PROSPECTS OF A CENTRALIZED OFF-THE-GRID SOLAR ALTERNATIVE FOR RURAL POWER SUPPLY IN NIGERIA

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Abstract

Nigeria's significant energy deposits for power generation remainunder-utilisedwith the current power generation less than4,000MW serving an estimated 170 millionpeople. Thus the energy supply and demand ratio remains unacceptably low in the country vis-a-vis her aspirations to achieve meaningful development. This paper proposes a centralized off the grid solar energy source as a more economical option to the grid connected electricity supply system for many rural communities in Nigeria.In a pilot study conducted for acertain community without a connection to the national grid system, analysis of the data collected showed the huge potential for the development and deployment of solar based energy supply systems to meet the energy requirements of such rural communities. The paper also investigated the energy consumption pattern for the various categories of households studied.This energy mix approach to tackling the energy challenges facing Nigeria, when vigorously pursued will lift the country out of its present energy gridlock which has crippled economic and infrastructural development. This also has the potential of transforming rural communities into economic hubs and reducing urban migration.

Keywords: Centralized, Off-The-Grid, Solar alternative,Rural power supply, Nigeria

IIntroduction

The power generation growth in Nigeria has suffered a huge set back in the last few decades negatively impacting the social and economic well-being of her people. This inadequate power generation level could be attributed to many factors ranging from material to immaterial such as logistics, policy guidelines, infrastructure etc. Thecut in available power for meaningful development will continue into the foreseeable future until a holistic approach is adopted towards the salvation of the sector. With current energy generation standing at about 4,000MW serving an estimated population of 170 million, Nigeria's noble aspirations of being one of the top 20 developed economies by 2020 as captured in the vision 2020 policy paper of the federal government may not become a reality, given the link between the development of any economy and the available energy base.

A direct correlationhas been suggested between the energy consumption and the economic development of any nation[1]. Countries with higher energy demand seem to be more advanced technologically and economically and vice versa. The annual increase on global energy demand has been estimated at about 1.5% till 2030 according to IEA 2009 report.Increasein energy demand is driven by certain factors some of which are: industrialization, technological and infrastructural development, continued increase in population and individual energy requirements.

The energy consumption structure in Nigeria indicates that about 65% of available energy is consumed by the domestic sector[2]. This suggests a significant room for development of the industrial sector to at least the current proportion of the domestic sector. OECD countries have an average domestic demand of 30-35%. Figure 1 below captures the GJ capita of other nations. The figure shows that energy consumption of developed economies to be mostly in the industrial sector (manufacturing, transport and services) contrary to Nigeria's energy use pattern.

