Research Article


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Abstract:
This research presents thermal building and renewable energy integration: A review of modeling approaches and procedures. Past literatures shows that buildings consume 40% of energy from heating, cooling and fossil fuels. Little efforts were made in the area of combining renewable energy sources and integrating them into buildings. This research tends to offer solution to the problem of CO₂ emissions and the amount of environmental impact emanating from over dependency on fossil fuels and other sources of electricity generation by mixing renewable energy resources and integrated into buildings using Nigeria as case study. From the results obtained, 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. It would be very difficult to achieve a total of 131,122 MW of electricity projected for 2030 in the country if the country does not adopt renewable energy mix.

Keywords: Thermal building; renewable energy; mathematical modeling; electricity generation.

I. INTRODUCTION

Electricity is essential in modern society as it plays major roles in the lives of humans and industries at large. Previous literatures shows that about 1.2 million people are living without access to electricity in the world today, mostly those living in rural areas in Africa and Asia. This fact echoed the generation of electricity from distributed resources where there is strong affinity for the presence of renewable resources in order to meet the needs of local communities in rural areas. Buildings generally constitutes 40% of the total world energy consumption [6]. In 2018, the international energy agency stated that renewable energy was expected to increase by 25% in shares. Building complexes and service providers demand for electrical power and heating/cooling is enormous. Some of these demands could be met by empowering local renewable energy providers, although past literatures shows that their CO₂ contribution may be higher than what was realized initially and better estimates could be made by fully utilizing carbon footprints. [13]. However, the use of integrated systems including renewable, which would incorporate both supply and demand at both local and district would likely produce overall better efficiencies and then reduce carbon emissions and carbon footprints. It is paramount to note that the main objectives and challenges of renewable energy integration in buildings is the incorporation of systems technically and economically viable in collecting and processing renewable energy sources that are useful for buildings and contributes to development of a standard energy system. Reducing the consumption of energy in buildings consists of two synergetic approaches: implementing energy efficiency approaches and using renewable energy to offset the remaining building energy needs. PV technologies is rapidly growing when compared to other sources of renewable energies.[13]. The solar photovoltaic thermal energy systems comprise of PV technologies and solar thermal components integrated into one system and enables the generation of electricity and heat. Some reviews were made in literatures concerning renewable energy systems but they provide a very general overview without providing sufficient details or are focused on specific country or application type without stating how to fully capture or integrate the renewable energy resources into buildings.[3],[5] thermal storage plays major roles in industrial, residential and commercial applications whenever the demand and supply are not equal. There have been several promising developments in this field by incorporating phase change materials (PCMs) into buildings.[11] justified that the integrated approach for accessing the performance of any building would be realized when ever PCMs were introduced. Also, the primary aim of integrating this modeling into buildings is to preserve the integrity of buildings by processing all energy transport paths at a level that would commensurate and eschew all uncertainties that may emanate in future. There is need to critical review the status of renewable energy resources currently available in Nigeria, and the potential to utilize 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 master plan 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. Harnessing renewable energy resources has gained prominence in the last few decades. Integrated renewable energy system is an effective and a viable strategy that can be employed to harness renewable energy resources to energize remote rural areas of developing countries. The resource-need matching, which is the basis for integrated renewable energy system, makes it possible to provide energy in an efficient and cost-effective manner. Mathematical models for key components of such integrated renewable energy system as biogas generator, hydropower generator, wind turbine, PV system and battery banks were developed. 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 Master plan, 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. Therefore, in the present study, Thermal building and renewable energy integration: A review of modeling approaches and procedures is used to develop approximate analytical solutions for heat transfer in convective-radiative buildings.

2. SOLAR THERMAL INTEGRATION IN BUILDING
Solar collectors can be fully integrated into buildings facades because integrating solar systems into buildings has become a necessity if the system is economically viable. [6]. Presently these collectors have been used in varieties of applications such as; solar hot-water supplying, solar space heating and cooling. These solar thermal technologies are not playing the desired roles it should play in the reduction of buildings fossil fuel consumption and consequently greenhouse emissions although the increase in oil price has recently started to bulge the market.

