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Framework of Sustainable Energy Development in a Bereft Power Supply Economy of Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

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ABSTRACT

Attempts at improving energy performance of any nation borders on increasing energy supply to meet up energy demand; and also reducing energy consumption through efficiency practices to attain sustainable energy utilization. Nigeria as a nation is bedeviled with the problems of inadequate energy supply as well as inefficient utilization of the low-supplied energy. In spite of the enormous and abundant energy resources across the country (renewable and non-renewable alike), the question of sustainable energy development in Nigeria remains a farce. All spheres of energy development (generation, transmission and distribution) together with consumption is occasioned by irregularities that have plunged the nation into a protracted energy crisis for decades due to its inability to harness adequately the abundant energy resources, and sustainably utilize the low-supplied energy. This study therefore attempts to review the state of energy development in Nigeria with its attendant limitations in terms of energy supply and its utilization in a bid to attaining a sustainable national energy development. Thus, a framework of strategies towards attaining sustainable energy development through the deployment of renewable energy resources and energy efficiency practices is therefore proffered.

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1. INTRODUCTION

Energy development involves all activities of policies and operations that bring about obtaining energy primarily from natural resources through conventional or non-conventional applications to power the national economy. Sustainable energy development has today become a global concern that requires the development and implementation of technologies as well as policies that can improve the energy situation of a country without exhausting resources for all generations; in a manner that the society is not adversely affected socially, economically and environmentally. However, this development mainly focuses on effective and efficient electrical energy supply essential for modern life and economy. It is generated from either renewable sources or non-renewable sources which are mainly fossil fuels, hydroelectricity, nuclear power and other sources like solar, wind, biomass, etc. Sources other than renewables are prone to depletion, and cause environmental degradation and pollution, climate change, etc. Thus, the need for a sustainable energy development which produces energy sources that meet today's demand and thereby eliminating the feared danger of depletion, environmental degradation and climate change; and can be used over and over again. Exploration of sustainable energy is harmless to the environment and equally cost-effective.

Electric energy is on the top grade in energy hierarchy and it is fundamental and inevitable to our daily lives. It is used in homes, industry, agriculture, education, defence and transportation. In fact, the economic growth of any nation depends heavily on the electrical power supply. The per capita consumption of electricity is an index of the standard of living of the people of the country; and to maintain a steady growth and development, the electricity industry is always engaged in a continuous planning process which now calls for a sustainable dimension. Thus, sustainable generation, transmission and distribution planning becomes very crucial in the expansion planning of the utility alongside population growth [1].

Nigerian society has for many years being experiencing a critical problem of energy poverty occasioned by extreme electricity shortage. The power sector is characterized by low generating capacity in spite of the nation's abundant reserves of hydro-energy, petroleum, coal and gas. This has resulted in unsatisfactory electricity power supply that has left many of the citizens without access to steady power supply for decades unabated. Socio-political, financial and structural factors which are mutually exclusive are known to be responsible for this deficiency [2,3]. Nigeria as a nation is endowed with enormous energy resources more than many countries combined that are exclusively out of energy poverty; yet, Nigeria presents a persistent and complex scenario of unresolved energy issues in the face of massive reserve of energy resources. In addition, the persistent menace of corruption in the Nigerian public service has ravaged every sector of the economy, including energy, and has drawn the country backward among comity of nations [4].

Nigeria is the most populous black nation of the world with a population of about 180 million people with an annual growth rate of about 6%. It is heavily endowed with an abundance of natural resources which are grossly unharnessed. Nigeria is among the major oil producing and exporting countries in Africa with average of 2.5 million barrels per day. As an entity, it is among the countries with the largest natural gas reserves in the world, with an estimated 182 trillion cubic feet of established reserves. It is also endowed with extensive coal reserve of between 1.5 billion to 2.5 billion metric tonnes. In addition, there is the much availability of renewable resources like water, wind and sun energy, from which appreciable power can be generated as shown in Table 1 [2,4,5].

