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# CURRENT STATUS AND OUTLOOK OF RENEWABLE ENERGY DEVELOPMENT IN NIGERIA

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**ABSTRACT**
***Over 80% of the current Nigerian primary energy consumption is met by petroleum. This overdependence on fossil fuels derived from petroleum for local consumption requirements should be a serious source of concern for the country in two ways – depletion of the resources and negative impact on the environment. This paper presents a critical review of the available renewable energy resources in Nigeria, namely; biomass, hydropower, solar and wind energy. It examines the current energy situation in the country and equally discusses the various energy policy documents developed by the government. Using the scenario-based International Atomic Energy Agency models, the projected energy demand and supply structure of the country through 2030 are presented and analysed. Overall, this study shows that Nigeria will overcome her present energy crisis if she explores the abundant renewable energy resources in the country. The data presented in this paper is a crucial eye-opener for relevant government agencies towards developing these energy resources in tackling the present energy crisis in Nigeria.***

***Keywords:*** *renewable energy, per capita energy, Nigeria, biomass, fossil fuels, growth scenario*

## 1. INTRODUCTION

Energy is a vital ingredient for development and a powerful engine of social and economic change in any country or region. It is at the heart of everybody's quality of life and a critical factor for economic development. The need for energy can never be over-emphasised in the contemporary world; it is indeed fundamental to the fulfilment of basic individual and community needs in our modern society. Lighting and heating a house, running a factory, lighting a street, keeping a hospital open and operational, provision of potable water, etc, all require energy. Since the aforementioned services are the indices by which a nation's progress and level of development are measured, it follows that the amount of energy consumed by a country at a particular instant of time largely determines the country's economic and social development [1, 2].

Renewable energy is energy generated from natural resources such as sunlight, wind, rain, tides, and geothermal heat. It is derived from natural processes that are constantly replenished. Each of these renewable sources has unique characteristics which influence how and where they are used. Globally in 2012, about 19% of total energy consumption came from renewables, with 9% coming from traditional biomass like fuelwood, and 10% from modern renewables such as biomass for heat production and vehicle fuel , geothermal, biofuel, solar, wind and hydropower [3]. The share of renewables in electricity generation at the end of 2015 is around 23.7 % with 16.6% coming from hydropower, 3.7% from wind and 3.4% from other new renewables [4].

To date, fossil fuels, majorly coal, oil and natural gas have been the principal sources of energy worldwide. For instance, more than three-quarters amounting to 78.4% of total world energy demands in 2012 was fulfilled by fossils [3]. Still, report shows that the demand for these fuels grows in absolute terms through 2035 [4]. However, burning of fossil fuels has been identified to create two adverse effects on our environment; (i) it produces greenhouse gas (GHG) emissions that cause global warming, and (ii) the by-products of burning, such as sulphur dioxide, soot, and ash that are responsible for global dimming by changing the properties of the clouds [5]. Therefore, the need to conserve our environment

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from these pollutants led to a global search for alternative clean energy sources. Another driver responsible for the interest in the renewable energy is the rising concerns about the security of energy supplies. Sustainability is a key factor influencing the long-term viability of any energy resource, and it comes as no surprise that it is at the forefront of the global campaign to abandon the use of dwindling fossil fuels reserves.

Though blessed with abundant renewable energy resources, Nigeria is yet to fully harness them to play a significant role in energy production. However, the Nigerian government has taken some steps towards encouraging the use of renewable and alternative energy resources in different sectors of the economy. For example, the long term renewable energy masterplan developed by the Energy Commission of Nigeria (ECN) is to address the challenges of moving towards clean, reliable, secure and competitive energy supply in Nigeria. The main goal of this document is to reduce projected energy use by 20% by 2020 and meet 20% of the Nation's electricity needs with Class 1 renewable energy sources like solar energy, wind energy and fuel cell by year 2020.

Similarly, the Federal Executive Council approved in 2007 the biofuel Policy framework presented by the Nigerian National Petroleum Corporation (NNPC). The policy was targeted at supplying the internal market with 10% ethanol blend with gasoline (E10) to drive engines and vehicles [6, 7]. This mandated NNPC to set up a Renewable Energy Division (RED) to develop private sector driven investments in ethanol production as alternatives to fossil fuels [8, 9]. The biodiesel projects initiated includes the Biodiesel Nigeria Limited's biodiesel initiative in Lagos State, Aura Bio-Corporation's Tolao Biodiesel project in Cross River State and the Shashwat Jatrophal Biodiesel Limited's biodiesel project in Kebbi State [10, 11].In the same vein, the Federal Government established six energy centres for research across the geopolitical zones, affiliated to the ECN saddle with the responsibility of developmental research on renewable energy application in the nation [12].

The prime aim of this paper is to review the electric energy demand and supply in Nigeria, and examine the current status of renewable energy resources and their potentials towards contributing to the socio-economic growth of the country. The quantitative data on the available renewable resources such as biomass, hydropower, solar and wind energy with their current usage are presented. The novelty of this work over the existing studies [13-16] on this subject is that data are not just presented in their raw form but the amount of energy that could be generated are estimated from technical point of view using the approach of the authors' previous study. The distribution across the country as well as the estimated amount of these resources is analysed. The information presented in this article will serve as an essential tool to sensitise relevant government agencies and non-governmental organizations towards fully tapping these abundant energy resources to practically contribute to the energy production in Nigeria.

## 2. CURRENT ENERGY SCENARIO IN NIGERIA

Nigeria is a rich country blessed with both fossil fuels such as crude oil, natural gas, coal, etc, and renewable energy resources like solar, wind, hydro and biomass. Details of this are shown in Table 1 constructed with data obtained from the Nigerian National Petroleum Corporation, Renewable Energy Masterplan and Ministry of Mines and Steel Development [17]. It is seen from the table that Nigeria has a reserve of 36.22 billion barrels of crude oil, 187 trillion Standard Cubic Foot (SCF) of natural gas at standard temperature and pressure (60 degrees F and sea level), and 2.374 billion tonnes of coal and lignite of which virtually nothing has been tapped. The Nigeria's reserve for large hydropower is estimated at 11,250 MW and 3,500 MW for small hydropower. Nigeria has a reserve of 11 million hectares of forest and woodland and 72 million hectares of agricultural land waste land. Based on the available statistics, Nigeria produces about 227,500 tonnes of fresh animal wastes daily. If fully utilised, this quantity is equivalent to 6.8 million $m^3$ of biogas production every day [18].

Despite this abundance of energy resources in Nigeria, the country is currently facing energy crisis due to the country's grossly inadequate energy supply that is incapable to meet the ever-growing demand. Essentially, the major energy-consuming activities in Nigerian households are cooking, lighting and use of electrical appliances. Based on estimates carried out in [19], cooking accounts for about 91% of household energy consumption, lighting uses up 6% and the remaining 3% goes to the use of basic electrical appliances such as television and pressing iron.

To date, the national energy supply in Nigeria is entirely dominated by fossil fuels. Renewable energy resources are grossly underutilised in the country despite their availability in reasonable quantities. Table 2, obtained from Central Bank of Nigeria (CBN) report, shows the primary energy consumption by type. It is apparent from the table that while coal has over a long period been neglected, petroleum has constituted over 80% of the commercial primary energy consumed in the country. However, it is paradoxical to say that in spite of Nigeria's rich oil and gas sector, 58% of the population do not have access to electricity which is a secondary form of energy fuelled by the petroleum with which Nigeria is richly endowed [20].

