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Renewable Energy in Nigeria Manuscript on a Research proposal

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ABSTRACT
This work presents single capsule that shows a holistic narrative of the energy access sector in view of energy penetration, sustainability, technology advancement and energy policy evolution. From available records, renewable energy sources in Nigeria are equitably distributed throughout the country, unlike the fossil reserves that are mostly concentrated in the south-south geopolitical zone. Also, there are huge potentials buried within untapped renewable energy in the country, namely wind, small-scale hydropower, geothermal, tidal and biomass energy. Variable renewable energy now dominates total investment in electricity power generation systems. This dominance of variable renewable energy in investment has thrust the systems integration task of matching electricity supply with demand to center stage, presenting new challenges for energy policy and planning as well as for the institutional organization of power systems. Despite these challenges, there is ample reason to believe that variable renewables will attain very high levels of penetration into energy systems, particularly in regions well-endowed with solar and wind potential. Similar to their success with mobile phone telephony, many developing countries have a significant opportunity to leapfrog directly to more advanced energy technologies that are low cost, reliable, environmentally more benign, and well suited to serving dispersed rural populations.
The prime objectives of this paper are:
(1) To review the current status of the energy resources, the energy demand, and supply in Nigeria
(2) To explore the prospects of utilizing renewable energy resources and to increase the energy efficiency as a possible means of sustainable development in Nigeria.

BACKGROUND

Nowadays energy sufficiency can be considered as a driver that promotes the development of a country. Energy supply has influence on the economic and social aspects as it influences positively or negatively the environment depending on the energy source and the efficiency of its life-cycle processes. It is known that energy is necessary to enhance human life quality. It is useful for multiple purposes like automation of processes or day to day activities [1] becoming an essential part of humans' life. Energy poverty is considered as the lack of electric lightning to perform household activities after sunset, situation faced by the population of some developing countries with undeveloped and inadequate energy supply infrastructures.

Improvement of energy supply systems became a major concern to governments and decision makers in order to increase people's life quality and enhance the development of their countries. In order to analyze alternatives to improve the energy supply, several sustainability-measuring methodologies analyzing the economic, environmental or social factors have been established. Those assessments are guided by short-term economic gains or long-term environmental and social effects [3]. In both cases they provide decision makers an overview of the different electricity generation technologies available for the country [4] with the common goal to reduce risks of inadequate investments.

Since conventional sustainability dimensions (economic, environmental and social) are interlinked with Energy plays the most vital role in the economic growth, progress, and development, as well as poverty eradication and security of any nation. Uninterrupted energy supply is a vital issue for all countries today. The standard of living of a given country can be directly related to the per capita energy consumption. Energy supports the provision of basic needs such as cooked food, a comfortable living temperature, lighting, the use of appliances, piped water or sewerage, essential health care (refrigerated vaccines, emergency, and intensive care), educational aids, communication (radio, television,

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electronic mail, the World Wide Web), and transport.

Energy also fuels productive activities including agriculture, commerce, manufacturing, industry, and mining. Conversely, a lack of access to energy contributes to poverty and deprivation and can contribute to the economic decline. Energy and poverty reduction are not only closely connected with each other, but also with the socioeconomic development, which involves productivity, income growth, education, and health. Nigeria is one of Africa's dominant countries, with the highest population and greatest GDP on the continent, according to the International Monetary Fund. The government report found that of Nigeria's 25 operating power plants in 2015, 21 were operating at reduced capacity, and seven operated at less than 10% of their potential, causing missed production equivalent to financial losses of $7m a day.

Energy situation in Nigeria

Nigeria is Africa's energy giant. It is the continent's most prolific oil-producing country, which, along with Libya, accounts for two-thirds of Africa's crude oil reserves. It ranks second to Algeria in natural gas [15]. Most of Africa's bitumen and lignite reserves are found in Nigeria. In its mix of conventional energy reserves, Nigeria is simply unmatched by any other country on the African continent. It is not surprising therefore that energy export is the mainstay of the Nigerian economy. Also, primary energy resources dominate the nation's industrial raw material endowment. Several energy resources are available in Nigeria in abundant proportions.

