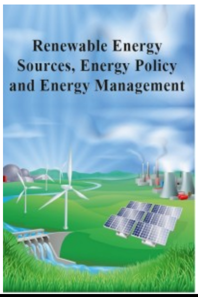
e-ISSN: 2717-9583

**Renewable Energy Sources Energy Policy and Energy Management**

journal homepage: https://dergipark.org.tr/en/pub/resepem




Original Research Article

# Assessment of Renewable Energy Potentials of The Northeast Geopolitical Region of Nigeria

hosted by Turkish JournalPark ACADEMIC

Richard Balthi MSHELİA

*Bayero University Kano, Faculty of Engineering, Department of Mechanical Engineering, Kano, Nigeria. - rbmshelia@gmail.com*
*orcid: 0000-0001-6739-2270*

## ARTICLE INFO

* Corresponding author
rbmshelia@gmail.com
Received 19 March 2021
Received in revised form
7 April 2021
Accepted 14 April 2021

Published by Editorial Board
Members of RESEPEM



## ABSTRACT

Energy is key to socioeconomic and sustainable development of any society. Northeast geopolitical region of Nigeria is the region with the least access to grid electricity and the region with the least per capita electricity consumption in Nigeria. A desk research was undertaken to assess the renewable energy resources available in the region and their viability for the generation of electricity to meet the needs of the region and those of other regions in the country. Five renewable energy resources were appraised: solar; wind power; hydroelectric power; municipal solid waste and biomass. It was found that 367,702.10 MW of electricity can be generated with the use of photovoltaic solar technology. It was also found that wind power technology is feasible in two of the states in the region. The study also revealed that up to 5,125 MW of electricity can be recovered from two states in the region when hydroelectric power technology is used. All six states in the region were found to be viable for the generation of electricity from municipal solid waste and biomass with each having a potential of generating up to 1,249 MW and 4,752 MW of electricity respectively. According to the study, since each of the states has at least two different renewable energy resources, friendly policies are needed to attract investors to exploit these resources for the benefit of the region and the country as a whole.
***Keywords:*** Biomass; Hydroelectric Power; Municipal solid waste; National; Nigeria; Renewable Energy; Solar Energy; Sustainable Development; Wind Power Energy.

## 1.Introduction

Energy is the lifeline of modern economies, and it is also equally an important factor in determining a society's quality of life. The need for energy in the 21st century can never be over-emphasised; it is the key to the fulfilment of basic individual and communal needs in the modern society. It is no surprise that the need for all to have access to affordable, reliable, sustainable, and modern energy is identified as the 7th agenda of the 17 listed sustainable development goals (SDGs) of the United Nation.

Electricity, as the easiest and most consumable form of secondary energy is critical to an economy's sustainable development while its absence can have negative effects that are harmful to the society as a whole [1]. Thus, the availability and accessibility of electricity is used as an index for assessing a country's or a society's quality of life [2].

Nigeria has a population of about 200 million people [3], however, only about 48% of this population has access to grid electricity [1]. In addition, most of the people who have access to electricity do not enjoy 24 hours supply as such they have to run personal generators to meet their electricity needs.

The northeast geopolitical region (NE) of Nigeria is one of the six geopolitical regions in the country, the others being: northwest; northcentral; southeast; southwest and south-south. North-eastern Nigeria which is made up of six states (Adamawa, Bauchi, Borno, Gombe, Taraba and Yobe) and has a population of about 27 million people [3] lies within longitude 9.9992 and 13.1520 and latitude 11.8846 and 7.9867 [4]. Of the six geopolitical regions in the country, it is the region with the least access to grid electricity – just about 16% of its populace have access to grid electricity. This is in sharp contrast to the south-south and south-west regions of the country where about 82% and 75% of their populace respectively have access to grid electricity [5]. The double jeopardy scenario facing the region is that in addition to the abysmal low access to grid electricity, the few who are connected to the grid have an average daily electricity supply of just about 5 hours – the least in the country [6].

The electricity woes of the region which is a miniature representation of the situation in the country persist in spite of the abundant renewable and non-renewable energy sources available in the region and the country at large. The sustainable development of any country is hinged on its ability to exploit its available primary energy sources for secondary energy production like electricity which is required for use by businesses and households. The need to fully exploit the region's existing primary energy resources becomes crucial in order for the region to grow sustainably and, as a result, to alleviate the sufferings of the people caused by inadequate electricity supply, this paper intends to appraise the renewable energy potentials of the northeast geopolitical region of Nigeria, with the aim of identifying the potentials and demerits of each source.

## 2. Background and Energy Scenario in Nigeria And the NE Region

The first instance of electricity generation in Nigeria dates back to 1896 when the first generating power plant was installed by English colonists in Lagos. The capacity of the electricity plant was 60 kW [7]. Since then, there have been numerous independent power plants dotted all-over the country. In 1951, an act of parliament birthed the Electricity Corporation of Nigeria (ECN) which was established to take over and coordinate all matters relating to the generation, transmission and distribution of electricity in the country [8]. In 1962, another Act of Parliament established the Niger Dams Authority (NDA) for the development of hydroelectric power. Ten years later, ECN and NDA were merged to form the National Electric Power Authority (NEPA) which was to be responsible for all power related matters [9]. Despite numerous efforts and interventions in the years following NEPA's establishment, it was clear that the organization, which held monopoly in the power sector, was unable to meet the country's needs. This reality led to the introduction of the National Electric Power Policy (NEPP) which was meant to be the beginning of the complete overhaul of the power sector so as to make it market driven and have it meet the electricity needs of the country. The policy led to the signing into law and creation of the Electric Power Sector Reform (EPSR) Act in 2005 which was expected to level the playing ground for potential investors and improve the wellbeing of its citizens [1]. The EPSR Act transformed and led to the unbundling of NEPA into the newly incorporated Power Holding Company of Nigeria (PHCN) comprising 18 separate successor companies that took over the assets, liabilities and employees of NEPA. The entities created by the unbundling of NEPA were 6 power generation companies (GENCOs), the Transmission Company of Nigeria (TCN) and 11 distribution companies (DISCOs) [9]. These companies were responsible for the generation, transmission, distribution, trading, bulk supply and resale of electricity in the country. As part of the process of overhauling the sector, Nigerian Electricity Regulatory Commission (NERC) was created to regulate the activities of the companies created. The functions of NERC were to regulate tariffs, ensure that companies provide quality service, and effectively oversee the electricity industry [10].