**Solar electric PV**
This system converts sunlight into electricity[9]. They consist of modules assembled in arrays and can be mounted on or near buildings. The power inverter converts the direct current into grid quality alternating currents (AC). It is advisable to integrate buildings with building-integrated photovoltaic (BIPV) products during renovations. This technology can act like roof shingles and tiles etc. BIPV may not be readily available because of its ability to add cost and complexities to projects, but it may help enhance the acceptance of the project on visible basis.

![Figure 1. Integration of all the solar systems technologies[6].](image1)

![Figure 2. Thin-film solar PV shingles [9].](image2)

![Figure 3. showing modules of solar panels installed for electricity generation[9].](image3)

**Solar thermal**
Solar water heating is another way to generate hot water and at the same time eliminate the cost of electricity or fossil fuels and eschew any environmental impact that may occur [9]. The solar water systems comprise of a collector which absorbs and transfers heat from the sun to water and it is stored in tank[19]. The solar water system is reliable and has low maintenance system because it is stationary and have few moving parts. The primary components of a solar water heater after the collector includes the pumps, hot water storage and controls. The solar ventilation preheating system is needed when there is high demand for ventilation air. In practice, the sun warms the collector surface, where the heat normally would be conducted from the surface to the thermal boundary of air. The heat would escape by convention the moment the fans draw the boundary layer through the holes in the collector.
This system can be added to a building in retrofit as long as the building have relatively high utility rates for heating, a relatively long heating season, and the building’s south-facing wall has enough surface area to mount the collector.

**Geothermal**

Geothermal energy uses the heat stored beneath the earth at extremely high temperatures to generate electricity. Geothermal heat pumps are used to tap the heat provide heating and cooling for homes and buildings[9].

**Winds**

Winds is produced by uneven solar heating. It is harnessed by employing modern wind turbines to generate electricity[9]. This wind turbines uses rotating propellers like blades to harness the energy in the wind and use it to drive a turbine that generates electricity. Before installation, it is paramount to ensure that the wind resource in the specific region is adequate. The potentials to generate winds aids its classification. Wind resource maps also determines the area that needs to be explored or not.

**Bioenergy**

Biofuels and biopower can be used to generate electricity or heat needed for buildings. Biofuels are liquid or gaseous fuels produced from biomass and are used for transportation, but some are used as fuels to produce electricity. Biopower is the production of electricity or heat from biomass resources[9].

**Table 1. Estimates of renewable energy potential in Nigeria (MW)[7]**

<table>
<thead>
<tr>
<th>Energy source</th>
<th>Power (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small and Large Hydro</td>
<td>64,000</td>
</tr>
<tr>
<td>Geothermal</td>
<td>500</td>
</tr>
<tr>
<td>Offshore wind</td>
<td>1600</td>
</tr>
<tr>
<td>Onshore wind</td>
<td>800</td>
</tr>
<tr>
<td>Solar Pv Panels</td>
<td>7000</td>
</tr>
<tr>
<td>Biomass</td>
<td>50</td>
</tr>
<tr>
<td>Nuclear power</td>
<td>20,000</td>
</tr>
<tr>
<td>Total</td>
<td>93,000</td>
</tr>
</tbody>
</table>