The country possesses the world's sixth largest reserve of crude oil. Nigeria has an estimated oil reserve of 36.2 billion barrels. It is increasingly an important gas province with proven reserves of nearly 5,000 billion m^3. The oil and gas reserves are mainly found and located along the Niger Delta, Gulf of Guinea, and Bight of Bonny. Most of the exploration activities are focused in deep and ultra-deep offshore areas with planned activities in the Chad basin, in the northeast. Coal and lignite reserves are estimated to be 2.7 billion tons, while tar sand reserves represent 31 billion barrels of oil equivalent. The identified hydroelectricity sites have an estimated capacity of about 14,250 MW. Nigeria has significant biomass resources to meet both traditional and modern energy uses, including electricity generation [(16].

Table1 shows Nigeria's energy reserves/potentials. There has been a supply and demand gap as a result of the inadequate development and inefficient management of the energy sector. The supply of electricity, the country's most used energy resource, has been erratic. Nigeria lies within a high sunshine belt and within the country; solar radiation is fairly well distributed. The annual average of total solar radiation varies from about 12.6 MJ/m2 -day in the coastal latitudes to about 25.2 MJ/m2 -day in the far North. Solar energy is renewable and its utilization is environmentally friendly. Consequently, when the availability and environmental costs of the

Table1 Nigeria's energy reserves/capacity as in December 2005: Energy and sustainable development in Nigeria: the way forward

Resource type	**Reserves**	**Reserves (BTOE)[c]**	**Reserves (× 10^7) TJ**
Crude oil	36.2 billion barrels	4.896	20.499
Natural gas	166 trillion SCF[a]	4.465	18.694
Coal and lignite	2.7 billion tonnes	1.882	7.879
Tar sands	31 billion barrels of oil equivalent	4.216	17.652
Subtotal Fossil		15.459	64.724
Hydropower, large Scale	11,000 MW		0.0341/year
Hydropower, small Scale	3,250 MW		0.0101/year

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Resource type	Reserves	Reserves (BTOE)[c]	Reserves (× 10^7) TJ
Fuel wood	13,071,464 ha[b]		
Animal waste	61 million tonnes/year		
Crop residue	83 million tonnes/year		
Solar radiation	3.5 to 7.0 kW h/m^2/day		
Wind	2 to4 m/s (annual average) at 10 m in height		

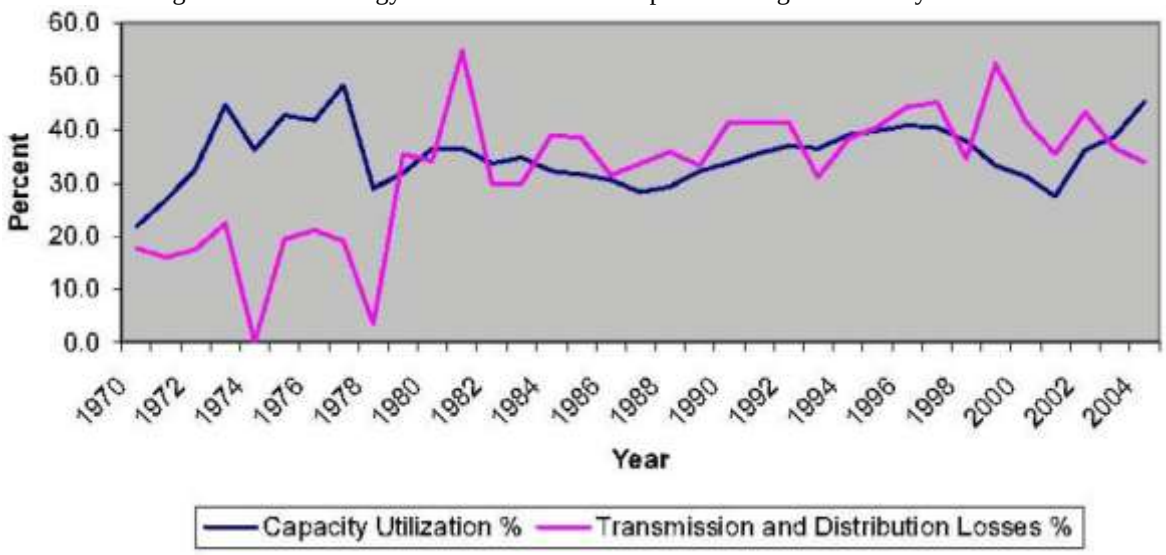
[a]SCF, standard cubic feet; [b]forest land estimate for 1981; [c]BTOE, billion tonnes of oil equivalent. Adapted from ECN[(18].