The unbundling of NEPA has not yielded the desired result as electricity generation and supply capacities have not improved since then. Aminu and Peterside [11] adequately captured the failures of the whole scheme in this sentence: "power sector privatization in Nigeria has only succeeded in entrusting the collective wealth of the people in the hands of few elites, retrenchment of workers, high electricity bills without commensurate services among other negative impacts". Adedeji [12] further buttressed this by stating in his finding that the NERC which oversees the players in the sector has fined these players for poor performance and inefficiency. Clearly, the current setting of the power sector is not living to the desired expectations had of it when it was unbundled. Researchers have stated that the best way of making the sector as efficient as it should be is by fully deregulating the industry which will encourage competition and eliminate government interference which is largely seen as the reason for the progress of the industry, they also alluded that fully deregulating the industry will spur the growth of RE resources in the energy mix of the country [1, 13-16].

Nigeria has 25 on-grid power generating plants whose installed capacity is approximately 12,500 MW. However, due to a myriad of factors such as poor maintenance and vandalism, only about 4,000 MW is currently in operation [17]. The energy mix supplying the national grid comprises power from hydroelectric dams which are all situated in the northern part of the country and natural gas power plants which are all based in the southern part of the country – close to the source of the required natural gas. The gas-powered plants are responsible for 80% of the power supplied to the grid while the hydroelectric dams are responsible for the remaining 20% [17]. Table 1 shows the name, location, installed and average operational capacities of the on-grid power plants in the country while Figure 1 shows the location of the plants on the map of the country [17].

**Table 1.** On-Grid Power Plants in The Country and Their Capacities

| S/N | Name | Type | Location (State) | Installed Capacity (MW) | Average Operational Capacity (MW) |
|---|---|---|---|---|---|
| 1 | AES | Gas | Lagos | 180 | 0 |
| 2 | Afam IV-V | Gas | Rivers | 724 | 2 |
| 3 | Afam VI | Gas | Rivers | 685 | 455 |
| 4 | Alaoji NIPP | Steam | Abia | 720 | 67 |
| 5 | ASCO | Gas | Rivers | 294 | 0 |
| 6 | Egbin | Steam | Lagos | 1,320 | 539 |
| 7 | Geregu | Gas | Kogi | 414 | 131 |
| 8 | Geregu NIPP | Gas | Kogi | 450 | 179 |
| 9 | Ibom | Gas | Akwa Ibom | 190 | 76 |
| 10 | Ihovbor NIPP | Gas | Edo | 434 | 182 |
| 11 | Jebba | Hydro | Kwara/Niger | 570 | 262 |
| 12 | Kainji | Hydro | Niger | 720 | 173 |
| 13 | Odukpani NIPP | Gas | Cross River | 561 | 64 |
| 14 | Okpai | Gas | Delta | 900 | 375 |
| 15 | Olorunsogo | Gas | Ogun | 335 | 189 |
| 16 | Olorunsogo NIPP | Gas | Ogun | 760 | 171 |
| 17 | Omoku | Gas | Rivers | 110 | 0 |
| 18 | Omotosho | Gas | Ondo | 335 | 163 |
| 19 | Omotosho NIPP | Steam | Ondo | 500 | 169 |
| 20 | Rivers IPP | Gas | Rivers | 136 | 0 |
| 21 | Sapele | Steam | Delta | 504 | 69 |
| 22 | Sapele NIPP | Gas | Delta | 450 | 111 |
| 23 | Shiroro | Hydro | Niger | 600 | 153 |
| 24 | Trans Amadi | Gas | Rivers | 150 | 0 |
| 25 | Transcorp Ughelli | Gas | Delta | 480 | 374 |
| | **TOTAL** | | | **12,522** | **3,904** |

**Figure 1.** Locations of On-Grid Power Plants on the Map of Nigeria [17]

Nigeria has one of the least per capita electricity consumptions in the world. With a paltry 156.73 kWh per capita, it is dwarfed by other countries even in the same West African subregion. For example, Ghana's per capita grid electricity consumption is about twice that of Nigeria (305 kWh) [18]. When the per capita electricity consumption of the 10 African countries with the highest nominal GDPs are juxtaposed, it is found that despite Nigeria having the highest nominal GDP, it has the 3rd least per capita grid electricity supply. As compared to Egypt and South Africa, the continent's second and third largest nominal GDP countries, Nigeria's desperate situation is more evident, as these two countries have per capita grid electricity supplies that are 32 and 13 times greater than Nigeria's. Figure 2 shows the countries with the largest 10 largest nominal GDPs in Africa (in descending order) and their corresponding per capita electricity consumption [19].

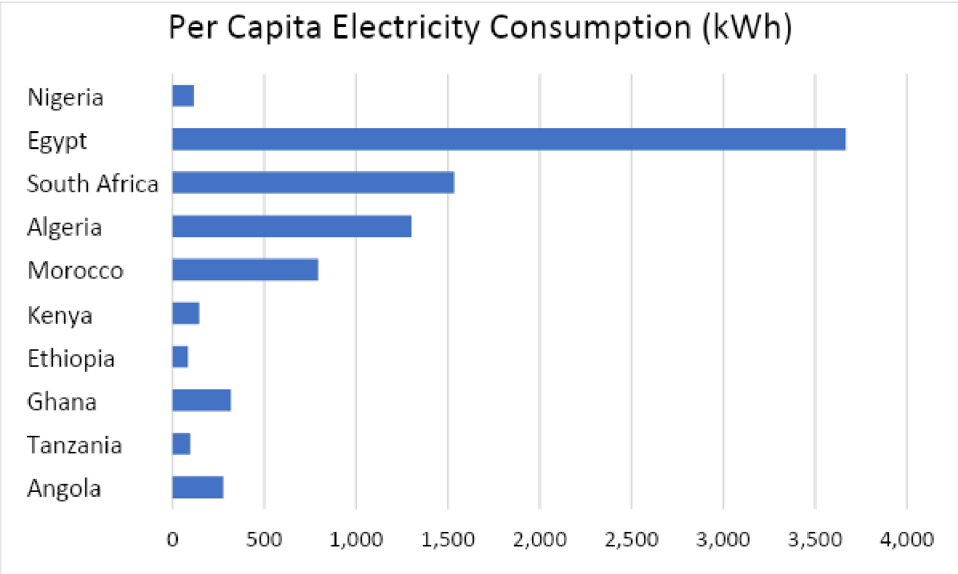



**Figure 2.** Per Capita Grid Electricity Consumption of the 10 Largest GDPs in Africa

Looking at the per capita electricity supply within Nigeria on region-by-region basis, the northeast geopolitical region has the least supply of electricity. According to Olaniyan et al., [5], per capita electricity consumption in North-Eastern Nigeria is just about 1 kWh, this far lower than what is obtainable in other geopolitical regions – for instance, the Southeast geopolitical region boasts of 36 kWh of electricity per capita. Even though the lack of electricity supply is prevalent across Nigeria, the Northern part of the country suffers more. Ohiare [20] pointed out in his research that Taraba state which is in the northeast geopolitical region in the year 2009 had the highest number of households (81.3%) without access to any form of electricity supply, whereas, Lagos state (Southwest Nigeria) recorded the least percentage of households without access to electricity at (6.1%). Monyei et al., [21] further exposed the energy poverty in the northeast by pointing out that the region's yearly per capita electricity consumption was just about 35.39 kWh while that of Lagos is 15 times higher (543.49 kWh). From Figure 3 which is a map of Nigeria showing electrified communities graphically and the energy poverty bedevilling NE Nigeria, it can be seen the northeast region has the least electrified communities.