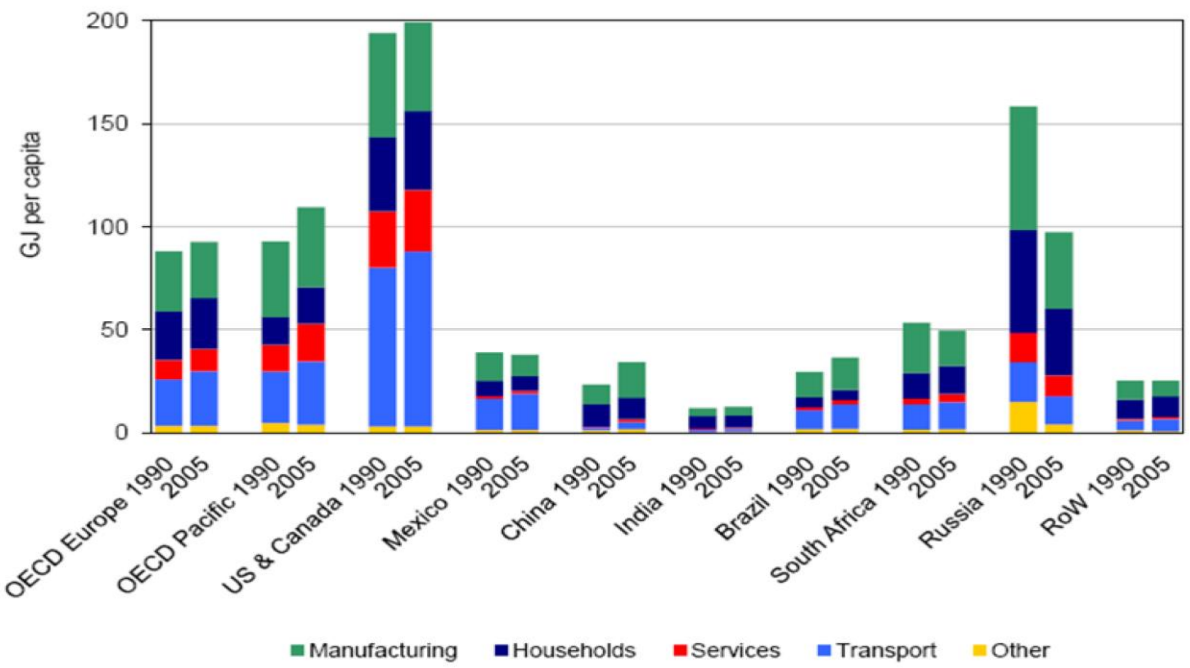

Figure 1. The per capita energy use patterns for some selected countries (source IEA, 2009).

Energy availability is a driving force to attaining development and industrialization and thus requires commensurate investment. The world over, energy supply stands at over 13.4 Btoe (Billion tons oil equivalent), more than doubled since 1970. Table1 belowsummarises the fuel type contribution of world energy supply (source: IEA, 2014). It is projected that this will continue to increase to meet global energy needs.

Table1: Fuel type contribution of world energy supply

Fuel type	**Amount (Btoe)**	**Percent Contribution (%)**
Coal	3.886	29
Oil	4.2076	31.4
Natural Gas	2.8542	21.3
Hydro	0.3216	2.4
Nuclear	0.6432	4.8
Renewables (biofuels, solar, wind, geothermal)	1.4874	11.1
TOTAL	**13.4**	**100**

In the light of the above table 1, world power generation is about 80% fossil fuel driven with its attendant pollution-related problems with little renewable energy mix. In Nigeria about 70% generated power is fossil based. These fossils have been subjected to irregular operations resulting in power outages and low energy generation. These coupled with high percent energy loss via the transmission lines (grid connection) underscore the need for alternative source.An approximated one-third of generated power is lost between transmission and distribution despite the current insufficient supply[3], [4].

Ofall energy forms, electrical energy has been the most popular with great ease of conversion to other forms.

In this paper an alternative renewable energy supply scheme is proposed to meet the energy needs of rural communities at reasonable distance from the national grid lines. Analysis of data collected from the pilot study conducted in one of the rural communities in Enugu state indicates that this solar option could be a more economical and sustainable approach in meeting the energy needs of these communities than the traditional grid connection.

The paper layout is structured into sections. Section I provides general introduction while section II explores the sustainable energy potential of Nigeria. Solar energy distribution in Nigeria for power generationis discussed in section III. Section IV focuses on solar economics, analysis of result of the pilot study and discussion. Conclusionis provided in section V.

IIRenewable energy potential inNigeria

The vast capacity for energy generation in Nigeria has been shown in many research findings [list some of them]. Fossil fueldeposits in Nigeria stands estimated at: crude oil at 37.2 billion barrels (about 2.79% of world's reserve), natural gas at 197 trillion cubic feet (about 2.90% of world reserve) and coal at 2.75 billion metric tons. Research findings indicate that these estimatescan meet the current and projected energy needs in the country for several decades to come[1].

Significant potentials for renewable energy sources in Nigeria for electric power generation as alternatives to fossil driven energy supply in Nigeria has been the subject of many articles [5]–[9]. These renewables: wind, solar, biomass, small-hydro, geothermalare however unevenly distributed within the entire regions of the country. The potentials are further explained below:

Wind

This is energy that is harvested from wind. Harvesting wind energy is possible via usage of blade-turbine-systems. The amount of energy derivable from the wind is proportional to the speed of the wind.Wind energy potential for some select cities in Nigeria is shown in table 2.