**Table 2. Renewable potential in Nigeria with current utilization[7]**

<table>
<thead>
<tr>
<th>Resource</th>
<th>Potential</th>
<th>Current utilization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large Hydropower</td>
<td>11,250 MW</td>
<td>1,900 MW exploited</td>
</tr>
<tr>
<td>Small Hydropower</td>
<td>3,500 MW</td>
<td>64.2 MW exploited</td>
</tr>
<tr>
<td>Solar</td>
<td>4.0 kWh/m²/day - 6.5 kWh/m²/day</td>
<td>15 MW dispersed solar PV installations (estimated)</td>
</tr>
<tr>
<td>Wind</td>
<td>2 - 4 m/s 10 m height mainland</td>
<td>Electronic Wind Information System (WIS) available</td>
</tr>
<tr>
<td>Biomass (non-fossil organic matter)</td>
<td>Municipal waste</td>
<td>18.5 million tonnes produced in 2005 and now estimated at 0.5 kg/capita/day</td>
</tr>
<tr>
<td>Fuel wood</td>
<td>43.4 million tonnes/yr. fuel wood consumption</td>
<td></td>
</tr>
<tr>
<td>Animal waste</td>
<td>245 million</td>
<td></td>
</tr>
<tr>
<td>Agricultural residues</td>
<td>91.4 million tonnes/yr. produced</td>
<td></td>
</tr>
<tr>
<td>Energy crops</td>
<td>8.5% cultivated</td>
<td></td>
</tr>
</tbody>
</table>

**Integrated renewable energy systems**

The primary aim of an integrated renewable energy systems is to combine the forms of energy to the needs of an isolated area in an efficient and economical manner. This system combines two or more renewable sources in order to meet the demands of the people. This approach requires deliberate and calculated strategies for matching needs and available resources to maximize the benefits and efficiency.
3. GOVERNING EQUATIONS AND BOUNDARY CONDITIONS:

The initial and boundary conditions:
The initial and boundary conditions for thermal building will be modeled using both analytical and numerical methods:

Solar Systems
2D implicit finite volume method which incorporated with phase change materials will be used to model the governing equations of a solar system[19].

Figure 7. Schematic of an integrated renewable energy source[7]

Figure 8. Proposed diagram of an integrated renewable energy source.

The interface between the solid and liquid phase will be modeled as a porous medium.

The mushy surface is modeled as follows:

Continuity Equation.
\[ \frac{\partial f}{\partial u} + \frac{\partial g}{\partial v} = 0 \] (1)

Momentum equation along (u) axis:
\[ \frac{\partial}{\partial t}(f) + \frac{\partial}{\partial u}(f^2) + \frac{\partial}{\partial v}(f g) = -\frac{\partial H}{\partial f} + H_r \left(\frac{\partial^2 f}{\partial u^2} + \frac{\partial^2 f}{\partial v^2}\right) + E_a H_r + \sin(\alpha) + T'(u) \] (2)

Momentum equation in (v) direction:
\[ \frac{\partial}{\partial t}(g) + \frac{\partial}{\partial u}(f^2) + \frac{\partial}{\partial v}(f g) = -\frac{\partial H}{\partial g} + H_r \left(\frac{\partial^2 g}{\partial u^2} + \frac{\partial^2 g}{\partial v^2}\right) - E_a H_r + \cos(\alpha) + T'(v) \] (3)

Energy equation
\[ \frac{\partial}{\partial t}(\rho h) + \frac{\partial}{\partial u}(\rho fh) + \frac{\partial}{\partial v}(\rho gh) = \frac{\partial}{\partial u} \left( k \frac{\partial T}{\partial u} \right) + \frac{\partial}{\partial v} \left( k \frac{\partial T}{\partial v} \right) + S_h \] (4)

Sensible enthalpy
\[ h_s = h_f + \int_{T_s}^{T} C_p dT \] (5)

the total enthalpy[16,17,18] is defined as
H= h_r + \Delta h

Let \( \Delta H = yL \)

Liquids and solidus could be found from the expression below
\( T_{solidus} < T < T_{liquidus} \)

If \( T < T_{solidus} \)
\[ y = \frac{\Delta H}{L} \] (6)

\[ y = \frac{\Delta H}{L} = \frac{T-T_s}{T_{liquidus}-T_s} \] when \( T_{solidus} < T < T_{liquidus} \)

Given that \( y = \frac{\Delta H}{L} = 1 \) at \( T > T_{liquidus} \)
The sources terms could be found from the expressions below:
\[ s_i = -A(y)f_i \frac{C(y)\sqrt{y}}{y^3 + \varepsilon} f_i \]
\[ s_h = pL \frac{\partial y}{\partial t} \]

\( p \) is the porosity. Function which governs the momentum equation which is based on Carman–Kozeny relationship for flow in porous media.