**Figure 3.** Electrified Communities in Nigeria [22]

The low access and supply of grid electricity to the northeast geopolitical zone has greatly lowered the quality of life of the residents of the region and hampered its economic development by restricting the growth of small and medium scale industries which are the backbone of most economies [23].

### 3. Energy and Renewable Energy Policies in Nigeria

The National Energy Policy of 2003 was the first comprehensive energy policy approved in the country. The policy which was developed by the Energy Commission of Nigeria (ECN) was aimed at outlining government's policy on the production, supply and consumption of energy. The main goal of the policy is to create energy security through a robust energy supply mix by diversifying the energy supply and energy carriers based on the principle of *"an energy economy in which modern renewable energy increases its share of energy consumed and provides affordable access to energy throughout Nigeria, thus contributing to sustainable development and environmental conservation"* [24].

Renewable Electricity Policy Guidelines (REPG) was developed in 2006 by the federal ministry of Power and Steel. Its mandate was to oversee the expansion of the energy mix of the country to include more renewables (at least 5%) [25]. REPG outlines the plans, policies, strategies and objectives of the government of Nigeria for the promotion of renewables in the power sector.

In 2007, Nigerian Biofuel Policy and Incentives (NBPI) was enacted, it was aimed at developing and promoting the domestic ethanol industry by inculcating its usage in everyday activities. In line with this, the state oil company was mandated to create an environment that promotes the blending of ethanol with fossil fuel for use in internal combustion engines so as to reduce the nation's dependence on imported gasoline, and also reduce environmental pollution, while at the same time creating a commercially viable industry that can precipitate sustainable domestic jobs [24]. The benefits of the policy as stated in the policy document was "to create additional tax revenue, provision of jobs to reduce poverty, boost economic development and empower those in the rural areas, improve agricultural activities, energy and environmental benefits through the reduction of fossil fuel related GHGs in the transport sector [26].
The National Renewable Energy and Energy Efficiency Policy (NREEEP) is now the ultimate policy guiding

generation and use of electricity from RE sources in the country, it also advances energy efficiency. NREEEP majorly exists to meet electric power supply targets in a sustainable manner [27]. The policy marks the initial steps of aligning the country's renewable energy and energy efficiency policies with those of the West African subregional group. The main renewable energy sources focused on in the policy are; hydropower, wind and, solar (photovoltaic and thermal) [27].

Objectives of the policy as reported in the policy document are thus [28]:

i. Set out a framework for action to address Nigerians' challenge of inclusive access to modern and clean energy resources, improved energy security and climate objectives;
ii. Recognise the national significance of renewable electricity generation activities by providing for the development, operation and maintenance, and upgrading of new and existing renewable electricity generation activities;
iii. Declare that the proportion of Nigeria's electricity generated from renewable energy sources shall increase to a level that meets or exceeds the ECOWAS regional policy targets for renewable electricity generation and energy efficiency for 2020 and beyond;
iv. Declare Energy Efficiency as a large, low cost, and under-utilized Nigerian energy resource offering savings on energy bills, opportunities for more jobs, improved industrial competitiveness, and lower air pollution;
v. Recognise that poverty mitigation and environmental protection are hindered by the continued predominance and inefficient use of oil and natural gas in meeting our energy needs;
vi. Take a step in the right direction and broadens the definition of energy security to include renewable energy and energy efficiency as equally important indigenous sources of energy, in addition to oil and gas;
vii. Incorporate provisions for renewable energy and energy efficiency generation activities into state policy statements and plans, and recognizes the importance of enabling framework conditions for private investment in renewable energy and energy efficiency;
viii. Set national targets for achievements in electricity from renewable energy and energy efficiency capacity addition by 2020 and beyond;
ix. Require the preparation of national action plan for renewable energy and for energy efficiency and sets a time frame within which implementation is required;
x. Recommend that signatory parties to this policy should collaborate in preparation of the action plans and work together in achievement of the final mandatory targets;
xi. Make it mandatory for the Ministry of power to facilitate the development of an integrated resource plan (IRP) and ensure the continuous monitoring and review of the implementation and effectiveness of the action plans prescribed under the national policy statement and;
xii. Facilitate the establishment of framework for sustainable financing of renewable energy and energy efficiency projects and programmes in Nigeria.

The renewable energy policies in the country can be said to have failed in achieving their objectives. This is so when the timelines for attaining major RE sufficiency milestones as outlined by the NREEEP policy document are examined. It would be noted that none of the targets for achieving RE sufficiency (as seen in Table 2) in the country as outlined in the NREEEP policy document has been attained and from the looks of things, none will be achieved.

**Table 2.** NREEEP Targets [29]

| Milestone | Targets |
|---|---|
| 2015 | 300 MW of Solar PV by 2015 |
| | 100 MW of Small Hydropower (SHP) |
| 2020 | 40 MW of Wind Power |
| | 30 MW of Biomass-fired capacity |
| 2025 | 4,000 MW of Solar PV |
| | 760 MW of SHP |
| | 18% of electricity from RE sources |
| 2030 | 20% of Solar PV by 2030 |

**4. Renewable Energy Potentials of Northeast Nigeria**

The potential for renewable energy (RE) in Nigeria is mostly unexploited in spite of the prevailing pervasive energy poverty in the country. The main barriers to the exploitation of RE resources in the country is the large oil and gas production activities in the south of the country together with government fuel subsidies, the lack of clarity/market information on private sector opportunities, and a general knowledge gap concerning financial support mechanisms available within and outside the country [30]. The huge RE energy potentials of Nigeria is such that when fully exploited, it will lead to the reduction of poverty in the country and also fast track its sustainable development [31]. If exploited, RE resources of the northeast geopolitical region will not only meet the needs of the region but those of other regions. These RE sources and their potentials will be explored methodically examined in the succeeding subsections.

### 4.1 Solar Energy

Solar energy is one of the most thriving RE sources in the world, owing to the simplicity and relative cheapness that comes with its installation and operation. Nigeria lies within a high sunshine belt which makes it possible for it to enjoy between 6 – 12 hours of sunshine on a daily basis. As reported by Uzoma et al., [32], Nigeria has an average solar radiation of about 5.8 kWh/m$^2$ per day and if solar collectors with conversion efficiency of 20% are used to cover 1% of Nigeria's land area, it is possible to generate 1,850×103 GWh of solar electricity per year; this is over one hundred times the current grid electricity consumption level in the country (5.8 kWh/m$^2$ x 0.2 x 365 days x 923768x106 m$^2$ x 0.01 = 3,911,233,712,000 kWh or 3,911,233.712 GWh or 3,911x103 GWh).