Table2 Wind speed variations for some selected locations in Nigeria [10]

Location	**Average wind speed at 10m height (m/s)**	**Mean power density (W/m^2)**
Bauchi	4.55	114.77
Gasau	5.94	164.07
Kaduna	5.15	100.66
Kano	7.78	369.45
Katsina	7.58	352.72
Potiskum	4.61	67.89

Biomass

Derivablefrom animal and plant related wastes, this energy source comprising mainly of municipal and industrial solid wastes, livestock wastes, agricultural residues and fuel-wood provides more grid quality electricity when compared with others renewable sources. Biogas, produced from biomass often produce low green-house gas emission when used for electricity generation[11]–[13]. The energy potential from agricultural residues in Nigeria is estimated at 697 Tera-Jouleswhile that for animal wastes (from cattle, pigs, chicken, sheep and goats) is at 46 Peta-Joules in 2010.

Small-Hydro Power (SHP)

Hydro and small hydro power (SHP) generation has been harnessed in the country feeding the national grid. Adequateutilization of this alternative energy source can appreciably close the energy gap in the sector by providing sustainable and clean energy. With a total capacity of about 734 MW and 30 MW exploited indicates the low level utilization of this sustainable source of energy. One observes that less than 5% of the exploitable small hydro-power has been exploited for electric power generation as shown [14].

Geothermal

Many sites have found with great potentialfor energy generation although this energy source. At the moment prospects for power generation using geothermal is still at explorationstage [15].Currently there is insufficient data available to the authors on estimate potential of this energy resource.

IIISolar energy distribution in Nigeria

This is energy coming from the sun's radiation. The annualtemperature range of about 32^{o}C to 42^{o}Cis normal in most parts of Nigeria[16]- [19]. Figure2 shows the average temperature(^{o}C) distributions in Nigeria from 1990-2009, while Figure 3 the average radiation (kWhm^{-2} per day) for Nigeria.

Figure 3 underpins the potential for sustainable energy generation via solar to boost the current level of electric power generation in Nigeria.

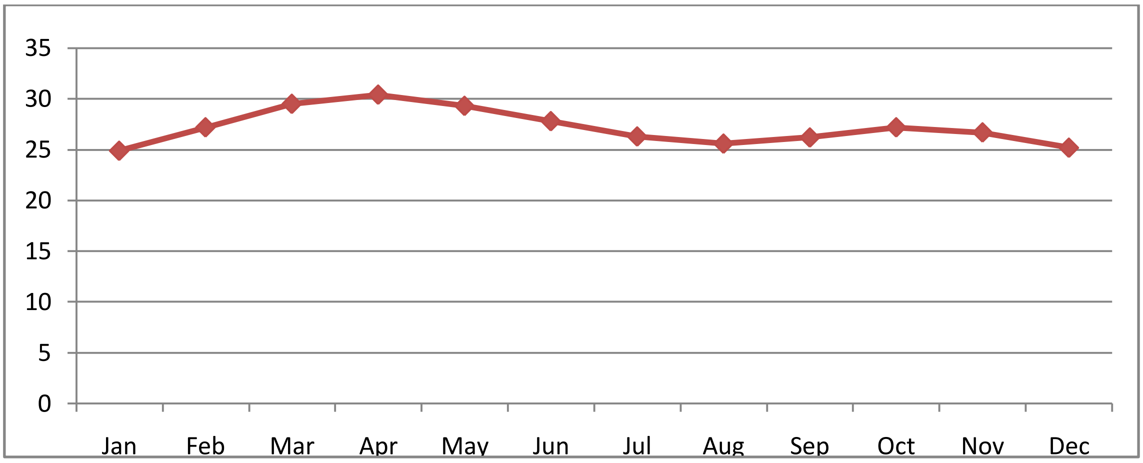

Figure 2. The average monthly temperature distribution in Nigeria fluctuating between (25-30)^{o}C on average.