The national grid is essentially hydro and thermal powered, in which less than 40% of the population is connected to the grid; and this meagre proportion is short of power for over 60% of the time [3]. In the face of the acute deficit in power supply, the energy sector operates at very high cost (over 8 billion Naira/53 million US dollars) and with more than 80% of this cost going into staff salaries and welfare. It is characterized with high energy losses in generation, transmission and distribution in both technical and non-technical dimensions; and with inadequate expertise [6]. With a lot of funds expended on the sector (over 40 billion US dollars) over the past decade, the country remains barely over 7,500 MW of installed generating capacity in a country of approximately

180 million people [5]. Regimes upon regimes; and energy programmes upon programmes, the story of energy poverty remains persistent. The scenario remains bleak for decades which require a strategic approach to address the constraints in all spheres of energy development in order to support national growth and economic development. Thus, the framework of sustainable energy development in a bereft power supply economy of Nigeria becomes essential.

2. CHALLENGES OF THE POWER SECTOR

As a nation, the power supply is expected to grow in line with power demand. But, according to David-West [7], the Nigeria peak load demand in 2010 is 12, 800 MW compared to its maximum generation of 3, 400 MW; creating a supply/demand gap of 73%. However, the reported peak load is a misnomer of the actual demand for electricity. In fact, access to electricity at the national level is 51% in favour of the urban areas, while rural access to electricity is under 20%. This has actually put Nigeria among other nations in a very bleak economic situation in terms of power generation per capita as indicated in Figs. 1 and 2.

Nigeria has gone through successive power reforms from the earlier time as a British Protectorate to now as a Democratic Nation. But, the electricity supply crisis ensued with a decline in generating capacity of the power sector coupled with the population explosion without a corresponding improvement/maintenance of power supply/transmission/distribution facilities. This is occasioned by such challenges as slow growth in generation capacity, market deregulation process delay, power lines and power distribution vandalism, poor maintenance of existing power system, lack of adequate funding and corruption among others [8]. The generating capacity as at 1993 was just about 1,669 MW, which up to this moment (2019) has sparingly reached 7,000 MW [2] in spite of earlier intervening reforms. Consequent upon slow growth and inadequate supply of the needed power on demand, the Federal Government began a gradual process of power revitalization by setting up the Electric Power Sector Implementation Committee. This committee facilitated the passage of the Electric Power Sector Reform Act of 2005. The sole aim of this act was to ensure and promote efficiency of the power sector through privatization. The privatization exercise later took effect to unbundle the prime utility company (Power Holding Company of Nigeria) into several successor companies likely to be more efficient in services provision to undo the ugly power situation of the country.

In summary, the power sector of Nigeria is still highly engrossed in inadequate power generation; inefficient technologies/equipment deployed for generation, transmission and distribution; and inefficient consumption in the industries and housing units due to inefficient appliances/behaviours. To confront the surmounting challenges, the need arises for further reforms focusing on sustainably increasing generation capacity to adequately meet the demand, in line with the expansion of both the transmission and distribution lines collectively with the deployment of sustainable and efficient technologies. Establishing public awareness and information programmes on energy efficiency and conservation equally becomes crucial. Sambo [9] has however, argued that the persistent energy poverty in Nigerian society is due largely to the lack of infrastructural development of the energy sector for decades.

Adequate energy supply is the power drive of all nations as it promotes economic growth and global competitiveness. Nigeria must therefore key-in to a sustainable reform for a successful development outcome among nations. According to KPMG [10], “The Nigerian power sector remains adequately positioned as the next destination for massive power investments.” All the drive issues of reform are to be regulated by adequate and appropriate guidelines which should include market issues, electricity transmission license, power purchase agreements, multi-year tariff order, grid code, metering code, market procedure and interim market rules [6].

3. A ‘SUSTAINABLE OUTLOOK’ APPROACH

The study focuses on attaining sustainable energy development for the Nigerian economy through formidable framework of energy resources utilization. To accomplish this goal, a textual analysis of the current state of energy development in conjunction with energy resources potentials of the country is undertaken. However, the current global energy development trend has a great and enhanced consideration for a sustainable outlook.

