Sustainable Energy Development in Nigeria: Issues, Challenges and Prospects

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Abstract:
The country, Nigeria is confronted with myriads of challenges hindering its access to reliable and sustainable power supply in both urban and rural areas. The existing energy infrastructures are incapable of translating the so many Renewable Energy Sources (available in almost every part of the country) to a sustainable energy supply system, capable of bridging the wide power supply-demand gap. This paper proposes the use of solar, biomass and small hydropower technologies for a sustainable energy development in rural and urban areas of the country. This work reviewed the present state of energy in the country, recommended the use of decentralised power system and off-grid/on-grid hybrid power system as a sustainable energy development model for the country. Then, the necessity for aggressive Renewable Energy Sources integration into the national energy mix through sustainable growth involving decentralised renewable energy system and distributed generation applications. This work will assist power sector stakeholders in making informed decisions towards promotion of green economy and growth of hybrid power system technology in Nigeria.

Keywords: biomass, electrification, solar energy, small hydropower, sustainable development.

Introduction
Energy is becoming absolutely indispensable in this present age as the socio-economic growth of any nation is directly/indirectly related to the country’s energy security. Access to reliable, sustainable and affordable electric power supply is essential for any meaningful socio-economic development of any modern society. Quality, reliable and effective electric power supply ensures development of small scale businesses, prevents rural-urban migration and improve standard of living of the people. It is almost impossible to live comfortably in the present global community without electric power supply. Sustainable energy is needed for rapid socio-economic development of any nation in raising the standard of living of its citizens (Adesanji, 2019).

Almost half of the world population are without access to electric power supply especially in African and Asian countries (Adesanji, 2019). Poor access to electricity contribute to increased poverty, unemployment and retarded socio-economic growth. A country is said to be
experiencing energy poverty when its citizens cannot access quality electric power supply to carry out their daily and basic needs such as cooking and lighting (Oyedepo, 2014: Adebanji, 2021).

Energy resources (taken from fossil fuels such as natural gas, coal and oil) are the most popular among all nations in the world. Its use for electricity generation however, will inevitably lead to continuous depletion of these energy resources and its negative effects on the environment. Hence, deployment of clean Renewable Energy Sources (RES) is essential for the social and economic growth for all nations.

The unpleasant current economic experience, high unemployment rate, low institutional development and stagnant technological growth in the country, can be traced to poor energy access. The country majorly depends on oil exports, making its economy vulnerable to fluctuations in global oil prices (Olanipekun & Adelakun, 2020). Perennial power outages have translated to energy poverty, social disorder, decayed infrastructures and retarded socio-economic development. The country faces considerable challenges in providing electricity access to its citizens, especially in the rural areas.

As population continues to rise, electricity generation may not be sufficient to meet up with the increasing demand. This places high demand on global request for sustainable socio-economic development in most developing nations. Hence, the need for diversification of Nigeria’s energy resources in order for to allow for a paradigm shift from heavy reliance on fossil fuel usage to a climate friendly energy sources. A well-developed sustainable energy sources will enhance viable grassroot economy, ensures rapid-socio-technological development, restore social order and enhance enviable political stability (Oyedepo, 2014).

A stronger, well-rooted and politically stable economy will be highly enhanced if the country invests in clean and sustainable energy technologies to supplement its presentational energy sources. Utilization of these sustainable technologies will speed up rapid growth of decentralised social infrastructures, which will in turn will curb social ills and stimulate economic growth.

Oyedepo (2014) expressed the significance of energy availability in economic growth of any nation. The author recommended energy efficiency and RES utilization as a mitigating factor in making sustainable development in Nigeria. The study argued that the current energy issues will continue unless government diversifies energy generation sources and adopt new technologies in reducing energy wastage/loss. Poudyal et al (2019) worked on solving the current energy crisis in Nepal with RES integration into the nation’s energy generation mix. The work reviewed the energy situation in Nepal, identified the various factors inhibiting rapid development of energy generation. Some of the factors identified are high priced hydro power projects, outdated and inadequate energy infrastructures, energy theft, ineffective energy management system, high distribution and transmission losses, geographical and political issues. The authors recommended the use of RES as a crucial step in mitigating the current energy crisis.