Solar energy conversion

Solar energy has the capacity to meet Nigeria's energy need and is the most promising of all other renewable energy source due to the level of radiation from the sun. The conversion of solar energy to electricity is accomplished in two basic ways: by use of photovoltaic cells and/ or by use of solar concentrators.

Photovoltaic (PV) cells;

A solar panel comprises of many arrays of photovoltaic cells known as modules. The PV cell is essentially made of semiconductor materials and as such is governed by the same operating principles[20]-[22]. Over the years the cost of PV cells has fallen due largely to the advances in the semiconductor technology and demand which has continued to witness phenomenal increase[23]. This and some other factors such as no greenhouse gas emissions and sustainability have made the uptake of this technology reach to about 40 GW globally as at 2010, with about 70% in Europe[24]. Figure 4 is the global installed PV technology of leading countries. With Germany accounting for about 44% of total solar and the rest of the world 8%.Solaruptake in the Nigeria and indeed Africa needs to be vigorously pursued in view of the potential benefits.

A typical set up of a PV array-energy conversion system is as shown in figure 5 in a block schematic form. This comprises the following components:

- PV array; this is the energy conversion hub made of solar cells.
- Maximum Power Point Tracker (MPPT); this optimises the power from the solar in other to transfer maximum power to the battery, it serves to regulate the output from the solar to match the battery bank for storage purposes.
- Protection (D.C); this may be made of isolators, breaker circuits and fuses for protection
- Inverter; converts the direct current from the solar panel/ battery bank side to an alternating current suitable for utilization
- Battery bank: serves to store the energy from the solar for use at some other time when the solar may not be outputting energy due to its intermittent nature
- Battery charger; this is optional but is used to maintain battery charge during use by converting part of the supply A.C back to D.C.
- Protection (A.C); serves the same purpose as the previous
- Metering; for grid connected systems this becomes important since it notes the amount of energy generated from solar source.
- Utility; load consumption occurs here to meet energy demand.

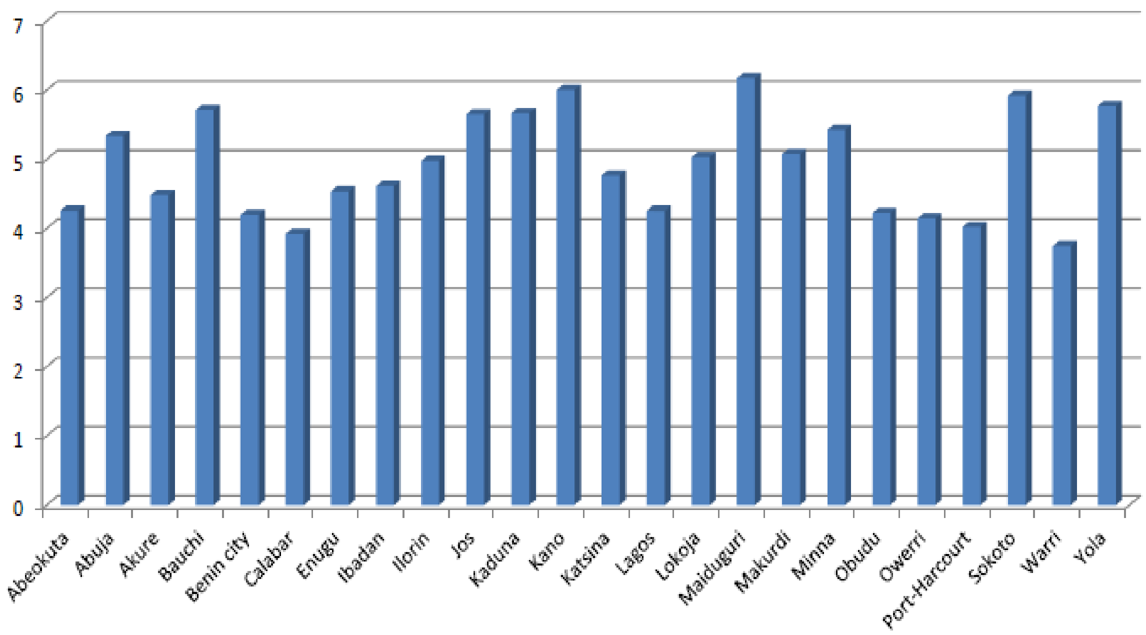

Figure 3. The average of annual solar radiation ($kWhm^{-2}$ per day) received for some selected cities in Nigeria.