The non-dimensional boundary conditions are obtained as follows:
\[ \theta = 0; x = y = \omega = V = 0 \text{ at } \tau = 0 \]
At \( \tau = 0 \) the boundary condition associated with the inlet of a room is represented as follows:
\[ X = 0 \text{ and } 0 \leq V \leq \Delta \theta = 0 ; y = 0 ; x = 1; \omega = 0 ; \Psi = 0 (7) \]
\[ X = 0 \text{ and } D \leq V \leq F: x = y = \Psi = 0 ; \frac{\partial \Psi}{\partial x} = 0 ; \omega = -\frac{\partial \Psi}{\partial y} (8) \]
\[ V = 0 \text{ and } 0 \leq S_x \leq X; x = y = \Psi = 0 ; \frac{\partial \Psi}{\partial x} = 0 ; \omega = -\frac{\partial \Psi}{\partial y} (9) \]
\[ V = F \text{ and } 0 \leq S \leq K; x = y = \Psi = 0 ; \frac{\partial \Psi}{\partial x} = 1 ; \omega = -\frac{\partial \Psi}{\partial y} (10) \]

At the outlet
\[ y (X, A) \geq 0 \text{ and } \bar{y} (X,A) \bar{n} = 0 \]
\[ V = \text{ and } K \leq S \leq X; x = y = \Psi = 0 ; \frac{\partial \Psi}{\partial x} = \frac{\partial \Psi}{\partial y} = \frac{\partial \Psi}{\partial n} = 0 (11) \]
\[ y (X, A) \leq 0 \text{ and } \bar{y} (X,A) \bar{n} = 0 \]
\[ V = \text{ and } K \leq S \leq X; x = y = \Psi = 0; \frac{\partial \Psi}{\partial x} = \frac{\partial \Psi}{\partial y} = \frac{\partial \Psi}{\partial n} = 0 (12) \]
\[ X = K \text{ and } F \leq S \leq K; x = y = \Psi = 0 ; \omega = -\frac{\partial \Psi}{\partial y} = -\frac{\partial \Psi}{\partial x} (13) \]
\[ \eta_{pv} = \eta_{mp} + \frac{q_{elic}}{Q_{in}} \]

**4. FOR SOLAR THERMAL IN THERMAL BUILDINGS**

The power, \( q \), from a solar collector is the solar radiation absorbed by the absorber, reduced by the heat losses. This is described by Equation 14, where \( S \) is the absorbed radiation, \( T_a \) is the temperature of the absorber \( n \) and \( T_i \) is the temperature of the ambient air. \( U \) is the heat loss coefficient \( (W/m^2K) \) describing the collector’s insulation capacity \( Q = S - U(T_a - T_i) \)

The momentary efficiency of a solar collector is calculated by the ratio of the power to the irradiance.
\[ \eta_{pv} = \frac{S}{Q} (19) \]

The global solar irradiation, \( G \), is the sum of the direct irradiation from the sun \( G_d \), and the diffuse irradiation, \( G_d \). The ground reflected irradiation, \( G_g \), which is often small enough to be neglected, is sometimes separated from the diffuse irradiation but it is often included in the diffuse irradiation model, as in this case also.

Energy absorbed from the sun

The parameters \( Q_0 \) and \( Q_1 \) are the incidence angle modifiers for beam and diffuse irradiance. The term \((\tau_0)\) describes the optical losses at normal incidence. Multiple reflexes between the glazing and the absorber are also included in this term.

