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Identification of Reserved Energy Resource Potentials for Nigeria Power Generation Improvement

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ABSTRACT
Electrical power is the most widely used form of power in the industrialized countries. In Nigeria the epileptic pattern of electricity supply has affected every aspect of our economy and therefore required a strong political will and commitment on the part of Government to tackle. The solution to this problem lies in identifying and harnessing the abundant reserve energy resources available in various locations all over the country. This paper thus dwelt on identifying various sources of reserve energy potentials that abound in Nigeria which when harnessed and deployed appropriately will be sufficient to provide for both immediate and future electric power need of the country. The approach deployed in the study include the review of available statistical data of Nigeria reserve energy resources; identify the scale of its availability, location and the realizable amount of electric power from such reserve. The results show that the proven and estimated reserved energy resources of coal, natural gas and new hydro potentials could contribute a total of 96,079.40MW to the grid system, and when added to the existing installed electric power generation capacity of 12,066MW will give a total of 108,145.40MW.

Keywords: Reserved energy resources, coal, natural gas, hydro potentials, installed capacity

I. INTRODUCTION

Electricity is very important to the social and economic development of any country. All aspects of the life of the citizenry is affected by power supply, ranging from keeping a clean home to running multinational companies. Without adequate power supply, business, homes and society at large cannot function to their full capacity. Goods and services would cost more than they should if every business owner has to own a private generating unit. Running a home will be rigorous if there is no means of storing food due to non functional refrigerating systems. Health care provision would be substandard. Unemployment would increase due to fewer companies and these may lead to high crime rate. Life would be boring if access to entertainment is limited due to inadequate power supply. The electric power system of a country must meet the electricity demand of the citizens. Every household and business office should have access to adequate power supply.

Energy is a means of satisfying important needs of a society. The industrial growth rate of Nigeria is a function of the amount of reserved energy resource available and the extent to which this reserved energy resource is utilized for the design and the construction of additional power plants in sufficient numbers. Nigeria has sufficient reserved energy resources of coal, natural gas and new discovered hydro potentials that can serve as an input to all economic activities. Reserved energy resources of coal, natural gas and new discovered hydro potentials are the energy producing installations basket that contains power plants fired by fossil fuels (coal and natural gas) and hydro potentials. The proven reserved coal in Nigeria is about 445 millions tones, consisting approximately of 81.05% sub-bituminous, 4.81% bituminous and 14.14% lignite coals. The estimated reserved coal in Nigeria is about 2,559 million tones, consisting approximately of 42.32% sub-bituminous, 45.17% bituminous and 12.51% lignite coals. The reserved proven coal and estimated coal can contribute 1,964MW and 12,082MW respectively to the grid system at 60% capacity utilization for over 100 years. The total reserved proven natural gas in Nigeria are 4 trillion cubic meters (or 142 trillion standard cubic feet) and 5.4 trillion cubic meters (or 189 trillion standard feet) respectively. The reserved proven natural gas and estimated natural gas can contribute 29,505MW and 39,270MW respectively to the grid system at a capacity of 60% for 100 years. The new discovered hydro potentials and the existing electricity generation capacity in Nigeria are about 12,525MW and 12,066MW respectively. The reserved estimated energy resources of coal, natural gas and new hydro potentials can contribute a total of 63,876.96MW to the grid system, and when added to the existing installed capacity of 12,066MW which included on-going power projects, will give a total of 75,942.96MW. Only 56.6% (42,943.6MW) of 75,942.96MW is utilized in the current generation and transmission capacities expansion that gives expanded 86-bus network with the reserved energy resources.

The reserved proven and estimated energy resources of coal natural gas and new hydro potentials have been identified to contribute a total of 96,019.4MW to the grid system, and when added to the existing installed capacity of 12,066MW will give a total of 108,145.40MW.

II. STATUS OF EXISTING RESERVED ENERGY RESOURCE POTENTIALS FOR POWER GENERATION IN NIGERIA.

The key factor in the Nigeria energy crisis is the very wide gap between the demand of electricity and the available supply in the country [1, 2, 3]. The electricity demand in Nigeria far outstrips the supply.

Presently, the estimated power demand in Nigeria is about 15,730 MW [1, 4]. There is need to harness all existing reserved energy sources in Nigeria in optimal proportion, in order to meet the present energy demand. It is the objective of this paper to identify the abundant reserved energy potentials in Nigeria for possible harnessing and deployment towards improving electricity supply, as a means of achieving sufficiency in the supply of electricity demand in Nigeria. The major sources of electric energy in Nigeria are the fossil fuels and water. All the fossil fuels are produced from the fossilization of carbohydrate compounds. The three types of fossil fuels used in power plants are solid fuel as coal, liquid fuel as oil and gas fuel as natural gas.