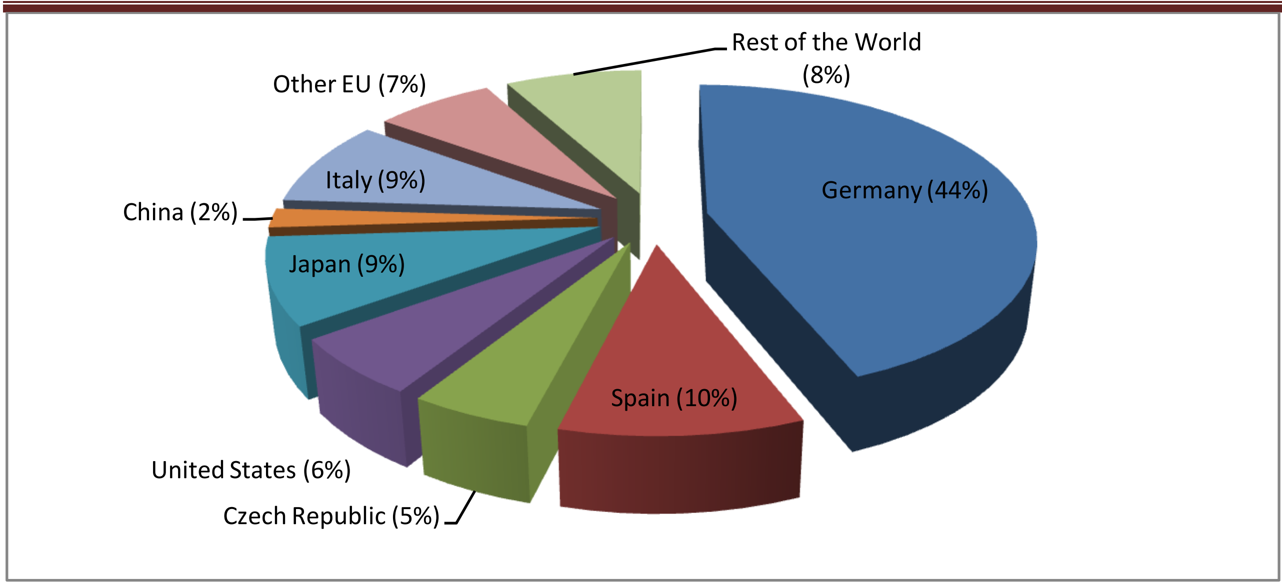

Figure 4. Percent up take of the global installed capacity of PV technology as at 2010 by country.

Sometimes a solar tracker may be incorporated into the PV array block to track solar insolation thus ensuring maximum energy capture. A set of focusing lenses may also be incorporated to maximise the amount of solar falling on the PV array.

The cost and efficiency of many PV cells will continue to improve as the driving technology improves. In the article an average cell efficiency of 20% is used for the analysis. This is due to the fact that most PV panels available in the country as at the time of research have an average operating efficiency of 20%.

