states while ED_{rs}, GDP_{rs} and POP_{rs} are the respective values for Rivers State. Table 2 shows the GDP and population of the various states.

If an average value of the energy demand estimated by various researchers is to be adopted (in this case 33.5 GW), the energy demand of the various states will be scaled up or down to this value using Equation (2)

$$ED_{s'} = \frac{ED_s}{ED_T} \times ED_{av} \qquad (2)$$

Where $ED_{s'}$ is the adjusted value of the energy demand of each state, ED_T is the total energy demand of the various states obtained by summing all the ED_s values in Equation (1) while ED_{av} is the average energy demand value adopted ($ED_{av} = 33.5\ GW$).

2.3 Solar and Wind Energy Potentials in Nigeria and Extractable Energies

The solar and wind energy potentials of various locations in Nigeria have been studied by several researchers. The solar irradiation values of several places in Nigeria can be found in the works of Abdullahi *et al.* (2017) and Akorede *et al.* (2017). Like the potentials of solar energy in Nigeria, the wind energy potentials of different locations in Nigeria have been studied by several researchers (Idris *et al.*, 2020; Eboibi *et al.*, 2017; Okeniyi *et al.*, 2015). The potentials of wind energy come in the form of the average wind speed measured over several years. Table 3 shows the solar irradiation values and the average recorded wind speed values of different locations in Nigeria cutting across all the 36 states and the FCT. The annual mean wind speed data (at 10 metres height) was obtained from Akorede *et al.* (2017) (but those on asterisk were obtained from https://www.worldweatheronline.com/ado-ekiti-weather-averages/**ekiti/**ng.aspx at 6 metres height; replacing Ekiti in bold with any other location directs to the site for wind data in that location). The solar irradiation values were obtained from Akorede *et al.* (2017), Abdullahi *et al.* (2017), Ikeagwuani *et al.* (2016) and Dike *et al.*, (2011).

The amount of electrical energy extractable from either wind energy or solar energy depends on the capacity factor for both energy systems and the amount of wind speed for wind energy system and the solar irradiation value for solar energy extraction. For wind energy, wind turbines are used for extracting the energy and converting it to electrical energy. The available energy in the wind E_a and the amount of energy extractable E_e are given by Equations (3) and (4) respectively,

$$E_a = \frac{1}{2} \times \rho \times A \times v^3 \qquad (3)$$
$$E_e = P_R \times Cf \qquad (4)$$

where ρ, A, v, P_R and CF are the density of the air, area of turbine blades, the velocity of the wind, the rated power of the wind turbine and the capacity factor respectively. The capacity factor used in this work relates to the diameter of the turbine D and the wind speed given by Equation (5),

$$CF = 0.087 \times v - \frac{P_R}{D^2} \qquad (5)$$

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The turbine used in this work is AN Bonus wind turbine with diameter 60 m and rated power of 1 MW. The wind speed at the 60 m height has to be estimated (Saturday and Aderibigbe, 2020). From Equation (5), the least wind speed required to operate the turbine is 3.2 m/s.

The amount of energy to be installed $E_{in,s}$ and the number of turbine units required n (same power rating) are given by Equations (6) and (7) respectively (Saturday and Aderibigbe, 2020),

$$E_{in,s} = \frac{ED_s}{CF} \quad (6)$$

$$n = \frac{E_{in,s}}{E_e} \quad (7)$$

The actual land area required for wind turbine installation is much smaller than the entire area required as wind turbines are spaced wide apart. Using a convention of 60 acres (0.2428 km^2) of land per megawatt of electricity produced, the land area A_l required in square kilometer is given by Equation (8),

$$A_l = E_{in,s} \times 0.2428 \quad (8)$$

where the energy installed is expressed in megawatt. For solar PV systems, the amount of energy to be installed depend on the capacitor factor and the energy demand as in Equation (6), but the capacitor factor is expressed as (Saturday and Aderibigbe, 2020),

$$CF = \frac{E_a}{P_k} = \frac{365 \times P_r \times G}{8760} \quad (9)$$

where E_a is the solar energy extractable per unit time, P_k is the peak power of the solar PV system (peak power of 1 kWp is assumed in this case), P_r is the performance ratio (usually taken as 0.75), G expressed in (kWh/m^2/day) is the average daily global irradiance, 365 represents the number of days in a year while 8760 is the number of hours in one year. In some cases, the total amount of solar energy available per annum E_{ann} is needed and this is obtained using Equation (10),