The poverty eradication and Universal Basic Education programs require energy for success. The absence of reliable energy supply has not only left the rural populace socially backward, but has also left their economic potentials untapped. Fortunately, Nigeria is blessed with abundant renewable energy resources such as solar, wind, biomass, and small hydropower potentials. The logical solution is increased penetration of renewables into the energy supply mix.

The Nigerian energy challenge

Nigeria's energy need is on the increase, and its increasing population is not adequately considered in the energy development program. The present urban-centered energy policy is deplorable, as cases of rural and sub-rural energy demand and supply do not reach the center stage of the country's energy development policy. People in rural areas depend on burning wood and traditional biomass for their energy needs, causing great deforestation, emitting greenhouse gases, and polluting the environment, thus creating global warming and environmental concerns.

Figure 1 From: Energy and sustainable development in Nigeria: the way forward



Indicators of the electricity crisis in Nigeria from 1970 to 2004. Adapted from Iwayemi[38].

In summary, the causal factors in Nigeria's energy crisis include the following:

Prevalence of a regime of price control.

Weak concern for cost recovery and lack of adequate economic incentives to induce the state-owned companies (NNPC and PHCN) to engage in efficient production and investment behavior. This seems apparent in the existence of large input and output subsidies. Multiplicity of economic and noneconomic objectives without

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proper identification of the trade-offs among these different objectives. This is implicit in its pricing policies in both electricity and petroleum products markets.

Institutional and governance failures which induced gross distortions and inefficiency in production, investment choices and high costs of operation, low return on investment, and expensive delays along with cost overruns in the state energy enterprises.

Energy Security and Growth

Over-dependence on subsidized oil and gas as primary energy sources has slowed down the development of renewable energy in Nigeria. Diversification to achieve a wider energy supply mix will ensure greater energy security for the nation. The domestic demand for petroleum products is growing rapidly. More importantly, the prices of fossil-related fuel stock such as natural gas, coal, uranium, and diesel have continually grown over time, while these sources will eventually run out. A national strategy that ties the future of energy supply to sources that may likely become too expensive or eventually run out is neither sustainable nor wise. This strategy will certainly not enhance energy security. In contrast, hydro, biomass, solar, and wind energy are infinitely available.

These are homegrown energy sources that cost nothing. While the capture technologies are expensive, the feed stock cost is essentially zero and operating costs are restricted to maintenance costs once the investments are made. In addition, improved energy efficiency yields the prospect that economic life cycle savings are greater than the costs of implementing measures. is an important consideration for the Nigerian energy sector, in terms of energy security and geo-political balance between the North, the Central belt, and the South of the country.

The reason is that solar, the primary and most abundant renewable resource, increases in intensity as one moves from south to north. The rural populaces, whose needs are often basic, depend to a large extent on traditional sources of energy, mainly biomass, used on inefficient appliances. to the energy security of the rural communities. Efficiency in energy use bears the potential to meet demands better while reducing the consumption of scarce resources

Table 2 RENEWABLE ENERGY CONSUMPTION

Electricity (TJ)	2013	2018
Heat (TJ)	18 266	25 214
Bioenergy (TJ)	4 196 688	4 526 138
Total (TJ)	4 214 954	4 551 352

Table 3 ELECTRICITY CAPACITY AND GENERATION

Generation in	2019 GWh %	2020 MW %
Non-renewable	25 059 75	11 002 84
Renewable	8 492 25	2 153 16
Hydro and marine	8 430 25	2 111 16
Solar	41 0	28 0
Wind	0 0	3 0
Bioenergy	21 0	10 0
Total	33 552 100	13 154 100

Table 4 TOTAL PRIMARY ENERGY SUPPLY (TPES)

TPES	2013	2018
Non-renewable (TJ)	1 413 245	1 637 987
Renewable (TJ)	4 569 607	4 954 442

