Assessment of Renewable Energy Sources & Municipal Solid Waste for Sustainable Power Generation in Nigeria

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Abstract. The demand for Energy in most Sub-Saharan African countries has become unimaginable despite its high potential of natural and renewable resources. The deficit has impeded the regions’ economic growth and sustainability. Nigeria as a nation is blessed with fossil fuels, abundant sunlight, hydro, wind and many among others, but the energy output to its population (185 million) still remains less than 4000MW. Currently, the clamour for an alternative but renewable energy source is the demand of the globe but it is quite expensive to achieve the yield that meets the Nigeria demand. Hence, this study aims at identifying and mapping out various regions with renewable energy potentials. The study also considers municipal solid waste as a consistent and available resource for power generation. Furthermore, this study examines the drawbacks inhibiting the inability to harness these renewable, energy generating potentials in full capacity. The study will enable the authorities and other stakeholders to invest and plan on providing a sustainable energy for the people.

1. Introduction

Energy, as a major driver of global development is accompanied with its own shortcomings having fossil fuels as its conventional energy source which has contributed to the degrading environment as well as the socioeconomic effect associated with it. However, the increasing clamour for energy and satisfying it with a combination of conventional and renewable resources is a huge challenge [1]. Energy demand in Sub-Saharan Africa grew by around 45% from 2000 to 2012, but accounts for only 4% of global demand despite being home to 13% of the global population [2]. According to the UN Framework Convention on Climate Change (the Kyoto protocol), the developed countries agreed to reduce the emission of greenhouse gas to 1990 emission level [3]. Hence, climate change and other negative effects of using fossil fuels for power production, along with a growing demand for energy coupled with concerns over energy security, are driving the expansion of renewable sources of energy [4]. Sustainable development within a society requires a supply of energy resources that, in the long term, is readily and sustainably available at reasonable cost and can be utilized for all required tasks without causing negative societal impacts [5]. International climate negotiations have long pitted developing countries (focused on providing access to affordable energy to their populations) against developed countries, responsible for most of the greenhouse gases emitted to date but leading the shift to greener energy sources [6]. Hence, Renewable Energy (RE) in simple terms can be described as the obtainable energies from natural sources that are constantly replenished. With RE technologies, countries can meet their policy goals to secure, reliable and affordable energy to expand electricity
access and promote development [7]. Globally, the call for renewable energy sources for a sustainable power in an eco-friendly manner is one of the major goals of the UNFCCC, IPCC and the EU among others. The RE sources in Nigeria are: solar; hydro; bioenergy and wind are in abundance to be harnessed in full capacity to its electric power supply issue. Currently, the utilization of Municipal Solid Waste (MSW) as a biogenic form of renewable energy source for power generation is on the rise globally. Nigeria as a nation is blessed with fossil fuels, abundant sunlight, hydro, wind and many among others, however the energy output to its population (185 million) still remains less than 4000MW. Presently, the sporadic power supply in Nigeria has severely impeded the socioeconomic growth of the nation. Seasonal variation, lack of maintenance and inabilities to recent technologies has hindered the power output from the hydropower stations in Nigeria. Also, the inadequate supplies of natural gas due technical faults and sabotage hinders continuous energy production from thermal power facilities. Hence, this study aims at identifying and mapping out various regions with renewable energy potentials in Nigeria. The study also considers MSW as a consistent and available resource for power generation. Developing the RE sector in Nigeria would be a viable opportunity to salvage our degrading environment as well as providing a sustainable electric power supply to the people for socioeconomic growth.

2. Methodology

The methodology employed in this study aims to identify the available renewable energy sources and display it on maps. The used data sets are Nigerian State boundary map; minor and major river maps; Population data; Settlement map; Dam data and Hydro-electric facility data were obtained from the National Space Research & Development Agency (NASRDA) Abuja, Nigeria. Also, a 40-year available average wind data (1968 – 2007) from [8] was adopted and displayed on a map. Solar potential sites map was reproduced from solar irradiation data for Nigeria on the solargis website [9]. The use of geospatial software (ArcGIS 10.2) was used to carry out the mapping of the potential sites for renewable energy resource for electricity.

2.1. Study Area

Nigeria is a country located in the western part of the African continent which lies between the latitudes 5°N and 15°N and longitudes 5°E and 15°E and a landmass of approximately 924,000km² [10]. It is blessed with many natural resources like crude oil, natural gas, limestone, gold and as many among others. Also, Nigeria has an immense potential of hydropower generation because of two great rivers (Rivers Niger and Benue) entering from the Northeast and Northwest, and with an access to 840 km coastline in the Southern part of the country [11]. The southern part of Nigeria lies on the coastline hence its tidal power potential can be utilized for power generation. However, the northern part of Nigeria is close to the Sahara region, hence it tends to experience a lot of sunlight and medium winds for a considerable electrical power generation. The abundance of biomass such as MSW among others, can be utilized as a resource for electrical power generation in Nigeria.