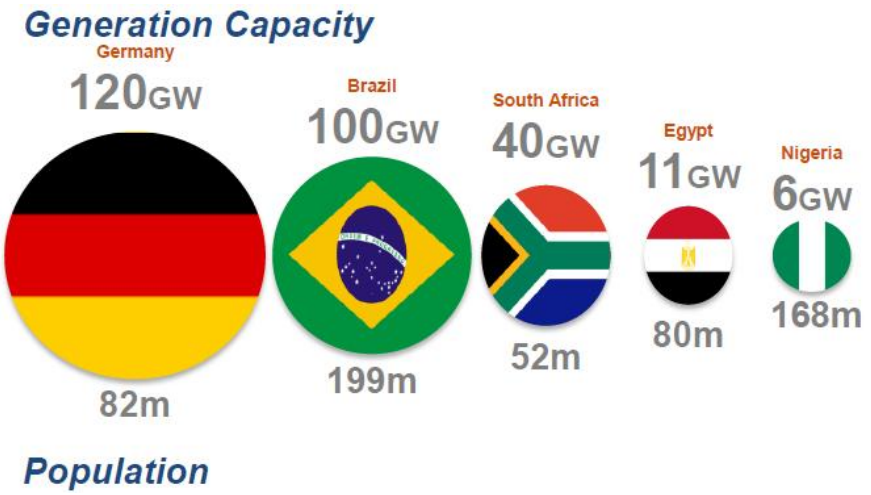

Fig. 1. Putting Nigeria in perspective of population to generation capacity ratio
Source: KPMG [10]

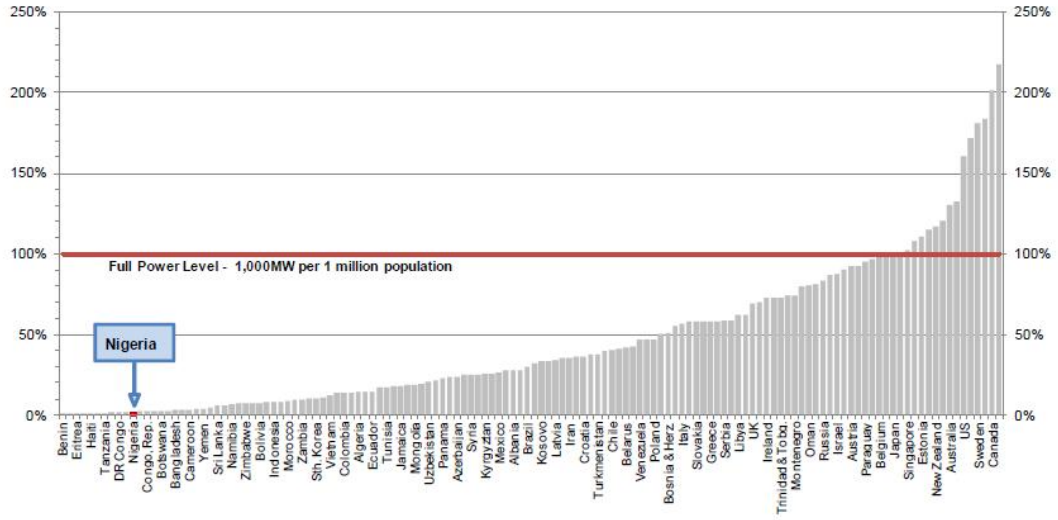

Fig. 2. Generation capacity per capita (2010)
Source: US energy information administration, CSL research in David-west [8]

This is consequent upon the fact of persistent depletion of the non-renewable sources; the environmental degradation and pollution due to resources exploitation; the associated climate change and loss of biodiversity etc.; and the fear of energy scarcity. The dimension of a sustainable outlook is mainly focused on the deployment of the renewables in the energy-mix in power generation. The Nigerian government has recognized this potential and has established renewable energy research and development centres across the country (at Usman Danfodio University Sokoto, University of Nigeria Nsukka, etc.) as subsidiaries of the Energy Commission of Nigeria (ECN). Unfortunately, the activities of these centres have been limited to solar photovoltaic development, and solar energy products and devices like solar cookers, water heaters, dryers, etc. on a very minimal level. Solar power generation has not actually been introduced into the power grid; and other renewables like wind, biomass, etc. have outrightly been ignored.