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Total (TJ)	5 982 852	6 592 429

Table 5 RENEWABLE ENERGY CONSUMPTION BY SECTOR

Consumption by sector	2013	2018
Industry (TJ)	296 295	179 813
Transport (TJ)	0	0
Households (TJ)	3 814 814	4 248 356
Other (TJ)	103 844	123 184
Renewable share of TFEC	82.2	79.7

Energy situation in Nigeria

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Several energy resources are available in Nigeria in abundant proportions. The country possesses the world's sixth largest reserve of crude oil. Nigeria has an estimated oil reserve of 36.2 billion barrels. It is increasingly an important gas province with proven reserves of nearly 5,000 billion m3. The oil and gas reserves are mainly found and located along the Niger Delta, Gulf of Guinea, and Bight of Bonny.

Most of the exploration activities are focused in deep and ultra-deep offshore areas with planned activities in the Chad basin, in the northeast. Coal and lignite reserves are estimated to be 2.7 billion tons, while tar sand reserves represent 31 billion barrels of oil equivalent. The identified hydroelectricity sites have an estimated capacity of about 14,250 MW. Nigeria has significant biomass resources to meet both traditional and modern energy uses, including electricity generation[16]. Table1 shows Nigeria's energy reserves/potentials. There has been a supply and demand gap as a result of the inadequate development and inefficient management of the energy sector. The supply of electricity, the country's most used energy resource, has been erratic.

1. Lack of preventive and routine maintenance of GENCOs's facilities, resulting in huge energy losses.
2. Frequent major breakdowns, arising from the use of outdated and heavily overloaded equipment.
3. Lack of coordination between town planning authorities and GENCOs, resulting in poor overall power system planning and overloading of GENCOs equipment.
4. Inadequate generation due to operational/technical problems arising from machine breakdown, low gas pressure, and low water levels.
5. Poor funding of the organization.
6. Inadequate budgetary provision and undue delay in release of funds to GENCOs.
7. GENCO's inefficient billing and collection system.
8. High indebtedness to GENCOs by both public and private consumers who are reluctant to pay for electricity consumed when due.
9. Vandalizing and pilfering of GENCOs equipment.

6.1 Access to reliable and sustainable energy is both a significant challenge and opportunity in Nigeria

Access to reliable energy is a major issue for Nigeria

Nigeria's maximum available capacity on the grid is 5.4GW, despite current consumption needs averaging 12.9GW per annum

This capacity constraint, combined with erratic supply to users, results in a per capita consumption of 144kWh, ranking 10th lowest globally

A significant portion of the economy is powered by small-scale generators with 74% of energy in Nigeria being self-generated by generators in 2019

6.3. Renewables are ideally-placed to address Nigeria's energy needs

Backed by a supportive government and increasing capital from investors and donors, renewable energy is fast emerging as one of Nigeria's most exciting new sectors

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With an average 6.25 hours of sunshine daily across the country, alongside hydropower, biomass and wind potential, Nigeria is ideally placed to capitalize on technological improvements in the sector and accessibility to renewable energy sources With over 80% of the population experiencing inadequate energy supply, there are opportunities across the energy value chain to address this unmet, and growing need

6.4 Current Constraints

Generation Transmission Distribution Retail Current Constraints

GENCOs are constrained by inadequate transmission capacity and payment challenges to supply sufficient power to meet consumer demand

Transmission

Low demand intensity in many areas makes cost recovery difficult

Outdated transmission infrastructure systems experience ~40% losses and frequent outages (~90% of which are unplanned)

Distribution

Non cost reflective tariffs disincentives Distribution companies (DisCos) from regularly providing electricity to end costumers

In addition the absence of proper metering and low collection rates pose major financial challenges for DisCos

Retail

Non-reliable supply from DisCos drive consumers to explore other power options (e.g. diesel generators) • As a result, end-users pay higher total costs for switching between grid electricity and self-generated power

As a result of challenges across the value chain, customers can be considered across 3 categories:

On -Grid - 40% of Nigerian households are considered 'On-grid' with over 4 hours of electricity supply

Bad-Grid - 40% of Nigerian households are considered 'bad-grid'. While these households have access to the grid they experience power outages up to 40% of the time within 24 hours