2.1 Coal Fuel Resources

Coal is the most abundant and widely distributed fossil fuel with a total estimated reserve of about 990 billion tones worldwide [5]. Over 42% of global electricity supply is derived from coal-fired power plants [6]. Available data on global coal reserves proves that, at current production levels, global coal reserve could last for over 147 years, whereas gas reserves are expected to last around 63 years [7]. The total global hard coal production in the year 2006 was 5,370MT. The total global brown coal/lignite production in 2006 was 914MT. Global coal production is expected to reach 7billion tones in 2030 with China accounting for about half of the increase.

Coal is formed by the decomposition of vegetation which is buried under the earth millions of years ago. The four types of coal are as follows: lignite; sub-bituminous; bituminous; and anthracite. Lignite is the soft, brownish-black coal that forms of the lowest of the coal family. The sub-bituminous is a dull black coal which gives off more energy than lignite when it burns. Nigeria sub-bituminous coals has a high calorific value of 5,000 to 6,000 cal/g or 5,500 to 6,500 air dried, low ash and low sulphur content, with good storage characteristics. Bituminous or soft coal has more energy packed in it. Anthracite is the hardest coal and it gives off a great amount of heat when it burns [8].

The selection of coal is based on calorific value, weatherability, sulphur content, grindability index, storage characteristics, ash content and particle size. Coal has long been discovered in economic quantities in different parts of Nigeria. It is the first fossil fuel to be discovered in Nigeria. The coal of sub-bituminous grade occurs in about 22 coal field spread in over 13 states of the federation. It means that there are over 13 coal mines and more than 22 coal blocks located across Nigeria [9].

Table1 shows the various coal sites located in different parts of Nigeria with their grades and quantities in million tones specified. The estimated coal resources of the country are about 2,559 million tones while the proven reserves are about 445 million tones, consisting approximately of 42.32% sub-bituminous, 45.17% bituminous and 12.5% lignite coals.

Table 1: Existing potential coal mines sites with reserves in Nigeria [9].

S/N	State	Type of Coal	Estimated Reserves (Mil. Ton)	Proven Reserves (Mil. Ton)
1	Enugu	Sub-bituminous	456	140
2	Imo	Lignite	40	-
3	Ebonyi	Sub-bituminous	50	-
4	Anambra	Lignite	30	-
5	Delta	Lignite	250	63
6	Kogi	Sub-bituminous	502	164
7	Nassarawa	Bituminous	156	21.42
8	Benue	Sub-Bituminous	75	57
9	Enugu	Bituminous	1000	-
	Total		**2,559**	**445.42**

The total available estimated coal deposit of 2,559 million tones can support 12,082 MW capacities at 60% capacity utilization for over 100 years. Unfortunately, Nigeria's coal deposit is presently not being utilized for power generation. Coal deposit accounts for zero megawatts in the current on-grid electric power energy mix in the country, a major reason for the shortfall in power supply. There is need to incorporate coal into the national energy mix for electricity generation, because it is abundant, efficient and less expensive than most other energy mix options.

The challenges facing coal power generation include uncertainties in the actual reserves of coal on which long-term projects could be based, low productivity of the coal mines, low level of mechanization of production facilities, and absence of cost – effective transportation system. Coal power generation technology is readily available and easy to acquire. These technological methods for the development of clean coal are presented as follows:

- Optimizing existing power plants so as to reduce emissions and increase the amount of electricity produced with the same amount of coal.
- Use of circulating fluidized – bed technology to mix fuel and air to obtain combustion. This technology includes supercritical and ultra supercritical combustion. Biomass rice straw and other low grade fuels can be used in these boilers. Burning biomass as a fuel in the boiler reduces the level of CO_2 emissions, and oxy-combustion for collecting CO_2 – rich flue gas.
- The use of gasification technology to turn coal into a gas and remove impurities from the coal gas before it is combusted.
- The use of carbon capture and storage technology to capture the carbon diode from the flue gas and store it underground or reuse it.

