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The Smart Grid and Renewable Energy Integration in Nigeria

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Km: Kilometer

MW: Megawatt

ECN: Energy Commission of Nigeria

TCN: Transmission Company of N igeria

NEPA National Electric Power Authority

NERC: Nigeria Electricity Regulatory Commission

GDP: Gross Domestic Product

NIPP: National Integrated Power Projects

IPP: Independent Power Plants

PHCN: Power Holding Company of Nigeria

MVA: Megavolt amperes (one million volt amperes)

VA: Volt-ampere

kV: Kilovolt (one thousand volts)

DSM: Demand side management

kWh/m^2: Kilowatt hour per square meter

mWh/y: Megawatt hours per year

kWp: Kilowatt peak

mWp: Megawatt peak

GWH: Gigawatt hours

Abstract

Nations striving towards development cannot afford to undermine the essence of energy. Nigeria as one of the countries has been wallowing in its power situation with insignificant improvement. This is at a time when developed nations have shifted their attention to renewable sources in the quest for sustainable development. Global efforts are being made towards the adoption of renewable energy sources as a substitute for presently dominating fossil fuels. These efforts are prompted by challenges such as pollution, a major issue in the list of global crisis.

The potential opportunities renewable energy could offer are challenged by inadequate supply for present energy demands and the intermittent nature of some sources.

This paper focuses on current solutions being developed, aimed at bridging the gap between renewable energy sources and its successful implementation within the Nigerian context. Nigeria currently features renewable energy sources such as the hydropower. It holds potentials in other renewable energy sources, which remain untapped. Advances in the area of power management systems and grid technologies provide a great solution to some of these challenges, also contributing major economic benefits among many other gains. This paper introduces the smart grid concept as a solution to the energy challenges, offering a place for renewable energy sources by helping to solve inherent problems with various technological initiatives while providing an improved energy demand and supply experience.

1.0 Introduction

1.1 Overview

Nigeria, a West African country is centered on geographical coordinates 10N and 8W with a total land area of 923768 km, making it the 14th largest nation in Africa.[1] Nigeria is partially landlocked with a coastline of 853 km. IT borders Benin and Cameroon to its West and East respectively, with Chad and Niger at the North. The population is about 16,2471,000, with an annual growth rate of 3.2%.[2] Nigeria is made up of 36 states which the six geopolitical zones; the North-East, North-West, North Central, South East, South-West and the south-south. Major cities include Lagos (commercial capital), Port Harcout, Ibadan, and Abuja the capital.

Figure 1: Nigeria map
Source: UN Data, *Nigeria* 2014

The country has two major seasons; the dry and the rainy season. Dry seasons occur from December to February, while the rainy season is between June and September.[3] Annual rainfall is about 150-200cm in the southern tropical belt, 50-150cm in the central region and less than 50cm in the North.[4] Vegetation belts are made up of Mangrove swamps, rain forest, woodland savannah, and the Guinea and Sudan Savannah.[5]

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1 Oxford Business Group, *The Report: Nigeria,* 2012
2 ibid
3 ibid
4 ibid
5 Embassey of Federal Republic of Nigeria, *About Nigeria*, Washington, DC 2009

1.2 Economy

The country economy stands as the second largest in Africa,[6] with GDP per capita of US$1509.0 and GDP growth rate of 7.13% in 2011.[7] Nigeria is blessed with great potentials in its reserves such as coal, zinc, tin, limestone and lead. However, it is popularly known for its oil and natural gas, which have been major sources of revenue. These abundant resources, even so, have not transformed to quality of living as about 68% of the population still live below the poverty line of $1.25 a day.

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[6] Op Cit
[7] ibid

2.0 Energy Profile

2.1 Introduction

Energy is pertinent to national development; its importance for a developing nation like Nigeria can therefore, not be overemphasized. Of serious concern, therefore, is the country's energy situation.

Crude oil which serves as the pillar of the Nigerian economy is a major energy source. Of even higher potential is the country's natural gas resource,[8] much of which is being flared in spite of awareness of the wasteful and polluting nature of this activity. Security issues in the Niger Delta region of the country have, however, contributed its setbacks in maximizing exploration activities, with ripple effects on the economy. Biomass, primarily as fuel wood serves as a major energy source popular among the rural dwellers to meet off-grid energy needs.

Efforts are being made towards renewable energy options with little impact made presently. Hydro power as a major renewable source is still largely untapped, with only about 19% of available potential being harnessed. Other renewable energy sources, such as solar and wind have no significant footprint as their use is limited to small-scale applications like community projects, such as solar pumps, and street lighting.

Nigeria is faced with numerous challenges stemming from energy inadequacies as it has not been able to meet up with its energy needs over time. Coupled with this is the quest for a qualitative energy mix for a sustainable development.

2.2 Energy Mix

Nigeria currently suffers a huge energy deficit with a poor mix despite proven available resources. Grid electricity is grossly inadequate with only 50.3% of the population of about 168 million with grid accessibility. Total installed capacity is estimated to be 6852MW with about 60 % of this available for supply.[9] These figures are, however, ridiculous for a nation with such huge population and available energy potential. Generation was once reported to have dropped as

[8] Uzoma, Nnaji and Nnaji 2012
[9] Nigeria Electricity Privatisation (PHCN) n.d.

low as 2628.6 MW in 2013; coming after a recent value of about 4000 MW was recorded.[10] This sharp decline was attributed to disruptions in gas supply to some plants. Total available output is characterized by fluctuations of such due to issues of gas supply, security, and water levels in the case of hydro power.

Nigeria hasn't made any significant progress in the power sector over the past years despite claims of financial input. This is largely due to lack of political will, among many other obstacles. Various efforts are, being put in place for the improvement of this sector such as privatization and reform programs. The total energy need may not be absolutely estimated as underlying needs may not be fully accounted for a value of 200,000 MW has been put forward.

Biomass dominates total energy consumption up to about 82% according to EIA estimates. The majority of rural dwellers lack accesses to the grid, hence the use of fuel wood to meet off-grid energy needs in the rural areas where it has become a commonplace.

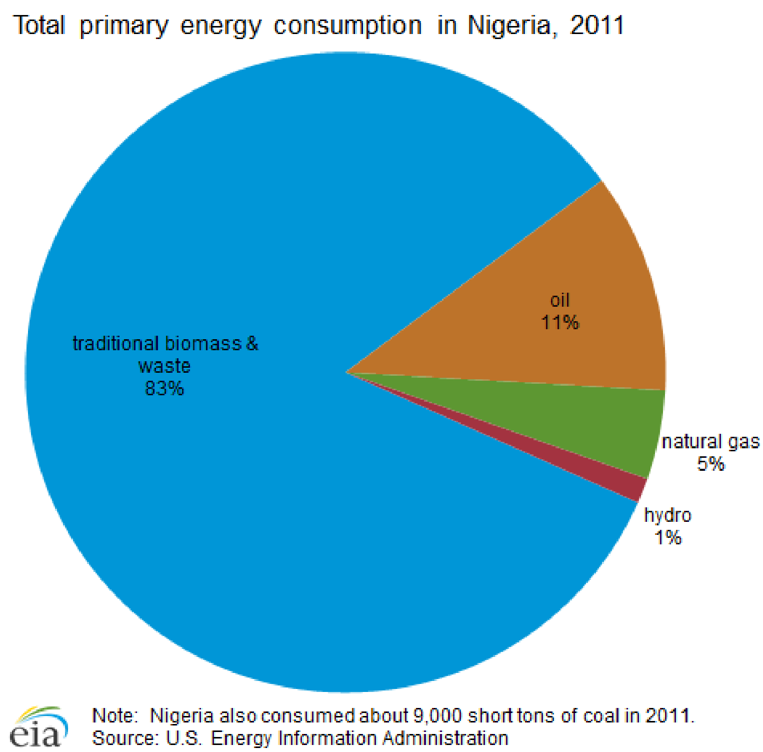

Figure 2: Primary Energy Consumption, 2011
Source: U.S. Energy Information Administration

Fossil fuels also serve the energy mix, second only to biomass in its consumption amounts. The use of fossil fuel penetrates every sphere of energy consumption even for domestic generation as it supplements or in some cases replaces grid electricity due to reliability needs. Generators are found in every nook and cranny, meeting residential and industrial energy needs. They have in some cases replaced the public supplies. Extra cost incurred in the commercial use of these plants is passed on to consumers in form of increased prices. This has serious economic effects as the World Bank ranks Nigeria 147 out of 189 in its ease of doing the business index for 2013.

[10] The PUNCH, *2013:Nigerian Economy in Perspective*, January 1, 2014

Figure 3: Use of Generators for Meeting Energy Needs of Businesses
Source: Investigating Post, Power Generation in Nigeria, 2013

Nigeria boasts of large amounts of natural gas reserves even more than its much acclaimed crude oil in energy terms.[11] Much of these are being burnt off as associated gas in the wasteful flaring practice despite the level of pollution it poses to the environment. Natural gas which could serve for power plants with better efficiency is underutilized due to poor infrastructure, wavering policies and security challenges in the oil rich Niger delta region of the country. Natural gas consumption is estimated to be about 5.03 billion cubic meters,[12] majorly fuelling the thermal generating plants.