Off -Grid - 20% of Nigerian households are considered 'off-grid' with no grid energy supply. Generators are an established and widespread alternative energy source

Given Nigeria's natural resources, multiple renewable technologies offer investment opportunities:

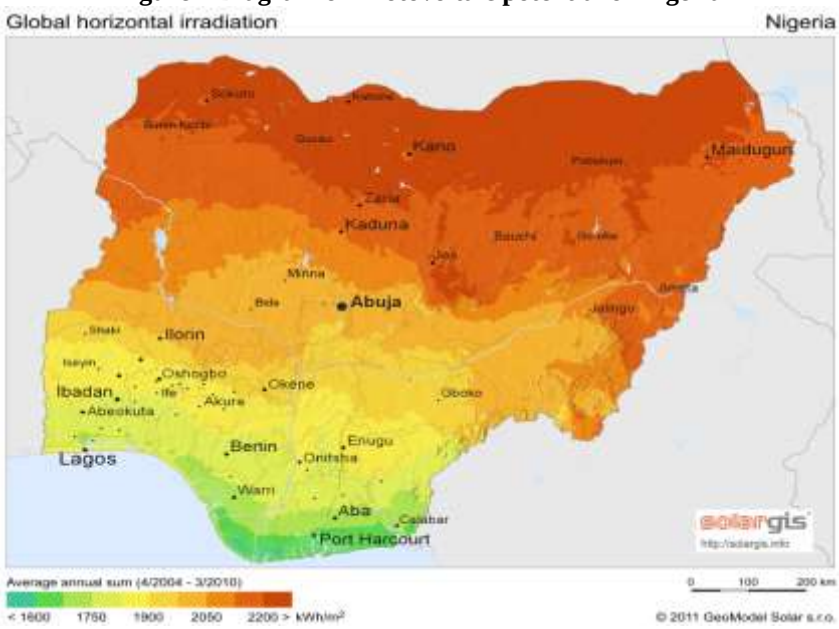
Solar Power

Nigeria has enormous solar energy potential, with fairly distributed solar radiation averaging 19.8 MJm2/day and average sunshine hours of 6.25h/day

The assumed potential for concentrated solar power and photovoltaic generation is around 427GW

According to estimates, the designation of the 5% most suitable land in central and northern Nigeria for solar thermal would provide a theoretical generation capacity of 42.7GW - over 4 times the current Nigerian grid capacity

Figure 1 Diagram of Photovoltaic potential of Nigeria



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This PVOUT map provides a summary of estimated solar photovoltaic (PV) power generation potential. It represents long-term average of yearly/daily potential electricity production from a 1 kW-peak grid-connected solar photovoltaic (PV) power plant