Nigerian coal can be utilized for power generation; steam production; in cement production and for brick making; as a heat source and reducing agent for steel production; as a domestic fuel; and as feedstock for the production of chemicals, liquid fuels, gaseous fuels, batteries, carbon electrodes. About 95% of Nigeria's coal production has been consumed locally; mainly for railway transportation, electricity production and industrial heating in cement production [10]. The development of a vibrant coal industry is needed to harness these potentials of coal effectively into the country's energy delivery system.

2.2 Natural Gas Fuel Resources

Natural gas is a gaseous fossil fuel that is versatile, abundant, eco-friendly and relatively clean compared to coal and oil. Natural gas is a natural occurring gaseous mixture of hydrocarbon gases found in underground reservoirs. It is formed from the remains of marine micro-organisms. Natural gas consists of mainly 80% methane and small percentage or fractions of other gases such as ethane, propane, butane, pentance [11]. Natural gas has other heavier hydrocarbons with some impurities such as water vapour, sulphides, carbondioxides [12]. The calorific value of natural gas is about 55,000KJ/kg, which is equal to about 37,000KJ/m^3 at one atmospheric pressure and 20^{o}C temperature. It is highly compressed in small volume at large depth in the earth. The largest potential resource for power generation in Nigeria is natural gas. The current estimate of total Nigerian natural gas reserves is about 5.4 trillion cubic meters (or 189 trillion standard cubic feet) and the total proven natural gas reserves is about 4 trillion cubic meters (or 142 trillion standard cubic feet). The estimated natural gas reserves can support 39,270 MW capacity power plants operating at a capacity factor of 60% for 100 years. The natural gas reserves or gas wells are generally located in the Niger Delta region of the country as presented in table2.

Table 2: Existing potential Natural gas reserves in Nigeria.

S/N	State	Percentage Reserves (%)	Estimated gas Reserves in trillion cubic meters ($x\ 10^{12}$ cubic meters)	Proven Gas reserves in trillion cubic meters ($x\ 10^{12}$ cubic meters)
1	Rivers	24	$1.278\ x\ 10^{12}$	$0.96\ x\ 10^{12}$
2	Bayelsa	15	$0.7986\ x\ 10^{12}$	$0.60\ x\ 10^{12}$
3	Akwa-Ibom	20	$1.0648\ x\ 10^{12}$	$0.80\ x\ 10^{12}$
4	Delta	20	$1.0648\ x\ 10^{12}$	$0.80\ x\ 10^{12}$
5	Edo	12	$0.6389\ x\ 10^{12}$	$0.48\ x\ 10^{12}$
6	Ondo	4	$0.2130\ x\ 10^{12}$	$0.16\ x\ 10^{12}$
7	Imo	3	$0.1597\ x\ 10^{12}$	$0.12\ x\ 10^{12}$
8	Abia	3	$0.1597\ x\ 10^{12}$	$0.12\ x\ 10^{12}$
	Total		$\mathbf{5.377\ x\ 10^{12}}$	$\mathbf{4\ x\ 10^{12}}$

The current level of reticulation of gas wells in Nigeria is the major constraints to the location of gas power plants to the Southern edge of the country. Nigeria holds the largest natural gas reserve in Africa, but has limited infrastructure in place to develop the sector which leads to the flaring of the gas [13].

Apart from the export potential of the Nigerian gas, local demand opportunities are power generation, cement industry, iron and steel plants. The largest single consumer of natural gas in Nigeria is PHCN and it accounts for about 70% used to operate electricity generating gas plants at Afam, Ughelli, Sapele and Egbin.

2.3 Hydro Power Resources

Nigeria has abundant and undeveloped hydropower resources. Hydropower resources are classified as large, medium, intermediate, small, mini and micro. The classification of hydro schemes in Nigeria is presented in table3.

Table 3: Classification of hydro schemes in Nigeria.

Scale of hydro scheme	Capacity Range (MW)
Large	> 100
Medium	50 – 100
Intermediate	10 – 50
Small	1 – 10
Mini	0.5 – 1
Micro	< 0.5

2.3.1 Large Scale Hydropower Resources

Large scale hydropower is defined internationally as any hydro installation rated at greater than 100MW. Medium scale hydropower is any hydro installation rated at the range 50 to 100MW, whereas intermediate scale hydropower is any hydro installation rated at the range 10 – 50 MW. Both the large, medium, and intermediate scale hydropower schemes are considered for on-grid power generation.

In large scale hydroelectric plants, hydroelectric power is obtained from conversion of potential energy stored in the heights of artificial lake to electricity using water wheel turbines coupled to synchronous generators. Despite the huge capital outlay for its construction, the running cost is low and the energy is pollution free. Their use is constrained by actual rainfall which limits the output available. The hydropower potential in Nigeria has been proven, but its development is hindered by financial or investment cost per KW difficulties.