$$E_{ann} = 365 \times P_r \times G \times P_k \quad (10)$$

The area of land required for solar energy installation $A_{l,s}$ is critical in solar PV system usage. The area can be estimated using Equation (11),

$$A_{l,s} = \frac{E_{in,s}}{P_K} \quad (11)$$

2.4 Economics of solar and wind energy utilization of the various states

Several economic parameters can be employed in adjudging the economic viability of any project. These include among others the payback period method, the discounted payback period method, the net present value (NPV) method, the internal rate of return or return on investment method, the levelized cost of electricity (LCOE) method (Saturday *et al.*, 2018). The LCOE method and the NPV methods are adopted in this work. The LCOE and the NPV are given respectively in Equations (12) and (13),

$$LCOE = \frac{IC + \sum_{i=1}^{n} \frac{AC_{O\&M}}{(1+r)^{-i}}}{\sum_{i=1}^{n} \frac{E_{in,s}}{(1+r)^{-i}}} \quad (12)$$

$$NPV = \sum_{i=1}^{n} \frac{NACF}{(1+r)^i} - IC \quad (13)$$

where n is the project life span (20 years was adopted in this work), IC is the cost of installing the system (in monetary value per kW or MW of electricity produced), $AC_{O\&M}$ is the cost of operating and maintaining the system annually, $NACF$ is the net annual cash flow which is the difference between the annual revenue which comes from the sale of generated electricity and the cost of operating and maintaining the system annually ($AC_{O\&M}$), and r is the discount rate. Onshore wind energy system is considered in this work and the installation cost varies between $1,200 per kW and $1,600 per kW (Wind Power Monthly, 2020). Since the values are on the downward trend, the lower value is adopted in this work. For a solar PV system, utility-scale system is adopted with installation cost of $1.44 per Watt (Fu *et al.*, 2018). The $AC_{O\&M}$ for wind energy

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system and solar PV system adopted in his work are ($27/MWh) and $0.001454 per kWh respectively. The price of electricity used in this work is ₦55 per kWh. A discount rate of 9% is adopted; this value is low but power projects are usually funded with funds borrowed at low interest rates hence the choice of low value here. Since the NPV represents the net present value, for two different states with different population values as well as energy demand values, for same wind speed, the state with higher energy demand will go with higher NPV value, suggesting that the project in that state is doing better, which is not true. To avoid this, the NPV per energy demand was used to judge the economic viability of operating the different energy systems in the various states.

2.4.1 The Relationships between the LCOE and the Speed and the Solar Irradiation

The LCOE depends on the wind speed for wind energy system and the amount of solar irradiation for solar energy system. The relationship between the LCOE and the independent parameter in each system can be obtained by curve-fitting the data obtained for the various states using curve-fitting capabilities in Microsoft Excel.

3. RESULTS AND DISCUSSION

Table 4 shows the energy demand value of the various states and the FCT viz –a –viz the amount of installed. The difference between the energy demand value and the available installed power will give each state government an idea of the additional power installation required if the state government takes over the ownership of the power installations in their states with or without private partnership. Plants proposed and those under construction are not included in Table 4; that information is in Table 1.

Table 5 shows the LCOE and the NPV per energy demand for wind energy system for the various states while Table 6 shows LCOE and the NPV per energy demand for solar energy system. For the wind energy system, LCOE and NPV were not evaluated for Bayelsa, Delta, Anambra, Ebonyi and Ondo states because the wind speeds in the selected locations are lower than the cut in speed of the selected wind turbine. For electricity price of ₦55 per kW-hr ($0.1339 per kW-hr), only four states in the southern part (Cross River, Enugu, Lagos, and Oyo) have LCOE value lower than the electricity price; all the other states have LCOE value higher than the electricity price hence goes with negative NPV. For the northern part, five states- Benue, Kogi, Nasarawa, Gombe and Taraba states have LCOE values higher than the price of electricity in Nigeria; all the other states and the FCT has LCOE values lower than the electricity price of $0.1339 per kW-hr. Generally, states which LCOE is higher than the price of electricity has negative NPV, indicating that it is not economically viable to operate wind energy system in those states going by the current installation cost and electricity price if the aim is to make profit.