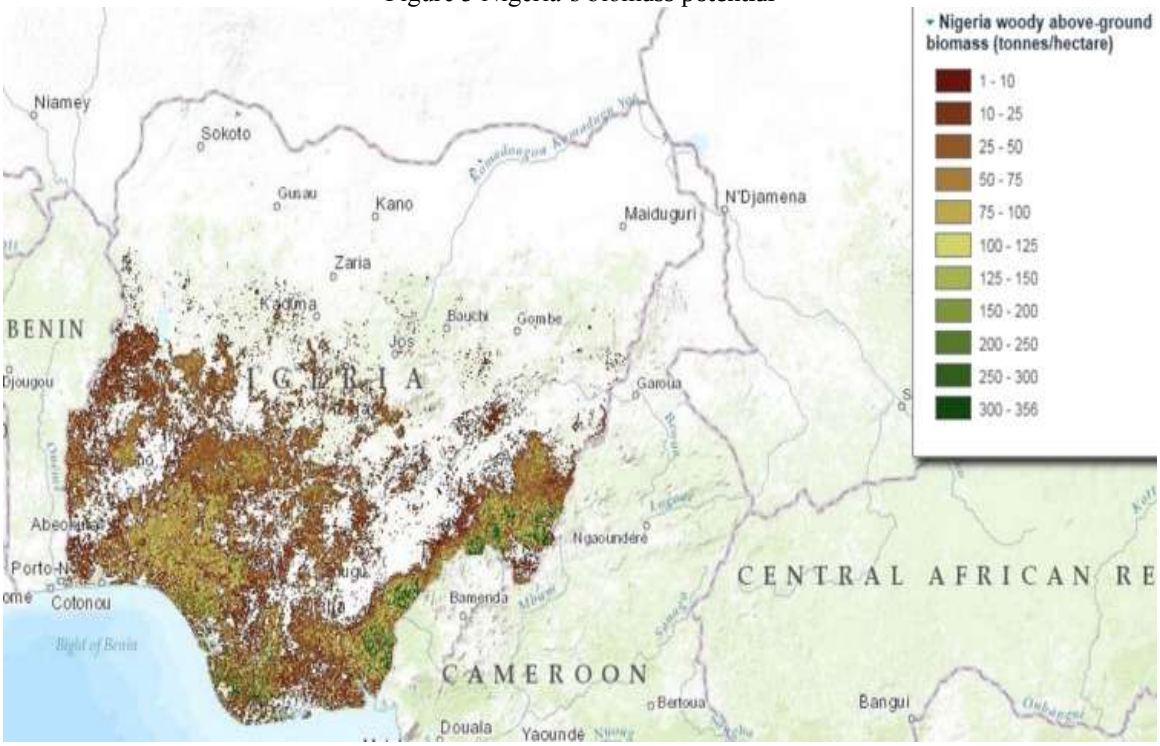
Biomass Power

The biomass resources of Nigeria are mainly crops, forage grasses, shrubs, animal wastes and waste arising from forestry, agriculture and municipal and industrial activities

According to estimates, the daily production of animal waste in Nigeria is about 227,500 tons, which could produce ~30% of electricity consumed by the grid in 2018. And crops such as sweet sorghum, maize, and sugarcane are the most promising opportunities for biofuel production

Though the technology itself is not yet widely established in the country, there are number of successful cases of agri-businesses producing energy for own use with biomass feedstock as well as pilot biomass mini-grids powering communities such as Wuna community in Abuja funded by USADF

Figure 3 Nigeria's biomass potential



Hydro Power

Hydropower has been a substantial contributor to Nigeria's grid for a number of decades, accounting for ~20% of total grid supply today

While large scale hydro power is well established, there is significant untapped potential in small hydropower across Nigeria

A multitude of river systems, providing a total of 70 micro dams, 126 mini dam and 86 small sites, supply a technically exploitable capacity of 3.5GW, but only 1.7% (0.06GW) of these resources is currently being tapped

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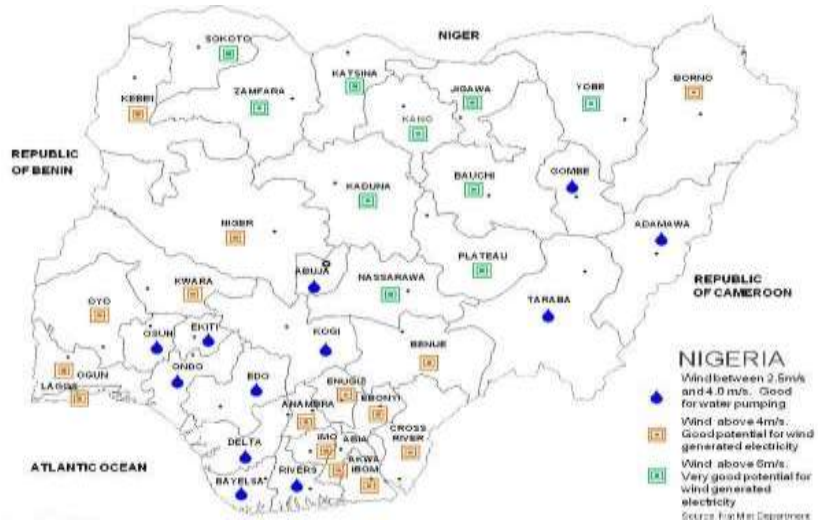
Figure 4 Nigeria's biomass potential