2.2. Hydropower

Hydropower is the largest renewable energy source, and it produces around 16 % of the world’s electricity and over four-fifths of the world’s renewable electricity [7]. Hydropower in Nigeria currently accounts for about 19% of the total installed commercial electric power capacity. Also, the overall large-scale potential (exploitable) is in excess of 18,600 MW but unfortunately, just about 19% is currently tapped [12]. Hydropower can be described as a RE source that utilizes the energy of a fast-moving water or falling water channelled through a water turbine for the generation of electric power. In recent studies, hydropower potential sites are distributed in 12 Nigerian states and in the river basins. However, Small Hydro Power (SHP) potential sites exist in virtually all parts of Nigeria and there are over 278 unexploited sites with total potentials of 734.3 MW [13]. Small hydropower projects are generally considered to be more environmentally favourable than both large hydro and fossil fuel powered plants because they do not involve serious deforestation, rehabilitation and
submergence [14]. At the moment, the large scale operational hydro-electric power facilities in Nigeria are; Kanji, Jebba, and Shiroro respectively. However, the shift of attention to the use of fossil fuel for power generation contributed to the decay of these hydro-power facilities as a result, the extent of their output is below the installed capacity [15]. Generally, hydropower is the most flexible source of power generation available and is capable of responding to demand fluctuations in minutes, delivering base-load power and, when a reservoir is present, storing electricity over weeks, months, seasons or even years [16]. Furthermore, tidal power is another form of hydropower that is unpopular. The use of tidal power can be extracted from moon-gravity powered tides by locating a water turbine in a tidal current for the purpose of generating electric power supply [17]. The southern part of Nigeria has a coastline of about 840km and its proximity to the Gulf of Guinea can be utilized by harnessing its tidal power potential. The concept of power generation in tidal power is similar to hydro power generation by extracting energy from a difference in hydrostatic head which occurs from rising and falling tides. However, tidal power is not a common technology because of the financial cost implications and other constraints, which should be examined before embarking on such project. The figure 1 shows the hydropower potential in Nigeria which comprises of rivers, coastline, hydropower stations, and dams for proposed power generation, irrigation, and for water supply purposes.

![Figure 1. Hydropower potential Map](image)

2.3. **Solar Energy**

The geographical location of Nigeria lies in the equatorial region, which is an advantage for receiving abundant solar energy, hence it could be harnessed daily in full capacity for electrical power generation. Solar power can be simply described as the solar radiation from the sun to the earth surface which converts its energy directly into heat or electricity. It was reported in [18] that the annual
average daily solar radiation in Nigeria is about 5.25kW h/m²/day which varies between 3.5kWh / m² / day at the coastal areas and 7kWh / m² / day at the northern boundary. According to [19], there is a possibility to generate $1850 \times 10^3$ GWh of solar electricity per year which is over 100 times the current grid electricity consumption level in Nigeria. An alternative energy source (solar) in the rural areas for socioeconomic development, eco-friendly and better quality of life can promote poverty alleviation in Nigeria. Generally, the two main types of solar energy systems are currently the solar-thermal conversion and solar electric (photovoltaic) conversion. The most commonly available in Nigeria is the photovoltaic conversion which uses silicon panels that generate an electrical current when light shines upon it. The average amount of sunshine hours all over Nigeria varies between 4 - 7 hrs daily [20]. Figure 2 shows the solar irradiation in Nigeria, and delineates the areas of higher intensity suitable for solar power which shows that the northern part of Nigeria is the most suitable sites for large scale solar farms.

![Figure 2. Solar Irradiation Map](image)