Adewuyi et al (2020) discussed on the challenges of the Nigeria’s energy sector and compared it with the practical experiences from other countries of the world. The work was aimed at the readiness of the Sub-Saharan Africa in meeting the Sustainable Development Goals (SDGs) in the year, 2030. The required reforms towards improving Nigeria’s energy were also suggested. Adebanji et al, (2021) compared issues and challenges of grid-connected and off-grid hybrid power system with respect to future prospects and policy formulation. The work identified some major barriers to sustainable energy development in Nigeria. The authors used a typical case of Oyan river, Nigeria with Small hydro-solar PV-Diesel hybrid system. The work recommended the use of Off-grid HPS for electrification of distant villages and the use of Grid-connected HPS in the cities for complementary power supply to the grid.

Mayer and Overen (2021) reviewed the off-grid system in South Africa in order to reveal the numerous strategies of ensuring sustainable and
effective rural electrification process. The authors recommended 50 kWh/monthly electricity production through RES and introduction of incentives as a way of encouraging the would-be investors. Adugbe et al (2023) assessed the current developments in the Nigerian power sector from inception, 1898 till date in order to identify the issues and challenges in the industry. This was carried out by evaluating the different reforms programmes implemented in the sector by different past administrations till date. Some of the challenges identified are energy losses, financial constraints, energy theft e.t.c. The authors recommended the use of distributed generation, smart grid system implementation and provision of smarter meters.

Nyasapoh et al (2023) worked on the roles or contribution of RES in attaining sustainable development of Ghana. The research was carried out through comprehensive literature review using search engines. The authors concluded that a sum of USD 22.6 billion is needed to be invested in order for a ten year programme (2020-2030). The report also revealed that despite the abundant RES in Ghana, only 59 MW (1.12%) have been integrated into the energy generation mix.

This work reviewed the energy situation in the country, recommended the use of decentralised power system and off-grid/on-grid hybrid power system as a sustainable energy development model for the country. This study also proposes the use of solar, biomass and SHP technologies for a sustainable energy development in both rural and urban areas in Nigeria.

Energy situation in Nigeria

Electric power generation in the country is ineffective, insufficient and largely unreliable. The country, Nigeria, depends majorly on fossil fuels for her electricity generation. The installed electricity generation capacity is 13,000 MW, fluctuating between 3500 MW and 5000 MW from large hydro power (17.6%) and natural gas (82.4%) (Adugbe et al, 2023). The power sector in Nigeria has passed through various reforms aimed at repositioning the sector for effective service delivery, yet the efforts seem not to be producing any meaningful outcome. The country is abundantly endowed with diverse sources of energy, spread across the country. This is as shown in Figure 1. The energy sources and its level of utilization is as shown in Table 1. It is shown from Table 1, that fuelwood constituted the highest energy usage in the country. This is common among the rural dwellers with no electricity access.

Figure 1. Nigeria’s Energy Resources Distribution Map
Source: GEN 11, 2017
Sustainable Energy Development Model

It is necessary to enhance sustainable energy strategy for rapid and significant improvement in the energy sector. A sustainable energy strategy considers all aspects of energy use within a country in ensuring a holistic and sustainable long term plan that considers the social and economic life of its citizenry. This ensures that the present energy needs are met without causing harm to the environment in the future. The idea of developing a robust, efficient and effective energy model for a country or nation without destroying the present and future social, environmental and economic life of a country is referred to as sustainable energy system (Adewuyi et al, 2020).

Nigeria is endowed with huge RES which should contribute to alleviating the power supply deficit and diversity in the country’s energy mix. RES application in the rural areas (potable solar lantern, solar home systems, mini hydro and small winds) do not need costly installation of transmission line and are becoming cheaper as a result of increasing number of users along with improved technical expertise.