Hydro power serves as a major renewable energy input to the grid. Nigeria has been able to utilize some of its rivers for hydro electric power generation which stands at about 20.9% of total electricity production capacity in 2011.[13] Previous statistics however shows a decline to this point. Available potential from hydro power is estimated to be about 10,000MW, thus rendering current capacity relatively low with a large room for improvement. Percentage

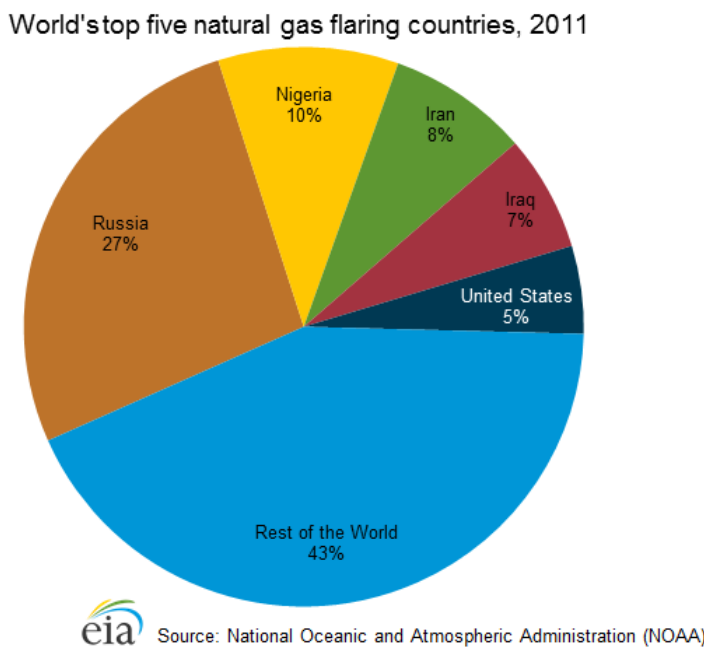

Figure 4: World's Top Five Natural Gas Producing Countries, 2011

[11] Uzoma, C C, C E Nnaji, and M Nnaji. "The Role of Energy Mix in Ssustinable Development of Nigeria," *Continental Joournal of Social Science* 5 (2012): 21-29.
[12] Central Intelligence Agency. *The World Factbook* n.d.
[13] The World Bank *Nigeria Data*, n.d.

of total primary energy supply is also put at 0.4% for hydro in 2009.[14]

Solar and wind energy are still largely untapped with no grid input from these sources. Solar, however, exhibits more potential for generation. The usage of these sources is extremely limited to community pilot projects and other minor uses such as pumping, solar heating and street lighting. Various policies are being put in place to encourage the integration of these sources.

Coal production and consumption have experienced a sharp decline since the discovery and exploration of oil. Consequently this saw to the replacement of coal-powered train engines, which constituted a large share of coal consumption. With mining operations which commenced in 1916, coal served as a source of energy, forming about 70% of commercial energy consumption from 1958-1959.[15] This value will now drop to a miserable 0.02% in 2001 and 9,000 short tons in consumption in 2010 according to EIA estimates.[16] Meanwhile, the US with the largest amount of recoverable reserves, coal still remains a major source. As the use of coal is faced with strong criticism regarding its polluting effect, efforts are being made with the development of viable technologies for safer coal usage. Coal, however, remains a viable global energy source, fueling about 41% of world electricity in 2009.[17] The Nigerian government is making efforts to revive the coal industry to utilize available coal to further diversify the country's sources and most importantly fill the gap between supply and demand, which characterizes the energy sector. These efforts saw the Federal Ministry of Mines and Steel sign a Memorandum of understanding with a Nigerian-Chinese consortium with the objective of developing a coal-fired power plant with the capacity of about 1000MW.[18]

Considerations for nuclear power as part of the nation's energy mix are growing. However, being faced with vulnerability concerns, its usage is still far from general acceptance. Coupled with this is the huge expertise and responsibility requirement associated with nuclear energy management. Thus, Nuclear energy still isn't much of a reality.

[14] International Renewal Energy Agency, *Renewable Energy Country Profile: Nigeria.* n.d.
[15] Op Cit.
[16] US Energy Information Administration, *Nigeria Analysis* 2013.
[17] World Coal Association, *Coal – Energy for Sustainable Development,* 2012.
[18] Op Cit.

2.3 Energy Policy

The national energy policy was formulated by the Energy Commission of Nigeria. The ECN shoulders the responsibility of formulating policies and implementation strategies that guide the energy sector of the country. The NEP formulated in the year 2003 recognizes the need to put in place a policy based on a wider energy perspective with regard for energy-related sectors. The national energy policy sets out objectives with the necessary strategies for the successful actualization of its laid down policies, with the goal of maximizing energy resources for sustainable development.

Private sector participation is highlighted to ensure efficiency in management of the energy sector, especially with regards to finance. This has become necessary as government alone can no longer shoulder the financial responsibility needed to attain the desired status as it has been doing in the past. Much of the fiscal input is however, hoped to come from foreign partnerships. Indigenous firms are, however, encouraged. The NEP maps out strategies to create an enabling and attractive environment for foreign investors while also making incentives for local participation. The need for a variety in the energy mix for a sustainable energy supply is also discussed with an emphasis on renewable energy such as solar, wind and hydro power. Hydro which already serves as a major grid input is to be further harnessed with the creation of Small Hydro Electric Project to cater especially for the rural dwellers that lack access to the grid.

3.0 NIGERIA POWER SYSTEM

3.1 Introduction

Nigerian Power system has not been one marked with significant success. Inadequacies characterize the system at all levels, leaving a huge deficit of energy demand. It started in 1896 when power generation began with the Electricity Corporation of Nigeria established in 1951 taking over National Electric Supply Company.[19] Progress saw the development of the Nigeria Dams Authority responsible for hydropower development, later merged with ECN to from the National Electric Power Authority. NEPA later transformed to PHCN which itself was then unbundled into 18 successor companies all under the reforms which ushered in privatization to bring about the much needed improvement in the sector. The Nigerian Electricity Regulatory Commission was also established as a regulatory body, with the objective to customer's interest in relation to electricity generated. The National Integrated Power Projects (NIPP) also came on board with the Independent Power Plants forming an integral unit as a move by the federal government to increase capacity generation.

3.2 Generation

The low level of generation has earlier been emphasized. Generation stations consist of three (3) hydropower stations and 11 thermal stations, giving a total of 14 generation stations, half of which are over 20 years old. Installed capacity is put at 7876MW with less than 4000MW available.[20] Hydropower forms about 20.9% of total generating capacity but findings prove a much higher potential in excess of 10,000 MW.

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[19] Kusamotu & Kusamotu, *Power Privatization Historial Overview,* n.d.

[20] Sambo, A. S., B. Garba, I. H. Zarma, and M. M. Gaji. "Electricity Generation and the Present Challenges in the Nigerian."n.d.

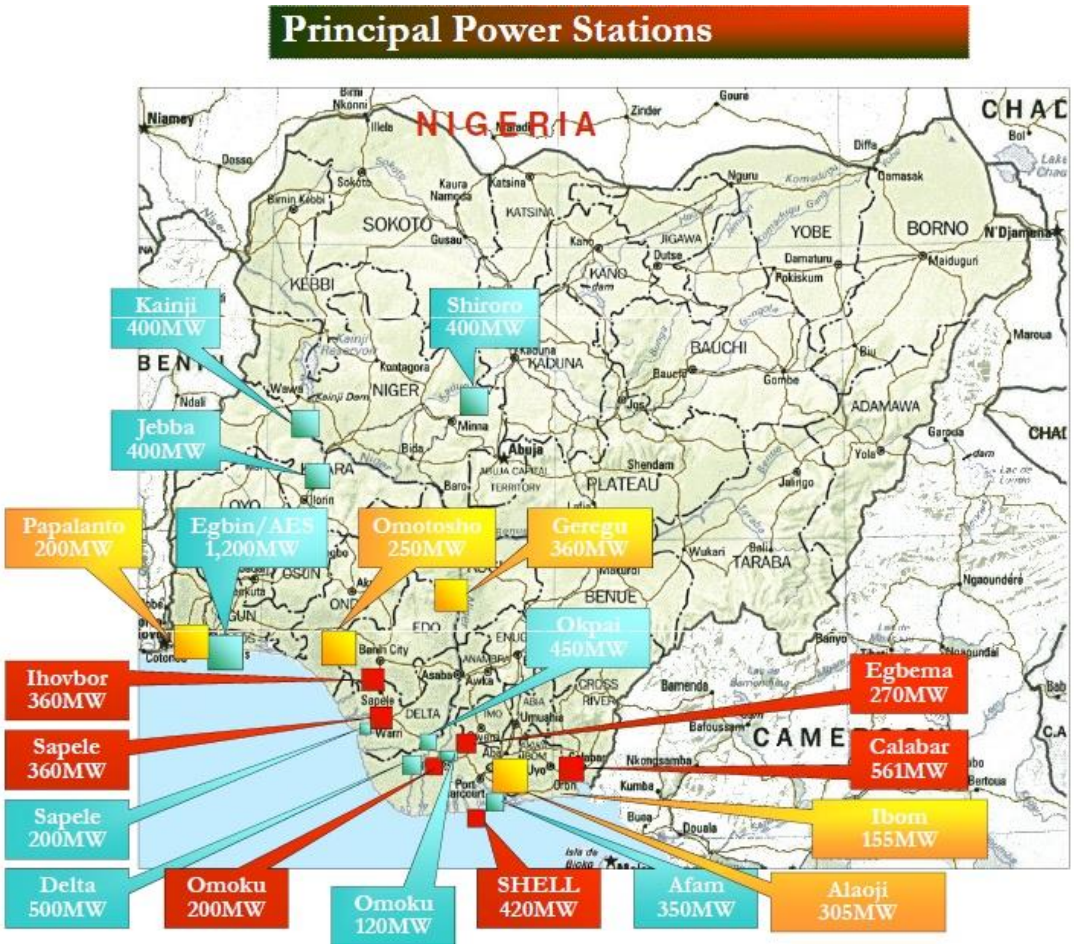

Figure 5: Principal Power Plants
Source: Labo, **H.S.** *Current Status and Future Outlook of the Transmission Network,* 2010