2.4. Wind Power
Wind energy is presently used by some countries around the world as a renewable energy source for electric power generation. Wind power is verily available depending on the location and/or the particular season of the year. Wind technologies convert the energy of moving air masses at the earth's surface to electric power with the help of a wind turbine generator. There have been various studies worldwide on the prospects of local wind sites for electrical power generation, and Nigeria is not an exception. In a way to ascertain this assertion, Ogbonnaya et al in [21] carried out a study to see the possibilities of utilizing wind as an energy source in Nigeria using a 4 year of wind data from seven cities (Enugu, Jos, Ikeja, Abuja, Warri, Sokoto and Calabar). And it was reported that Sokoto is capable of a power potential as high as 97 MWh /yr. In [20], it was reported that due to the varying
topography and roughness of the nation, large differences in wind distribution within the same locality exist. According to the report using a 40 year (1968 − 2007) available average wind data from 44 wind stations across the Nigerian states obtained from NIMET shows that the wind regime is found to lie majorly between poor to moderate regimes, with the southern states having their mean wind profile at 10 m height in the range between 3.0 − 3.5 m/s, depending on the states, and Northern states capable with mean wind speeds of between 4.0 − 7.5 m/s [22]. Furthermore, it was also reported that wind speeds are generally weak in the south except for the coastal regions and offshore which have the potential for harvesting strong wind energy throughout the year but strongest in the hilly regions of the North, while the mountainous terrains of the middle belt and northern fringes demonstrated a high potential for a great wind energy harvest. Studies have shown that the highlands of Jos and some identified locations in the north-western part of Nigeria have the best potential sites for wind power and can be linked to the national electrical grid unlike the southern states with marginal wind that is only suitable for standalone electrical and mechanical applications like battery charging, street lighting and water pumping using small scale wind turbines [23,24]. In addition, reports state that the southern region of Nigeria, has its highest potential for wind energy harvest between the months of February and July (wet season), while in the northern region, the windier seasons vary with location [25]. The figure 3 shows the isovents (m/s) across Nigeria based on measurements from NIMET’s 44 stations at 10m height over a period of 40 years (1968 - 2007).

![Figure 3. Isovents (m/s) across Nigeria [8,23]](image)

2.5. Biomass

Biomass energy is simply the type of energy derived from organic materials that can be utilized for power generation. Biomass can be used directly through direct combustion or processed into another form such as biofuel (methane, ethanol etc). The combustion of biomass releases carbon emissions but has been classified as a renewable energy source according to the United Nations legal framework, because plants can always be regrown through reforestation, and municipal solid waste is continuously generated provided human inhabitants and other anthropogenic activities are present. In most cases, biomass incineration technologies are constructed with one form of emission control system to reduce greenhouse gas (GHGs) emissions to the stipulated standards [1].
2.6. Municipal Solid Waste (MSW) as an Energy Resource

Municipal Solid Waste (MSW) is one of the major environmental problems facing mankind in the world today. However, efforts are being made globally to control the disposal, reduce the existing backlog in the environment landfills, transform and reuse it for human sustainable development. Recent estimates show that the waste sector contributes about one-fifth of global anthropogenic methane emissions [26] of which methane is a greenhouse gas that is 23 times more harmful for climate change than the same volume of CO₂ [27]. The exponential population growth in Nigerian urban cities is simultaneous to the increasing quantity of MSW generated which is of great concern with limited technological solution. The World Bank in [28] reported that Nigeria as a developing nation with a total urban population exceeding 70 million has its per capita generation of MSW as 0.56 kg/capita/day and estimated projection is expected to be at 0.8 kg/capita/day by 2025. MSW as a resource for electrical power generation can be achieved by thermo-chemical conversion technologies (incineration/combustion, gasification, Refuse Derived Fuel (RDF)) and Biochemical conversion technologies (landfill gas, anaerobic digestion). Waste-to-Energy technologies are able to convert the energy content of different types of waste into various forms of valuable energy, hence electric power is produced and distributed through local and national grid systems [29]. The choice of technology is dependent on the economic viability and technical know-how due to some major criteria which include: Lower operational cost; Net operational cost; Complexity in technology and higher efficiency. According to [30], thermo-chemical conversion is preferably used due to its ability to ensure that the contribution of both biodegradable and non-biodegradable components of the waste are used for the energy output. However, the incineration with energy recovery is a good option for Nigeria in order to rapidly reduce the large volume of MSW in the environs, and simultaneously solve the current electric power crisis. Also, landfill gas recovery for power generation is an alternative because of the scarcity of land resources and it is considered a long-term plan for power generation and also a contingency plan for the future. The figure 4 and 5 below show the settlement and population maps of Nigeria as an indication of humans and their anthropogenic activities in Nigeria.