*Table 1: Energy Resources in Nigeria*

| Resource | | Reserves (natural units) | Production level (natural units) | Utilisation (natural units) |
|---|---|---|---|---|
| Crude oil | | 36.22 billion barrels | 2.06 million bpd | 445,000 bpd |
| Natural gas | | 187 trillion SCF | 7.1 billion SCF/day | 3.4 billion SCF/day |
| Coal and lignite | | 2.734 billion tonnes | insignificant | insignificant |
| Tar sands | | 31 billion barrels of oil equivalent | 0 | 0 |
| Large hydropower | | 11,250 MW | 1,938 MW (167.4 million MWh/day) | 167.4 million MWh/day |
| Small hydropower | | 3,500 MW | 30 MW (2.6 million MWh/day) | 2.6 million MWh/day |
| Solar radiation | | 3.5 – 7.0 kWh/m$^2$/day | excess of 240 kWp of solar PV or 0.01 million MWh/day | excess of 0.01 million MWh/day solar PV |
| Wind | | 2 – 9 m/s at 10 m height | - | - |
| Biomass | Fuelwood | 11 million hectres of forest and woodland | 0.12 million tonnes/day | 0.12 million tonnes/day |
| | Animal waste | 245 million assorted animals in 2001 | 0.781 million tonnes of waste/day in 2001 | not available |
| | Energy crops and agric. residues | 72 million hectares of agric. land and all waste lands | excess of 0.256 million tonnes of assorted crops residues/ day in 1996 | not available |

* SCF – standard cubic feet * bpd – barrel per day

*Table 2: Primary Energy Consumption by Type.*

| Type | Percentage of Total | | | | | | |
|---|---|---|---|---|---|---|---|
| | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | average |
| Coal | 0.03 | 0.03 | 0.03 | 0.03 | 0.05 | 0.05 | 0.04 |
| Hydropower | 11.93 | 14.20 | 17.39 | 12.04 | 17.03 | 23.90 | 16.08 |
| Natural Gas | 2.84 | 1.90 | 4.54 | 5.50 | 7.52 | 8.73 | 5.17 |
| Petroleum Products | 85.20 | 83.87 | 78.04 | 82.45 | 75.44 | 67.32 | 78.71 |

Source: CBN Annual Report (2005, 2007)

The per capita energy consumption in Nigeria is one of the very lowest in the world – about one-sixth of the energy consumed in developed countries. This is directly linked to the level of poverty in the country. Figure 1 is presented to illustrate the per capita energy consumption in Nigeria for 2002 – 2011. The falling trend of energy consumption from 0.754 toe/capita in 2002 to 0.703 toe/capita in 2009 before stabilising at 0.721 toe/capita in 2011 could be observed. These values may be compared with a value of 1.253 toe/capita obtained in Gabon, 2.186 toe/capita in Libya and 2.795 toe/capita in South Africa for the year 2011. The scenario in the chart could be linked to a steady increase in population without a corresponding increase in energy production and consumption.

It is a fact that no country can develop or witness any significant growth without proportional growth in its primary energy exploration for secondary energy production like electricity as mostly required by the industries and consumers.

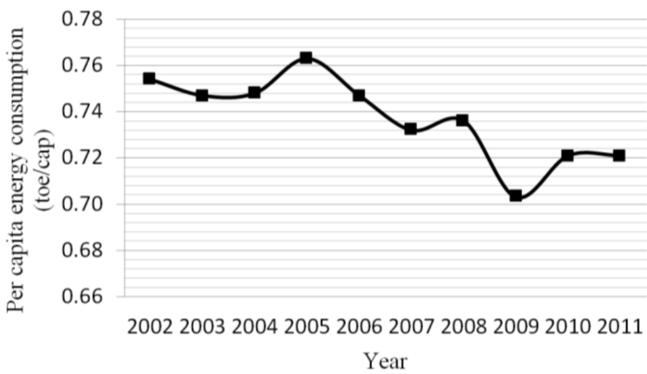


*Figure 1: Per capita energy consumption in Nigeria for 2002 – 2011.*

Evidently, Nigeria provides a classic example. The per capita electricity consumption per annum in Nigeria is plotted and shown in Figure 2 along with a few other

African countries [21] . As shown in the figure, the per capita electric energy consumption in Nigeria for an average household of five people was 149 kilowatt-hours (kWh) per annum for the year 2011. This value is among the lowest ten in the world. Incidentally, studies have shown that there is a strong correlation between energy consumption and economic growth; access to modern electric energy directly contributes to economic growth and poverty reduction of a country through creation of wealth [22]. The abysmal low annual per capita electricity consumption in Nigeria obviously constitutes a major roadblock to economic progress and social well-being of the citizenry.

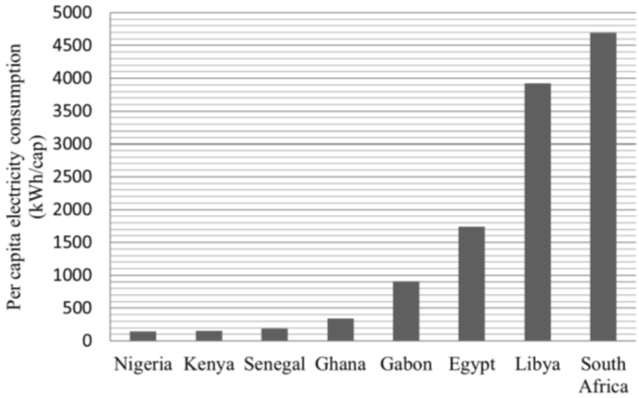


*Figure 2: Per capita electricity consumption of a few African countries.*

## 3. ENERGY DEMAND AND SUPPLY PROJECTIONS FOR NIGERIA

In a bid to aggressively address the lingering energy crisis faced in the country, the International Atomic Energy Agency (IAEA) scenario-based model was used to model the demand structure of Nigerian energy sector in four scenarios. The developed model is for the analysis of energy demand tagged "Model for Analysis of Energy Demand" (MAED). It evaluates future energy demands based on medium to long term scenarios of socioeconomic, technological and demographic development. These are combined to give an overall picture of future energy demand growth. Similarly, another model called MESSAGE i.e. the Model for Energy Supply Strategy Alternative and General Environmental impacts, also developed by IAEA was used to estimate the supply strategy for meeting the energy demand in Nigeria. MESSAGE combines technologies and fuels to map energy flows from supply to demand. The four scenarios used were reference growth, high growth, optimistic I and optimistic II with average GDP growth of 7%, 10%, 11.5% and 13% per annum respectively [17] .

The projected energy demand and corresponding electricity demand for the country from 2005 through 2030, using the previously mentioned MAED model, are depicted in Figures 3 and 4 respectively. Similarly, Table 3 presents the projected electricity supply by fuel mix for Nigeria for the reference growth scenario. From the table, a total of 17,303 MW was targeted for the year 2010. It is however, unfortunate that even as at 18th October 2015; Nigeria's peak electricity generation was less than 4,500 MW [23] . This value is approximately equal to 26% of the target. Judging by this development, it would be very difficult to achieve a total of 131,122 MW of electricity projected for 2030 in the country.

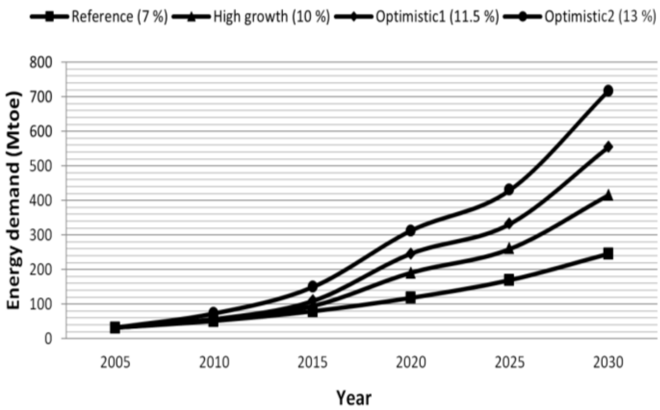


*Figure 3. The energy demand projections for the four economic growth scenarios.*

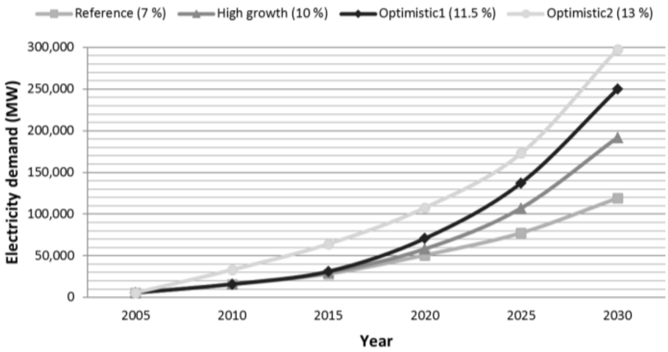


*Figure 4: The electricity demand projections for the four economic growth scenarios.*

*Table 3: Projected Electricity Supply by Fuel Mix for 7% Growth.*

| Scenario | 2010 (MW) | 2015 (MW) | 2020 (MW) | 2025 (MW) | 2030 (MW) |
|---|---|---|---|---|---|
| Coal | 0 | 2,393 | 6,515 | 9,305 | 15,815 |
| Gas | 13,555 | 23,617 | 37,733 | 56,086 | 85,585 |
| Hydro | 3,702 | 4,962 | 6,479 | 9,479 | 11,479 |
| Small hydro | 40 | 90 | 140 | 227 | 701 |
| Nuclear | 0 | 0 | 3,530 | 7,005 | 11,872 |
| Solar | 5 | 10 | 34 | 75 | 302 |
| Wind | 0 | 126 | 1,471 | 3,019 | 5,369 |
| Total Supply | 17,303 | 31,197 | 55,903 | 85,196 | 131,122 |

*Source: Energy Commission of Nigeria (2008)*

The contribution of renewable energy resources for the targeted electricity generation is shown in Table 4. The main renewable energy resources expected in the reference growth scenario are large and small hydropower, solar and wind energy. Overall, the aforementioned renewable energy resources were to constitute about 13% of the total energy resources in year 2010. Thin contribution is targeted to increase to 36% of the total energy production by 2030.