Hydropower accounts for over 22% of the total power generation in Nigeria. The existing large scale hydropower generating plants in Nigeria are the 760MW capacity Kainji Dam, 578MW capacity Jebba Dam and 600MW capacity Shiroro Dam, all located in Niger State. Tables 4, 5, and 6 show the commissioned large scale hydroelectric schemes in Nigeria, the on-going hydropower projects in Nigeria and technically exploitable large scale hydropower potentials in Nigeria.

Nigeria has large undeveloped hydropower potentials, some of which have been shown to be technically and economically viable. Some of these sites are shown in table 5 [14].

Table 4: Commissioned large scale hydroelectric schemes in Nigeria.

S/N	Location of hydro power plant	Installed capacity (MW)	Available capacity (MW)	Commissioned date
1	Kainji	760	465	1968
2	Jebba	578	482	1984
3	Shiroro	600	450	1990
	Total	**1938MW**	**1397MW**	

Table 5: On-going or planned hydropower projects in Nigeria

S/N	Location of hydro power plant	Capacity (MW)	Costing (US$M)
1	Ikom	730	1,140
2	Lokoja	1,050	1,405
3	Zungeru	450	1,425
4	Mambilla (hydro)	3,960	5,940
5	MAkurdi (hydro)	1,060	1,593
6	Onitsha (Hydro)	1,050	1,575
7	Gurara (Abuja hydro)	300	450
	Total	**8,600MW**	

Table 6: Various technically exploitable large scale hydropower potentials in Nigeria.

S/N	Location of hydro power plant	River	Average discharge (m^3/%)	Maximum head (m)	Potential capacity (MW)
1	Donko	Niger	1,650	17	225
2	Jebba	Niger	1,767	27.10	500
3	Zungeru II	Kaduna	343	97.50	450
4	Zungeru I	Kaduna	343	100.60	500
5	Shiroro	Kaduna	294	95.00	300
6	Zurubu	Kaduna	55	40.00	20
7	Gwara	Jamaare	75	50	30
8	Izom	Gurara	55	30	10
9	Gudi	Mada	41.50	100	40
10	Kurra II	Sanga	5.50	430	25
11	Kurra I	Sanga	5.0	290	15
12	Richa II	Daffo	4.0	480	25
13	Richa I	Mosari	6.50	400	35
14	Mistakuku	Kurra	2.0	670	20
15	Korubo	Adamawa	128	37	35
16	Kiri	Adamawa	154	30.50	40
17	Yola	Benue	-	-	360
18	Kramti	Kam	80	100	115
19	Beli	Taraba	266	79.20	240
20	Garin Dali	Taraba	323	39.60	135
21	Sarkin Danko	Suntai	20	180	45
22	Gembu	Dongu	45	200	130
23	Kasimbila	Kastina Ala	170	45	30
24	Katsina Ala	Kastina Ala	740	49	260
25	Makurdi	Benue	3,185	25.90	1,060
26	Lokoja	Niger	6,253	31.40	1,950
27	Onitsha	Niger	6,635	15.25	1,050
28	Ifon	Osse	80	50	30
29	Ikom	Cross	1,621	15.5	730
30	Afikpo	Cross	1,704	10	180
31	Atan	Cross			180
32	Gurara (Abuja)	Gurara			300
33	Mambilla	Danga			3,960
	Total				**12,525MW**

In order to meet the increasing growth of power requirement in the country, there is need to increase the contribution of hydropower resources in the national energy mix by harnessing all identified feasible hydropower potentials in the various parts of the country. Table 6 lists the various technically exploitable large scale hydropower potentials, their locations and power generation capacity in megawatts [16].

The estimation of the total technically exploitable large scale hydropower potential for Nigeria stands at 12,525MW as presented in table 6. This figure, when added to the 1,938MW (kainji, Jebba and Shiroro), already developed, gives the gross hydropower potential for Nigeria to be 14,463MW. The current hydropower generation of 1,938MW is about 13% of the nation's hydropower potential and, this represents 30% of the total installed grid-connected electricity generation capacity of the country.

2.3.2 Small Scale Hydropower Resources

Small hydropower is defined internationally as any hydro installation rated at less than 10.00MW. A sub-set of this is called pico-hydro or micro-hydro which can be defined as tiny systems of under 10.00MW. The small scale hydropower potential is estimated at 3,500MW. The lists of on-going small scale hydropower sites in Nigeria are presented in table 7 [15].