The NE region of the country is one of the regions with the highest solar irradiation [33], this makes the use of solar technology a viable RE resource in the region. Figure 4 is the solar irradiation map of Nigeria, it can be seen from it that the NE which falls within Zone I, on average is the most irradiated geopolitical region in the country.

To estimate the amount of electricity that can be generated by the use of photovoltaic (PV) solar technology in NE Nigeria, equation 1 was used thus [35]:

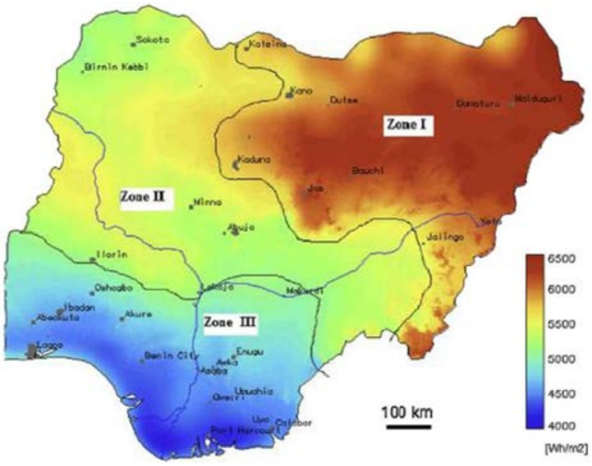



**Figure 4.** Nigeria's Solar Radiation Map [34]

$$E = 365 G_{hi} \mathrm{Pr} \qquad \text{(Eqn.1)}$$

Where
E = Power obtainable/m$^2$
Ghi = Solar irradiation for the given location
Pr = Performance ratio of the PV panel = 20%.

For this study, it was assumed that horizontally stationed PV panels with rated power of 1 kW per module and 0.75 performance ratio for the entire system. Using solar irradiation data found in literature for each of the states [35-37], Table 3 presents the potential amount of electricity that can be generated if 1% of the landmass of each state in the region is used for solar PV technology with the aforementioned specification. The following equations were used for this estimation.

$$P_{1\%} = E \times 1\% \; of \; Land \; mass \text{ (Eqn. 2)}$$

Where
P1% = Power obtainable from 1% of the land mass of each state (kWh)
E = From Equation 1 (kWh/m$^2$)

**Table 3.** Electricity Generation Potentials from Solar Energy in the North East

| State | Annual Average Irradiation per Day ($kWh/m^2$) | Power Obtainable Per Square Metre per Year considering performance factor ($kWh/m^2$) | 1% of Land Mass ($m^2 \times 10^3$) | Power Obtainable when 1% of landmass is used (MW) |
|---|---|---|---|---|
| Adamawa | 5.92 | 432.16 | 369,170 | 43,829.81 |
| Bauchi | 6.11 | 446.03 | 708,980 | 86,875.37 |
| Borno | 6.22 | 454.06 | 708,980 | 88,439.41 |
| Gombe | 6.0 | 438.00 | 187,680 | 22,583.47 |
| Taraba | 6.06 | 442.38 | 544,730 | 66,202.65 |
| Yobe | 6.55 | 478.15 | 455,020 | 59,771.38 |
| **Total** | | | **2,756.77** | **367,702.10** |

As can be seen from Table 3, generation of electricity through solar PV technology is viable in all states of the region. That notwithstanding, Borno state is the most viable state in the region, it has the double advantage of having the highest solar irradiation and the largest landmass. Even though, Gombe state has the least solar irradiation level and the smallest landmass thus making it the state with the least solar energy potential. Nevertheless, it still has the potential of generating 22,583 MW of power, this is about 4 times the current grid capacity of Nigeria and about the exact amount of the forecasted residential, commercial and industrial electricity demands of the country by the year 2030 [38]. The siting of solar projects in the NE will be a feasible renewable and sustainable energy project. Even if financial constraints will hinder the siting of large solar farms, mini off-grid systems that will serve communities that are currently without can be considered.

### 4.2 Wind Energy

Wind energy is one of the most economical and reliable RE source, its versatile nature and suitability for use as an off-grid source makes it one of the most desirable RE resources especially in far flung locations where extending grids to reach those places will not be cost effective [39]. Wind power projects are not without their disadvantages, one of the major disadvantages especially in developing countries is the high technical expertise they require. Another general drawback to wind power is the intermittent nature with which electricity is generated making it unsuitable for use as sole energy source [40], [41].

Research has shown that Nigeria as a country has high potentials for generation of electricity using wind power technology, this potential however, is largely untapped. In instances where attempts were made, the projects were largely abandoned due to inappropriate evaluation of its potentials, poor management and maintenance operations and management [31].

To determine the wind power potentials of NE Nigeria, this research utilised secondary data which originated from Nigeria Meteorological Agency (NIMET) in conjunction with data from literature. Data used include the mean monthly wind speed for the different locations within the NE geopolitical region at the standard height of 10 m and the effective wind area of each of the states in the region. Air density (ρ), wind speed (v) and the area swept by wind turbine rotor are the crucial parameters for determining wind power potentials of a wind turbine, but in instances where available data is limited, the capacity factor approach is used [35]. Capacity factor (CF) of a wind turbine is the ratio of the actual power produced over a given period of time to the hypothetical maximum capacity of the wind turbine or any generating facility running full time at rated power [42]. The CF is estimated using equation 3 [42]:

$$CF = 0.087V - \frac{P_R}{D^2} \quad \text{(Eqn. 3)}$$

Where PR is the rated power, V the wind speed and D turbine blade diameter.

Using the details for a commercially available wind turbine (NEG Micron), which has a rated power of 1000 kW, speed of 16m/s, cut in speed of 3m/s and rotor diameter of 60 m [35], the potential wind power energy of the region on an annual basis is then estimated using equation 4 [42]:

$$WPE = 8760 \times P_R \times CF \quad \text{(Eqn. 4)}$$

Given that the optimal radius between one wind turbine to another is 5 rotor diameters [43], and assuming 1% of the effective wind areas in each of the states is used for the wind power project [44], the annual potential amount of energy that can be recovered in each state of the region is presented in Table 4 along with the wind velocity at 10m, the corresponding capacity factor, and the effective wind area.