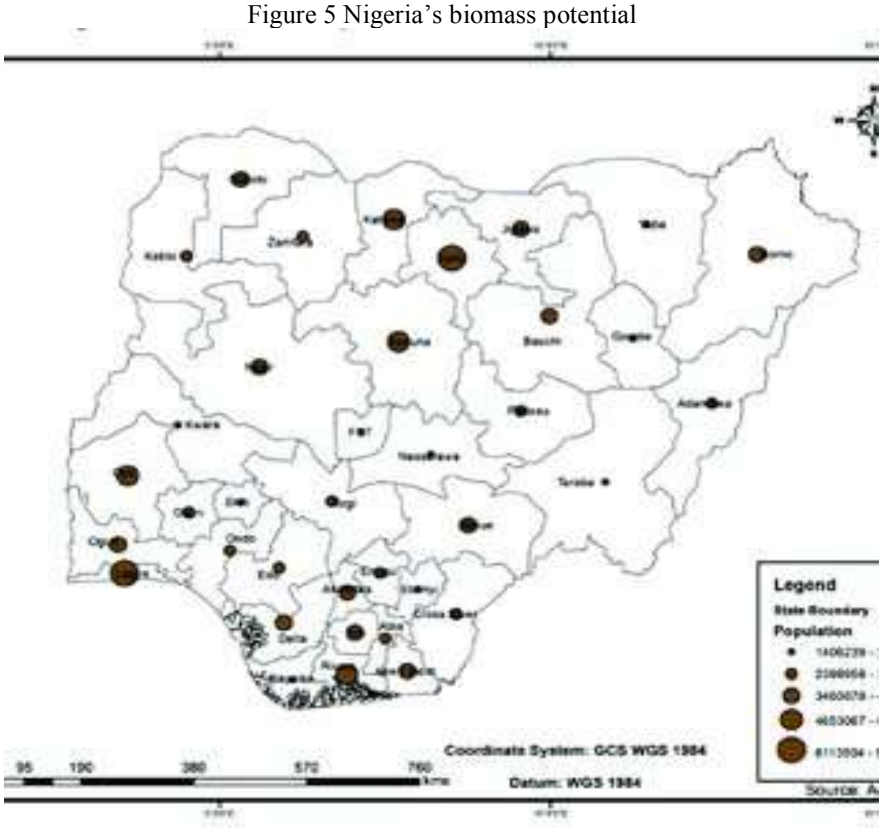


Wind Power

Wind energy potential in Nigeria is modest compared with other technologies, with annual average speeds of about 2.0 m/s at the coastal region and 4.0 m/s at heights of 30m in the far northern region of the country1

Wind speed of up to 5m/s were recorded in the most suitable locations, which reveals only a moderate, localized potential for wind energy. As a result, wind energy has not been considered for detailed assessment in this document

Figure 5 Nigeria's biomass potential



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Benefit of rural electrification

Education

Access to electricity facilitates sustainable economic and social growth. First, through an increase in educational achievement. Students who were previously forced to study when the sun was shining are now able to study by the light of LEDs early in the morning or late into the night. In Kenya for example, interviews with school teachers revealed that access to light has allowed for extra hours of teaching earlier and later in the day to cover material not adequately reviewed during normal hours. Additionally, schools with access to electricity are able to recruit higher quality teachers and have seen improvements on test scores and graduation rates, raising the human capital entering the labor force in the future.

Productivity and efficiency

In addition to improved education, rural electrification also allows for greater efficiency and productivity. Businesses will be able to keep their doors open for longer and generate additional revenues. Farmers will have access to streamlined modern techniques such as irrigation, crop processing, and food preservation. In 2014, rural communities in India gained more than US$21 million from increased economic activity driven by recent additions of electricity.

Local market failures as the national grids fall short of their demand for electricity. As of 2017, over 1 billion people worldwide lack household electric power – 14% of the global population.[1] Electrification typically begins in cities and towns and gradually extends to rural areas, however, this process often runs into obstacles in developing nations. Expanding the national grid is expensive and countries consistently lack the capital to grow their current infrastructure. Additionally, amortizing capital costs to reduce the unit cost of each hook-up is harder to do in lightly populated areas (yielding higher per capita share of the expense). If countries are able to overcome these obstacles and reach nationwide electrification, rural communities will be able to reap considerable amounts of economic and social development.