The optimal performance of these plants is often challenged by various disturbances stemming from ageing infrastructure, poor maintenance and inadequate gas supply in the cases of the thermal plants. Hydropower which is dependent on water levels is also challenged by variations in this regard. Work is being done to see to the integration of solar and wind renewable sources are also underway. Efforts are also being made to revitalize the coal industry in Nigeria. Much is still needed to be done to match capacity with capabilities, with high investment opportunities.

3.3 Transmission and Distribution

The Transmission Company of Nigeria shoulders the management of the radial transmission network of 330kV and 132kV lines.[21] The network consists of 5, 523.8km 330kV lines and 6801.49km of 132kV. Substations of 330/132KV with a total installed transformation capacity of

[21] Op Cit

7,688M VA which translates to 6,534.8MW real power equivalent; and also 105 substations of 132/33/11 kV with capacity of 9130 MVA which translate to 7760.5MW. For the 330/13 2kV, and 132/33 kV available capacity is put at 7,364MVA and 8448 MVA respectively with an average transmission loss of 8.5%.[22]

The current infrastructure is strained by prevailing demands, which have been detrimental to the lines. Challenges include inadequate infrastructure, high losses along the lines. The lines are also susceptible to failures as radial lines are without necessary redundancies.[23] Portions of the grid have become obsolete arising from poor maintenance, a bye product of inadequate funding.

There are however ongoing projects aimed at improving the current infrastructure which borders on wider coverage and line improvement.

Distribution is currently under control of 11 distribution companies with line running 33kV and below.[24] The distribution is presently poor with features such as low voltage profile, poor billing system and frequent outages. Much hasn’t been done to remedy the situation. Challenges facing distribution include transformer overloading, without the appropriate protective measures, bad feeder pillars, and substandard equipment in some cases. All these culminate to poor customer service. Manpower is also a major challenge both in quantity and quality and as in all other cases, poor funding. Most of these challenges are hoped to fade out with the ongoing reforms. Security of the lines is also a major hurdle, as undue taps occur along the lines which are not accounted for.

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[22] Labo, **H.S.** *Current Status and Future Outlook of the Transmission Network,* 2010
[23] ibid
[24] Op Cit

3.4 Outlook

Much is expected from the ongoing reforms and National Integrated Power Project coming on board, though returns from these moves may not surface soonest. The challenge of meeting energy demand must be solved. IAEA modeling tools, the MESSAGE and the MAED, have been used for analyzing energy projections. Four scenarios were posited for a period of 25 years. The reference and high-growth scenarios are based on 7% and 10% GDP growth respectively. Then the optimistic scenario I and II; I with 11.5% GDP growth and II with 13% GDP for vision 20:2020. The major means to the various levels of growth is identified as the growth and structure of the economy; with demand on grid electricity serving a chief ingredient. Base year for the projection is set at 2005 with suppressed demand which should gradually diminish and therefore absent by 2010.

Scenario	2005	2010	2015	2020	2025	2030
Reference (7%)	5746	15730	28360	50820	77450	119200
High Growth (10%)	5746	15920	30210	58180	107220	192000
Optimistic I (11.5%)	5746	16000	31240	70760	137370	250000
Optimistic II (13%)	5746	33250	64200	107600	172900	297900

Figure 6: Electricity Demand projections per scenario, MW
Source: A. S. Sambo, Matching Electricity Supply with Demand in Nigeria 2008

Results from the projection indicate a rise of 5,746 from the reference year to 297,900 MW in 2030. This translates to cost in investment and operation of US$ 484.62billion within the period.[25]

Supply projection depends heavily on demand as electricity must be used as it is being generated. Hence, the MESSAGE tool, from the International Institute for Applied System Analysis, uses the energy demand projection as input working data. Supply would incorporate in addition to demand, conversion and utilization processes, which results in the eventual supply. Supply is projected to rise from 6440MW in 2005 to 276229 in 2030 in the optimistic scenario.[26]

[25] Op Cit
[26] ibid

Variations in the final energy use at different periods are also considered as well as emission ontrols. The projections are midterm as technological development may pose uncertainties in the long run.[27]

[27] ibid

4.0 Smart Grid Initiative

4.1 Introduction

Energy concerns are growing globally. The required level of reliability and efficiency is on the increase. Recently growing concerns has also prompted the renewable energy solutions for a sustainable energy profile, while playing down on fossil primary energy sources. It therefore, becomes pertinent to develop the current electricity infrastructure to meet proliferating demands.

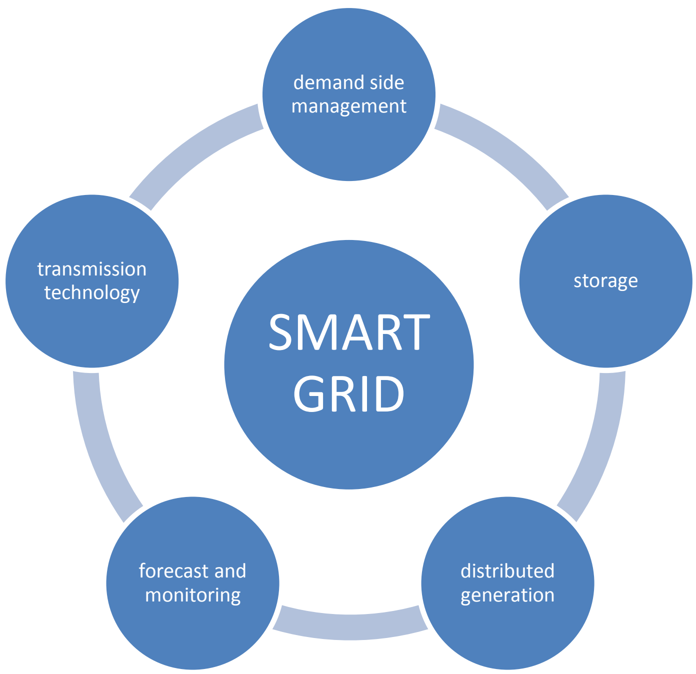

Figure 7: Elements of the Smart Grid
Source: Author

The smart grid simply, is used to describe a technological advancement in the system we have today in a way that improves its overall efficiency. It is "an electricity network that uses digital and other advanced technologies to monitor and manage the transport of electricity from all generation sources…"[28] The smart grid platform with its various integral parts aims to solve the challenges being faced while improving the existing system.

Electric grids are complex interconnected systems and infrastructure from generation to consumption level. Current system consists of large centralized plants with high voltage

[28] Iinternation Energy Agency. *Smart Grids road Map,* 2011

transmission to substations stations where the high voltage is stepped down for distribution to consumers at various levels. The unidirectional system lacks the necessary feedback system to support control operation. The current grid is thus prone to reliability issues required in growing energy demands let alone projected requirements. Today's grids are characterized by partial control, poor integration and optimization, reactive maintenance, fragility and focus on utility.[29]

Various needs are arising with development, revealing the inadequacy in the existing infrastructure. Consumers will demand for better service quality. There is the need to redress the use of traditional energy sources. Distributed generation as a developmental approach for increased capacity and the integration of renewable energy needs be catered for. As concerns for the environment increase, it will become pertinent to reduce the carbon footprint. There will also be a need to enable the development of new products and services for a liberalized market.[30]

Technologies in the present grid are relatively obsolete as compared to developments experienced in sectors like ICT. The smart grid will operate in a duplex communication system, promising better efficiency. It has been described as a win-win situation for stakeholders. Consumers will now get involved in power management decisions with the aid of household the devices. Utilities will also profit in the long run. Initial cost estimates are huge but returns on better efficiency and improved billing systems among many other improvements. The smart grid promises security, control, optimization, enabling self-healing and improved interaction with a focus on customers.[31]

4.2 Technologies

Various technological propositions and concepts have been put forward towards the smart grid implementation. Most of these technologies are not out of the box as they are based on infrastructure will help achieve the smart grid objective.[32] They cut across the different stages from generation to consumption as illustrated in the above diagram. Some of these concepts will be discussed as follows.

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[29] National Instruments *Grid2030: Intelligence through SCADA.* n.d.
[30] European Commission. "European Technology Platform - SmartGrids Vision and Strategy for Europe's Electricity." 2006
[31] Op Cit
[32] U.S. Department of Energy, *The Smart Grid: An Introduction* n.d.