On a global scene, many countries are turning towards renewable energy sources in their power

mix on a very significant level. Examples are; Germany already generates about 13% of its electricity from renewable sources; in the United Kingdom (UK), there is already a rule that any new building must reduce its carbon emission by 10% through use of renewables; member states of the European Union (EU) are required to generate one-fifth ($1/5^{th}$) of their power from renewable sources by the year 2020; and the United States of America (USA) has legislated that all publicly traded utility power companies should generate 15% of their power from clean sources like windmills, solar panels, etc. by the year 2020 [3,4]. Nigeria should therefore adopt a changing energy mix trend to include non-hydro renewables and natural gas. The hydropower generation as it is presently could be doubled to increase its contribution in the mix since much of the hydropower potential is grossly unexplored. There is also the need to introduce a decentralized renewable energy capacity in the form of off-grid solutions in all the six (6) geopolitical regions of the country based on the local renewable sources potential to serve the regions including the remote and rural communities that have being deprived of access to electricity for decades [11]

4. OPPORTUNITIES IN THE POWER SECTOR

Based on the geographical and socio-economic landscape of Nigeria, several opportunities abound in the bid to overturn the current scenario into a plausible and more sustainably efficient venture. Some of these opportunities as observed, and in line with Deloitte Global [11] presentations are as follows:

4.1 Renewable Energy Opportunities

There are ample opportunities to explore in renewable energy sources in all regions of the country. Principal among these are, solar, wind, tidal wave and biomass. These opportunities will become evident for firms in this sector in the form of research and development, project management, consulting, as well as capacity building and skills training.

4.2 Restructuring Utilities

This opportunity would tend to encourage greater private participation in the electricity market in which private sector players will emerge, with a particular focus on sources for project funding.

4.3 New Technologies and Systems

There is the need to consider new innovations and adopting new technologies in order to modernize the national utilities. This can be achieved by the introduction of smart metering (to avert power theft) and process automation systems (to reduce power loss) so as to ensure the sustainability of the power industry. Application of DSM (demand-side-management) in most utilities is equally essential.

4.4 New-build and Project Supply Opportunities

Within the traditional thermal and hydropower sectors, there are opportunities within the new build and civil construction and supply of inputs environment for power generation projects. There are also the noted renewable energy opportunities, spanning solar, wind, geothermal and biofuel related technologies.

4.5 Skills Development

Presently, there is a substantial level of skills deficit in the power sector and sectors that support it that creates an opportunity for foreign investors to partner with the national government in order to develop technical training schools and fund more students enrolling in science and engineering programmes on long-term plans. But for immediate requirements of professionals in the sector, it is necessary for the government to import skills and facilitate skills transfer through tailor-made programmes.

4.6 Technologies and Systems for Rural Electrification

There is need for a rigorous focus on rural electrification and use of renewable energy technologies (RETs) in stand-alone off-grid or mini-grid systems to reach out to large sections of the rural communities. This will unlock opportunities for investors, financiers, technology owners, builders, project managers and entrepreneurs in rural electrification projects.

4.7 Scenario Planning

For the onward success or sustainability of the power industry, the government and the utility agencies will need to engage in scenario planning in order to get a view of what is really required for successful operations.

4.8 Improved Stakeholder Engagement

It is required and very important to develop clear stakeholder engagement strategies for new entrants, vis-à-vis policymakers, regulators, utilities and operators.

Others are diversified investment attraction and portfolio optimization.