### Table 1. Nigerian Energy Sources

<table>
<thead>
<tr>
<th>Resources</th>
<th>Quantification</th>
<th>Utilization characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude oil</td>
<td>37.062 billion barrels</td>
<td>22% utilization of refineries</td>
</tr>
<tr>
<td>Natural gas</td>
<td>182.3 million std cubic foot</td>
<td>18% indiscriminately fared</td>
</tr>
<tr>
<td>Coal and Ignite</td>
<td>2.7 billion tonnes</td>
<td>7% contribution to net GDP</td>
</tr>
<tr>
<td>Tarsands</td>
<td>31 billion barrels of oil equivalent</td>
<td>Negligible usage</td>
</tr>
<tr>
<td>Large hydro</td>
<td>11,250 MW</td>
<td>1930 MW (17% utilised)</td>
</tr>
<tr>
<td>Small hydro</td>
<td>3500 MW</td>
<td>64 MW (2% utilised)</td>
</tr>
<tr>
<td>Solar</td>
<td>3.5-7.0 kWh/m²/day</td>
<td>27% capacity factor, negligible factor</td>
</tr>
<tr>
<td>Wind</td>
<td>2.0-4.0 m/s at 10 m height</td>
<td>Negligible utilisation</td>
</tr>
<tr>
<td>Fuel wood</td>
<td>11 million hectares of forest</td>
<td>43.4 million tonnes/year of consumption</td>
</tr>
<tr>
<td>Municipal waste</td>
<td>30 million tonnes/year</td>
<td>0.5 kg/capita/day</td>
</tr>
<tr>
<td>Animal waste</td>
<td>1.05 tonnes/day</td>
<td>Negligible utilisation</td>
</tr>
<tr>
<td>Agricultural residues</td>
<td>91.4 million tonnes/yr produced</td>
<td>Negligible utilisation</td>
</tr>
<tr>
<td>Energy crop</td>
<td>28.2 million hectares of arable farming</td>
<td>8.5% cultivated</td>
</tr>
</tbody>
</table>

Source: Oyedepo, 2012

Some of the most common RES in the country are solar, wind, small hydro power and biomass (Bamisile et al, 2017). Even though, the RES in the country are very abundant, its utilisation at present is very limited. Modern technologies are needed for accelerated development and utilisation of RES to increase its contributions to the current energy supply mix (Oyedepo, 2014).

Viable Sustainable Energy Development Model

The three most viable energy options that is sustainable in Nigeria are the solar energy generation in decentralised systems, the SHPs technology and biogas generation using biomass technology. These three categories of RES are sustainable and will surely improve the standard of living of both rural and urban dwellers. All other RES such as wind technology, may not be feasible for now due to the low speeds in most parts of the country unless improved technology is employed at a higher heights. Significant exploration of RES is imperative for economic and environmental growth of the nation.

Solar Energy

The country is well positioned in the equatorial region. It has an average value of almost 19.8 MJ/m² with about 6 hours of sunshine per day. It ranges between 9 hours in the northern part and 3.5 hours in the coastal areas (Oyedepo, 2014). It has an abundant solar potential due to...
its location in high sunshine region as shown in Figure 2. The average annual solar intensity of 6898.5 MJ/m²-year (1934.5 kWh/m²-year) offers a great opportunity for effective investment in RES at an affordable price. The need to invest more in production of electricity from solar energy becomes more imperative as population increases, individual press for a higher standard of living in terms of material goods, with corresponding increase in electric power demand, especially in rural and developing regions (Oyedepo, 2014).

![Figure 2. Solar Radiation Map of Nigeria](image)

**Small hydro power (SHP)**

The country is abundantly blessed with large waterfalls, dams and rivers which can be effectively be used in the generation of electricity in both urban and rural areas. This opportunity can be effectively utilized to increase the percentage contribution to the hydroelectric power generation to the national energy mix and also as a means of electric power production to the remote rural area (Okedu et al, 2020). Despite, the abundant rivers and dams that spread all over the country, the use of SHPs for electricity generation is very low and limited to about three states. The country’s SHP potentials is as shown in Figure 3.