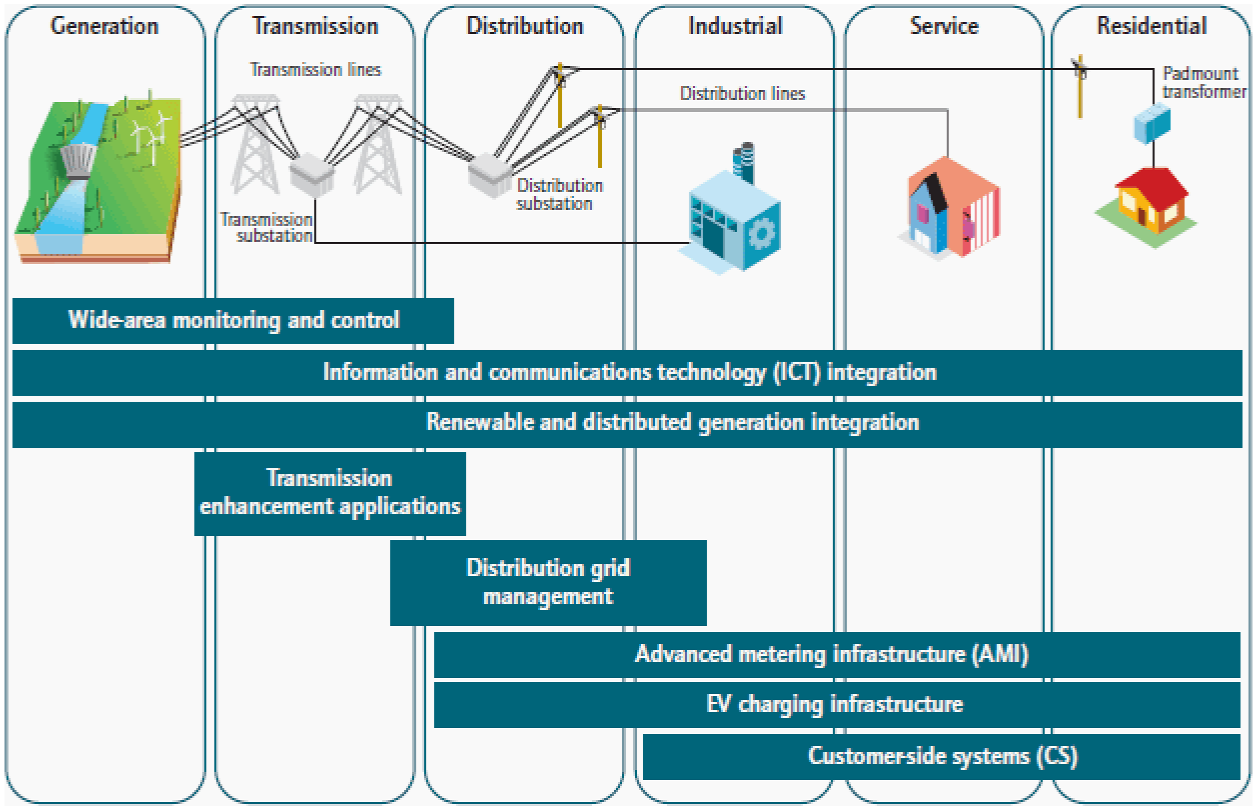

Figure 8: Storage Device Application Domain
Source: Electrical Engineering Portal, *Smart Grid Overview*, 2012

4.2.1 Monitoring

Monitoring is important to help collect real-time data of system components and parameters as regards performances to increase system visibility. Monitoring will incorporate advanced sensors, communication and control tools. With the proliferation of highly sensitive electronic equipment, the essence of power quality cannot be overemphasized. This will aid in the efficient control of the system by operators as data collected in real-time could help in preventing black-out and system failures. Data analysis could also improve efficiency in making projections on general performance.

This major concept will play an important role in seeing to the successful integration of intermittent sources. In essence, real-time data monitoring will help to prompt necessary actions in good time to help in mitigating threats thus improving reliability.

Synchrophasor technology takes sub-second reading, such as phasor units of voltage and current physical characteristics, which helps to maintain grid reliability and also serve as useful calibrating models for system resources such as generation, storage and load.[33] A supervisory control and data analysis (SCADA) system helps to provide real-time monitoring and control of systems,[34] communicating large amounts of data for control to help sustain reliability.

4.2.2 Advanced Metering Infrastructure

Advanced Metering Infrastructure is used to describe an integration of various technologies, which consist of smart meter, data management systems, which operate within a duplex communication system between consumer and utilities.[35]

Traditional meters are known to record usage data over a period of time. Readings are then taken by operators to determine consumption. There are also prepaid meters, which run down energy credits on usage and may be recharged once exhausted. This helps to eliminate the meter reading and inaccurate billing in some cases. AMI in addition to the present system, integrates technologies such as to enable communication between utilities and consumers in near real-time.

Advanced metering infrastructure will be a major concept within the smart grid. Resident on the consumer side, it provides information, which helps to implement the demand response, where consumers make informed decision regarding energy consumption or power usage. Smart meters would help perform such functions as providing pricing information, collection of consumption data, quality monitoring while maintaining communication with other household devices. Technologies such as the Internet, fiber optics and radio signals may help provide the necessary communication.[36] The Home area network links the smart meter and other devices to provide the means for consumer interaction for energy management purpose. Energy management may involve set points that limit energy usage and load control.[37] AMI may also provide remote connection and disconnection and provide means for improved diagnosis from load profiles.[38]

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[33] California ISO, *Smart Grid Road Map and Architecture.* (EPRI 2010)
[34] Taylor, Tim, and Hormoz Kazemzadeh. "Integrated SCADA/DMS/OMS:Increasing Distribution Operations Efficiency."n.d.
[35] *What is the Smart Grid,* SmartGrid.gov n.d.
[36] (National Energy Technology Laboratory (NETL) 2008), Advanced Metering Architecture
[37] ibid
[38] Op Cit

4.2.3 Advanced Forecasting and Variable Generation

Advanced forecasting "determines resources needed to serve demand based on load forecast..."[39] Demand (consumption) and supply (generation) must be appropriately matched for grid optimization. Advanced forecasting helps to provide the necessary information to assist in dealing with contingencies. Advanced forecasting will provide prior information of resources, load and grid conditions, which would help in effective scheduling and dispatch; helping utilities to plan according to consumer requirement from analyzed data.

Forecast would bring about a dynamic nature in all levels of the power system while helping to balance variable generation, keeping the grid stable.

4.2.4 Storage

Energy storage generally is not an efficient process. Within the smart grid platform with the aid of advanced storage techniques, energy storage would become an integral part of the power system. This will work in collaboration with variable generation. Storage facilities could also help to get the best of renewable resources and for regulation purposes such as frequency checks. Storage technologies include the popular battery and flywheel. Storage helps to defer the need for additional capacity infrastructure.

4.2.5 Transmission Technology

HVDC and FACTS are mature transmission technologies, Flexible AC transmission based on power electronics help to improve the control and transmission optimization. HVDC transmission systems are suited for long distance transmission. High voltage DC transmission has proven to be more efficient for long distance transmission, thus providing the platform for transmission of off-shore wind and solar farms to load centers.[40] Hybrid systems will combine the suitability of AC and DC transmission technologies for grid transmission. The smart grid involves diverse concept and system that actually brings about it actualization. These concepts serve as the intelligent features of the grids and may incorporate various technologies to help achieve the definitive smartness.

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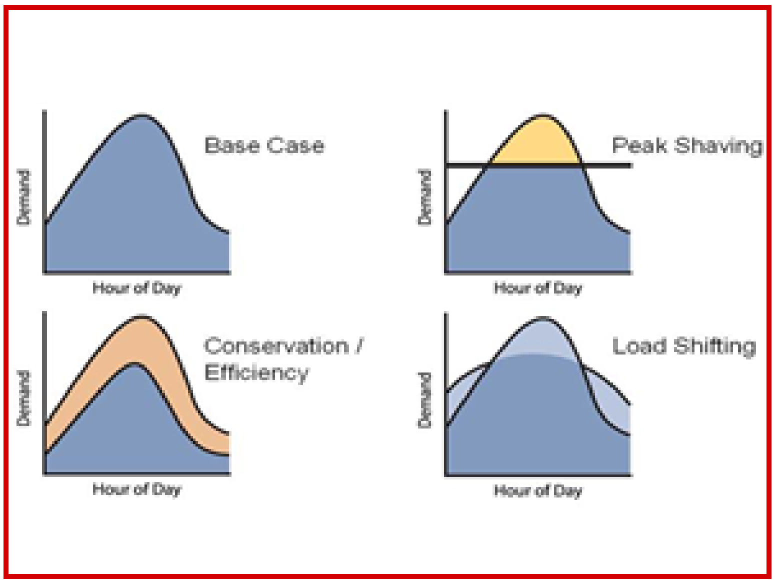
[39] Op Cit
[40] Op Cit

4.2.6 Demand side management

Demand-side management is basically power control from the consumer end. It describes all processes involved in grid interaction by consumers with an end to achieving grid stability. Challenges of demand and supply are shared by utilities and consumers for mutual benefit. Old systems provide minimal control options for consumers as no path exist for information backflow. Hence consumers take supply as is and cannot actually partake in grid management.