Table 7: On-going small scale hydropower sites in Nigeria [15].

S/N	Dam/River	Location of small hydropower plant	Capacity (MW)
1	Ezioha – Mgbowo Dam (UNIDO)	Enugu State	0.03
2	Waya Dam (UNIDO)	Bauchi State	0.15
3	Obudu Cattle resort Dam (UNIDO)	Cross River State	0.03
4	Ikpoba Dam (UNIDO)	Edo State	3.12
5	Tunga Dam (UNIDO)	Plateau State	1.60
6	Ta-Hoss Community (UNIDO)	Plateau State	0.10
7	Omi Community (UNIDO)	Oyo State	0.625
8	Oyan Dan (UNIDO)	Ogun State	9.00
9	Erin – Ijesha (UNIDO)	Osun State	3.00
10	Ikere Gorge (UNIDO)	Ogun State	5.00
11	Bakalori (UNIDO)	Sokoto State	3.20
12	Tiga (UNIDO)	Kano State	6.00
13	Evboro II Village	Edo State	0.04
14	Kakara, Mambilla	Plateau State	0.40
15	Ketti Health Centre		0.05
16	Kwaita Health Centre		0.0066
17	Kurmi Dauda		0.007
18	Bagel I (NESCO)	Plateau State	1.00
19	Bagel II (NESCO)	Plateau State	2.00
20	Kurra (NESCO)	Plateau State	8.00
21	Lere I (NESCO)	Plateau State	4.00
22	Lere II (NESCO)	Plateau State	4.00
	Total		**51.3586MW**

The United Nations Industrial Development Organization (UNIDO) under her regional Centre for small hydropower in Africa (RC-SHP) with office in Abuja has developed many small scale hydropower sites in Nigeria. The existing small scale hydropower schemes of Ikere Gorge, Bakalori and Oyan dam developed by UNIDO require rehabilitation in form of refurbishment and turbine installation. So far about twenty two small hydropower plants with aggregate capacity of 51.11MW have been installed in Nigeria by UNIDO, NESCO and the government as shown in table 7. NESCO has about 30 MW in operation at various sites in Plateau State.

Some other small scale hydropower sites that have been investigated are listed in table 8 . Each of the river basins in the country has potentials for small scale hydropower. These hydropower sites have a total estimated capacity of 234.71MW.

Table 8: Some investigated small scale –hydropower sites in Nigeria [15].

S/N	Dam Site	Town	State	Water Head (m)	Discharge (m^3/Sec)	Potential capacity (MW)	Stage
1	Jibia	Jibia	Katsina	18.00	290 – 400	31.30	Pre- feasibility
2	Fajina	Ajiwa		12.50	400 – 500	30.00	"
3	M/Fashi	M/Fashi	Katsina	12.00	320 – 553	23.00	"
4	Mairuwa	Funtua	Katsina	8.00	350 – 550	16.80	"
5	Gwaigwaye	Funtua	Katsina	12.00	600 – 900	43.20	"
6	Zobe	Dutsinma		19.80	600 – 900	71.30	"
7	Sabke	Mapadua		12.50	250 – 350	18.70	"
8	Iddo	Iddo		15.00	2.699	0.24	Investor forum
9	Sepeteri	Sepeteri	Oyo	14.23	1.984	0.17	"
	Total					**234.71MW**	

Most of the small scale hydropower potentials are undeveloped as shown in table 9.

Table 9: Overall distribution of small scaled hydropower potential among seven River basins [17].

S/N	River Basin	Status	TYPE CAPACITY					
			Micro No.	Capacity (MW)	Mini No.	Capacity (MW)	Small No.	Capacity (MW)
1	Sokoto Rima	D	-	-	-	-	1	3.0
		U	10	3.20	11	8.40	10	29.6
2	Hadejia Jama'are	D	-	-	-	-	1	6.0
		U	8	2.80	20	11.40	7	31.60
3	Chad	D	-	-	-	-	-	-
		U	10	6.40	8	6.80	2	5.60
4	Niger	D	-	-	-	-	-	-
		U	16	6.40	23	18.20	22.00	191.00
5	Upper Benue	D	-	-	-	-	-	-
		U	8	3.20	36	27.00	25.00	185.10
6	Lower Benue	D	-	-	-	-	5.00	19.00
		U	11	4.40	23	19.20	17.00	138.0
7	Cross River	D	-	-	-	-	-	-
		U	17	7.00	6.00	4.60	5.00	21.80
	Total	**D**	**-**	**-**	**-**	**-**	**7.00**	**28.00**
		U	**80**	**24.50**	**126.00**	**95.60**	**86.00**	**704.10**

D = Developed and U = Undeveloped.