4.9 Framework of Sustainable Energy Development

The proposed framework is intended to provide a working plan for the operation of the power sector in terms of generation, transmission and distribution; and energy consumption efficiency in consideration of the overall energy resources potential of the country based on sustainability principles, and in recognition of the observed opportunities.

Nigeria as a country is divided into six (6) geopolitical regions, and each of the regions is endowed with enormous renewable (see Table 1) and non-renewable energy resources. They are; the North-central, North-west, North-east, South-west, South-east and South-south regions. The abound resources in these regions include; large and small water bodies for hydropower, sunshine for solar power, strong winds for wind power, ocean tides and biomass from the enormous waste disposal across the country.

4.9.1 Framework of sustainable power Generation

The main consideration in this venture is the renewable energy resources in the various regions of the country, e.g:

4.9.1.1 Hydropower source

Hydropower systems make use of turbines to generate electrical power by using the energy in moving water to spin the turbines. At present, the hydro energy provides just about 10% of the nation's electricity. There is a very high hydropower potential of large and small rivers; and some few water falls. According to Idris, Kura, Ahmed and Abba [2] the total technically exploitable large scale hydropower potential is estimated at over 10,000 MW capable of producing 36,000 GWh of electricity annually. Only about one-fifth (19%) of this potential has been developed as at 2001, and since then, there has not been any significant improvement. The small hydropower potential is estimated at over 734 MW. The current hydropower infrastructures are in dire need of rehabilitation; and their actual energy output is far below their operation capacity. The hydropower source cuts across all the regions of the country; as such, the maximal exploitation should be the prerogative of all regions.

4.9.1.2 Solar power source

The solar energy derived from the sun is direct, non-polluting and inexhaustible; and its utilization is a factor of availability and the appropriate technology.

There is a great solar power generation potential in Nigeria which has been undermined and utilized on a very meagre scale (less than 5% of total generation).

Table 1. Renewable energy potential in Nigeria

Energy resources	Estimated reserve
Large hydropower	11,250 MW
Small hydropower (<30 MW)	3500 MW
Fuel wood	11 million hectares of forest and woodland
Municipal waste	30 million tonnes/year
Animal wastes	245 million assorted animals in 2001
Energy crops and agricultural residue	72 million hectares of agricultural land
Solar radiation	3.5-7.0 kW h/m2/day
Wind	2-4 m/s at 10 m height Wind speeds in Nigeria range from a low 1.4 to 3.0m/s in the Southern areas, except for coastal line and 4.0 to 5.1m/s in the North. The Plateau area particularly interesting.

Source: Energy Commission of Nigeria (ECN), "Draft National Energy Master Plan [2014]"
Adapted from Energypedia at https://energypedia.info/wiki/Nigeria_Energy_Situation [12]

In fact, the entire geography of Nigeria has fairly well distributed solar radiation across all regions. This is because; Nigeria is located in a high sunshine belt of the equatorial region of the globe. The annual average of total solar radiation varies from about 12.6 MJ/m^2/day in the south-coastal areas to about 25.2 MJ/m^2/day in the far north. The solar radiation intensities range from 3.5 – 7.0 kWh/m^2/day; and sunshine duration ranges from 4.0 – 9.0 hours/day [2]. Nigeria receives about 4.85 x 10^{12}Kwh of energy per day from the sun; and an average of 1.804 x 10^{15} Kwh of incident solar energy annually. This annual solar energy insolation value is about 27 times the nation total energy resources in energy units [13]

According to Oji et al. [14], solar energy can be used to generate power in two ways;

i. **Solar-thermal conversion:** Solar thermal systems also called concentrated solar power (CSP) are used to produce electricity by the process of heating of fluids to produce steam to drive turbines for large-scale centralized generation.
ii. **Solar electric (photovoltaic) conversion:** This is the direct conversion of sunlight into electricity through a photocell. This could be in a centralized or decentralized form. It is made up of a balance of system (BOS) which consists of mounting structures for modules, power conditioning equipment, tracking structures, concentrator systems and storage devices. However, it could be small-scale for stand-alone systems or large-scale connected to national grid. Both of these systems are suitable for the Nigerian solar energy demand.