**5. MODELING OF WIND ELECTRIC CONVERSION SYSTEM**

Power output from wind system is expressed as a function of wind speed. A simple model for the wind system output can be expressed as follows:
\[ P_{r} = \frac{V^2}{2} \frac{c_{p}}{c_{v}} V r \leq V f (30) \]
\[ 0 \text{ else} \]
The logarithmic wind profile could also be modeled by simplifying $(U_x)$ in the direction of the mean wind and assuming that turbulent fluxes and momentum are in contact at the surface.

$$U_x^2 = u'^2w^1$$

Where $U_x^2$ is friction velocity, $u'^2w^1$ is time averaged magnitude of the vertical turbulent transport of horizontal turbulent momentum. From Reynolds decomposition

$$U(x,t) = \bar{U}(x) + U'(x,t)$$

Where $U(x)$ and $W(x)$ corresponds to the mean components of the wind velocity after averaging (it is a function of space) $U(x,t)$ and $W(x,t)$ $t$ stands for fluctuating components of wind velocity (function of time and space). $U(x)$, and $W(x)$ are instantaneous velocities of the wind, $u'$ and $w'$ are the fluctuating components of the wind.

According to prandtl mixing layer equation, let $u'$ and $w'$ be expressed in terms of the mixing length considering constant gradient.

$$u' = -\partial \bar{u} / \partial x$$

$$w' = -\partial \bar{w} / \partial x$$

Therefore:

$$\bar{u}'^2w^1 = \partial^2 \bar{m} / \partial x^2 = U_x^{'}$$

Where $\bar{m}$ denotes mixing length

Where $k$, is the von Karman’s constant and $z$ is the height. Substituting (37) into (36) gives

$$U_x^{'} = k^2z^{'} / \partial \bar{m} / \partial x$$

$$U_x = k/z$$

Therefore:

$$\bar{u}'^2w^1 = \partial \bar{m} / \partial x$$

Wind speed as stated in section a fall to zero at some distance above the ground (roughness length) called $Z_0$. Integrating this expression

$$\bar{u}'^2w^1 = U_x^{'}$$

$$\bar{u}'^2w^1 = U_x^{'}$$

$$\bar{u}'^2w^1 = \int \frac{dx}{Z_0}$$

Biogas Modelling

Biogas is used for various needs such as cooking, storage for future use, pumping water and producing electricity in the order of priority. Following notations are used to express total biogas used in a day.

**Differential transformation method:**

The heat transferred in resistant form which normally emanates from conduction, convention and radiation is presented using differential transformation method[12].

$$\dot{q} = \frac{d\dot{q}}{dt} \frac{1}{R} (T_1 - T_2)$$

In terms of heat dynamics, the differential equation can be presented as follows:

$$\dot{q} = HT \frac{d\dot{q}}{dt} \approx HT \frac{d\dot{q}}{dt}$$

### Table 3. Input data on renewable sizing and other parameters in Nigeria. (Okafor et al., 2017)

<table>
<thead>
<tr>
<th>Types</th>
<th>Size and unit numbers</th>
<th>Life</th>
<th>Relevant information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind</td>
<td>10, 50, 100, 500, 1000 turbines</td>
<td>15yrs</td>
<td>Weibull distribution $k = 1.83$</td>
</tr>
<tr>
<td>Solar</td>
<td>1, 10, 100, 1000, 3000 kW</td>
<td>20yrs</td>
<td>De-rating factor-90%</td>
</tr>
<tr>
<td>Hydro</td>
<td>500 L/s flow rate</td>
<td>25yrs</td>
<td>Scaled annual avg 1/4 50, 100, 150 L/s</td>
</tr>
<tr>
<td>Battery</td>
<td>1, 1000, 5000, 10000, 15000, 20000 kW</td>
<td>845kWh</td>
<td>Nominal capacity 225 Ah</td>
</tr>
<tr>
<td>Converter</td>
<td>0.1, 10, 50, 100, 500, 100 and 2000 kW</td>
<td>15yrs</td>
<td>Efficiency 90%</td>
</tr>
<tr>
<td>Grid extension</td>
<td>-</td>
<td>-</td>
<td>Price of Electricity= $0.14/kWh</td>
</tr>
<tr>
<td>Diesel generator</td>
<td>1500kw</td>
<td>5000h</td>
<td>30%minimum load</td>
</tr>
</tbody>
</table>

**Hydropower generator**

This refers to generation of rotary mechanical power from falling water. This mechanical power most often is used to generate electricity[7]. Continuous and large amounts of electrical energy can be obtained from hydropower as compared to PV or wind systems. Energy obtained from hydropower generator can be given as Energy obtained from hydropower (kWh) = $Pwht (g * Q * \rho * h) x 1000$ (46)

**Battery tank**

This is required to store and provide energy when there is a load demand and the renewables are not able to fulfill the requirements of electricity demand, commonly referred as days of autonomy. Size of battery depends on number of days of autonomy ($B_a$), rated battery capacity, maximum depth of discharge ($D_{in}$), temperature correction ($T_c$) and life of the battery.