*Table 4: Target for Renewable Energy Contribution to Electricity Generation in Nigeria.*

| Resource | 2010 (MW) | 2015 (MW) | 2030 (MW) |
|---|---|---|---|
| Large hydro | 1,930 | 5,930 | 48,000 |
| Small hydro | 100 | 734 | 19,000 |
| Solar PV | 5 | 120 | 500 |
| Solar Thermal | 0 | 1 | 5 |
| Biomass | 0 | 100 | 800 |
| Wind | 1 | 20 | 40 |
| Total RE | 2,036 | 6,905 | 68,345 |
| Total Energy Resources | 16,000 | 30,000 | 192,000 |
| Percentage of RE (%) | 13 | 23 | 36 |

Source: Renewable Energy Master Plan for Nigeria, ECN 2005.

## 4. OVERVIEW OF DRAFT ENERGY PLANS IN NIGERIA

The Energy Commission of Nigeria is the government body saddled with the responsibility to coordinate activities within the energy sector as well as overseeing the implementation of the objectives spelt out by the Energy Policy. The Commission has developed a number of draft policy documents for the energy sector of the country. Quite a number of these documents have provisions that are relevant to the development of the Policy Guideline. The 1999 Constitution of the Federal Republic of Nigeria, the National Economic Empowerment and Development Strategy (NEEDS) in 2004, the National Electric Power Policy (2001), Electric Power Sector Reform Act 2005 and the National Energy Policy of 2003 [24, 25] are all examples, to mention but a few. The 1999 Constitution places electricity generation, transmission and distribution on the Concurrent Legislative list. The intent is to involve all tiers of government in most aspects of the electricity supply industry. The following are the set of targets proposed by NEEDS to be met by the power sector by 2007, some of which include highlights of the Federal Government's mandate to the former public utility National Electric Power Authority (NEPA):

- Expeditiously implement the electric power sector reform program
- Increase generation capacity from the existing plants from 4,200 MW to 10,000 MW
- Increase transmission capacity from 5,838 MVA to 9,340 MVA
- Increase distribution capacity from 8,425 MVA to 15, 165 MVA
- Reduce transmission and distribution losses from 45% to 15%
- Explore alternative energy sources, such as coal, solar power, wind power, and hydropower
- Deregulate the power sector to allow increased private sector participation

The Electric Power Sector Reform (EPSR) Act of 2005 of which most of the significant provisions of National Electric Power Policy (NEPP) of 2001 are contained, was passed to liberalise the power sector and remove government's monopoly on generation and distribution. Consequently, the Nigerian Electricity Regulatory Commission (NERC) was established to create a level playing field for all stakeholders and licence players in the sub-sector. The EPSR Act emphasises the role of renewable electricity in the overall energy mix, especially for expanding access to rural and remote areas.

The National Energy Policy (NEP) was developed by ECN and approved by the government in 2003. The document launched in 2005 is the origin of the various master plans, such as Renewable Energy Master Plan (REMP), and National Energy Master Plan (NEMP) in 2007 drafted thereafter. The overall thrust of the energy policy stated in it is "optimal utilization of the nation's energy resources for sustainable development". The draft REMP articulates Nigeria's vision and sets out a road map for increasing the role of renewable energy in achieving sustainable development. The NEMP contains action plans that guide its implementation to ensure the development of nation's energy resources with diversified energy resources option for enhanced achievement of national energy security [17].

However it is worth stating here that most of the draft policy documents are yet to become legal documents as they are awaiting government approval. Before they can attain the final implementation stage, the following three levels are crucial [26]:

- Approval by the Federal Government
- Legislation into law by the National Assembly
- Strict adherence to implementation by concerned Ministries, Departments and Agencies (MDAs)

## 5. RENEWABLE ENERGY POTENTIAL IN NIGERIA

Renewable energy sources have contributed to Nigeria's energy mix in the last few centuries, notwithstanding in a largely primitive way. For example, fuelwood is the longest standing primary energy source for rural dwellers in Nigeria, just as for several other African countries. Similarly, large hydropower has contributed in no small measures as an energy source, providing about 32% of Nigeria's national electric grid supply [19].

Adoption of 'new' renewable energy sources such as solar photovoltaics, solar thermal, wind, small hydropower and efficient biomass in the country is relatively recent. Nigeria is endowed with abundant quantities of each of these resources. This section of the paper looks into the available and potential of renewable energy resources in the country.

### 5.1 Biomass Energy

Biomass is any organic material from plants and animals that store sunlight in the form of chemical energy. It is foreseen as one of the most important energy sources among the renewable energies in the near future. Generally, sources of biomass as shown in Figure 5 include virgin wood, energy crops and agricultural residues, industrial wastes, sawmill residues, etc. Biomass fuels are overwhelmingly the most important energy source for rural households, agricultural production and rural industries particularly in developing countries [19]. Modern biomass energy recycles organic waste from forestry and agriculture, like corn stovers, rice husks, wood waste and pressed sugarcane, or uses special, fast-growing "energy crops" such as willow and switchgrass, as fuel. Based on the US International Energy Agency (IEA) report, 11% of the world's energy, both heat and power, is currently derived from biomass [5].

The potential of biomass to help meet the global energy demand has been widely recognised in the literature [27-29]. Depending on the type, when combusted, the chemical energy in biomass is released as heat that is used to produce steam which could in turn be used to either drive a turbine for electricity production or provide heat to industries and homes. To combust biomass involves burning it in air at a flow rate of 4 – 5 kg of air per kg of biomass [6]. Biogas and biofuel technologies are now widely used to convert organic biomass matters to gaseous and liquid states respectively.

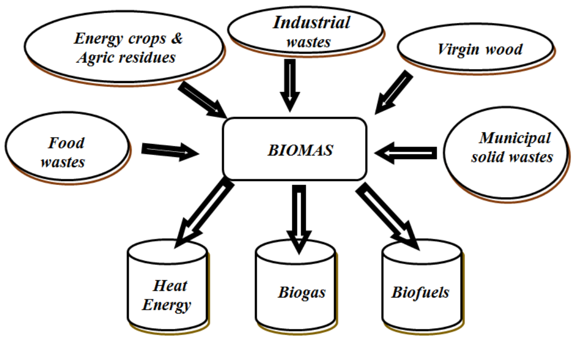


*Figure 5: Forms of biomass and products*

There exists a huge potential for the successful deployment of biomass energy in Nigeria, most especially in the rural agricultural areas. Majorly, the three forms of biomass available in Nigeria as shown in Table 1 are fuelwood, animal wastes and energy crops and agricultural residues. According to a report, Nigeria has a reserve of 11 million hectares of forest and woodland, 245 million assorted animals in 2001 and 28.2 million hectares of arable land, which is approximately equal to 30% of the total land. All these produce in excess of 1.2 million tonnes of biomass per day [20] . In 1990, a total estimate of 1.2 PJ of biomass, consisting of animal and agricultural wastes, and wood residues, was made for Nigeria. Furthermore, research revealed in 2005 that bio-energy reserves/potential of Nigeria stood at 13 million hectares of fuelwood, 61 million tonnes per year of animal waste, and 83 million tonnes of crop residues [30] .

#### 5.1.1 Fuelwood

Nigeria is naturally rich in fuelwood and is the most dominant biomass resource used in the country. It accounts for 60% of the biomass used in the country with agricultural residues accounting for most of the remaining 40%. Annually, Nigeria consumes over 50 million metric tonnes of fuelwood [31] . The annual production of agricultural biomass is enormous due to the fact that about 94% and 68% of Nigerian households are engaged in crop farming and livestock farming respectively. Currently, over 70% of the population, most especially the rural dwellers, take wood as the main source of fuel. The reason behind this is that these people cannot afford to pay for commercial cooking fuels such as kerosene and gas. Even those that can afford the price are often forced to resort to using wood and charcoal in larger cities whenever there is acute shortage of the cooking fuels in the country. However, excessive wood-gathering activity, without replacement, has caused critical depletion of this resource. The expected implication of this act on the environment is that woodlands run the risk of deforestation, which in turn increases the risk of other hazards such as erosion and flood particularly in the South-eastern part of the country.