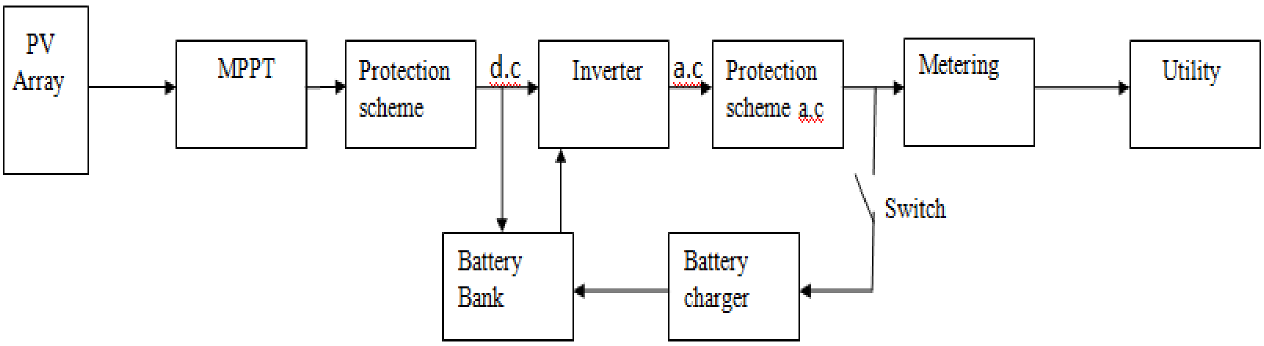

Figure 5. A simple block diagram schematic of a PV system for electricity generation

Concentrating Solar Power (CSP)

In the CSP method solar concentrators are used to harvest the heat energy of the sun which is then used to heat up a fluid (water), the heated fluid (steam) is channelled to rotate a turbine of adequate capacity for electric energy generation. The schematic for electric energy generation through CSP system is shown in figure 6. The various components of the block are briefly described as follows:

- Solar heat collector: this is mainly a convex mirror used to harvest and focus the heat energy from the sun for the purpose of heating up fluid.
- Heat exchanger: the heat from the sun is conducted to heat up fluid at the exchanger into steam (for the case of water as the fluid). This steam is now conveyed to the next block.
- Steam turbine: the steam is used for turning a turbine connected to an electric generator for the purpose of power generation.
- Generator: this actually utilises the rotation of the turbine for actual electric power generation and carried away for utility.
- Cold water reservoir: for storage of cold water for cooling and conduction of heat.
- Steam condenser: here the steam is cooled back to water and returned to the heat exchanger and the cycle is repeated.

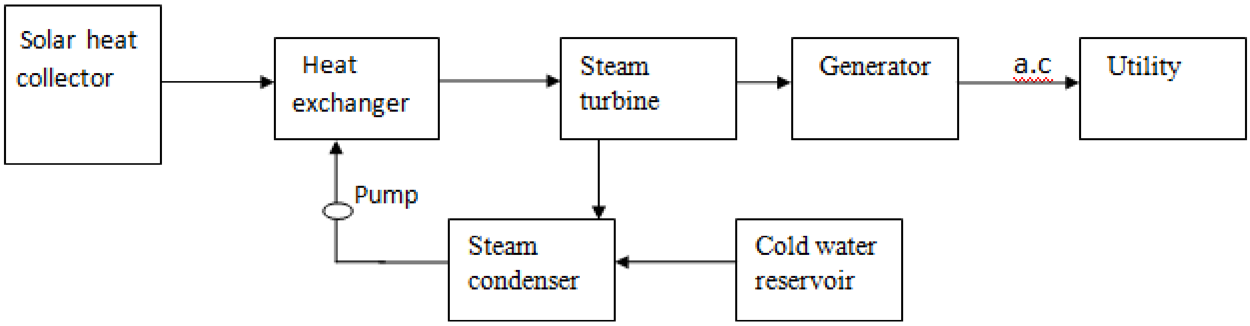

Figure 6. A simple block diagram schematic of a CSP system for electricity generation

IV The economics of solar PV alternative

Methodology

A pilot study was conducted in Ama-Nkanu community in Nkanu East Local Government Area, Enugu state, Nigeria comprising of 730 householdsof varying sizes and energy needs. On site determination and calculation of their energy requirements based on category of household was used. The electrical energy needs of this community was mostly for lighting, some cases to power other small electrical/electronic equipment such as: radios of varying types from transistor types to cassette recorder types with higher energy demand, televisions sets and some households possessing fridge/freezer. It was observed that quite a few of the residential houses use generators for private power supply, as such the energy use/demandfor these few residences was appreciably more than the others since appliances like television, fridges and high power radio cassettes were mostly found there. The demography of the community used for the study indicates an approximate population of less than 6,000 residents. For simplicity and ease, the homes were divided into 3 categories (A, B, and C) to reflect the level of energydemand. In the study energy efficient, low power electric bulbs were used throughout.