**Table 4.** Wind Energy Potential for the Six States in the Region

| State | Wind speed (m/s) | Capacity Factor $(\frac{m}{s} - \frac{kW}{m^2})$ | Annual Recoverable Energy (MWh/Wind Turbine) | Effective Wind Area ($km^2$) | Annual Recoverable Energy from 1% of Effective Wind Area (MW) |
|---|---|---|---|---|---|
| Adamawa | 4.16 [35] | 0.08412 | 736,891 | 17,081 | 159,650 |
| Bauchi | 3.2 [45] | 0.0006 | 5,256 | 24,098 | 1,607 |
| Borno | 6.88 [45] | 0.32076 | 2,809,857 | 72,767 | 2,593,415 |
| Gombe | 3.40 [46] | 0.018 | 157,680 | 17,428 | 34,856 |
| Taraba | 3.60 [47] | 0.0354 | 310,104 | 23,672 | 93,110 |
| Yobe | 5.24 [35] | 0.17808 | 1,559,980 | 44,880 | 888,025 |
| | **Total** | | **5,579,768** | **199,926** | **3,770,663** |

It can be seen from Table 4 that Borno state has the highest wind speed and effective wind area making it the most viable state for the siting of a wind power project in the region. Yobe state which has a similar climate with Borno equally has a high wind velocity making it suitable for wind power projects. It can also be seen from the table that if 1% of the effective wind areas of the two most viable states (Borno and Yobe) are used for generation of electricity using wind power, 2,681,440 MW of electricity can be generated. This is more than sufficient to meet the energy needs of the region and the whole country. The categories of wind available in the remaining 4 states make them suitable for off-grid hybrid power generation [48].

### 4.3 Hydroelectric Power

Hydroelectric Power (HEP) is one of the oldest forms of energy generation techniques in the world, it is also one of the cleanest energy generating technologies. Power is generated by building a dam across flowing water to drive turbines which in turn drive huge electrical motors that convert mechanical energy into electrical energy. HEP has assumed great significance because of its renewable nature, low operational cost and its high conversion efficiency (about 90%) [49]. HEP dams are responsible for producing about 25% of the world's electricity, supplying more than one billion people with power [50]. HEP is the most common RE source globally, this makes it pivotal in the supply of clean energy [51]. Though HEP dams are void of greenhouse emissions which happen to be the main concern of environmentalist at the moment, they are not devoid of other environmental effects, these effects include the disruption of ecosystem and risk of floods faced by communities that are situated at the river's downstream [52].

Researchers have stated that the total exploitable HEP in Nigeria from large scale HEP dams is about 14,120 MW and has the capacity to produce 50,832 GWh of electricity annually, however, only just about 13.50% of this potential is being exploited [31], [35]. As seen earlier in Table 1, there are only three HEP dams operational in the country. These dams have a combined power generating capacity of 1,890 MW.

Northeast Nigeria, despite having a number of rivers which can be exploited for the generation of electricity via small, medium and large-scale HEP dams, does not contribute a wattage of electricity to the national grid through this RE resource. Studies have shown that the rivers and waterfalls crisscrossing the region can be exploited using small and large dams to generate electricity that will sufficiently meet the energy needs of the region and those of other regions. Table 5 shows the rivers in the region and the potential amount of HEP energy that can be generated from each of them as obtained from literature [35].

**Table 5:** Hydro Power Energy Generation Potential in Northeast Nigeria [35]

| River | Location | State | Potential (MW) |
|---|---|---|---|
| Benue | Yola | Adamawa | 450 |
| Niger | Donka | Adamawa | 225 |
| Gongola | Kiri | Adamawa | 40 |
| Danga | Mambila | Taraba | 3,960 |
| Taraba | Garin Dali | Taraba | 135 |
| Dongo | Gembu | Taraba | 130 |
| Kam | Karamti | Taraba | 115 |
| Suntai | Sarkin-Danko | Taraba | 45 |
| Gongola | Krumbo | Taraba | 25 |
| | **Total** | | **5,125** |

The NE region falls within the Sahel and Sudan Savanna climate belt which is largely dry [53], therefore, it is not surprising that only two states have the potential for HEP projects. As can be seen from Table 5, the region has a potential for the generation of up to 5,125 MW of electricity from the rivers that flow through Adamawa and Taraba states. This potential however is left unexploited. It can be seen from the table that the region has the potential for the siting of eight large and 1 small hydroelectric power projects.

### 4.4 Municipal Solid Waste

Recovery of energy from municipal solid waste (MSW) is not an entirely new phenomenon, humans have since been burning solid waste and recovering energy from it in the form of heat and electricity [54, 55]. There are two fundamental types of waste to energy (WtE) technologies: Thermochemical conversion methods (incineration, pyrolysis, and gasification); Biochemical conversion [56, 57]. Thermochemical conversion methods involve the use of heat to burn the waste and then recover the energy given off while biochemical methods involve the natural or aided biodegradation of waste and recovery of energy given off in the form of methane.

NE Nigeria like most other parts of the country generates huge quantities of MSW and yet has poor solid waste management services as such wastes can be seen littering the streets and clogging drainages and waterways [58]. Conversion of the waste generated in the region into energy is an ingenious solution to solve the waste management problem and energy poverty of the region. To estimate the potential amount of energy that can be recovered from the MSW generated in the region using thermochemical conversion method which has been found to be the most suitable for the region based on the profile of the waste disposed of at dumpsites [55, 57], equation 5 is used [58]:

$$E = H_n \times W \times \frac{1000}{859.4} \times \eta \quad \text{(Eqn. 5)}$$

Where Hn is the net calorific value; W=average daily weight MSW (tonnes); η = conversion efficiency (22%).

Table 6 shows the annual quantity of MSW generated in the state capitals of the region [57], their calorific values [59–62] and the estimated recoverable energy.

**Table** 6. Potential Recoverable Energy from MSW in Northeast Nigeria

| State | Quantity of MSW (Tonnes) | Calorific Value (kcal/kg) | Recoverable Energy (MWh/day) | Recoverable Energy (MW) |
|---|---|---|---|---|
| Adamawa | 49,447 | 593.05 | 7,506.86 | 114.16 |
| Bauchi | 71,700 | 1,307.92 | 24,006.43 | 365.09 |
| Borno | 61,317 | 1,212.85 | 19,037.74 | 289.53 |
| Gombe | 135,871 | 615.70 | 21,415.26 | 325.68 |
| Taraba | 19,750 | 1,200 | 6,067.02 | 92.27 |
| Yobe | 12,736 | 1,260.39 | 4,109.28 | 62.49 |
| **Total** | **350,821** | **6189.91** | **82,142.59** | **1,249.22** |

Bauchi state has the highest waste to energy potential in the region, this might not be unconnected to the fact that it has the highest population in the region as such generates a fairly large amount of MSW. Though a careful look at the data presented in Table 6 will reveal that the determining factor for its high energy recovery potential is the calorific value of the waste generated there. Collectively, the region has a potential for generating 1,249 MW of electricity from its waste, this is about a third of the current electricity generation capacity of the whole country, this makes the recovery of energy from MSW is a viable RE source in NE Nigeria. Note that this data reflects only the state capitals as data for other locations within the states are not available because there are hardly any formal waste management systems outside state capitals [57].