**Required battery capacity in ampere-hour as given as**

$$R_c = \frac{\text{Load in Amps} \times B_a}{\eta_{dis} \times T_c}$$

$$E_{in}(f) = (E_{Bat}(t) + E_{PV}(t)) \times \eta_{inv}$$

**Modelling of inverter**

The inverter is used in converting D.C current to A.C current when there is need for an A.C current in an integrated renewable energy system

6. RESULTS AND DISCUSSION

Four different cases were employed in order to ascertain the best viable options for grid planning in Nigeria. In table 3 the grid is
already assumed to be in place and is being supplied by an isolated network emanating from the diesel generator. This case is most noticeable in Nigeria because the nation relies on fossil fuels to meeting the demands of the population. However, it is imperative to also note that these components are very expensive because of high cost of maintenance. In addition, these diesel generators are highly emission intensive.

Table 4. Energy Resources in Nigeria[7]

<table>
<thead>
<tr>
<th>Resource</th>
<th>Reserve (natural units)</th>
<th>Production level (natural units)</th>
<th>Utilisation (natural units)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>36.22 billion tonnes</td>
<td>2.66 million bpd</td>
<td>44.68 billion bpd</td>
</tr>
<tr>
<td>Natural gas</td>
<td>187 million SCF</td>
<td>7.1 billion SCF/day</td>
<td>14 billion SCF/day</td>
</tr>
<tr>
<td>Coal and lignite</td>
<td>2.74 million tonnes</td>
<td>insignificant</td>
<td>insignificant</td>
</tr>
<tr>
<td>Tar sands</td>
<td>11 billion tonnes</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Large hydropower</td>
<td>16,250 MW</td>
<td>1,510 MW (1,576 million kWh/day)</td>
<td>1,674 million kWh/day</td>
</tr>
<tr>
<td>Small hydropower</td>
<td>3,080 MW</td>
<td>30 MW (215 million kWh/day)</td>
<td>26 million kWh/day</td>
</tr>
<tr>
<td>Solar radiation</td>
<td>3.5 - 7.0 kWh/m² day</td>
<td>excess of 240 kWh of solar PV or</td>
<td>excess of 0.1 kWh/m² day</td>
</tr>
<tr>
<td>Wind</td>
<td>2 - 9 m/s at 10 m height</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Forestry waste</td>
<td>11 million hectares</td>
<td>0.12 million tonnes/day</td>
<td>0.12 million tonnes/day</td>
</tr>
<tr>
<td>Municipal waste</td>
<td>3.9 million tonnes</td>
<td>0.781 million tonnes</td>
<td>not available</td>
</tr>
<tr>
<td>Biomass</td>
<td>77 million hectares</td>
<td>excess of 0.256 million tonnes</td>
<td>not available</td>
</tr>
</tbody>
</table>

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

Table 5. Primary Energy Consumption by Type[7].

<table>
<thead>
<tr>
<th>Type</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
<td>0.05</td>
<td>0.05</td>
<td>0.04</td>
<td>0.04</td>
</tr>
<tr>
<td>Hydropower</td>
<td>11.80</td>
<td>14.20</td>
<td>17.39</td>
<td>12.04</td>
<td>17.03</td>
<td>23.94</td>
<td>16.38</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>2.94</td>
<td>1.90</td>
<td>4.54</td>
<td>5.50</td>
<td>7.52</td>
<td>8.73</td>
<td>5.17</td>
</tr>
<tr>
<td>Petroleum Products</td>
<td>85.30</td>
<td>83.87</td>
<td>78.84</td>
<td>82.65</td>
<td>79.44</td>
<td>67.32</td>
<td>78.71</td>
</tr>
</tbody>
</table>


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.