DSM aims to engage the consumers with smart devices, which would present near real-time power data to consumers for decision-making and then relay responses to utilities.[41] Responses will increase visibility as well. With the aid of an energy dashboard system, consumers are presented with various options to initiate commands, which may involve powering off high power consuming appliances to help adjust usage as required to help maintain a balance. Responses may come in form of manual activity or automatic responses based on set limits. These include peak shaving, load shifting and conservation. These services rendered by consumers to utilities could involve incentive to help encourage participation. Motives for control of energy use may include pricing with the aid of the real-time pricing.

Figure 9: Demand Side Management
Source: Powerwise, *Demand Side Management* Regulation and Supervision Bureau



To aid DSM, technologies, such as building automation system and home area networks, would play an important role. Automation of systems will help control and monitor home systems, while networks help to communicate consumer-defined responses.

4.2.7 Distributed generation

Generation serves as the foundation of the power system. Primary energy sources such as coal and gas are the chief

[41] Op Cit

sources of fuel for electricity generation. Generation stations as they could be popularly found are large centralized units usually built at some remote location far away from major habitation. The smart grid would enable distributed generation technology, which aims to solve challenges related to generation as it currently is while providing ancillary services.

Distributed generation (DG) is not an entirely new concept as the case was similar before the advent of large scale generation that we have today. Various definitions have been proposed to explain distributed generation. Generally, DG is used to mean generation of a relatively small-scale. Distributed generation as it concerns this paper describes separate generation units that within the smart grid context, distributed generation may be in consonant with features as renewable energy sources and co-generation. Other components such as storage devices like batteries and flywheel may also be included under the term distributed resources.[42] The characteristic small-scale and separations from the main grid in some cases are major distinguishing features.

[42] Introduction to Distributed Generation Interconnection n.d.

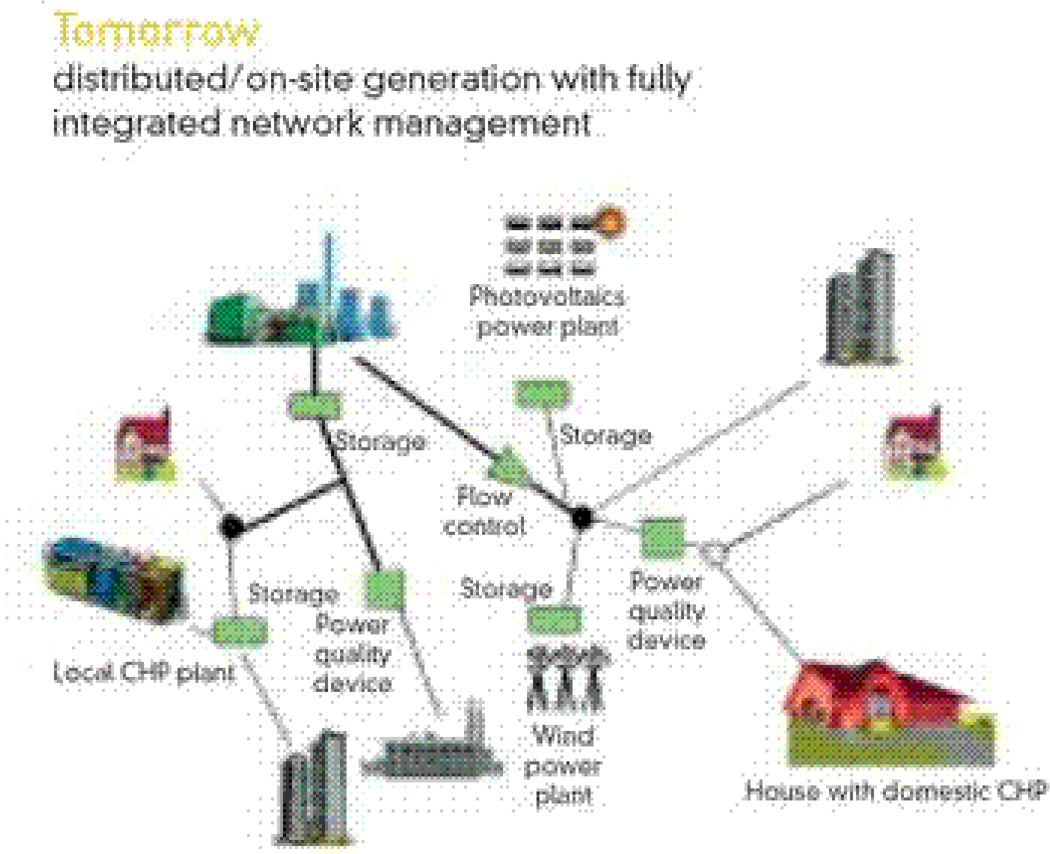


Figure 10: Distributed Generation
Source: Virginia Tech Department of History, Distributed Generation Publications

DG technologies which are currently being utilized for improved overall efficiency. Existing technologies include: micro turbines, fuel cells, and reciprocating engines. Renewable energy sources include PV cells and wind turbines could also serve as DG source.

DG systems could provide an economical alternative to peaking plants by helping reduce peak loads. They could serve as emergency systems or district units that supply electricity needs nearby loads and with the aid of Combined Heat and Power (CHP), also meet the thermal needs thus increasing efficiency. Some consumer may require specific power quality could benefit from such ancillary services such as voltage support, power quality and reactive power all enabled by DG. Renewable sources have the potential to thrive in this environment. DG may provide the platform to utilize low or medium scale generation capacity of solar PV cell arrays and wind farms, with better control as system visibility at this level is improved. The opportunity to build up generating units according to suitability to particular environmental factors will help optimize the use of location-specific resources such as wind speed and solar intensity.

5.0 The Smart Grid and Renewable Energy Integration in Nigeria

5.1 Introduction

It has become imperative to explore renewable energy sources in the light of challenges of traditional sources, such as depletion of resources and pollution. Renewable energy sources in Nigeria ,such as solar, wind and hydro, offer promising solutions to the looming crisis, serving as inexhaustible supplies and clean sources. The intermittent nature is, however, a huge barrier to integration efforts. Sources such as solar and wind unlike fossil fuel generation cannot be easily controlled and non-dispatchable[43] with increased penetration introducing regulation challenges.

5.2 Renewable Energy in Nigeria

5.2.1 Solar energy

The location of Nigeria gives rise to an appreciable amount of solar energy radiation with a fair distribution. Radiation levels vary across the country with 3.5 kWh/m^2 per day in the coastal latitude to 7 kwh/m^2 per day in the far north;[44] giving an annual average solar intensity estimated to be 1934.5 kW/m^2.[45]

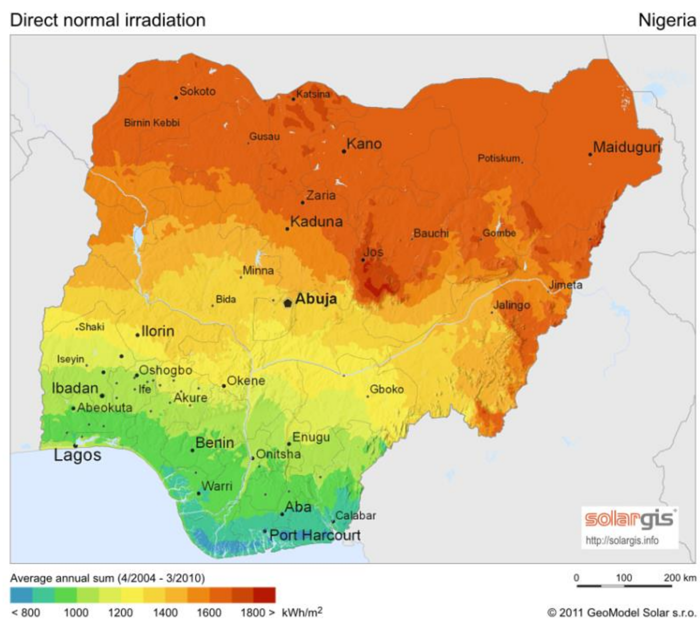


Figure 11: Direct Normal Irradiation Across the Country
Source: Solargis Info, *I-maps : Nigeria*

Solar energy usage has not gained much popularity in Nigeria. Its usage is limited to pilot and demonstration projects. Solar thermal energy has found various applications, including solar cooking, heating and drying applications. The ECN has developed solar water heaters, solar dryers, and solar cookers.[46] Solar energy applications serve various energy needs among the rural

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[43] National Renewable Energy Laboratory 2011
[44] A. Sambo 2009
[45] RENEWABLE ENERGY MASTERPLAN 2005
[46] ibid

dwellers as they are usually deprived of grid supply. Solar PV technologies are growing, though awareness is relatively low. PV installations are commonly found in street lighting. They find use in rural electrification projects as well as low and medium level uses such as solar pumps. PV cells have been installed to serve needs of rural clinics and schools.