Job creation

When expanding the electrical grid, there is a demand for thousands of jobs ranging from business development to construction. Projects to spread electricity create a wealth of job opportunities and help to alleviate poverty. For example, India set a target of 175GW of clean energy to be installed by 2022 to increase electrification throughout the country. An estimated 300,000 jobs will need to be created in order to reach these lofty goals.

Healthcare improvements

The availability of electricity can drastically increase the quality of healthcare provided. Improved lighting increases the time patients can come and get treatment. Refrigerators can be used to conserve incredibly valuable vaccines and blood. Sterilization measures will be improved and the implementation of high tech machines such as x-rays or ultrasound scanners can provide doctors and nurses the tools they need to perform.

Technology

Renewable off-grid enterprises have emerged in many areas to meet the demand for electricity in rural communities. Due to their geographical location and relatively low aggregate demand, expanding the nationwide grid to rural areas is expensive and challenging. Renewable energy based mini grids are less dependent on larger-scale infrastructure and can be implemented faster and cheaper.[9] Where an electric power distribution grid can be set up single wire earth return is often used. The following technologies are used extensively:

Photovoltaic

Wind mechanical water pumps

Small wind electric

Diesel solar hybrid power systems: especially for telecommunications worldwide. Fully commercial and the preferred option for remote telecommunications, commercially evolving for village power.

Challenges

Researchers pointed out that while many supportive policies have been put in place, cost for providing electricity to remote villages remains high. Furthermore, both energy resources and demand in these areas can be very volatile, making it difficult to plan appropriately. Another issue is that village location was determined historically based on soil, water, storage, etc., and might not be optimal for renewable energy generation.

To mitigate these issues, the Networked Rural Electrification Model has been proposed. In this model, villages in a selected area are linked up via an optimal network, which in turn connects to a few centralized generation facilities located at spots with better renewable energy resources. As such, each village is partially supplied by small local facility, and partially by the centralized facilities. This improves energy resources utilization as well as overall system flexibility and reliability.

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Viability of this model depends on the cost of building the optimal network. Based on multiplier-accelerated A* algorithm, the researchers have devised an effective method for evaluating all possible connections under complex geographical structure and hence practically optimize network design. Economic justification follows single power source.

CONCLUSIONS

As a sequel to Nigeria's participation in the Paris Agreement on Climate Change, there has been increased attention on the desirability and possibility of increasing power generation through renewable energy sources, thus meeting Nigeria's Intended Nationally Determined Contribution (INDC) 2030 target to mitigate climate change.60 Nigeria's renewable energy strategy in this regard includes solar power generation and a decrease in the predominant use of fossil fuel burning generator sets.

The renewable energy attitude is complemented by international donors like the USAID and World Bank and local visionaries like Zolar Electric and Arnergy Solar Limited that have invested in renewable energy in Nigeria. It is hoped that the investments will be reflected and enforcement will be complemented by wider adoption of renewable energy.

Recommendations

In this study, it is established that renewable energy and energy efficiency are two components that should go together to achieve sustainable development in Nigeria. The need to conserve the present energy generated in the country using energy-efficient products and the appropriate practices is essential for sustainable development. Therefore, it is recommended that the country should do the following:

Develop policies on energy efficiency and integrate them into the current energy policies. A comprehensive and coherent energy policy is essential in guiding the citizens towards an efficient usage of its energy resources.

Promote energy-efficient products and appropriate practices at the side of the end users and energy generation.

Create awareness on renewable energy and energy efficiency.

Establish an agency to promote the use of energy efficient products and ensure the appropriate practices.

Develop and imbibe energy efficiency technologies.

Develop appropriate drivers for the implementation of energy efficiency policies.

Clean energy facilities should be embraced in the different sectors of the Nigerian economy.

In the following, a partial list of potential clean energy opportunities in Nigeria is presented:

More efficient passive and full usage of solar technologies in the residential, commercial, and industrial sectors.

In addition to these, the existing research and development centers and technology development institutions should be adequately strengthened to support the shift towards an increased use of renewable energy. Human resource development, critical knowledge, and knowhow transfer should be the focus for project development, project management, monitoring, and evaluation. The preparation of standards and codes of practices, maintenance manuals, life cycle costing, and cost-benefit analysis tools should be undertaken on urgent priority.

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