The LCOE and the NPV for solar energy system depends on the solar irradiation value for the various locations. For the southern states, the LCOE values obtained for nine of the states is lower than the price of electricity while for the remaining 8 states, the LCOE values are each higher than the price of electricity. Anambra state has the lowest LCOE value followed by Enugu state; for the NPV per energy demand, Anambra state has the highest value followed by Enugu state. These two states have solar irradiation values of 4.825 kWh/m^2-day and 4.820 kWh/m^2-day respectively which are the highest in all the states in the southern region. For the northern region, all the states have LCOE values lower than the price of electricity, indicating that it is economically viable to operate, in commercial scale, solar energy systems in the indicated locations in all the northern states. Yobe state gave the lowest LCOE value followed by Kano state.

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Table 3: Solar irradiation and average wind speed values of different locations in Nigeria

State (Location)	Yearly averaged daily solar radiation ($kWh/m^2.day$)	Location in the state	Annual mean wind speed at 10m height (m/s)
Abia (Umuahia)	4.68	Umuahia	2.68*
Abuja FCT	5.39	Abuja	3.77
Adamawa (Yola)	5.774	Yola	4.16
Akwa Ibom (Uyo)	4.68	Uyo	2.55
Anambra (Awka)	4.825	Awka	2.08 *
Bauchi (Bauchi)	5.714	Bauchi	4.83
Bayelsa (Yenagoa)	4.175	Yenagoa	1.56*
Benue	5.077	Makurdi	2.42 *
Borno (Maiduguri)	6.4	Maiduguri	5.22
Cross River (Calabar)	3.925	Calabar	4.6
Delta (Warri)	3.748	Warri / Asaba	2.11 /2.16
Ebonyi (Abakaliki)	4.955	Abakaliki	2.39
Edo (Benin)	4.202	Benin	3.38
Ekiti (Ado Ekiti)	4.775	Ado Ekiti	2.77 *
Enugu (Enugu)	4.82	Enugu	5.73
Gombe	6.25	Gombe	2.53
Imo (Owerri)	4.146	Owerri	2.8
Jigawa	5.987	Dutse	3.47 *
Kaduna	5.672	Kaduna /Zaria	5.13 / 6.08
Kano	6.003	Kano	9.39
Katsina	4.766	Katsina	7.45
Kebbi	5.140	Yelwa	3.88

Table 3: Continuation

State (Location)	Yearly averaged daily solar radiation ($kWh/m^2.day$)	Location in the state	Annual mean wind speed at 10m height (m/s)
Kogi	5.035	Lokoja	2.92
Kwara (Ilorin)	5.23	Ilorin	5.04
Lagos (Ikeja)	4.256	Lagos Island	4.69
Nasarawa	5.170	Lafia	2.68 *
Niger	5.427	Minna	5.36
Ogun (Abeokuta)	4.258	Ijebu-Ode	3.62
Ondo (Akure)	4.485	Ondo (City)	1.77
Osun (Osogbo)	4.735	Oshogbo	3.33
Oyo (Ibadan)	4.71	Ibadan	3.86
Plateau	5.653	Jos	9.47
Rivers (Port Harcourt)	4.31	Port Harcourt	3.3
Sokoto	5.34	Sokoto	7.21
Taraba (Serti)	4.488	Jalingo	3.12 *
Yobe (Nguru)	6.660	Potiskum	5.25
Zamfara	5.150	Gusau	6.17

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Table 4: Energy demand values of the various states

State	Energy Demand, MW	Available installed power, MW	State	Energy Demand (MW)	Available installed power, MW
Akwa Ibom	1059.72	731	Abuja (FCT)	411.63	
Bayelsa	183.79	305	Benue	629.67	848
Cross River	597.66	562	Kogi	394.80	
Delta	1584.06	2851	Kwara	225.67	2638
Edo	850.47	1951	Niger	598.51	
Rivers	2593.89	2041	Plateau	391.43	
Abia	495.29	1216	Nasarawa	147.70	35
Anambra	627.64	2000	Adamawa	300.41	40
Imo	1383.71	338	Gombe	144.31	
Ebonyi	156.49		Taraba	200.40	
Enugu	342.84		Bauchi	581.47	
Lagos	6896.93	1590	Borno	546.97	
Ogun	1194.56	1347	Yobe	100.82	
Ondo	751.55	787	Kaduna	1442.77	
Osun	653.06	13	Kano	3381.69	10
Ekiti	180.91		Katsina	789.36	
Oyo	2143.41		Jigawa	465.80	
			Kebbi	225.59	
			Sokoto	480.45	100
			Zamfara	344.56	