Vigorous research efforts have globally been made to develop more efficient woodstoves to replace the inefficient traditional three-stone open fires commonly used for cooking in rural areas, as shown in Figure 6. These research efforts have started to yield positive results, one of which is the Save80. The Save80, shown in Figure 7, is a high-quality energy efficiency metal cookstove that saves up to 80% of the required firewood compared to the traditional open fires where only 5–10% of the wood is converted into heat energy. It is developed specifically for use in areas with low fuelwood availability as well as in a number of refugee camps throughout Africa. The "Efficient Wood Fuel Stoves for Nigeria" programme is a joint initiative of the German NGOs, and a Nigerian counterpart, Developmental Association for Renewable Energies (DARE) to promote dissemination of more efficient cooking stoves to households in Nigeria.

*Figure 6: The traditional three-stone cooking stove*

*Figure 7: Highly efficient wood saving stove*

It is the third registered Clean Development Mechanism (CDM) project in Nigeria tagged CDM project 2711. So far over 4,500 Save80 stoves have been sold to customers at reduced price [32] . During the lifespan of the project, it aims to distribute about 12,500 Save80 stoves to improve women's welfare and livelihoods in the project area of the Guinea Savannah zone of Nigeria.

### 5.1.2 Animal waste

The process involved in the conversion of animal waste to biogas to electric energy include the following: mixing of waste to homogenise it; digestion of waste in an anaerobic digester; separation of sludge; biogas collection from digester; and power generation from biogas. Estimates made in 2001 gave the total number of cattle, sheep, goats, horses and pigs as well as poultry in Nigeria as 245 million. These all together produce 0.78 million tonnes of animal waste daily which is equal to $7.644 \times 10^9$ MJ with the calorific value of animal dung assumed as 9,800 MJ/tonne [33]. Table 5 shows the biogas production rates for a number of feedstock materials, majorly animal wastes [34].

*Table 5: Biogas production rates for a variety of feedstock materials*

| Resource | Gas production ($m^3$/kg) | Methane content (%) | Retention time (days) |
|---|---|---|---|
| Cattle manure | 0.2 – 0.33 | n/a | n/a |
| Poultry manure | 0.31 – o.56 | 58 – 60 | 9 – 30 |
| Pig manure | 0.49 – 0.76 | 58 – 61 | 10 – 15 |
| Sheep manure | 0.37 – 0.61 | 64 | 20 |
| MSW | 0.31 – 0.35 | 55 – 60 | 15 – 30 |

According to a study reported by Odeyemi [35], Nigeria has a potential of about 6.8 million $m^3$ of biogas production every day from animal waste only. The referenced feedstock materials for biogas production in the study include poultry manure in homes and commercial poultry farms.

### 5.1.3 Energy crops and agricultural residues

Agricultural residues are classified into crop or field residues and processing residues. While crop residues are the materials left on the farm after harvesting the target crops, processing residues are produced mainly after crop processing [36]. Crop residues produced in Nigeria include straw leaves and stalks of cereal, cassava peelings and cocoa pods. On the other hand, processing residues include cocoa husk, coconut shell and husk, rice husk, etc. The major agricultural crops grown in Nigeria are millet, yam, cassava, sorghum, rice, groundnut, oil palm, jatropha, soyabeans, and maize. Among all, the crops that have sustainable potential as biomass feedstock for biofuel production include sugarcane, sorghum, cassava, rice, and maize, while oil palm, groundnut, jatropha, soyabeans, sunflower, castor oil, and sesame are famous for biodiesel production [37]. Table 6 shows the estimated production data and biofuel type of major Nigerian agricultural crops for the year 2004 [36].

Using the residue to production ratio (RPR) approach, Iye and Bilsborrow [31] estimated the energy potential from major agricultural crop residues in Nigeria from 2001 – 2006 under three different scenarios. According to the study, Scenario 2, which is a more realistic one, yielded a total sum of 22.52 Tg of feedstock, which is equivalent to 264.88 PJ potential energy. On the other hand, processing residues produced a total of 17.41 Tg feedstock, equal to 204.68 PJ of energy. This gives a grand total of 39.93 Tg and 470 PJ annual feedstock and potential energy respectively as illustrated in Table 7. It could be observed from the table that cassava and yam peelings form about 95% of the total processing residues.

*Table 6: Estimated crop output and biofuel type in 2004 for Nigeria.*

| Resource | Crop production (million metric tonnes) | Crop residue production (million metric tonnes) | Derivable biofuel type |
|---|---|---|---|
| Cassava | 45,000,000 | 29,000,000 | bioethanol |
| Yam | 33,500,000 | 22,000,000 | bioethanol |
| Millet | 8,000,000 | 11,000,000 | bioethanol |
| Maize | 7,500,000 | 3,000,000 | bioethanol |
| Rice | 4,600,000 | 1,800,000 | bioethanol |
| Potato | 1,000,000 | 600,000 | bioethanol |
| Cowpea | 3,000,000 | 4,050,000 | biodiesel |
| Groundnut | 2,800,000 | 6,000,000 | biodiesel |
| Oil palm | 1,000,000 | 400,000 | biodiesel |
| Sugar cane | 800,000 | 300,000 | bioethanol |
| Sweet potato | 3,000,000 | 2,000,000 | bioethanol |
| Cocoyam | 2,000,000 | 1,500,000 | bioethanol |
| Coffee | 200,000 | 400,000 | biodiesel |
| Cashew | 180,000 | 300,000 | biodiesel |
| Plantain | 250,000 | 9,450,000 | bioethanol |
| Sorghum | 11,000,000 | 2,500,000 | bioethanol |

*Table 7. Average annual agricultural crops residues for bioenergy production in Nigeria (2001-2006).*

| Crop | Residue type | Residue amount (Gg) | Energy (PJ) |
|---|---|---|---|
| Maize | Stalks | 5,938.01 | 69.83 |
| | Cob | 1,473.70 | 17.33 |
| Cassava | Stalks | 1,052.54 | 12.38 |
| | Peelings | 7,716.56 | 90.74 |
| Rice | Straw | 2,918.50 | 34.32 |
| | Husk | 806.37 | 9.48 |
| Groundnut | Straw | 1,369.25 | 16.10 |
| | Husk | 1,038.14 | 12.20 |
| Yam | Peelings | 6,372.83 | 74.93 |
| Sorghum | Straw | 5,304.86 | 62.39 |
| Millet | Straw | 4,571.40 | 53.76 |
| Groundnut | Straw | 1,369.25 | 16.10 |
| Total | | 39,931.41 | 469.56 |

* Gg – gigagrams (equal to $10^9$ g) * PJ –petajoules (equal to $10^{15}$ J)

The results of a study of the availability and productivity of grasses, weeds and leaves as energy resource, conducted by Osadolor [38] in six selected sites across Nigeria is shown in Figure 8. The objective of this study was to ascertain that the resources will be available for use as energy raw material in the country. It should, however, be noted that the results shown in the figure is the calculated average values for three years – 2001 to 2003. It is glaringly evident in the figure that Buruku-Jos has the highest biomass production of 1,742 g/m$^2$ per year, followed by Ekpoma. The study revealed an annual incremental yield of the resources which varied from 26 g to 402 g.

### 5.1.4 Municipal Solid Wastes

Another source of biomass in Nigeria is municipal solid wastes (MSW). These are materials generated from the daily activities of humans. Essentially, MSW contains two basic components – biodegradable and non-biodegradable matter [37] The biodegradable fraction is usually treated by anaerobic digestion for production of biogas, which could in turn be used for cooking or power generation depending on the scale of production. Municipal solid wastes management in Nigeria includes both open dump in unmanaged sites and controlled sanitary landfills. Organised sanitary landfills are limited to major urban cities such as Abuja, Lagos, Ibadan, Akure and other State capitals. The average MSW produced per capita per day significantly varies from place to place in Nigeria. However, 20 kg of MSW per capita has been estimated to be produced in the country annually [39]. Going by the 2006 census figure of 160 million inhabitants, the total generated MSW will be at least 3.2 million tonnes per year. With increasing urbanisation and industrialisation, the annual MSW generated will continue to increase. Therefore, biogas production from these wastes will be a profitable and viable means of reducing the menace and nuisance of urban wastes in many cities.