There are over 278 unexploited small hydropower sites with a total capacity of 734.3MW [18]. Table 9 shows the small scaled hydropower potentials in surveyed 12 states in Nigeria [19].

Table 10: Summary of small hydropower potential distribution according to states [17].

S/N	States	River Basin	Hydropower Potential			
			Total Sites	Developed (MW)	Under developed (MW)	Total capacity (MW)
1	Sokoto	Sokoto – Rima	22.00	8.00	22.60	30.60
2	Katsina	Sokoto – Rima	11.00	-	8.00	8.00
3	Niger	Niger	30.00	-	117.60	117.60
4	Kaduna	Niger	19.00	-	9.20	59.20
5	Kwara	Niger	12.00	-	38.80	38.80
6	Kano	Hadejia Jama'are	28.00	6.00	40.20	46.20
7	Bornu	Upper – Chad	29.00	-	20.80	20.80
8	Bauchi	Upper – Benue	20.00	-	42.60	42.60
9	Adamawa	Upper – Benue	38.00	-	12.70	162.70
10	Plateau	Lower – Benue	32.00	18.00	92.40	110.40
11	Benue	Lower – Benue	19.00	-	9.20	69.20
12	Cross River	Cross River	18.00	-	28.10	28.10
	Total		**278.00**	**32.00**	**702.20**	**734.20**

Small – scaled hydropower plants have the following advantages:

a. They function as protection against flooding
b. The movement and turbulence caused by the rotation of the turbines cause more oxygen to be produced on the water, thereby revitalizing the water and enriching it with fresh oxygen that is good for all living creatures around the river, particularly for the fish in the water. It promotes their growth and is good for fishermen along the river.
c. Filters mounted in front of the turbines, filters out all dirt in the water, and help to keep the river clean, as the collected dirt is removed from the river and disposed outside of the river.
d. They lead to new water landscapes. The dammed river can be used for recreational purposes, and it also creates a new habitat for several wild lives.
e. Small hydropower plants do not destroy the environment as the water in the river is used and returned to the river. They are environmentally friendly form of renewable energy source for the production of electricity.

f. They supply reliable electric power throughout the year.
g. They lead to a healthy decentralization of electricity supply. Repair or rehabilitation work at one plant does not affect the energy supply of a region, as in the case with large plants.
h. In contrast to fossil burning plants, they do not produce dangerous emissions or toxic waste that is harmful to humans and environment.
i. The capital cost of small scaled hydropower plant is relatively small, thereby making private investors affordable to finance it, without large credits.
j. They are quick to construct and can supply renewable and uninterrupted energy on to the national grid within a short and reasonable period of time.

2.4 Prospects For Solar Energy Usage In Nigeria

Nigeria lies within the tropical region between latitude 4°N and 14°N, where there is abundance of sunshine energy all year round [20]. Annual average of daily solar radiation in Nigeria varies as high as 7kW/m^2 per day in the northern border regions to as low as 3.5KW/m^2/day in the coastal regions of the south. Annual average of daily sunshine hours varies from 9 hours in the Northern boundaries to 4 hours in the southern axis.

Viability of solar PV power generation in Nigeria depends on the intensity and duration of insolation or the amount of solar radiation (sun's rays) energy received on a surface area in a given time. Areas of very high solar radiation intensity and long hours of sunshine are most promising sites for solar PV and solar thermal power plants. Areas of low solar radiation intensity and shorter duration of sunshine are least viable for solar PV and solar thermal power plants.

The potential for the solar power plant can be classified as very high, high, medium and low solar radiation (sun's rays) intensity. At a medium solar radiation intensity of 5kWh/m^2 per day and 10% conversion efficiency, solar radiation on 1% of the land area of the country will generate approximately the daily energy equivalent of the energy from a 192,000MW gas power plant working at full capacity for 24 hours per day [15].

Solar inputs during the rainy season lasting from April to October in Nigeria, especially when it is cloudy for a prolonged period of time, will produce small results, thereby reducing electricity production in that period. Also, solar inputs during the dry season lasting from October to March in Nigeria, produces reasonable results, thereby increasing electricity production in that period.