Figure 12: Solar PV Installations in Nigeria
Source: Ecofriend, *Solar Power Bring Light to Dark Nigerian Village*

Solar energy initiatives are on the rise with various Research and Development projects. The Sokoto Energy Research Centre has developed solar water heaters as well as solar cookers. National Centre for Energy Research and Development Nsukka has also developed chick brooders. There are demonstration projects for solar stills. An estimate 264 kWp of module installation was recorded in 1999 with an estimate of 1.74 MWp for 2004.[47]

Solar energy in Nigeria has got more to offer however. According to Sambo, with 1% of Nigeria's land area covered by solar collectors, given prevailing efficiencies and an average radiation of 5.5kWhm^{-2}/day., it will be possible to generate 1850×10^{3} GWh of electricity per year; which is over 100 times grid consumption level.[48] However, there is currently no grid input from solar energy.

Solar energy is basically driven by the unavailability of grid supply. Its growth is hindered various inherent challenges. High cost of system components is a major discouragement. Furthermore, the present level awareness has not matched up as to initiate a transition, so the majority would rather stick to traditional sources. Standards and regulatory policies to support solar energy integration remain largely inadequate coupled with security challenges associated

[47] Ibid
[48] Op Cit

with standalone installations as well as the current low level of technical expertise in these technologies.

5.2.2 Wind Energy

Nigeria experiences strong winds from April to October arising from the seasonal rain-bearing westerly winds and strong North-East trade winds from November to March.[49] The southern regions experience winds ranging from 1.4 to 3 m/s while speeds could reach 4-5.12m/s in the extreme North. Studies indicate potential of up to 8 MWh/y in Yola, 51 MW/yr in Jos plateau and 97 MW/yr in Sokoto at a height of 10m.[50] The Nigerian Meteorological Agency (NMA) helps to collect wind data in Nigeria from stations, mainly airports and urban centers, using various instruments. Generally, the southern parts of the country experience relatively weak wind speeds as compared to the Northern parts, except for the coastal regions and offshore.[51] The mountainous regions in the North, however, receive the strongest winds, consequently; major initiatives are found in the North.

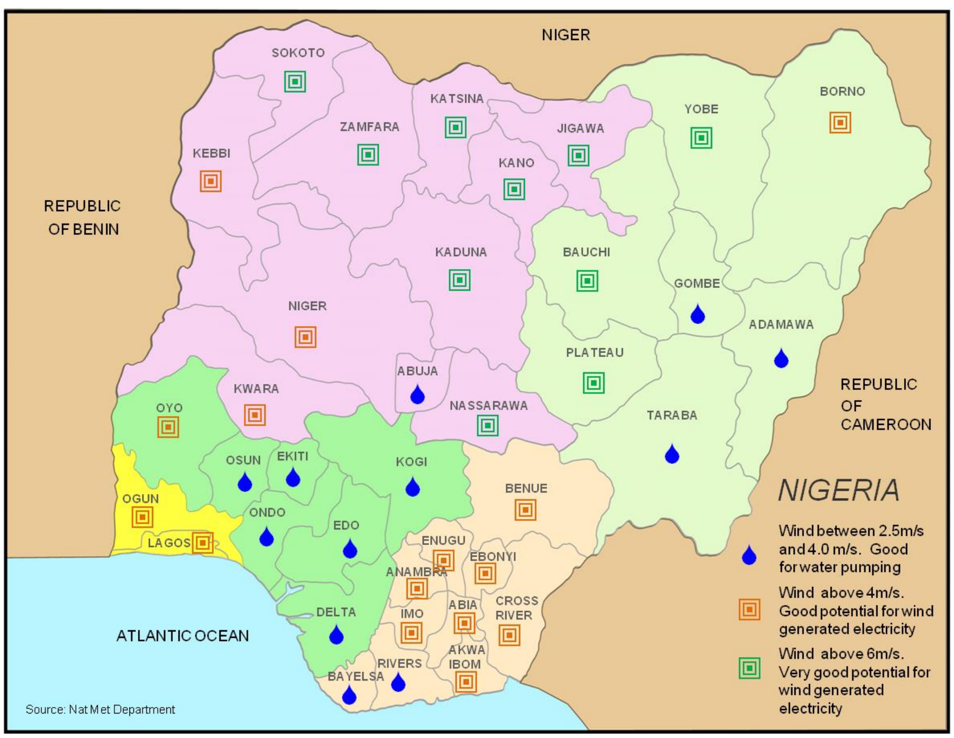

Figure 13: Wind Speeds Across Nigerian States

Source: Nigeria Energy, *Wind Power*

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[49] Op Cit p. 16
[50] Ibid
[51] Ibid p. 100

Wind speeds could vary drastically from one region to another within the country, a result of variations in topography.[52] Nigeria has not witnessed appreciable wind energy penetration. Wind pumps manufactured in Nigeria by the Tractor and Equipment (T&E) division of UAC were successfully installed as test units in Sokoto and Kaduna. However these wind pumps suffer poor maintenance leading to abandonment in some cases. Sayya Gidan 5 kWp wind electricity project at Sokoto and Danjawa village 0.75 kWp are two existing pilot projects.[53]

There is need to explore wind energy resources which is one of lowest prices renewable technologies available. Wind energy could serve as viable option for rural dwellers. They could also be combined with other sources to form a hybrid system. Wind farm could be adopted for off-grid/grid connected generation.[54]

Similar challenges to solar energy face wind energy in Nigeria. First is the high cost of wind energy equipment, although it is hope that this would fade out with time. Nigeria lacks particular policies needed to see to the growth of wind energy. Current level of technical expertise in these technologies is still low slowing down development. Furthermore, research and development in wind energy needed to be improved upon as well as data sources. An increase in awareness level would, however, be needed to create the needed spark for growth.

5.2.3 Hydro Energy

Rivers Niger and Benue and tributaries constitute major large hydro potentials in Nigeria.[55] Kainji, Jebba and Shiroro dams are the three developed large hydro facilities in Nigeria with total capacity of 1930MW.[56] As earlier stated, hydro power serves as a major renewable energy source, constituting about 30% of total installed grid capacity. However, the Renewable Energy Master Plan puts that only about 14% of nation's hydro potentials is being exploited.[57]

Water resources abound in Nigeria. The central shores of the Niger Delta receive about 3400mm depth of rainfall which then decreases to 500mm in the Northern regions. Rainfall in the Jos Plateau region is about 1400mm while the eastern range is about 2000mm. The South

[52] Ibid p. 99
[53] Ibid p. 105
[54] Ibid p. 110
[55] Op Cit
[56] Op Cit p. 42
[57] Ibid p.42

experiences a long duration of rainfall of about eight months in a year, while the North is relatively low with about 3 months in a year. The quantity and duration of rainfall as well as topography, makes the southern, plateau and South-Eastern region suited for hydro power development.[58]

Large scale hydro potential is estimated to be 10,000, which translates to 36000GWh [59] of electricity. The REMP emphasizes on the development of small hydropower (SHP) development.[60] Results gathered from 12 states gave a 734MW potential of SHP from 277 sites; with a possibility of about 2500MW for the entire nation. SHPs could provide electricity in remote areas out of grid electricity reach. SHP projects in plateau, Sokoto and Kano states, with total installed capacity of 30MW.[61]

S/No	State (pre 1980)	River Basin	Total Sites	Total Capacity (MW)
1	Sokoto	Sokoto-Rima	22	30.6
2	Katsina	Sokoto-Rima	11	8
3	Niger	Niger	30	117.6
4	Kaduna	Niger	19	59.2
5	Kwara	Niger	12	38.8
6	Kano	Hadeija-Jamaare	28	46.2
7	Borno	Chad	28	20.8
8	Bauchi	Upper Benue	20	42.6
9	Gongola	Upper Benue	38	162.7
10	Plateau	Lower Benue	32	110.4
11	Benue	Lower Benue	19	69.2
12	Rivers	Cross River	18	258.1
Total			**277**	**734.2**

Table 1: Small Hydropower Potentials Across Some Selected States
Source: Renewble Energy Master Plan, 2005

[58] Ibid p. 39
[59] Op Cit
[60] Op Cit p. 39
[61] Ibid p. 43

Challenges facing hydro power development include in sufficient data collection to ascertain available potential. Also identified is the lengthy period in project execution due to bureaucracy as well as lack of technical standards in hydro power equipment. Water rights issues occur in some cases where water is diverted.[62]

5.2.4 Biomass

Biomass resources are vast in Nigeria. They include; fuel wood, agricultural waste and crop residue, saw dust and wood shavings, animal and poultry waste, and industrial/municipal wastes.[63] Biomass consumption is huge in Nigeria, making up to 37% of total energy demand. Combustion of fuel wood is popular leading to an increasing rate of deforestation. This serves rural dwellers for off-grid heating needs. Annual consumption of fuel wood is about 43.4×10^9 out of 144 million tons/year of biomass energy resources.[64]

Biomass resources in the country follow the vegetation pattern. Woody biomass is abundant in the southern rainforest region while crop residues are mainly found in the Guinea savannah of the North Central region.[65] Biomass could lend itself in solid or converted liquid/gaseous forms for consumption. However, solid consumption is common in highly inefficient combustion.