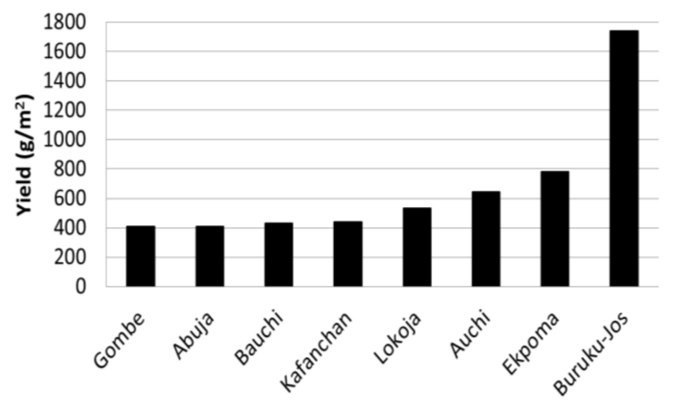


*Figure 8: Average annual biomass production across selected areas in Nigeria.*

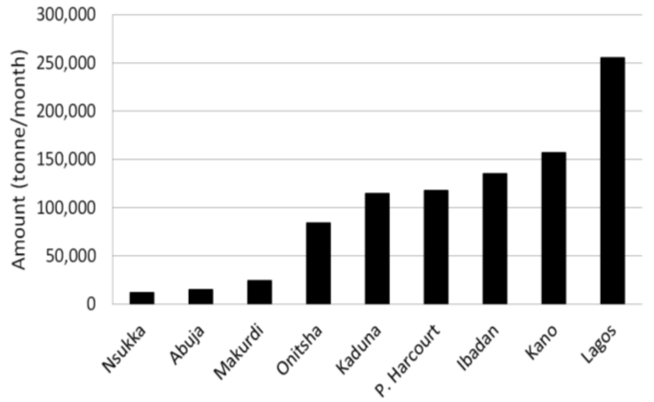


*Figure 9: Monthly MSW generated in nine major cities in Nigeria.*

Figure 9 is presented to illustrate the monthly amount of MSW generated in a few major cities in Nigeria [40] . It follows from the results that a total of 10.98 million metric tonnes of MSW will be generated per annum from these nine cities.

### 5.2 Hydroelectric Power

Hydroelectric power (HEP) is one of the few sources of energy that has assumed great significance since the beginning of the twentieth century. It produced about a quarter of the world's electricity and supply more than one billion people with power. HEP plants are continuously gaining importance as a renewable and non-polluting source of electricity generation [41]. Statistically, it is the most common form of renewable energy and plays a very important role in the global energy production [42] . According to the International Energy Agency (IEA), the global generation of electricity from hydropower in 2011 was 3,402.3 TWh, accounting for almost 17% of total global energy production. The global technical potential is estimated at more than 16,400 TWh/year. Figure 11 shows the values of installed capacity as percentage of the total of 3,756 TWh by region in 2012, where OECD is the Organisation for Economic Co-operation and Development. Currently about 20% of world’s hydropower potential is used effectively [42] .

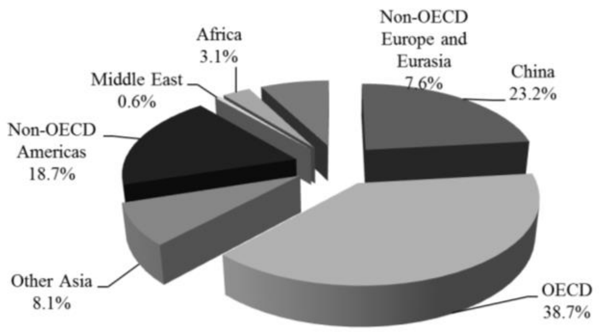


*Figure 10: Hydropower installed capacity by region as at 2012*

Nigeria has three main hydropower plants. These plants are located at Kainji, Jebba, and Shiroro power stations with installed capacities of 760 MW, 560 MW and 600 MW respectively; totalling 1,900 MW [41]. These three hydropower plants contribute about 35.6% power to the National Grid [43], thus making hydropower the country's largest renewable energy source. The fourth hydropower station, owned by a private utility service company, the Nigerian Electricity Supply Corporation (NESCO) limited, is located at six different sites in Plateau State but has a total potential of just 21 MW [37]. Shiroro power plant was commissioned in 1990 with an installed capacity of 600 MW. Kainji and Jebba power stations operate as two hydro generation plants, each being from the River Niger. Kainji began operation as Nigeria's first hydro power plant in 1968 while the Jebba plant was commissioned in 1985 [44]. The installed capacity of the hydropower plants in Nigeria has remained stagnant for many years while the output power produced has continued to decline due to lack of proper maintenance leading to loss of generating units and seasonal fluctuations in the volume of water flowing into the reservoirs [37] .

Hydro-energy has the most potential for development in rural areas of Nigeria due to its abundance and generally available well-known technology. Its projects create favourable conditions for new productive activities related to the supply of materials and equipment which usually generates employment during construction. Since the main obstacle to these projects is lack of finance, it is advisable to concentrate on small hydropower stations that can complement rural electrification programmes in addition to the advantage of water supply and irrigation systems from the dams [45] . However, there was a shift in attention to fossil fuels due to the vast deposits in the country, at the expense of the hydropower sector. The result was that the three existing hydro plants (Kainji, Jebba and Shiroro) were neglected to the extent that they now perform well below installed capacity [46].

Nigeria has considerable hydro potential sources exemplified by her large rivers, small rivers and streams. Nigerian rivers are distributed all over the country with potential sites for hydropower scheme which can serve the urban, rural and isolated communities. An estimation of rivers Kaduna, Benue and Cross River at Shiroro, Makurdi and Ikom indicates that a total capacity of about 4,650 MW is available, while the estimate for the river Mambillla plateau is put at 2,330 MW. A large number of untapped hydropower potential of about 12,190 MW has been identified in various locations across the country, as shown in Table 8 [47] . Recently, the federal government of Nigeria signed $1.293bn contract with a Chinese company for the development of Zungeru power plant aimed to generate about 700 MW.

*Table 8: Nigeria’s hydropower potentially identified locations and their capacities.*

| Location | River | State | Potential Capacity (MW) |
|---|---|---|---|
| Mambilla | Danga | Taraba | 3,960 |
| Lokoja | Niger | Kogi | 1,950 |
| Makurdi | Benue | Benue | 1,060 |
| Onitsha | Niger | Anambra | 1,050 |
| Ikom | Cross | Cross River | 730 |
| Zungeru I | Kaduna | Niger | 500 |

| Location | River | State | Potential Capacity (MW) |
|---|---|---|---|
| Zungeru I | Kaduna | Niger | 450 |
| Yola | Benue | Adamawa | 360 |
| Gurara | Gurara | Niger | 300 |
| Katsina Ala | Katsina Ala | Benue | 260 |
| Beli SE | Taraba | Kano | 240 |
| Donka | Niger | Adamawa | 225 |
| Afikpo | Cross | Ebonyi | 180 |
| Afikpo | Cross | Ebonyi | 180 |
| Garin Dali | Taraba | Taraba | 135 |
| Gembu | Dongo | Taraba | 130 |
| Karamti | Kam | Taraba | 115 |
| Sarkin-Danko | Suntai | Taraba | 45 |
| Kiri | Gongola | Adamawa | 40 |
| Oudi | Mada | Benue | 40 |
| Richa I | Mosari | Nassarawa | 35 |
| Gwaram | Jama'are | Adamawa | 30 |
| Ifon | Osse | Ondo | 30 |
| Kashimbila | Katsina Ala | Benue | 30 |
| Korubo | Gongola | Adama/Taraba | 25 |
| Kura II | Sanga | Kano | 25 |
| Richa II | Dafo | Kano | 25 |
| Mistakuku | Kurra | Plateau | 20 |
| Kura I | Sanga | Kano | 15 |
| Kafanchan | Kongum | Kaduna | 5 |
| Total | | | 12,190 |

Small hydropower (SHP) has been in existence in Nigeria since 1923. However, SHP technology is still at its infancy in Nigeria with the scheme operated in only three States of the country [46]. If properly deployed, SHP can be the most affordable and accessible option to provide off-grid electricity services especially in rural communities. Based on Nigeria's level of hydropower development, small hydropower station is defined to be of capacity between 2 MW and 10 MW, though, there is no internationally precisely agreed range or limit, and most countries use this limit to define SHP.

Pre-feasibility studies and reports had already been prepared for twelve (12) identified sites and four (4) river basins, over 278 unexploited SHP sites with total potentials of 734.3 MW were identified and are awaiting investments, however, SHP potential sites exist in virtually all parts of Nigeria with an estimated capacity of 3,500 MW [48]. So far about nine (9) small hydropower stations with aggregate capacity of 39 MW has been installed in Nigeria by private companies and the government as shown in Table 9, with the power stations in Bakalori, Tiga and Oyan requiring rehabilitation [47]. In contrast to the developed countries where SHP plants find broad adoption in electricity production and other applications, little attention is given to its significance in Nigeria despite its vast potential and the high energy demand. However, a 2004 estimation indicated a total capacity representing 23% of the nation's hydropower potential if the remaining States were surveyed [46] .