The country stands to have an increased per capita energy consumption when it overcome its current challenges and adopt SHP technologies with lesser negative effects on the environment. Most of the SHPs facility potentials scattered all over the country should be harnessed for electric power production. This will enhance rural electrification and speed up socio-economic growth. So many developed nations of the world have shown interest in development of Small hydro power (SHP) projects because of its least negative socio-environmental effects. China, for instance, as of year, 2022 has developed SHP plants of over 58,000, with a combined capacity of over 13000 MW. Some other developed countries that are actively involved in SHPs are France, Italy and Sweden (IRENA, 2022).
Biomass Technology

Biomass potentials in the country are such as in form of biomass, biogas and fuel wood. Almost 90% of the energy consumed in the rural areas are from biomass (Adebanji et al, 2023). Biomass resources in Nigeria are estimated to have $8 \times 10^5$ MJ with 80 million m$^3$ worth of firewood being used yearly for cooking and other purposes (Oyedepo et al, 2018). The Biomass resources potentials for electric power production in the country is as shown in Table 2.

<table>
<thead>
<tr>
<th>Biomass</th>
<th>Power potential (MW)</th>
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<tbody>
<tr>
<td>Agro-residues</td>
<td>14,889.65</td>
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<tr>
<td>Wood residues</td>
<td>562.215</td>
</tr>
<tr>
<td>Animal residues &amp; food wastes</td>
<td>17,170</td>
</tr>
<tr>
<td>Combustible municipal solid waste</td>
<td>6529.53</td>
</tr>
<tr>
<td>Total</td>
<td>39,151.395</td>
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</tbody>
</table>

Source: Akhator et al, 2019

Hybrid Power System (HPS) Technology for Rural Electrification

Hybrid Power System (HPS) is a system that is using more than one source(s) of power to generate electricity. Renewable energy hybrid system therefore, refers to composition of at least one renewable energy source with or without using conventional energy source, which may be grid-connected or stand-alone. HPS prevents fluctuations that could be obtained from a single source of RES. It proffers solutions to problems of fuel flexibility, emission economic emissions and reliability (Bajpai and Dash, 2012). It helps in making the best use of their best operating characteristics for higher efficiency. Hence, it is complementary in nature. Some of its benefits are reliability, security of supply, improved power quality, reduced carbon emission and improved system performance. Most of the common types are Solar PV-Diesel and Wind-Diesel.
The recent advancement/development in renewable energy technologies (RET) and power electronic converters has greatly enhanced the use of HPS for off-grid power generation in remote rural areas. This has made the conversion of generated unregulated power to useful power at the consumer’s end to be very easy (Oyedepo, 2014).

Decentralised Power System
Decentralised power system refers to the process of generating, storing and distributing power in a localised way, energy produced closer to where it is consumed. It reduces transmission losses and lower carbon emissions. It increases power supply security. Adoption of RET as a decentralized energy systems can help bridge this energy access gap, uplifting living standards, and fostering rural development (Adebanji et al., 2021). Renewable energy sources adoption as a decentralized energy systems in the country represents an opportunity to address a multitude of pressing challenges, ranging from energy access and environmental sustainability to economic diversification and health improvement.

There is need for decentralised energy system that brings power nearer to people. Effective implementation of decentralised energy system can be used for rural electrification by providing environmentally benign, that is reliable and sustainable. The idea of using DG in a decentralised energy system will indeed be a better alternative as stated by Adugbe et al., (2023). Electricity generation in the country must be decentralised so that each state or region can generate and consume its electricity at the point of production. Decentralised RES technologies provides an effective template in meeting the basic energy needs of the rural dwellers.