Solar power generation is suitable for all regions of the country but most suitable for the northern regions. It is a very promising renewable energy sources because of its limitless potential and capacity to be installed at the very point of load or load centre making it suitable for remote and local communities not connected to national grid [15].

4.9.1.3 Wind power source

Wind energy is obtained from airflow through wind turbines to generate electric power. It is the differences in atmospheric pressure due to difference in temperature that cause the wind flow. Wind power system occurs in a process whereby wind blades or 'rotor' catch and spin the wind. The spinning movement is transformed into electrical energy by the generator. The minimum speeds that the wind can blow for a small turbine is 36 x 10^7 m/s and large plant requires speed of 58 x 10^7 m/s [13].

The wind power source distribution in Nigeria varies greatly based on the regional climate variation. Earlier studies on the cost benefit analysis using wind energy conversion systems for electric power generation and energy supply in some states in Nigeria have indicated vast opportunities in wind systems for electricity generation. This is particularly evident in northern states, the mountainous parts of the central and eastern states, and in offshore areas where wind is abundant throughout the year [13].

It is estimated that Nigeria has annual average wind speed of 10m heights, varying from 3m/s in the coastal areas and above 5 - 7m/s in the far north where vegetation is less [2]. At wind speed of 3.5m/s or greater, wind powered system can provide energy at cost cheaper than photovoltaic, diesel and grid extension, therefore making the northern states ideal location for wind power system [13]

4.9.1.4 Biomass

Biomass is the conversion of stored energy in the plant materials (vegetable matter) into usable energy. It is the cheapest and most accessible source of fuel in Nigeria particularly in the rural areas, and even in some urban households.

There is much biodegradable waste disposal in both the rural communities and the urban centres across the country. This situation presents biomass which is a plant derived matter as a great renewable resource for power generation. This requires the deployment of biomass technologies such as "digesters" to generate biogas as a sustainable by-product for power generation. Biomass resources of plants, animal wastes, municipal and industrial activities as well as aquatic biomass are enormous; and plant biomass can be utilized as fuel for small-scale industries [16,17]. The biomass resources of the nation have been estimated to be about 8 x 10^2MJ; however, the available methods of converting biomass to energy are; burning, alcohol fermentation, anaerobic digestion, and pyrolysis, suitable for all regions of the country.

4.9.1.5 Tidal waves

Nigeria is a coastal country along the Atlantic Ocean making it a good potential for tidal energy

from the waves of the Atlantic. Tidal wave can be a very efficient and sustainable source of power if the difference between the high and low tide is great [18]. Therefore, the appropriate technology can be deployed to take advantage of the tidal waves for power generation for the coastal regions of the country.

4.9.2 Framework of sustainable power transmission

Transporting electricity over long distances is technologically and economically challenging that the proponents of electricity market have tended to support regional markets as a more sustainable option. There are fundamental changes away from traditional ways in the manner that grids are designed, built and managed today. Deployment of intelligent/smart grid system of transmission of renewable resources that would optimize a balance between demand and supply of electricity would be essential. This system would ensure transmission without loss of power even over long distances as exemplified today in China and some European countries using high-voltage direct current (HVDC) option of electric power transmission. However, the first sustainable approach is the 'unbundling' system in which production and transportation of electricity is separated to create room for competition and an open and transparent market. This should be supported by adequate grid planning to ensure technological developments and advancements in the aspect of energy transportation across long distances.

This shall be based on specifications and objectives related to regional planning policy, environmental and nature protection targets and economic criteria in terms of efficient, considerate and timely infrastructure investments [19].