Resource	Quantity (million 27 ones)	Energy Value ('000 MJ)
Fuel wood	39.1	531.0
Agro-waste	11.244	147.7
Saw Dust	1.8	31.433
Municipal Solid Waste	4.075	-

Table 2: Biomass resources and estimated quantities
Source: Sambo, A.S. "Strategic Developments In Renewable Energy In Nigeria." *International Association for Energy Economics*, 2009

[62] Ibid p. 50
[63] Op Cit p. 16
[64] Op Cit p 77
[65] Op Cit

Initiatives such as improved clay stoves developed by the Sokoto Energy Research Centre (SERC) and the steel-based wood stoves by National Energy Research and Development Centre (NERDC) serve as efficient alternatives to the traditional three-stone wood stove. Local production of biomass briquettes also exists, which provide improved efficiency than unbriquetted biomass.[66] Bio gas designs are available, as well as biodigesters. Work is being done on bio gas technology by the SERC and NCERD which include pilot projects. The UNDP has also helped in the introduction of bio gas technologies.[67] Biofuel from Jatropha, sugarcane, and maize could also serve as viable energy sources.

Biomass is by far a major energy source for the rural dwellers, and these resources are abundant. It is thus imperative that the source is developed. Potentials are, for power generation from fuel wood lot, bio gas, as well as bio gases and ethanol production.[68]

Other globally identified renewable energy sources such as hydrogen, ocean and geothermal energy do not feature in the Nigeria renewable energy perspective. Though they hold the prospect for future sources, significant work has not been carried out on the viability of these sources in Nigeria.

[66] Op Cit p. 15
[67] Op Cit p. 83
[68] Op Cit p. 17

5.3 Renewable Energy Integration

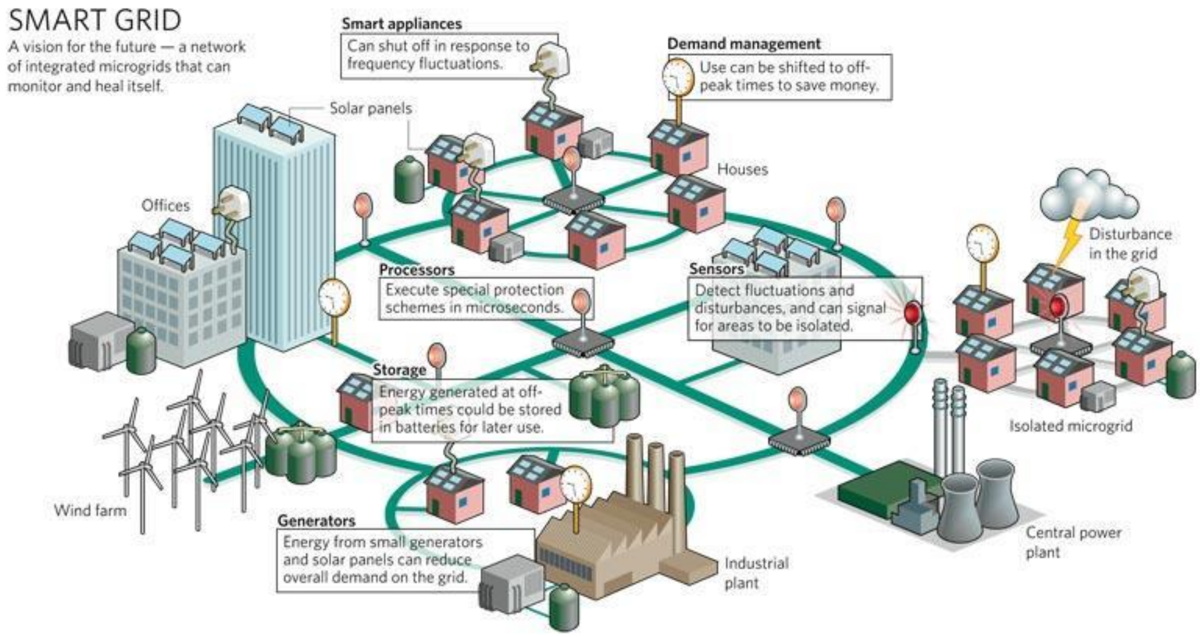

Figure 14: Renewable Energy Integration in the Smart Grid
Source: Intelligent Dots, *Smart Grid*, 2012

Efforts to ensure integration renewable energy sources aim to tackle variability as it affects stability, with deployment of technologies to ensure the required level of control. The smart grid as earlier introduced encompasses various technologies and concepts which provide efficient power management functions making it possible to accommodate challenges of renewable energy sources in Nigeria. This section thus outlines the opportunities offered by the smart grid to make renewable energy integration in Nigeria feasible.

The smart grid covers diverse concepts and technology. Fundamental concepts already introduces would, however, be discussed with respect to renewable energy integration. These technologies and approaches may overlap in function, and they include:

- Demand-Side Management
- Storage
- Distributed generation
- Forecasting
- Transmission technology
- Monitoring

Demand-Side Management

Demand-side Management (DSM) is vital for an effective deployment of renewable energy sources. Intermittent sources would increase variable generation, which would in turn prompt an increase in demand response programs. This involves consumer and utility interactions on power management basis, which allows consumers to make informed decisions on energy consumption for the benefit of both parties. DSM may include a variety of concepts and technology in action for consumer to react to information provided by utilities. The smart grid infrastructure provides the enabling environment for a robust two-way information travel to implement operations.

Variation in generation introduced by renewable source could be well catered for by corresponding responses on the part of consumers. For instance, a brief drop in capacity due to a brief cloud cover or sudden drop in wind speeds in the case of wind turbines may require that consumers momentarily cut down on consumption. Storage options such as battery and UPS systems may then cater for such periods. On the other hand, storage may be encouraged during off-peak periods.

Incentives may well be attached with consumer responses to encourage participation. With the aid of real-time pricing offered by utilities, consumers may want to cut costs on during peaks, which often come with high prices. These prices serve as signals from utilities to initiate necessary control measures. All of these would help reduce the base load capacity and cushion the effect of renewable sources on grid operation.

Storage

The intermittent nature of renewable energy sources makes storage imperative to harnessing these sources. As earlier stated, energy storage is largely an inefficient process. However, efforts are being made to improve storage technologies dubbed “advanced storage." Storage generally provides back-up for intermittent generation, converting non-dispatchable PV systems and wind turbine systems to dispatchable ones[69]. The smart grid gives room for grid operation of storage technologies in highly efficient management processes. Some storage technologies/methods include;

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[69] Op Cit p. 6-1

Hydro power depends mainly on volume of discharged flow among other factors. It thus suffers from variation in rainfall patterns which could lead to low water level, hence reduced generation. The Pumped Hydro storage system uses the power available at off-peak periods to pump water at some reservoir height, transforming excess energy to potential energy. Energy stored could then be made available for electricity generation at peak periods or to some extent, help in bridging the gaps that occur during droughts..[70]

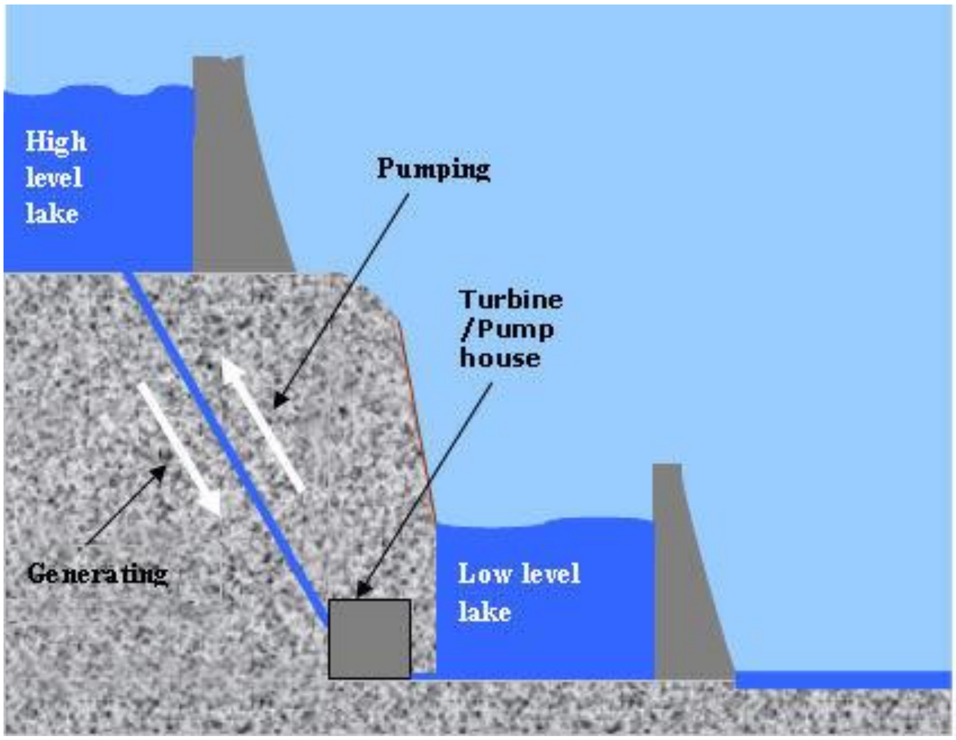

Figure 15: Pumped Hydroelectric Energy
Source: Hydroelectric Energy, *Bath County Storage Station* 2013

Flywheel technology helps to store kinetic energy in a spinning rotor. Charging increases the rotational speed which is made available for discharge through a generator, consequently slowing down rotational speed. Flywheels are well suited for power applications.