Prospects and Barriers to Sustainable Energy Development in Nigeria
Prospects
The abundant RES in the country signifies a suitable and profitable markets for private-sector involvement in electricity generation. The future global economy is most likely to be determined by increasing RES utilisation for electric power generation. The advocacy for developing economies is to pursue large scale investment in RES, energy efficiency and clean cooking. Countries that adopt the opportunities provided by RET in providing steady sustainable energy growth will achieve multiple benefits such as GDP multiplier, job creation, cheaper energy provision, improved health and agricultural outcomes

Challenges
Most people in the rural areas depend entirely on using wood and biomass for their energy needs thereby leading to high deforestation, greenhouse gasses emission and aiding global warming and environmental issues. The abundant energy resources in the country do not correlate with sustainable energy growth. As the population increases, there is more energy demand and the energy generation is insufficient, thereby creating a wide power demand-supply gap.

One of the major challenges confronting the growth of RES in the country is the lack of competent indigenous technical personal. These shortcomings can be attributed to the inability to incorporate local energy needs, unavailability of spare parts, lack of skilled labour for repair, maintenance and installations. The high capital investment required for RES is also still a major barrier for sustainable development in most developing countries of the world, even though the initial capital has been greatly reduced in most developed countries. Even though renewable energy sources are now more affordable in developed countries globally, the initial investment involved in renewable energy installation in developing countries remains a major barrier to its development (Oyedepo, 2014).

The insecurity situation and high level of vandalism in the country have even contributed in no small measure in hindering rapid development of RES in Nigeria. The recurrent attacks especially in the northern part of the country serves as a serious setback in attracting
would-be investors and international donor organisations. Some other identified major challenges towards sustainable energy growth in the country are poor or lack of reliable finance services, lack of political will or poor management of resources at all levels of governance, lack of awareness, defective policies and regulations and defective quality control system (Oyedepo et al, 2018).

Strategies for Tackling the Challenges

The growth, strength and prospects of a country’s energy sector depends solely on the effectiveness of its past, present and future policies. In order to promote rapid development and utilisation of RET in the country, there is need to formulate responsive and effective policies that will address the present and future energy needs of the people. These policies need to be formulated effectively in tackling short-term and long term barriers in the energy sector. There is need to formulate policies that will attract investors into RES industry through subsidies, loans, grants, tax-holiday and other fiscal assistance.

In order to ensure rapid growth of RES technologies, there is need for local adaptation such as water pumping, solar cooker, street lighting by encouraging participation and investment of the people in the host communities. More awareness about benefits and advantages of RES technologies needs to be created through proper orientation and enlighten about the dangers of using fossil fuels. Government (at all levels) needs to mount up serious campaigns against deforestation, vandalisation and all negative enviromental practices. The available research and development centres should be well-equipped to support the global green economy drive. In order for the full adaptation of RES as a sustainable energy model, there is need to seek technical assistance from NGO’s and other developing nations in relation to adapting the emerging technologies to the local environment and training the local experts in management of the new technologies (Udoma & Arciszeweski, 2010).

Intensive research should be carried out on increasing renewable energy sources, energy efficiency and energy management strategies in ensuring sustainable development. Energy efficiency reduces basic energy needs required to provide services. Efficient energy use will ensure optimal management of the limited available energy and also enhancing preparation for medium and long term energy plan.

Conclusion and Recommendations

The study emphasised the need to diversify the current monopolised electric power generation system, by allowing RES to actively contribute to the national energy generation mix. This will enhance viable economic growth, grassroots social development and political stability. It is very glaring that the country is abundantly blessed with fossils and clean energy resources, which if properly harnessed, can be used to achieve her major SDGs. It is imperative to create more awareness in enhancing local/decentralised energy system. Sustainable energy system provides significant opportunities for governments (at all levels) and would-be investors to aggressively invest in Solar PV, Biomass and Small hydro power generation systems for a viable economic growth in the country. Efficient, reliable and decentralised energy system that incorporates clean energy sources at affordable price is needed for any sustainable development. A decentralised renewable energy system will surely enhance access to affordable, reliable and environment-friendly modern energy services at lower cost of energy, especially for the rural dwellers.

References


Oyinna, B., Okedu, K.E., Diemuodeke, O.E., David, L.E., Negedu, I.O., Osemudiamen, E.A.,