*Table 9: Existing SHP schemes in Nigeria*

| River | State | Installed Capacity (MW) |
|---|---|---|
| Bagel I | Plateau | 1.0 |
| Bagel II | Plateau | 2.0 |
| Ouree | Plateau | 2.0 |
| Kurra | Plateau | 8.0 |
| Lerre I | Plateau | 4.0 |
| Lere II | Plateau | 4.0 |
| Bakalori | Sokoto | 3.0 |
| Tiga | Kano | 6.0 |
| Oyan | Ogun | 9.0 |
| Total | | 39.0 |

The small and large hydropower potential of Nigeria stand at 3,500 MW and 11,235 MW respectively [49] . The Federal Government put in place a framework towards exploring available potentials for SHP, thus requiring the efforts of every sector. However, private sector participation has increased only in fossil-based sources rather than in hydropower and other renewable sources. Figure 11 shows some SHP surveyed in some selected States of Nigeria [46].

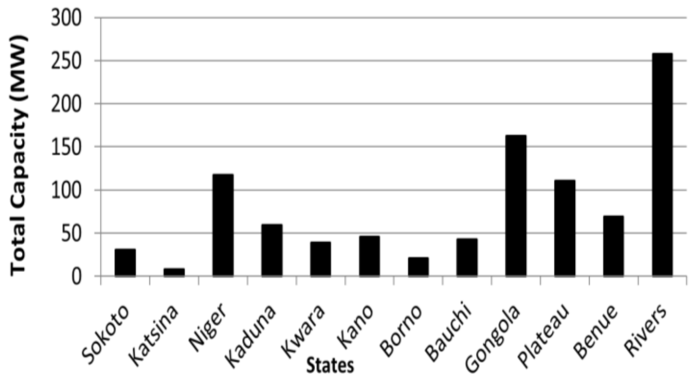


*Figure 11: Small hydro potential surveyed in some selected States of Nigeria.*

For small and medium hydropower, the hydropower projects are located in nine states (Gombe, Kaduna, Kano, Katsina, Ondo, Ogun, Oyo, Sokoto, and Zamfara). The total capacity of the hydropower projects is given as150 MW [25, 50] . Although planned renewable energy accounts for about 68% and 70% of the additional 7,125 and 8,858 MW to be added to the grid by 2020 and 2030, respectively, the majority of that is large-scale hydropower plants aimed at addressing irrigation and water supply problems in addition to power supply [50].

### 5.3 Solar Energy

Nigeria is richly endowed with solar energy with an annual average daily sunshine of 6.5 hours, ranging from 4 hours at the coastal areas to 9 hours at the far northern boundary. Studies have shown that Nigeria receives an average solar radiation of 3.5 kWh/m$^2$ a day at coastal latitude and 7 kWh/m$^2$ a day at the far north [12, 51, 52]. If the right technology is put in place, solar radiation in almost every locations in Nigeria is viable for electricity generation [16, 53]. Figure 12 shows the yearly average daily sum of global horizontal irradiation for cities across Nigeria between period of 2004 – 2010 as obtained from GeoSUN Africa, Stellenbosch South Africa, a subsidiary to SolarGIS weather data provider [54].

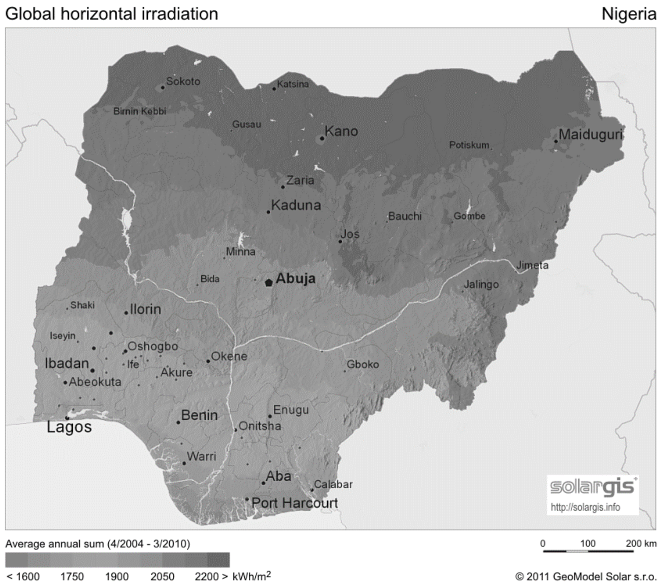


*Figure 12: Nigeria solar radiation map.*

Despite the availability of solar power resources in the Nigeria, solar PV installation is limited and disperse in country with majority in remote areas for standalone applications like solar water pump. Though solar PV installation is said to have been on gradual increase, it was reported by Sambo in year 2010 to have reached about 1MW [55]. More than 80% of the installations belong to government agencies for water pumping, street lighting, vaccine refrigerators, and community lighting. Its domestic application is not yet pronounced because people are yet to be convince that it's viable alternative to small size generators due to high capital cost.

Nigeria is also far behind in research on solar cell development and manufacturing. However, the National Agency for Science and Engineering Infrastructure (NASENI) took a giant step towards having Nigerian branded solar PV by establishing a solar assembly plant in Karshi, Abuja in the year 2011. The solar assembly plant commenced operation in the same year, even though none of the component parts is been manufactured in Nigeria yet. Effort like this should be supported by the government and private sector to ensure sustainability. The researchers in the country should also embark on relevant research that will take the country to a level of locally producing accessories components soonest with expectation of attain production of solar cells. Local manufacturing of solar PV will drastically bring down the cost of installation and promote availability and accessibility thereby promotes adoption of solar energy as viable alternative source of energy in the country.

#### *5.3.1 Solar Irradiance Data Collection*

The Solar irradiance and the Sunlight day hours determines the potential solar energy that can be generated at any specific location. Estimating potential electricity generation from solar radiation can be tasking because of associated incessant variation and changing dynamics of weather conditions [56]. These factors are hindering reaching the full potential of solar energy for electrical energy generation. Despite this variation, it has been established that the minimum solar radiation in any part of Nigeria is viable for electricity which can fulfil the daily energy needs for lighting, heating, and powering appliances like computer system, television, and refrigerators [57].

In Nigeria, the major source of weather data is Nigerian Meteorological Agency (NIMET) which has sparse data gathering centre at airports around the country. Most of the airports have limited facilities to capture accurate solar radiation data because there primary interest lies in other weather data such as temperature, relative humidity, rainfall for their smooth operation. Institutional research centre is another source of solar radiation data in the country but apart from been site specific, data measured are usually on short term basis in a period of one year or two years. The PVGIS-3 Africa solar irradiance data was used for assessment of potential solar electricity generation by PV modules mounted at horizontal and optimal inclination for selected Nigeria cities covering a period of 1985- 2004 [58, 59]. The sites were randomly picked across the six geopolitical zones of the country from the far north of Sokoto (NW), Maiduguri (NE), through the central Abuja (NC), Ilorin (NC), down till south, Ibadan (SW), Enugu (SE) to Portharcourt (SS). Table 10 shows the monthly average global irradiation at horizontal and optimal inclined surface (kWh/m$^2$/day) of some selected Nigeria cities.