### 4.5 Biomass

Biomass is any material that is biological in origin, be it plants or animals that store sunlight in the form of chemical energy. Biomass can be classified into five groups, this classification is done based on origin of the material, these five categories are: wood and woody biomass; herbaceous biomass; aquatic biomass; animal and human waste biomass; and biomass mixtures [63]. The most common sources of biomass energy are virgin wood, energy crops and agricultural residues, industrial wastes, and sawmill residues. Biomass fuels are the most important energy sources for domestic rural households in developing countries, in these locations, biomass accounts for about 40% of rural energy needs and about 70% of their domestic fuel [44]. Technologies for generation of electricity from biomass can be classified into direct burning, physical conversion, biological conversion and liquefaction technology. Direct burning is the most used biomass energy conversion technology.

Nigeria has a huge potential for the successful deployment of biomass energy, the country has abundant fuelwood, animal wastes, energy crops, and agricultural residues. Nigeria has biomass potential of up to 1.2 million tonnes per day, this comprises of 11 million hectares of forest and woodland, 245 million assorted animals and 28.2 million hectares of arable land (30% of the country's total land mass) [64]. Another research found that the country has bio-energy reserves/potential comprised of 13 million hectares of fuelwood, 61 million tonnes per year of animal waste, and 83 million tonnes of crop residues making it total bioenergy reserves reaching an estimated of 1.2 Peta Joules [65]. These diverse biomass resources are scarcely being exploited, according Sambo [66], only fuelwood and agricultural residues are the biomass resources being exploited in the country with shares of 60% and 40% respectively.

Even though the northeast region of Nigeria falls within the Sahel Savanna and Sudan Savanna climate belt which has limited rainfall [53], the region is not without its own share of biomass energy resources, particularly fuelwood, agricultural residues and animal wastes [67]. Using data from literature [35, 67, 68], the annual energy that can be generated from the region's biomass resources are presented in Table 7.

**Table 7.** Potential Annual Biomass Energy Resources of Northeast Nigeria

| Biomass Type | Energy | | |
|---|---|---|---|
| | **Joule ($\times 10^{12}$)** | **MWh** | **MW** |
| Fuelwood | 2,250 | 625,000 | 71 |
| Agricultural Residue | 146,500 | 40,694,444 | 4,645.48 |
| Animal Wastes | 1,146.6 | 318,611.11 | 36.37 |
| **Total** | **149,897** | **41,638,055** | **4,752.85** |

Generation of energy from agricultural residues is the most viable biomass energy resource in the region. It can be seen that 99% of the energy that can be generated from biomass sources in the region is from agricultural residues. This energy source alone has the potential to generate more energy than is currently generated by the gas power plants and the hydroelectric power plants in the country. Though biomass energy source has its inherent disadvantages particularly fuelwood – which is the felling of trees at rates faster than they regenerate thus making them unsustainable, if generation of energy from this source is taken up then an aggressive afforestation programme can be initiated so that the rate of use becomes lower than the rate the trees regenerate thus making it sustainable.

## 5. Conclusion

The energy poverty in Nigeria is one of the highest in the world – even among developing countries. Within Nigeria, the NE geopolitical region is the region with the least per capita electricity consumption and access to grid electricity despite having abundant RE resources. This study appraised the potentials for the generation of electricity from these sources.

It was found that the region has vast untapped solar energy, wind energy, HEP energy, MSW and biomass energy sources. It was found that all the 6 states in the region are suitable for the generation of electricity with the use of solar PV technology. The region was estimated to be able to generate up to 367,702.10 MW of electricity using this technology. Though the potential for electricity generation via solar technology is enormous in NE Nigeria, one of the major hindrances to this is the investment cost involved. Solar power projects have been proposed and abandoned in a number of locations in NE Nigeria because the investment cost of PV panels and backup batteries have been prohibitive. This problem can be solved by introducing public private partnerships (PPPs) agreements that have investors make the initial investments and then gradually recoup their investments. Borno and Yobe states were found to be the states with the potential for generation of electricity using wind power technology. The two states were found to have the potential of generating up to 3,481 GW of electricity using this technology. The remaining states were noted to be suitable for small scale off-grid hybrid wind power technology. Adamawa and Taraba states were found to have the potential for generating 5,125 MW of electricity if the rivers that flow through the states are utilized for generation of power using HEP dam technology. This was found to be achievable via the deployment of 8 large scale dams and 1 small scale dam.

For MSW as a RE resource in the region, it was found that the wastes generated in the region are sufficient for the production of energy that can meet the current energy needs of the region. This resource was found to not only solve the electricity needs of the region, it also solves the solid waste management problems of the region since solid waste will become a sought-after primary energy resource.

The region was found to have biomass energy resources capable of meeting its energy needs, and the use of agricultural residue as a biomass energy resource has been identified as the most viable option. It was found that if 50% of the agricultural residues in the region and the available fuelwood and animal wastes are used for energy generation, 4,752 MW of energy could be generated from these biomass energy sources.

The electricity generation potential of hybrid systems was not considered in this study because the aim is to know how much energy can be generated from each of the RE resource analyzed.

Generation of energy from these RE sources is the key to the energy sufficiency, socioeconomic and sustainable development of the region. Though the initial investments required for the deployment of these technologies are high and might not be affordable to the governments in the region, it is advised that policies which will make the environment suitable for local and foreign investors be made so that the huge energy potentials of the region can be exploited.

## 6. References

[1] N. V. Emodi and S. D. Yusuf, ‘Improving electricity access in Nigeria: obstacles and the way forward’, International Journal of Energy Economics and Policy, vol. 5, no. 1, p. 335, 2015.

[2] R. Nadimi, ‘Quality of life modelling in terms of energy consumption’, International Association for Energy Economics (IAEE), 2017.

[3] National Bureau of Statistics, 'Population', 2020. https://nigerianstat.gov.ng/elibrary?queries[search]=population (accessed Jul. 01, 2020).

[4] R. B. Mshelia, I. S. Diso, and A. A. Adamu, 'The Role of Solid Waste Composting in Mitigation of Greenhouse Gas Emissions in States of North Eastern Nigeria', International Journal of Environmental Pollution and Environmental Modelling, vol. 3, no. 4, pp. 147-154, 2020.

[5] K. Olaniyan, B. C. McLellan, S. Ogata, and T. Tezuka, 'Estimating Residential Electricity Consumption in Nigeria to Support Energy Transitions', Sustainability, vol. 10, no. 5, pp. 1–22, 2018.