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.

Table 6. Projected Electricity Supply by Fuel Mix for 7% Growth[7]

<table>
<thead>
<tr>
<th>Scenario</th>
<th>2010</th>
<th>2015</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>0</td>
<td>2,393</td>
<td>6,650</td>
<td>9,305</td>
<td>11,815</td>
</tr>
<tr>
<td>Gas</td>
<td>13,955</td>
<td>23,617</td>
<td>37,733</td>
<td>56,086</td>
<td>85,585</td>
</tr>
<tr>
<td>Hydro</td>
<td>3,702</td>
<td>4,962</td>
<td>6,479</td>
<td>9,497</td>
<td>11,479</td>
</tr>
<tr>
<td>Small hydro</td>
<td>40</td>
<td>90</td>
<td>140</td>
<td>227</td>
<td>701</td>
</tr>
<tr>
<td>Nuclear</td>
<td>0</td>
<td>0</td>
<td>3,530</td>
<td>7,005</td>
<td>11,872</td>
</tr>
<tr>
<td>Solar</td>
<td>5</td>
<td>10</td>
<td>34</td>
<td>75</td>
<td>302</td>
</tr>
<tr>
<td>Wind</td>
<td>126</td>
<td>1,471</td>
<td>3,019</td>
<td>5,369</td>
<td></td>
</tr>
<tr>
<td>Total Supply</td>
<td>17,303</td>
<td>31,197</td>
<td>55,903</td>
<td>85,196</td>
<td>131,122</td>
</tr>
</tbody>
</table>

Figure 10. Per capita energy consumption in Nigeria for 2002 – 2011

Figure 11. The energy demand projections for the four economic growth scenarios.

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. It would be very difficult to achieve a total of 131,122 MW of electricity projected for 2030 in the country.

Figure 12. Renewable energy potentials of Nigeria

Most of the Nigeria power generating facilities are operating at low efficiency. Therefore, the present Transmission and distribution network should be technically reviewed so as to accommodate renewable energy contribution to the national grid. Grid connected to the wind, solar, biomass power project can be developed on a fast track basis which can be
commissioned within 1-2 years. This could be a quick fix for the ongoing electricity crisis and contribute to improving the revenue and fiscal stability of the country.

7. CONCLUSION

This paper presented a critical review of the status of renewable energy resources currently available in Nigeria, and the potential to utilize 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 master plan 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. Harnessing renewable energy resources has gained prominence in the last few decades. Integrated renewable energy system is an effective and a viable strategy that can be employed to harness renewable energy resources to energize remote rural areas of developing countries. The resource need matching, which is the basis for integrated renewable energy system, makes it possible to provide energy in an efficient and cost-effective manner. Mathematical models for key components of such Integrated renewable energy system as biogas generator, hydropower generator, wind turbine, PV system and battery banks were developed. 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.

Nomenclature

Where ηo is overall efficiency of hydropower generator

\(Q\) - discharge of water in m³/sec

\(\rho\) - density of water = 1000 kg/m³

\(h\) - Height of the overhead tank in m

\(g\) - acceleration due to gravity in m/s²

\(E_{inv}(t)\) = is the energy output of the inverter in kWh

\(E_{bat}(t)\) and \(E_{pv}(t)\) are energy stored in battery bank and energy generated by PV array

Where \(T_1 - T_2\) are temperatures of each media.

\(Pr\) is rated electrical power (kW)

\(vc, \ vr\) and \(vf\) are cut-in, rated and cut-off wind speed respectively in m/s

\(\rho\) denotes density,

\(k\) is thermal conductivity,

\(S_s\) denotes the source terms,

\(h\) denotes specific enthalpy,

\(f\) and \(g\) denotes velocities components in the \(u\) and \(v\) direction.

\(h_s\) = sensible heat

\(T_r\) = reference temperature

\(Y\) = liquid fraction during phase change

\(L\) is the specific enthalpy of melting

Conflict of Interest

None declared

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