4.9.3 Framework of sustainable power distribution

It is a fact that the power distribution system is the lifeline infrastructure that determines the level of development of any nation and it plays a significant role in its industrialization and the general economic development. As such, both the transmission and distribution systems should be reliable, efficient and sustainable. A reliable power distribution system ensures safety of energy end-users, and promises reliable and quality electricity at affordable prices. The advancement of the power distribution system is known to have direct impact on the development potential of economic growth particularly in the urban centres. Promoting efficient power distribution infrastructure according to the 'International Copper Association Asia' [20] has enormous benefits among which are:

i. The environment-link economic sizing of cables campaign in Japan, Korea and China creates annual energy saving potential of 51 Billion kWh which is enough to power 27% of total residential lighting in United States.
ii. Energy efficient distribution transformer programmes in India and China helps to reduce 192 Billion kWh or a net savings of USD 138 Billion.

Therefore, all nations of the world aspiring to attain a sustainable power supply to its citizenry must drive towards achieving reliability in power distribution infrastructure. This can be accomplished by the following:

i. Power loss reduction with the use of energy efficient transformers and power cables (high conductivity cables).
ii. Power reliability enhancement by use of underground cabling systems to prevent power theft and mitigate challenges caused by visual pollution.
iii. Mitigating power quality issues by creating awareness and deploying solutions to ensure reliability and quality in the energy supply.

4.9.4 Framework of sustainable power consumption

The power consumption unit is the end-point (terminal) of energy supply chain. It deals with the energy end-users and their pattern and manner of consumption. It is therefore necessary to establish a framework of sustainable consumption so that many of the benefits of greater technological efficiency attained may not be lost to irrational behaviour [21].

Sustainable power consumption typically targets energy efficiency which is the application of efficient appliances/equipment/installations; and energy conservation which concerns human behaviour in energy use. It is about shaping the behaviour of power consumers in the direction of energy efficiency and conservation. The framework focuses on the human dimension of energy use which according to Abdul Majid and

Hussaini [22] can foster significant boost in the efficient use of all energy resources if well understood and implemented. The human dimension according to Lutzenhiser [23] can amplify or reduce the effects of technology-based efficiency improvements in energy consumption. Therefore, the prime agenda of the framework of sustainable power consumption is to attain energy efficiency and conservation which has countless benefits in environmental and socio-economic sense. This can be achieved through government policies and regulations on energy utilization; and by providing public awareness/information programmes on energy efficiency and conservation. On this note, Grady [24] has presented the proposal of the Garrison Institute which stipulates the 'TIME model' on attaining energy efficiency on the public or consumer domain as follows:

T – Targeting: To recognize consumption pattern so as to regulate it towards efficiency through targeting and auditing programmes, etc.
I – Informing/engaging: Helping people to develop capacity to be mindful of their energy use through 'people-centered-initiative.'
M – Motivating: U se financial and non-financial mechanisms to turn intentions into behaviour in efficient use of energy.
E – Empowering/enabling: Use concerted effort to remove financial and structural barriers to power consumption; and to provide better choice sets through policies and legislation, etc.

5. CONCLUSION

The Nigerian Power Sector has been in operation for decades and has witnessed several transformative reforms in policy and pattern of operation; yet the energy poverty of the nation remains unabated. This is because a 'sustainable outlook' has not been deployed in the successive reforms; and the policies evolved have not been sustainably strategic. As such, available opportunities could not be adequately tapped or harnessed for growth and posterity of the sector and the general society. The sustainable outlook calls for adequate maintenance of all infrastructures of electricity production and transportation, with an increase in generation capacity of existing facilities which are grossly under-utilized far below their installed capacities; and to be accompanied with broad introduction of renewable resources into the energy-mix. The enormous potentials of the renewable resources across all regions of the country have been subsequently ignored in past reforms. Therefore, efficient and sustainable utilization of the abundant renewable and non-renewable energy resources of Nigeria on the platform of effective and good governance is the panacea to the relentless energy/power problem of the nation. The study further recommends adequate grid planning to ensure technological developments and advancements in all the facets of operation (generation, transmission and distribution) so as to liberate the power industry out of the present state of impasse.

DISCLAIMER

This manuscript was presented in a Conference.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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