Solar power plants are operated with other sources of electricity, at best, as back-up facilities. Though sunlight is free of charge, energy and material costs of conversion, installation cost; maintenance cost and storage cost are still high.

2.5 Wind Power Classification

Wind turbines may be classified according to the range of wind speed at which they operate. The table 11 gives wind power classification at 50m [21].

Table 11: wind power classification.

Wind power class	Resources potential	Wind power density at 50m (W/m^2)	Wind speed at 50m (m/s)	Wind speed at 50m (m/h)
1	Poor	0-200	0.0-6.0	0.0-13.4
2	Marginal	200-300	6.0-6.8	13.4-15.2
3	Fair	300-400	6.8-7.5	15.2-15.8
4	Good	400-500	7.5-8.1	15.8-18.1
5	Excellent	500-600	8.1-8.6	18.1-19.3
6	Outstanding	600-800	8.6-9.5	19.3-21.3
7	superb	>800	>9.5	>21.3

2.5.1 Wind Farms

A wind farm is a collection of wind turbines in the same location and used for large scale generation of wind power electricity usually hundreds of megawatts. The process of integrating several individual wind turbines at a common bus to get a common output is usually referred to as wind harvesting. Either the consumers (for a stand-alone system) or the utility grid is then fed from the wind bus via a main step-up transformer [21].

2.5.2 Site Selection For Wind Farm Installation

Points considered for selecting a site for wind farm installation includes [21]:

- Open Space: The installation of wind power generation station requires open space availability.
- Consistently bent trees and vegetables: This is a sure sign of strong wind regime in any given area.

- Accessibility: A site chosen for wind farm installation must be one with accessibility for construction, monitoring and maintenances, and power transmission.

During the site visit, other purposes to be born in mind include:

- Check for potential site constraints;
- Permission for the wind plant or its transmission lines;
- Probable local land owners resistance to selling the necessary land and easements;
- Availability of possible location for a wind monitoring station.

2.5.3 Wind Resources Assessment/Data Collection

The wind data used in this study were obtained from the Nigerian Meteorological Agency, Oshodi, Lagos. The data was captured by direct measurement at Latitude (N) $5^0 29'$ and Longitude (E) $70^o 02'$ at a height of 10m by a cup-generator anemometer. The data collection spanned a period of 11 years (2000 – 2011). The recorded wind speeds were computed as the mean of the speed for each month. The site wind speed parameters considered in this study for the wind resource assessment of Owerri include the mean wind speed, most probable wind speed, wind speed carrying maximum energy, mean wind power output and capacity factor of the selected site[21].

The monthly surface wind resource measurement results of Owerri in eastern Nigeria are presented in tables 12, 13 and 14 respectively [21].

Table 12: Eleven years monthly mean wind speed data of Owerri

Month	**10cm height**
January	3.52
February	3.54
March	3.64
April	3.70
May	3.45
June	3.55
July	3.32
August	3.34
September	3.31
October	3.04
November	2.67
December	3.00
Annual	**3.35**

Table 13: Extrapolated monthly mean wind speed

Month	30m height	55m height	70m height
January	4.74	5.60	5.98
February	4.77	5.62	6.00
March	4.90	5.78	6.17
April	4.98	5.88	6.27
May	4.65	5.48	5.85
June	4.78	5.64	6.02
July	4.47	5.27	5.63
August	4.61	5.43	5.80
September	4.46	5.26	5.61
October	4.10	4.83	5.15
November	3.60	4.24	4.53
December	4.04	4.76	5.09

Table 14: Mean wind speed mean with power density variation at 50m hub height

Month	**Mean wind speed (m/s)**	**Power Density (W/m^2)**
January	5.45	99.15
February	5.48	100.8
March	5.63	109.30
April	5.73	115.23

May	5.34	93.27
June	5.50	102
July	5.14	83.18
August	5.29	90.67
September	5.12	82.21
October	4.70	63.59
November	4.13	43.15
December	4.64	62.38
Annual	**5.20**	**86.124**

The monthly variation of the mean wind speed at 10m height and the extrapolations at 30m, 55m and 70m are presented in tables 12 and 13 respectively.

Table 14 contains the monthly estimated mean speed with power density variation of Owerri, in eastern Nigeria, at 50m hub height. The monthly mean wind speed varies between 2.67m/s in November and 3.70m/s in April at 10m height and the corresponding monthly mean power density, varies between 11.65W/m^2 and 31.02W/m^2 respectively. This shows that any wind farm installed in Owerri will have its minimum and maximum outputs in the months of November and April respectively.