#### *5.3.2 Estimation of Solar Energy Potential in Nigeria*

There are two numerical approaches to estimate the annual energy production from solar irradiance. The first method involves estimation based on solar PV module area as stated in equation. (1) [60].

$$E = ArG_{hi}P_R(kWh) \qquad (1)$$

*Table 10: Monthly averaged daily global irradiation (kWh/m²/day) in Nigeria (2001 – 20012).*

| Month | Sokoto | | Maiduguri | | Abuja | | Ilorin | | Ibadan | | Enugu | | P. Harcourt | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $H_h$ | $H_{opt}$ | $H_h$ | $H_{opt}$ | $H_h$ | $H_{opt}$ | $H_h$ | $H_{opt}$ | $H_h$ | $H_{opt}$ | $H_h$ | $H_{opt}$ | $H_h$ | $H_{opt}$ |
| Jan | 4.69 | 5.33 | 6.00 | 7.00 | 5.85 | 6.61 | 5.79 | 6.48 | 5.69 | 6.33 | 5.71 | 6.24 | 5.63 | 6.09 |
| Feb | 5.16 | 5.63 | 6.45 | 7.12 | 6.19 | 6.69 | 6.09 | 6.54 | 5.89 | 6.27 | 5.78 | 6.09 | 5.57 | 5.83 |
| Mar | 5.35 | 5.52 | 6.77 | 6.97 | 6.09 | 6.19 | 5.96 | 6.06 | 5.42 | 5.48 | 5.24 | 5.28 | 4.72 | 4.74 |
| Apr | 5.77 | 5.63 | 6.88 | 6.62 | 6.23 | 5.98 | 6.00 | 5.77 | 5.43 | 5.22 | 5.25 | 5.08 | 4.75 | 4.60 |
| May | 5.71 | 5.34 | 6.67 | 6.09 | 5.12 | 4.75 | 5.13 | 4.78 | 4.51 | 4.21 | 4.54 | 4.28 | 4.02 | 3.80 |
| Jun | 5.66 | 5.19 | 6.21 | 5.55 | 4.45 | 4.08 | 4.54 | 4.18 | 3.87 | 3.58 | 4.01 | 3.74 | 3.38 | 3.18 |
| Jul | 4.97 | 4.63 | 5.63 | 5.12 | 4.20 | 3.89 | 4.13 | 3.84 | 3.46 | 3.23 | 3.92 | 3.68 | 3.26 | 3.09 |
| Aug | 4.58 | 4.42 | 5.32 | 5.05 | 4.04 | 3.85 | 3.93 | 3.76 | 3.37 | 3.23 | 3.84 | 3.69 | 3.43 | 3.31 |
| Sep | 5.26 | 5.30 | 6.07 | 6.10 | 4.28 | 4.26 | 3.93 | 3.90 | 3.26 | 3.23 | 3.69 | 3.66 | 3.15 | 3.12 |
| Oct | 5.53 | 5.91 | 6.59 | 7.09 | 5.16 | 5.41 | 4.87 | 5.08 | 4.05 | 4.17 | 4.28 | 4.40 | 3.60 | 3.67 |
| Nov | 5.14 | 5.80 | 6.24 | 7.18 | 5.90 | 6.58 | 5.64 | 6.21 | 5.12 | 5.58 | 5.24 | 5.64 | 4.36 | 4.61 |
| Dec | 4.73 | 5.48 | 5.84 | 6.93 | 5.63 | 6.45 | 5.57 | 6.31 | 5.39 | 6.04 | 5.56 | 6.14 | 5.34 | 5.82 |
| Average | 5.21 | 5.34 | 6.22 | 6.40 | 5.26 | 5.39 | 5.13 | 5.23 | 4.61 | 4.71 | 4.75 | 4.82 | 4.26 | 4.31 |

*$H_h$is Irradiation on horizontal plane; *$H_{opt}$ is Irradiation on optimally inclined plane

Source: PVGIS © European Communities, 2001-2012

*Table 11: Estimated electricity generation from 1kWp PV module in selected Nigerian cities.*

| City | Latitude (North) | Longitude (East) | Optimal Inclination Angle (º) | Yearly Averaged daily radiation (kWh/m²/day) | Annual Electricity Generation (kWh) |
|---|---|---|---|---|---|
| Sokoto | 13°3'25" | 13°3'25" | 0 | 5.21 | 1,426 |
| | | | 15 | 5.34 | 1,462 |
| Maiduguri | 11°49'59" | 13°9'0" | 0 | 6.22 | 1,703 |
| | | | 16 | 6.4 | 1,752 |
| Abuja | 9°4'0" | 7°28'59" | 0 | 5.26 | 1,440 |
| | | | 15 | 5.39 | 1,476 |
| Ilorin | 8°29'29" | 4°32'40" | 0 | 5.13 | 1,404 |
| | | | 14 | 5.23 | 1,432 |
| Ibadan | 7°23'47" | 3°55'0" | 0 | 4.61 | 1,262 |
| | | | 14 | 4.71 | 1,289 |
| Enugu | 6°27'9" | 7°30'37" | 0 | 4.75 | 1,300 |
| | | | 12 | 4.82 | 1,319 |
| Port-Harcourt | 4°47'5" | 7°0'19" | 0 | 4.26 | 1,166 |
| | | | 11 | 4.31 | 1,180 |
| Total | | | | 71.64 | 19,611 |

In (1), $E$ is estimated annual energy in kWh , $A$ is total solar panel area in m², $r$ is solar panel yield (%), $G_{hi}$ is yearly average daily irradiation on PV module at horizontal/inclination, and $P_R$ is system performance ratio, coefficient for (typical value for roof mounted system with modules from mono-crystalline or polycrystalline silicon is 0.75)

To assess the potential electricity generation for the selected location with average global irradiance for horizontal or optimal inclined ($G_{hi}$), the performance ratio ($P_R$) is taken as 0.75 and a unit peak power ($P_K$) of 1 $kW_p$ PV module is assumed. The total annual estimated energy output (E) of a photovoltaic system is calculated from equation (2) [61-63].

$$E = 365 P_K G_{hi} P_R \ \ (kWh) \qquad (2)$$

Table 11 presents the estimated solar energy that can be generated in different cities across Nigeria for both horizontal and optimal inclined solar PV modules. The yearly sum of estimated electricity that can be generated from 1 $kW_p$ PV module at horizontal solar irradiance ranges from 1,703 kWh in the far north to 1,166 kWh at the southern part of the country. The Northern part demonstrates strongest potential for solar electricity as Maiduguri has the highest yearly average daily global irradiance of 6.22 kWh/m² per day at horizontal and 6.4 kWh/m² at optimal inclined angle of 16º.The solar radiation reduces towards the central part of the country. For example, Ilorin the fourth city on the Table 11 has daily horizontal irradiance of 5.13 kWh/m² and 5.23 kWh/m² at optimal inclined angle of 14º. The lowest solar irradiance was recorded at the far south in Port

Harcourt with 4.26 kWh/m$^2$ a day at horizontal and 4.31 kWh/m$^2$ a day at optimal inclined angle of 11º with corresponding generation of 1,166 kWh and 1,180 kWh respectively. Considering the worst scenario when the generating capacity was minimum, solar PV modules with 10% conversion efficiency in 1 hectare (10,000 m$^2$) surface area will generate a total annual energy of 1.166 GWh.

### 5.4 Wind Energy

Wind energy exploration in Nigeria has not been significant as most of the existing wind energy systems are abandoned due to inappropriate evaluation of its potentials, operations and management [18]. Given the inadequate and epileptic power supply being experienced in the country, using wind energy conversion system to supplement the energy obtained from the serving hydropower and thermal power plants will be a wonderful initiative. However, given the huge initial investment capital, the government could encourage many individual users to adopt it by giving adequate incentives, such as feed-in tariff. With the current deregulation of the power industry in Nigeria, the Council for Renewable Energy in Nigeria (CREN), whose responsibility, among others, is to coordinate renewable energy development and implementation plan for the country, was created by the government [64].

#### *5.4.1 Wind Data Collection and Analysis*

Lots of research works [65-73] have been carried out on assessment of wind energy potentials spread across the six geo-political zones in Nigeria. These works were studied and the wind data used in the present study were obtained from [65-67, 69, 74, 75], most of which originated from the Nigeria Meteorological Services (NIMETS) Oshodi, Lagos, spanning a period of 36 years. It was observed that there is a wide disparity in the values of wind speed of certain sites as presented in different literature. However, the disparity may be due to year difference and height of wind data collection. While some authors standardised their data to 10 m above the sea level, some presented theirs at different heights. To this end, the sources of the data used in this work are as indicated in Table 12 to pre-empt any unnecessary confusion.

The entire country is divided into six geo-political zones. Generally, the northern parts of the country are windier than the southern parts. Based on the available data from literature, the North-West has the highest wind speeds which range from 3.88 m/s to 9.39 m/s at Yelwa and Kano respectively. This is followed by North-East zone having Jos leading the zone with a wind speed of 9.47 m/s. In the South-East of Nigeria, we have wind speed data for only two sites: Enugu and Ogoja having 5.73 m/s and 2.80 m/s respectively. For the South-Western part of the country, the least obtainable annual mean wind speed is 1.77 m/s at Ondo and the highest of above 4.5 m/s in cities like Lagos Island, Lagos Mainland and Shaki. In the North-Central geo-political zone, Minna is found to have the highest with a wind speed of 5.36 m/s while Bida has the least of 2.46 m/s. Lastly, the South-south zone records the highest wind speed of 4. 65 m/s at Calabar while Port-Harcourt has the least wind speed in the zone with a value of 3.30 m/s. Generally speaking, with most parts of Nigeria having an average wind speed of 3.0 m/s shows that wind energy is viable in the country.