[6] B. Bamidele, O. Omowumi, and O. Nathaniel, 'Investigating Electricity Consumption in Ogun State, Nigeria', Journal of Engineering Studies & Research, vol. 26, no. 1, pp. 7–16, 2020.

[7] N. Edomah, C. Foulds, and A. Jones, 'Energy transitions in Nigeria: The evolution of energy infrastructure provision (1800–2015)', Energies, vol. 9, no. 7, pp. 484, 2016.

[8] C. O. Awosope, 'Nigeria electricity industry: issues, challenges and solutions', Covenant University 38th Public Lecture, 2014.

[9] O. Omeje, T. Oluwabusayo, I. Adeleke, and F. Okafor, 'Investigating energy saving potentials in university of Lagos'.

[10] C. Etukudor, A. Abdulkareem, and O. Ayo, 'The daunting challenges of the Nigerian electricity supply industry', Journal of Energy Technologies and Policy, vol. 5, no. 9, pp. 25–32, 2015.

[11] I. Aminu and Z. B. Peterside, 'The impact of privatization of power sector in Nigeria: a political economy approach', Mediterranean Journal of Social Sciences, vol. 5, no. 26, p. 111, 2014.

[12] A. O. Adedeji, 'Privatisation and Performance of Electricity Distribution Companies in Nigeria', Journal of Public Administration and Governance, vol. 7, no. 3, pp. 190–203, 2017.

[13] T. K. Olugbenga, A.-G. A. Jumah, and D. Phillips, 'The current and future challenges of electricity market in Nigeria in the face of deregulation process', African Journal of Engineering Research, vol. 1, no. 2, pp. 33–39, 2013.

[14] E. Adhekpukoli, 'The democratization of electricity in Nigeria', The Electricity Journal, vol. 31, no. 2, pp. 1–6, 2018.

[15] M. C. Amobi, 'Deregulating the electricity industry in Nigeria: Lessons from the British reform', Socio-economic planning sciences, vol. 41, no. 4, pp. 291–304, 2007.

[16] C. Osueke and C. Ezeh, 'Assessment of Nigeria power sub-sector and electricity generation projections', International Journal of Scientific & Engineering Research, vol. 2, no. 11, pp. 1–7, 2011.

[17] 'Energy Sector – GET.invest'. https://www.get-invest.eu/market-information/nigeria/energy-sector/ (accessed Feb. 24, 2021).

[18] P. Akhator, A. Obanor, and E. Sadjere, 'Electricity situation and potential development in Nigeria using off-grid green energy solutions', Journal of Applied Sciences and Environmental Management, vol. 23, no. 3, pp. 527–537, 2019.

[19] IndexMundi, 'Electricity consumption per capita - Country Comparison', 2020. https://www.indexmundi.com/g/r.aspx?v=81000 (accessed Feb. 25, 2021).

[20] S. Ohiare, 'Expanding electricity access to all in Nigeria: a spatial planning and cost analysis', Energy, Sustainability and Society, vol. 5, no. 1, pp. 1–18, 2015.

[21] C. G. Monyei, A. O. Adewumi, M. O. Obolo, and B. Sajou, 'Nigeria's energy poverty: Insights and implications for smart policies and framework towards a smart Nigeria electricity network', Renewable and Sustainable Energy Reviews, vol. 81, pp. 1582–1601, 2018.

[22] S. O. Jekayinfa, J. I. Orisaleye, and R. Pecenka, 'An Assessment of Potential Resources for Biomass Energy in Nigeria', Resources, vol. 9, no. 8, p. 92, 2020.

[23] A. Ado and M. M. Josiah, 'Impact of deficient electricity supply on the operations of small scale businesses in North East Nigeria', The Business & Management Review, vol. 6, no. 2, p. 240, 2015.

[24] N. V. Emodi and N. E. Ebele, 'Policies promoting renewable energy development and implications for Nigeria', British Journal of Environment & Climate Change, vol. 6, no. 1, pp. 1–17, 2016.

[25] A. Iwayemi, C. Diji, B. Awotide, A. Adenikinju, and P. Obute, Towards sustainable universal electricity access in Nigeria. CPEEL, 2014.

[26] N. D. N. B. Policy, 'Incentives', Nigerian National Petroleum Corporation (NNPC), Abuja, Nigeria, 2007.

[27] A. M. O. Bamgbopa et al., 'A review of Nigeria energy policy implementation and impact', Research Gate, 2019.

[28] Ministry of Power, 'National Renewable Energy and Energy Efficiency Policy (NREEEP)', 4, 2015.

[29] E. O. Falobi, 'The role of renewables in Nigeria's energy policy mix', IAEE Energy Forum, no. 1, pp. 41–46.

[30] T. Curristine, Z. Lonti, and I. Joumard, 'Improving public sector efficiency: Challenges and opportunities', OECD journal on budgeting, vol. 7, no. 1, pp. 1–41, 2007.

[31] S. O. Oyedepo, 'Energy and sustainable development in Nigeria: the way forward', Energy, Sustainability and Society, vol. 2, no. 1, pp. 1–17, 2012.

[32] C. Uzoma et al., 'Renewable energy penetration in Nigeria: a study of the South-East zone', Continental J. Environmental Sciences, vol. 5, no. 1, pp. 1–5, 2011.