2.6 Fuel Cells For Distributed Generation

A fuel cell is a chemical system which converts the chemical energy of a conventional fuel such as a primary battery directly into electrical energy. The by-product of a fuel cell produced from this process is a low-voltage direct current electrical energy.

In fuel cells, the chemical energy of the reactants is converted directly into electrical energy as an isothermal process, meaning that this system does not rely on thermal energy conversion and is not bounded by Carnot cycle limitations, applicable to electrical power plants such as steam turbine and gas turbine. Thus, heat is not involved in the conversion process and high conversion efficiency is possible, about 40-60%. The efficiency of fuel cells and costs per kilowatt of power do not depend on the size or rating of the fuel cell. Fuel cells are used as portable power plants for spacecraft and locomotives.

The main advantages of a fuel cell are low emission of greenhouse gases and high energy density. In a fuel cell, the noise emission is low. The only emissions are harmless gases and water.

Therefore, fuel cells are expected to be used extensively in Nigerian electricity industry. In recent years, fuel cell research and development have received much attention for their higher energy conversion efficiency and lower or non-greenhouse gas emissions than thermal engines in the processes of converting fuel into usable engines [22].

There are many different types of fuel cells, with the principle difference between them being the type of electrolyte and/or the type of fuel that they use. The different types of fuel cells are: proton exchange membrane (PEMFC), solid oxide (SOFC), molten carbonate (MCFC), phosphoric acid (PAFC) and aqueous alkaline (AAFC).

The performance of fuel cells depends on numerous factors such as: the electrolyte composition, the geometry of the fuel cell- particularly the surface area of the anode and cathode, the operating temperature and gas pressure.

2.7 Comparison Of Reserved Energy Resource Potentials

The identified reserve energy resource potentials for electricity generation in Nigeria is presented in table 15 and compared in table 16. The reserved proven estimated energy resources of coal, natural gas and new hydro potentials have been identified to contribute a total of 96,079.4MW to the grid system and when added to the existing installed capacity of 12,066MW will give a total of 108,145.40MW.

Table 15: Reserved energy resource potentials in Nigeria.

S/N	ELECTRICITY RESOURCE MIX	RESERVE VALUES IN THEIR EQUIVALENT UNITS	CAPACITY CONTRIBUTION (MW)
1.	Coal Fuel		
(a)	Proven coal fuel reserve	445.42×10^6 tons	1,964.20
(b)	Estimated coal fuel reserve	2,559×10^6 tons	12,081.96
2.	Natural Gas Fuel		

(a)	Proven natural gas fuel reserve	4×10^{12} cubic meters or 142×10^{12} cubic feet	29,505
(b)	Estimated natural gas fuel reserve	5.3×10^{12} cubic meters or 189×10^{12} cubic feet	39,270
3.	Provisional hydropower potentials		
(a)	Large hydropower scale		12,525
(b)	Small hydropower scale		734.20
4.	Crude oil	33billion bbl	
5.	Tar sands	31 billion oil equivalent	
6.	Fuel Wood (Estimated)	13,071,464	
7.	Biomass Fuel		
(a)	Estimated Animal Waste	61×10^{12} tonnes/year	
(b)	Estimated Crop Residue	83×10^{12} tonnes/year	
8.	Solar Radiation	3.5-7.0 kWh/m^3/day	
9.	Annual Average Wind Energy	2-4m/second	
	Total		**96,079.4MW**

Table 16: Comparison of electricity generation by proven and estimated fuel reserves and existing with on-going generation by fuel in Nigeria.

Electricity Resource Mix	Percentage	Capacity Contribution (MW)
Total Proven and Estimated Reserve Capacity	88.84	96,079.40
Total Existing and On-going Electricity Generation Capacity	11.16	12,066
Grand Total	100.00	108,145.40MW

III. CONCLUSION

The major challenge facing Nigeria power system is how to provide electricity to a rapidly growing population with a sustainable energy reserved resources mix. Reserved energy of coal, natural gas, new hydro potentials, solar radiation and wind energy resources have been identified to form a very strong energy producing installation basket for sustainable power generation in Nigeria.

The reserved proven and estimated energy resources of coal, natural gas and new hydro potentials have been identified to contribute a total of 96,079.40MW to the grid system and when added to the existing installed capacity of 12,066MW will give a total of 108,145.40MW.

With new generating schemes introduction in Nigeria power industry based on these reserved energy resources, large and small scale organizations, which have been affected by the incessant power supply, will now be stabilized.

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