Category A: The lower class rural households

These depend entirely on subsistence farming with no other means of sustenance. This category made up about 30% of the entire rural population. Energy requirements for this category of households were mainly for lighting and sometimes to power small transistor radios. The energy needs structure is thus shown in table 4 indicating the low energy consuming appliances.

Total number of residence 219

Table 4. Energy needs estimated for category A

Type of energy need	Average per home	Demand per home(watts)	Total demand(watts)
Lighting	3	100	21900
Radio	1.5	12	2628
Total demand		**112**	**24,528**

*Category B:*The middle class rural households

This category consists of the average rural families with just a little support from relatives in the cities. They were mostly farmers with grownups helping in the farming activities and support. This category of households made up a larger portion of the entire community, about 65% of the entire population. Their energy consumption varied slightly from the nature and type of home appliances they use, ranging from portable radio to tape recorders, television sets.Table 5 captures their energy requirement.

Total residence 475

Table 5. Energy needs estimated for category A

Type of energy need	Average per home	Demand per home(watts)	Total demand(watts)
Lighting	6	160	76,000
Radio	2.8	35	16,625
Television	0.03	8	3,800
Total demand		**201**	**95,475**

Category C: The upper class rural households

This category get by mostly depending on external support; some were retirees with strong root in urban areas. Some engage in farming from a small to medium scale for economic reasons. Consequently, some could afford the use of more sophisticated and energy consuming appliances to meet their needs. Most often than not these were powered by generators for limited times. They made up the remaining 5%of the entire community and their energy requirement is as tabulated in table 6.

Total residence 36

Table 6. Energy needs estimated for category C

Type of energy need	Average per home	Demand per home(watts)	Total demand(watts)
Lighting	8	250	9,000
Radio	2	120	2,880
Television	1	300	3,600
Others (fridge etc)		10	360
Total demand		**720**	**15,840**

Thus the estimated total energy demand for the entire community was shown to be about 135,843 watts (peak demand). Using a power factor of 0.8 accounting for the fact that not all appliances such as light bulbs, television sets and fridges will be on at the same time. This gives the expected energy demand for the community to be 108,674.4 watts. However, in the study 120 kW was used accommodating future growth and increase in energy use for a couple of sometime in the future. Average consumption time in this pilot study for the community was about 7.5 hours per day thus total energy requirement per day was 900 kWh.

Results

A: Grid connected system

A grid line extension cost for linkingthe community in the pilot study with a distance of about 15 km to the nearest grid point is shown in the table 7 below.

Table 7. The cost of connecting the community to the national grid.

Description	**Number of units**	**Cost per unit (US$)**	**Cost (US$)**
Grid extension (km)	15	25,000	375,000
Distribution transformer (120 kVA/11)	1	20,000	20,000
Sub-Total			395,000
Miscellaneous installation cost	25% of sub- total		98,750
Total in US$			**493,750**

This cost captured in table 7 excludes the energy generation, transmission, operations and maintenance cost, fuel cost etc. the cost of energy from national grid currently stands at $0.0822/kWh, for the Enugu Electricity Distribution Company (EEDC).Building this into the grid connection raises the energy cost per day for this community by $73.98 and $27,002.7 per annum. Thus the levelised energy cost for the entire project life time stands at about **$1,708,871.5**.

B: Solar Powered System

The cost estimation for a solar power generation to meet the energy needs of the community was carried out below and shown in table 8.

With a PV cell efficiency of 20% [25] and expected power output of 120kW peak, the rating of the required PV array to supply this is 857kW_p

Table 8. Cost determination estimate for the PV system [26].