#### *5.4.2 Estimation of Wind Power Potential*

To estimate the potential of wind energy at a particular site, three parameters are usually required: the cross-sectional area of the turbine blade (A), the site air density (ρ) and the wind speed (V). Thus the power available in the wind can be obtained through the expression in equation (3).

$$P = {}^{1}\!/_{2}\, \rho A V^3 \qquad (3)$$

In (3), ρ is the air density at sea level normally given as 1.225 kg/m$^3$ with variation of 10-15% due to changes in atmospheric temperatures and pressure. A is the area swept by the windmill rotor obtained in sq-m using the expression A = πD$^2$ where D is the diameter of the circular edge of the windmill blades and V is the wind speed in m/s. However, when little knowledge of the site data is known, estimation of the wind energy could be obtained using the capacity factor approach formulated in [70]. Capacity factor (CF) could be defined as 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 [76]. The expression for CF of the earlier mentioned method which is entirely based on Rayleigh distribution is presented in equation (4).

$$CF = 0.087V - \frac{P_R}{D^2} \qquad (4)$$

Where $P_R$ is the rated power of the turbine

The goal here is to find a simple way to estimate the CF when very little is known about a site and wind turbine. Adopting this method, a commercially available wind turbine, NEG Micron turbine [68], with rated power ($P_R$) of 1000 kW, rated speed of 16 m/s, cut in speed of 3 m/s and rotor diameter, D, of 60 m was used in this study. The annual energy estimation for each zone in kWh/y is presented in equation (5).

$$AWE = 8760 \times P_R \times CF \qquad (5)$$

*Table 12: Capacity factor and estimated annual energy output for the selected cities.*

| Zone | City | Annual mean wind speed (m/s) at 10 m height | Annual wind speed (m/s) at 70 m height | Capacity Factor | Estimated Annual Energy (MWh) |
|---|---|---|---|---|---|
| South-West | Shaki | 4.50[64, 67] | 5.80 | 0.2264 | 1,983 |
| | Iseyin | 4.01[64, 67] | 5.16 | 0.1715 | 1,502 |
| | Lagos Mainland | 4.61[67] | 5.94 | 0.2387 | 2,091 |
| | Lagos Island | 4.69[67] | 6.04 | 0.2477 | 2,170 |
| | Ibadan | 3.86[64, 67] | 4.97 | 0.1547 | 1,355 |
| | Ijebu-Ode | 3.62[67] | 4.66 | 0.1278 | 1,120 |
| | Oshogbo | 3.33[67] | 4.29 | 0.0953 | 835 |
| | Ondo* | 1.77[67] | 2.28 | 0.0000 | 0 |
| | Benin | 3.38[67] | 4.35 | 0.1009 | 884 |
| South-South | Port-Harcourt | 3.30[67] | 4.25 | 0.0920 | 806 |
| | Calabar | 4.60[67] | 5.92 | 0.2376 | 2,082 |
| | Ogoja | 3.68[67] | 4.74 | 0.1345 | 1,179 |
| South-East | Enugu | 5.73[65, 67] | 7.38 | 0.3642 | 3,191 |
| | Oweri | 2.80[66] | 3.61 | 0.0359 | 315 |
| North-West | Yelwa | 3.88[67] | 5.00 | 0.1569 | 1,375 |
| | Sokoto | 7.21[65, 67] | 9.29 | 0.5300 | 4,643 |
| | Gusau | 6.17[65, 67, 73, 75] | 7.95 | 0.4135 | 3,622 |
| | Kaduna | 5.13[65, 67, 73, 75] | 6.61 | 0.2970 | 2,602 |
| | Kastina | 7.45[73, 75, 76] | 9.59 | 0.5569 | 4,879 |
| | Zaria | 6.08[76] | 7.83 | 0.4034 | 3,534 |
| | Kano | 9.39[65, 67, 73, 75] | 12.09 | 0.7743 | 6,783 |
| North-Central | Ilorin | 5.04[65, 67] | 6.49 | 0.2869 | 2,513 |
| | Bida* | 2.46[67] | 3.17 | 0.0000 | 0 |
| | Mina | 5.36[65, 67] | 6.90 | 0.3228 | 2,827 |
| | Abuja | 3.77[67] | 4.86 | 0.1446 | 1,267 |
| | Lokoja | 2.92[67] | 3.76 | 0.0494 | 433 |
| North-East | Bauchi | 4.83 [73-75] | 6.22 | 0.2634 | 2,307 |
| | Potiskum | 5.25[65, 67, 73] | 6.76 | 0.3104 | 2,719 |
| | Maiduguri | 5.22[65, 67, 74] | 6.72 | 0.3071 | 2,690 |
| | Jos | 9.47[65, 67] | 12.20 | 0.7833 | 6,861 |
| | Yola | 4.16[74] | 5.36 | 0.1883 | 1,650 |
| Total | | | | | 70,218 |

*cities where the annual wind speed is less than the cut-in speed of the chosen wind turbine

Table 12 shows the potential CF for the selected cities of each zone together with their potential wind energy output. The result shows that all the selected cities having the CF of between 0.10 and 0.20 have good potential for electricity production. On the other hand, cities exhibiting above 0.20 CF are considered to have very good potential for electric energy production. It is observed that those cities in the south are mostly coastal areas that are directly influenced by the wind from the Atlantic Ocean. In this study, cities with CF of 0.0 to less than 0.10 are considered to be unsuitable for electricity generation. However, the wind speed in these areas is good for water pumping. Also shown in Table 12 is the annual wind energy realised from each city reviewed in this study. Overall, a total of 70,218 MWh wind energy is estimated per annum from the selected sites, which is quite appreciable. Notwithstanding, it is pertinent to add that this figure is just a rough estimate as the approach adopted in this study is not one hundred percent accurate.

## 6. CONCLUSION AND RECOMMENDATIONS

### 6.1 Conclusion

This paper has presented a critical review of the status of renewable energy resources currently available in Nigeria, and the potential to utilise them in meeting the current energy crisis facing the country. The renewable energy resources examined in the study include biomass, hydropower, solar energy and wind energy and estimates on their potential energy production capacity were provided. Traditionally, the fossil fuels that have been the major sources of energy in Nigeria are oil and natural gas. The need to address the challenges of moving towards clean, reliable, secure and competitive energy supply prompted Nigeria to develop a long term renewable energy masterplan for the country in 2005. The main goal of the draft document among others is to reduce the projected energy use by 20% by 2020 and equally meet 20% of the country's electricity needs with renewable energy sources by 2020.

The review showed that the per capita energy consumption in Nigeria is very low and grossly inadequate for sustainable economic development, and this is correlated with the high poverty level obtainable in the country. To aggressively address this lingering energy problem, two International Atomic Energy Agency models were used to project the energy demand and supply structure of the country based on four scenarios.

Conclusively, with the vast renewable energy resources reviewed in this study, the National Energy Policy as well as the National Renewable Energy Masterplan, Nigeria is well positioned to up-scale the use of renewable energy to meet the current energy crisis and at the same time reduce her dependence on fossil fuels. However, it is pertinent to add that the energy plans drafted must be given the required urgent approval by the Federal Executive Council to become a legal document, and must be properly and sincerely implemented.

### 6.2 Recommendations

Despite their availability in reasonable quantities, renewable energy resources are grossly underutilised in Nigeria. In the light of this scenario, the following recommendations are proposed:

(i) Even though the government via the Nigerian Electricity Regulatory Commission (NERC) has formulated a policy on feed-in tariff as it applies to renewable energy resources, you only read this on newspapers. It is imperative that NERC carries along and enlightens the major stakeholders and members of the public as well, on this policy to accelerate investment in renewable energy technologies.

(ii) One of the major factors militating against the deployment of renewable energy in Nigeria is lack of clear government policies. The government should provide adequate legal instrument for renewable energy development.

(iii) Though Nigerian government has already established research and development centres in the six geo-political zones in the country, these centres should be adequately strengthened financially to support the shift towards an increased use of renewable energy. It is also pertinent to add that the Energy Commission of Nigeria (ECN) should continuously monitor and evaluate the performance of these centres in terms of quality research outputs from them.

(iv) Efficient energy use and conservation of energy through energy saving bulbs, improved fuelwood stoves, efficient electrical appliances, etc, should be promoted by relevant government agencies and non-governmental organisations, to reduce the energy demand.

(v) To ensure long term development of renewable energy and energy efficiency, there must be human resource development at high level and manufacturing capacity building. Critical knowledge and technical know-how transfer should be the focus for project development and management.

(vi) The government should be more serious to take a pragmatic step towards realising the targets set by the ECN for the renewable energy contribution to electricity generation in Nigeria.

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