Batteries are popular with standalone PV installations. Irradiation varies in the day stemming from cloud covers as well as the nights. Battery-provided storage helps to sustain brief periods of interruptions as well as providing supply for the nights.

[70] Venkatesh n.d.

Other storage methods include:

- Super capacitors
- Superconducting magnetic energy
- Compressed Air energy storage

Storage technologies serve various functions as follows:

- Power quality: use of storage for protection against short periods of faults in power parameters, while maintaining power quality.
- Bridging power: storage helps to ensure continuity in power supply during periods of short breaks resulting from switching.
- Energy management: in this case, storage is needed for long discharge durations for reasons such as peak shaving, load following or outages..[71]

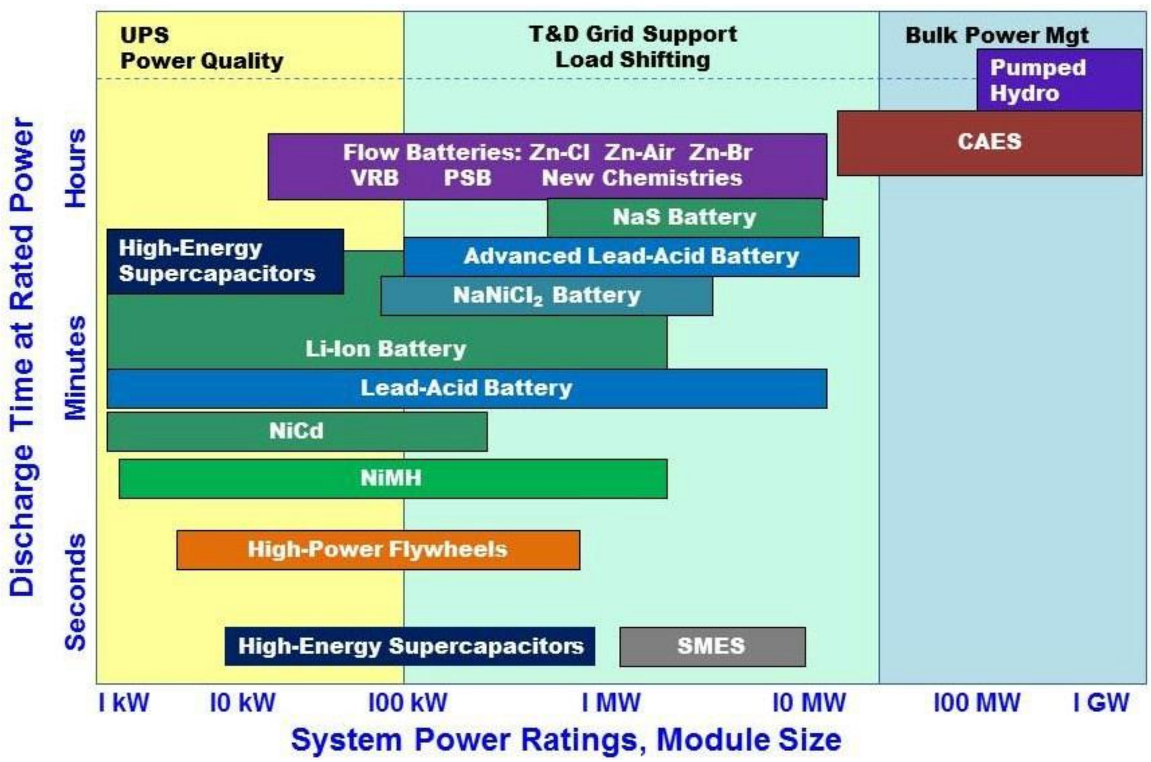

Figure 16: Storage Device Application Domain
Source: EPRI, *Smart Grid Roadmap and Architecture*" December 2010

[71] Op Cit p. C-2

Various storage techniques are suited for specific functions and may overlap in some cases.[72] They could help provide ancillary services such as area regulation of frequency as well as maintaining output characteristics for reliability. Storage at the consumer level serves economic purposes of an electrical energy time shift. Consumers may rely on stored energy when prices spring up and charge when prices drop. This would also provide UPS capabilities, which facilitate demand response functions.

A major challenge with storage is the cost of equipment, hence the need to compare economic benefits with other technologies that enable renewable integration.

Distributed generation

Provision for large scale generation for renewable energy poses a lot of challenges, including limited space for infrastructure installation. Distributed generation serves as a viable option with immense benefits to follow. Since renewable energy resource potentials are location specific, they could be well adopted for distributed generation. Community Solar PV installation, for instance, could be deployed to serve electricity needs while sending excess energy back to the grid as enabled by the smart grid infrastructure. Small Hydro Plants may also be set up in potential regions. The scale of these resources helps to improve reliability for operations while creating the possibility for ancillary services. Specific load characteristic needs could also be easily met at this level. Integrated storage technologies helps to provide the necessary back up as well as other distributed resources.

Distributed generation has the potentials for efficient and reliable operations given a clearer load perspective. Improved grid visibility as a result of scale would facilitate better demand-side management to enhance operations. Instability that would normally stem from distributed generation would be catered for by the smart grid elements.

Forecast

With everything changing fast, a result of variable generation, as well as consumer behavior, it is necessary that utilities get ahead of events to maintain grid stability. Accurate forecast would help utilities take necessary actions or precautions in good time while modeling resources accordingly.

[72] Op Cit p. c-1

Renewable energy resources such as solar and wind are highly weather dependent. A brief cloud or a drop in wind speed could result in significant impacts in solar and wind generation respectively. Hydro power as well varies with climate conditions. Ability to predict these events could help mitigate the effects of these changes, hence enhancing effective management of renewable resources.

Information gotten beforehand may as well be communicated intelligibly to consumers in order to initiate the demand response. Forecast may include temperature, cloud cover, precipitation, wind characteristic as well as solar intensity. Increased wind speed, which usually occurs in the nights (when demand is usually low) as well as high solar radiation levels could provide enough generation storage, which may be made available for peak periods. As electricity serves various purposes for consumers at various times of the day, consumption varies significantly. It is thus necessary that consumer behavior is well understood, to optimize resources. Forecast result could be translated to pricing information influencing consumer decisions on consumption. This would help shave peaks on the load profile while maintaining demand and supply equilibrium. Forecast influencing demand-side management with storage would help to achieve seamless renewable energy integration.

Monitoring

Monitoring ensures the order of operations at all levels. Smart grid technologies that monitor grid conditions receive data in real-time to ensure reliability of the system. Variability, a result of RE integration requires a high degree of grid visibility to ensure smooth running of system parameters and coordinated actions and reactions. It is also necessary to monitor renewable energy infrastructure such as wind and solar plants for various purposes such as maintenance and planning, as well as for security reasons. Remote controlled operation may also be required in some cases for optimization.

Transmission technologies

Transportation of power to load centers requires a high level of efficiency to get the best of generation. Transmission technologies include Flexible Alternating Current Transmission Systems (FACTS) to provide needed control and optimization of transmission operation with reduced losses. Solar and wind generation resources may be sited in remote locations, distant from load centers as is the case for off-shore wind farms. High voltage Direct Current (HVDC) is well suited for long distance transmission reducing losses, helping to get the best from generation. Dynamic Line rating optimizes the function of transmission infrastructure by identifying real-time current carrying capabilities to avoid overload conditions.[73] Super conductor technologies also help with line improvements.

[73] Op Cit

6.0 Conclusion and Recommendation

Nigeria is currently struggling in its energy sector with effects visible in the socio-economic life of her populace. The good news however is that potentials are to remedy the situation. Globally, indications are that, renewable are thriving and hoped to eventually replace traditional fossil fuel consumption as viable option in all its advantages. The challenges of renewable energy sources have been identified, and solutions are being worked out, which include the smart grid concept as discussed in this paper.

Research data indicates Nigeria's renewable resources are vast, but have remained largely untapped. Research has shown hydro, solar, wind and biomass sources as viable potential for generation; helping to improve the energy mix towards a more integrated energy profile. The current grid, among other barriers, hinders renewable energy integration. Therefore, the concept of the smart grid becomes imperative. The benefits of renewable energy integration cannot be overemphasized, and the smart grid is going to make this possible. It will introduce the many desired improvements required in the power system; from generation down to the consumer.

By adopting these technologies, Nigeria would be able to harness its renewable energy sources; first to meet its electricity needs, then pursuing a sustainable development by thriving on clean energy sources. To achieve these, there is need to put in place necessary modalities. Policies driving renewable energy integration should be promoted and strengthened at all levels. Awareness regarding the essence and advantages of these sources should be increased with stakeholder education. Research needs to be made more elaborate and updated to ascertain potential with accurate working data. These would help stimulate deliberate efforts towards harnessing these sources. Incentives could be offered to encourage participation. Pilot projects need be implemented and existing ones should be maintained and improved upon for large-scale deployment. Funding from government as well as the private sector will help to finance research projects and pilots who may then transform to market-oriented initiatives.

Channeling these efforts as well as adopting the smart grid initiative would thus make the renewable energy dream in Nigeria a reality.

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