3. Discussions and Challenges

The sporadic power supply in Nigeria is as a result of over-dependence on hydro-electric power and thermal power from gas fired plants. The Nigerian renewable energy potentials still remain untapped towards improving the existing power supply crisis in the nation. Nevertheless, the demand for electric power supply has grown exponentially compared to present power supply of about 4000MW from the national grid. Several efforts were made to improve the situation in the Nigerian power sector by the privatization of the sector which has low impact so far. However, the major challenges inhibiting the growth of renewable energy in Nigeria are as follows;

- Lack of firm policies, regulatory framework and its implementation for RE resources and technologies has thwarted the growth, therefore investors (foreign and local) are not assured of their investment returns. Also, poor economic incentives and multiple taxation systems (federal, state and local government taxes) limit investors from establishing business in Nigeria.
- Lack of political will and commitment by the federal government towards policy framework implementation. In 2005, the Nigerian government came up with a Renewable Energy Master Plan (REMP) which was targeted to increase energy generation capacity from 5000MW to 16000MW by 2015. However, the government has shown no commitment towards achieving these goals.
- Absence of proper orientation programs for energy saving and sustainability: seeing that most of the end users in Nigeria use high energy consuming light fittings for illuminating their homes thus depriving other grid users of constant supply of electricity. For instance, some houses use 100W bulbs as their security light and 60W bulbs for the inside of their houses. However, 10W LED bulbs could do the same home lightening.
• Poor maintenance, Affordability, and Sabotage: The deterioration of existing hydropower facilities and solar power pilot projects has led to low electric power productivity as a result of poor maintenance. Also, the high cost of RE technologies such as wind power, and solar panels is discouraging for local authorities and individuals. The concern on sabotage and loss of huge financial investment by the government has deterred the establishment of solar and wind farms for large scale power generation.

• Zero effort on energy recovery from MSW: the carbon component in MSW can be recovered in the form of electricity and heat for cooling otherwise if allowed to build up into heaps indiscriminately in the environment, the risk of decomposition will enhance the production of greenhouse gases like methane and carbon dioxide which contribute to global warming.

• Lack of funding for Research and Development (R&D) of RE technologies in the research institutes and tertiary institutions.

4. Conclusions
In conclusion, it is evident that Nigeria as a nation is blessed with abundant renewable energy resources to tackle its erratic electrical power supply but very little has been done. The renewable energy resource such as hydro power, solar, wind, and biomass with respect to MSW due to urbanization are displayed in maps in various parts of the country (See figures 1, 2, 3, 4 and 5) for better visualization and understanding. The solar irradiation intensity is abundant in the northern parts of Nigeria compared to the south, and also with solar energy, studies stated that there is a possibility of
generating about $1850 \times 10^3 \text{ GWh/yr}$ of solar electricity which is above 100 times the current grid electricity consumption level in the country.

![Population Map](image)

**Figure 5. Population Map**

However, hydro is the most common RE resource used for power generation in Nigeria that is not fully harnessed as a result of its huge capital and maintenance cost. The 3 major hydro power stations (Kanji, Jebba and Shiroro) generate in combination less than its installed capacity and the Small Hydro Power (SHP) potentials is still not fully exploited. Again, the tidal power can be explored using the coastal belt of Nigeria but the cost implications and other constraints need to be properly evaluated. Studies have shown that the Southern and Northern states in Nigeria have huge wind power potentials but results show that wind power generation can be sustainable in some parts of the Northern states (Sokoto, Jos, Katsina, Kano and Zamfara), and the coastline states from Lagos state to Akwa Ibom state. It was also deduced that seasonal variations in Nigeria influence the power generation output for instance the water levels in the hydro-power dams, and also the intensity of wind (depending on the location) and solar irradiation. MSW is generated by inhabitants everyday throughout the year in any society as a result of the human activities in such environment. The present mean per capita generation of MSW in Nigeria is $0.56\text{kg/person/day}$, having about 70 million residents in the urban areas shows that the power generation potential from Waste–to-Energy can be feasible and sustainable provided the right technology is used.

**5. Recommendation**

Firstly, it is recommended that the sensitization initiative on energy conservation to the people will promote a huge reduction in energy cost so that other grid users can benefit from constant power
supply. Also, the Nigerian government should invest not only its financial capacity, but its political will and implementation plan to ensure that renewable energy resources are fully harnessed. Decentralized energy system should be encouraged in order to ensure that electrical power generated from RE sources in rural communities conserves the energy lost during transmission, reduces the initial cost by the size and number of power lines to be constructed so that the power generated on-site is utilized within a defined locality. The need to integrate Independent Power Project of Nigeria is significant in order to encourage individuals, industries and other stakeholders to own their standalone renewable energy systems which enables them to generate, utilize and sell the excess energy to the national grid. The Energy Commission of Nigeria (ECN) should be more proactive in its jurisdiction to ensure that all areas of RE are fully explored through research and development and trainings for its expertise on the latest RE trend in the globe. And lastly, local content technology should be encouraged through research and development (R&D) and also there should be a synergy among the research institutes, tertiary institutions, and private investors with the aim of promoting exports and socio-economic development in Nigeria.

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