Table 5: LCOE and NPV per energy demand for wind energy system

Southern Region			Northern Region		
Location	LCOE, $/kW-hr	NPV per Energy demand, MW	Location	LCOE, $/kW-hr	NPV per Energy demand, MW
Akwa Ibom	1.7347	-128.01	Abuja (FCT)	0.1299	1.799
Bayelsa	n/a	n/a	Benue	1.0432	-71.240
Cross River	0.0897	3.52	Kogi	0.3249	-13.801
Delta	n/a	n/a	Kwara	0.0790	5.866
Edo	0.1740	-3.22	Niger	0.0732	6.327
Rivers	0.1882	-4.35	Plateau	0.0461	8.498
Abia*	0.3518	-17.43	Nasarawa	0.3518	-15.952
Anambra*	n/a	n/a	Adamawa	0.1061	3.699
Imo	0.4339	-23.99	Gombe	2.3215	-173.458
Ebonyi	n/a	n/a	Taraba	0.1780	-2.050
Enugu	0.0680	5.26	Bauchi	0.0836	5.496
Lagos	0.0872	3.73	Borno	0.0756	6.139
Ogun	0.1433	-0.76	Yobe	0.0751	6.181
Ondo	n/a	n/a	Kaduna	0.0640	7.065
Osun	0.1826	-3.90	Kano	0.0463	8.481
Ekiti*	0.2899	-12.48	Katsina	0.0538	7.879

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Oyo	0.1232	0.85	Jigawa	0.1329	1.555
			Kebbi	0.1218	2.441
			Sokoto	0.0552	7.770
			Zamfara	0.0631	7.137

Table 6: LCOE and NPV per energy demand for solar energy system

Southern Region			**Northern Region**		
Location	**LCOE, $/kW-hr**	**NPV per Energy demand, MW**	**Location**	**LCOE, $/kW-hr**	**NPV per Energy demand, MW**
Akwa Ibom	0.1246	0.7517	Abuja (FCT)	0.1084	2.0487
Bayelsa	0.1395	-0.4393	Benue	0.1150	1.5216
Cross River	0.1483	-1.1423	Kogi	0.1159	1.4459
Delta	0.1552	-1.6967	Kwara	0.1116	1.7871
Edo	0.1386	-0.3684	Niger	0.1076	2.1069
Rivers	0.1352	-0.0936	Plateau	0.1034	2.4464
Abia	0.1246	0.7517	Nasarawa	0.1129	1.6849
Anambra	0.1209	1.0476	Adamawa	0.1013	2.6172
Imo	0.1404	-0.5165	Gombe	0.0937	3.2250
Ebonyi	0.1177	1.2981	Taraba	0.1299	0.3304
Enugu	0.1210	1.0377	Bauchi	0.1023	2.5334
Lagos	0.1368	-0.2292	Borno	0.0915	3.3978

Table 6: Continuation

Southern Region			**Northern Region**		
Location	**LCOE, $/kW-hr**	**NPV per Energy demand, MW**	**Location**	**LCOE, $/kW-hr**	**NPV per Energy demand, MW**
Ogun	0.1368	-0.2242	Yobe	0.0880	3.6789
Ondo	0.1299	0.3236	Kaduna	0.1030	2.4737
Osun	0.1232	0.8660	Kano	0.0974	2.9217
Ekiti	0.1221	0.9476	Katsina	0.1224	0.9293
Oyo	0.1238	0.8144	Jigawa	0.0977	2.9011
			Kebbi	0.1136	1.6328
			Sokoto	0.1094	1.9686
			Zamfara	0.1133	1.6502