Component Description	**Lifetime (yrs)**	**Number of units**	**Cost per unit (US$)**	**Cost (US$)**
PV (kW)	25	600	850	510,000
Balance of systems (Inverters, Batteries and Installation) (kW)	Inverter:10 Battery:4	120	1,700	204,000
Replacement costs:		120	1,195	143,400
Total cost				857,400

The lifetime of these grid connection and PV projects are about 40-50 years and 25-30 years respectively. However in this study an average lifespan of 25 years for the solar and 45 years for the grid extension is used.

Discussion

The solar (PV) connected system of table 8 indicates a total cost of **$857,400**giving rise to a total energy consumption cost of $0.1044/kWh. This cost appears to be in close agreement to set energy cost target of the United States of America for 2015 according to [27]. Thus this alternative supply of energy through the use of centralised solar for this community appears to be sustainable in the light of international expectations and estimates. On the other hand observing table 7 of the grid connected system shows an estimated lifetime cost of $493,750.Building in the levelised cost of energy generation from the EEDC raises the energy cost to $**1,708,871.5** giving rise to energy consumption cost of $0.1156/kWh. Thus a comparative look at the two figures obtained from the two different approaches suggests the use of centralised solar PV system to be a more economical and viable option than the extension of the grid connection to accommodate such rural communities, with a cost reduction of $0.0112/kWh.

The energy use pattern of the communityas seen from tables 4, 5 and 6, indicated that the category C households had an average energy use of 440watts per home and 88watts per person using the average number of persons per home as 5. While that of category B was 201watts/home and 40.2watts per person,and also, category A was 112watts per home and 22.4watts per person. Thus a relationship is seen to exist between the availability and uptake of energy for this community. The more energy is readily available the higher the amount of energy consumed per person. This is important in projecting and modelling future energy uptake against population increase in such communities.

With over 60% of Nigeria’s population dwelling in the rural communities many of which are at reasonable distances from the national grid and with appreciable distance from one community to another, it is imperative that if the energy needs of these communities are to be met, alternative energy sources such as the solar option discussed in this paper need to be explored rather than the traditional grid extension with its attendant issues in Nigeria. Worthy of not also is the fact thatgrid connection scheme for power transmission/distribution in Nigeria has been grossly inefficient given the high percent of losses associated with it and the activities vandals. This approach is thus suggested in tackling the energy challenges facing Nigeria’s advancement towards a more stable and robust economy.

As the average lifespan of PV solar cells keep increasing, increasing efficiency, and the continuing trend into the near future as researches indicate, the unit energy cost of power from solar PV will even further be lowered making grid connected solar PV, and standalone solar systems robust and competitive in the light of traditional energy sources. At the present, grid connection of the PV systems is not as cost effective as the fossil fuels due to the cost of the PVs and the attendant balance of systems (BOS) which unfortunately do not fall proportionately as the PVs. With next to zero maintenance cost, massive uptake of solar technology has not been as projected due to the high cost of technology acquisition, this will likely fall in the coming years largely due to technological advancement and research innovations in the area and incentives from government.

V Conclusion

A renewable centralised solar (PV) energy supply scheme has been proposed as a more economical and feasible option to meeting the increasing energy needs of some rural communities not connected to the national grid system when compared to grid extension to such areas. This national grid connection has its attendant issues ranging from obsolete cables and components resulting in high percent of losses during transmission. Energy generation in Nigeria is fossil fuel driven and is not sustainable thus a demand on more sustainable energy sources as a mix.Exploring these renewable sources of energy and adequate investments in the energy sector will enable the nation rise out of its present energy-crisis situation.Many renewable energy sources such as solar, biofuel, wind geothermal abound in the country. These renewables have the capacity to transform poor economies into economic giants when adequately harnessed. This energy mix approach to tackling the energy challenges facing Nigeria will potentially transform the country into an economic giant.This also has the potential of transforming rural communities into economic hubs and reducing urban migration.

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