[33] 'Renewable Energy Potential – GET.invest'. https://www.get-invest.eu/market-information/nigeria/renewable-energy-potential/ (accessed Feb. 28, 2021).
[34] F. I. Abam, B. N. Nwankwojike, O. S. Ohunakin, and S. A. Ojomu, 'Energy resource structure and on-going sustainable development policy in Nigeria: a review', International Journal of Energy and Environmental Engineering, vol. 5, no. 2, pp. 1–16, 2014.
[35] M. Akorede, O. Ibrahim, S. Amuda, A. Otuoze, and B. Olufeagba, 'Current status and outlook of renewable energy development in Nigeria', Nigerian Journal of Technology, vol. 36, no. 1, pp. 196–212, 2017.
[36] G. I. Esbond and S. W. Funmilayo, 'Solar Energy Potential in Yola, Adamawa State, Nigeria', International Journal of Renewable Energy Sources, vol. 4, 2019.
[37] M. Abdullahi and S. K. Signh, 'Global solar radiation evaluation for some selected stations of north Eastern Nigeria', Scholars Research Library, vol. 5, no. 2, pp. 1–8, 2014.
[38] O. Ezennaya, O. Isaac, U. Okolie, and O. Ezeanyim, 'Analysis of Nigeria's national electricity demand forecast (2013–2030)', International Journal of Science and Technology Research, vol. 3, no. 3, pp. 333–340, 2014.
[39] S. Misak and L. Prokop, 'Off-grid power systems', 2010, pp. 14–17.
[40] P. S. Georgilakis, 'Technical challenges associated with the integration of wind power into power systems', Renewable and Sustainable Energy Reviews, vol. 12, no. 3, pp. 852–863, 2008.
[41] A. Mamen and U. Supatti, 'A survey of hybrid energy storage systems applied for intermittent renewable energy systems', 2017, pp. 729–732.
[42] M. F. Akorede, M. I. M. Rashid, M. H. Sulaiman, N. B. Mohamed, and S. B. Ab Ghani, 'Appraising the viability of wind energy conversion system in the Peninsular Malaysia', Energy conversion and management, vol. 76, pp. 801–810, 2013.
[43] D. Schwanz, R. E. Henke, and R. C. Leborgne, 'Wind power integration in Southern Brazil: Steady-state analysis', in 2012 Sixth IEEE/PES Transmission and Distribution: Latin America Conference and Exposition (T&D-LA), Montevideo, Sep. 2012, pp. 1–6, doi: 10.1109/TDC-LA.2012.6319089.
[44] M. Shaaban and J. O. Petinrin, 'Renewable energy potentials in Nigeria: Meeting rural energy needs', Renewable and Sustainable Energy Reviews, vol. 29, pp. 72–84, Jan. 2014, doi: 10.1016/j.rser.2013.08.078.
[45] A. Ahmed, A. Bello, and D. Habou, 'Analysis of wind energy potential in north east Nigeria', Journal of Energy and Natural Resources, vol. 3, no. 4, pp. 46–40, 2014.
[46] M. Ohakwere-Eze, A. Udo, C. Nosike, A. Alhassan, and M. Adamu, 'Appraisal of the wind potential as an alternative source of energy in Kashere, Gombe State, Naigeria.', FUDMA Journal of Sciences, vol. 4, no. 3, pp. 446–452, 2020, doi: https://doi.org/10.33003/fjs-2020-0403-411.
[47] G. S. Alabi and P. K. Olulope, 'Review of wind energy potentials and the possibility of wind Energygrid integreation in Nigeria', IJLRET, vol. 4, no. 5, pp. 59–68, 2018.
[48] M. Gul, N. Tai, W. Huang, M. H. Nadeem, and M. Yu, 'Assessment of wind power potential and economic analysis at Hyderabad in Pakistan: Powering to local communities using wind power', Sustainability, vol. 11, no. 5, p. 1391, 2019.
[49] Å. Killingtveit, '15 - Hydroelectric Power', in Future Energy (Third Edition), T. M. Letcher, Ed. Elsevier, 2020, pp. 315–330.
[50] S. S. Murthy and S. Hegde, '5 - Hydroelectricity', in Electric Renewable Energy Systems, M. H. Rashid, Ed. Boston: Academic Press, 2016, pp. 78–91.
[51] J. Zimny, P. Michalak, S. Bielik, and K. Szczotka, 'Directions in development of hydropower in the world, in Europe and Poland in the period 1995–2011', Renewable and Sustainable Energy Reviews, vol. 21, pp. 117–130, 2013.
[52] P. H. Gleick, 'Environmental consequences of hydroelectric development: The role of facility size and type', Energy, vol. 17, no. 8, pp. 735–747, Aug. 1992, doi: 10.1016/0360-5442(92)90116-H.
[53] A. G. Omonijo, O. Oguntoke, A. Matzarakis, and C. O. Adeofun, 'A study of weather related respiratory diseases in eco-climatic zones', The African Review of Physics, vol. 5, 2011.
[54] Y. E. Charrette, 'Waste to Energy Background Paper'. California, 2011.
[55] R. B. Mshelia, M. C. Onuigbo, and R. Yusuf, 'Energy recovery potential and greenhouse gas emissions from municipal solid waste in Gombe, Nigeria', Scientific Journal of Mehmet Akif Ersoy University, vol. 3, no. 3, Art. no. 3, Dec. 2020.
[56] K. A. Kalyani and K. K. Pandey, 'Waste to energy status in India : A short review', Renewable and Sustainable Energy Reviews, vol. 31, pp. 113–120, 2014, doi: 10.1016/j.rser.2013.11.020.
[57] Mshelia, Richard Balthi, 'Evaluation of greenhouse gas emissions from solid waste management practices in state capitals of north eastern Nigeria', Journal of Engineering Studies and Research, vol. 26, no. 4, pp. 40–46, 2020.
[58] L. Daura, 'Electricity generation potential of municipal solid waste in kano metropolis', Journal of Scientific and Engineering Research, vol. 3, no. 4, pp. 157–161, 2016.
[59] A. Abba, U. Babagana, A. Atiku, and B. Burmamu, 'Evaluation of Energy Potentials from Municipal Solid Waste: A Case Study of Yola, Nigeria', FUTY Journal of the Environment, vol. 13, no. 1, pp. 36–45, 2019.
[60] M. B. Oumarou, S. Shodiya, G. Ngala, and N. Aviara, 'Statistical modelling of the energy content of

municipal solid wastes in Northern Nigeria', Arid Zo. J. Eng. Technol. Environ. August, vol. 12, no. 2003, pp. 103–109, 2016.

[61] R. B. Mshelia and M. C. Onuigbo, 'Thermochemical energy recovery potential from municipal solid waste in Gombe, Nigeria', Annals of the Faculty of Engineering Hunedoara-International Journal of Engineering, vol. 18, no. 4, pp. 139–143, 2020.

[62] D. Tsunatu, T. Tickson, K. Sam, and J. Namo, 'Municipal solid waste as alternative source of energy generation: a case study of Jalingo Metropolis–Taraba State', International Journal of Engineering and Technology, vol. 5, no. 3, pp. 185–193, 2015.

[63] A. Tursi, 'A review on biomass: importance, chemistry, classification, and conversion', Biofuel Research Journal, vol. 6, no. 2, p. 962, 2019.

[64] A. S. Sambo, 'The place of renewable energy in the Nigerian energy sector', 2009, vol. 10.

[65] A. Agba, M. Ushie, F. Abam, M. S. Agba, and J. Okoro, 'Developing the biofuel industry for effective rural transformation in Nigeria', European Journal of Scientific Research, vol. 40, no. 3, pp. 441–449, 2010.

[66] A. S. Sambo, 'Strategic developments in renewable energy in Nigeria', International Association for Energy Economics, vol. 16, no. 3, pp. 15–19, 2009.

[67] E. L. Iye and P. E. Bilsborrow, 'Assessment of the availability of agricultural residues on a zonal basis for medium-to large-scale bioenergy production in Nigeria', Biomass and bioenergy, vol. 48, pp. 66–74, 2013.

[68] D. M. Kulla and A. I. Obi, 'Calorific values of wood species of Nigerian origin', Journal of Applied Science and Technology, vol. 10, no. 1, pp. 66–71, 2005.