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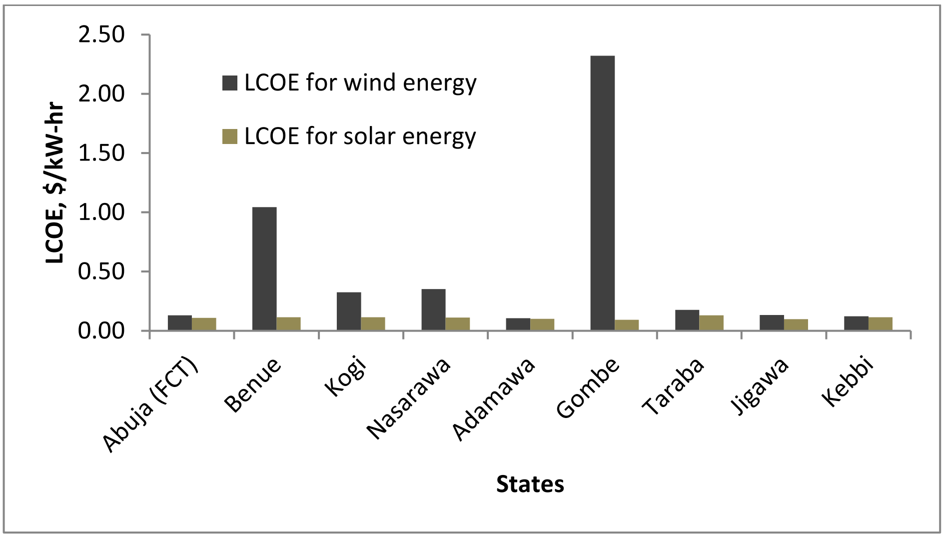

Fig. 3: Comparison of LCOE values from wind energy and solar energy systems for states with more viable wind energy utilization

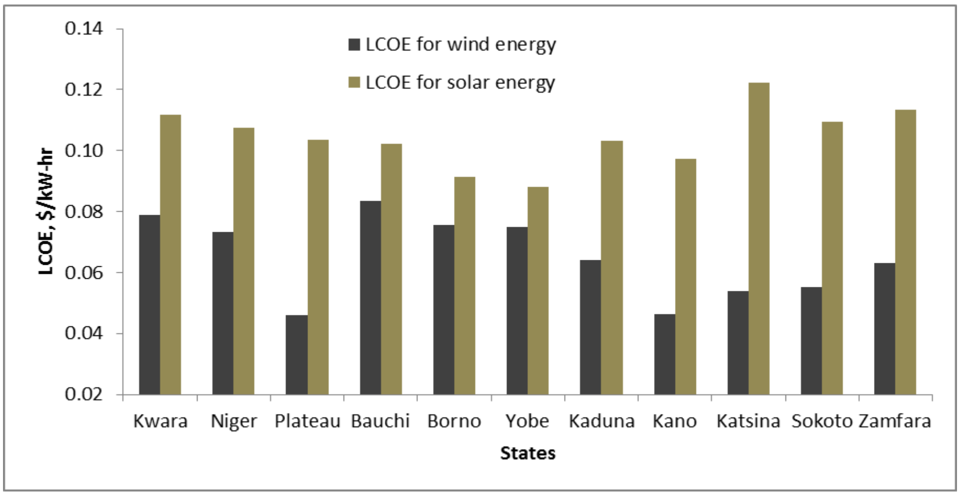

Fig. 4: Comparison of LCOE values from wind energy and solar energy systems for states with more viable solar energy utilization

4. CONCLUSION

This study reveals the potentials of various states in Nigeria, in harnessing wind and solar energies as alternative sources of power generation in the country, splitting the analysis into the southern and the northern parts of the country. The wind energy potentials are economically viable in many of the states in the northern part while solar energy potentials are economically viable in all the northern states. In the southern part, few of the states can operate wind energy system profitably while it is economically viable to operate solar energy system in many of the states. The study presents the need to implement these two energy

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systems in a proposed power structure. Although the power sector has been facing several challenges, there is room for improvement if the proposed structure is implemented, where state governments will be involved in power generation, transmission and distribution in partnership with private organizations within their localities and sell excess power to neighbouring states through the national grid. Concerted effort by the federal government is needed to achieve the desired progress in the sector. For each state, areas far from the national grid with appreciable wind and or solar energy potentials should be the starting points for the utilization of these energy systems to increase the renewable energy mix in our power sector.

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