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Developing Sustainable Renewable Energy for Rural Dwellers' Energy Sufficiency

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Abstract: *The issues connected with the worldwide growth in energy consumption, energy conservation, and finding environmentally benign ways of energy production may arguably be the most significant challenge facing mankind in the 21st century. Government policies on rewarding economic goals have failed due to inadequate supply of energy. A strong energy sector is essential for a vibrant and competitive economy. Whilst we proceed with increasing the energy generation capacity, transmission and distribution of existing energy from traditional sources through the development of energy systems that enhance social, economic and environmental performance; it is appropriate to focus on renewable and sustainable energy forms for rural areas. In this paper, we explored various renewable and sustainable energy options, namely: solar, wind, micro hydro, fuel cells and bio fuel; with the aim of proposing an environmental friendly and cost effective option that will ultimately solve the energy crisis both in rural and urban areas in Nigeria. Our methodology is purely empirical with data drawn from a pilot project carried out on a household in Magboro community, a suburb of Lagos. The result of the work revealed that the solar system based on photovoltaic cells is a viable renewable energy solution to the perennial power failure especially to the rural populace in Nigeria. The ultimate aim of this paper is to provide the springboard for the development of an enduring energy policy in Nigeria.*

Keywords: Rural populace, power sufficiency, renewable energy, energy consumption, energy conservation.

1. INTRODUCTION

Energy is the ability to do work [1, 2]. The nomenclature by which a form of energy is called emanated from the source of the energy. Some important forms and sources of energy include: the solar energy, derived from the sun; chemical energy; electrical energy; mechanical energy which basically manifest as kinetic energy (i.e. energy due to motion) and potential energy (i.e. stored energy) to mention but a few. One of the most important of these forms of energy is the electrical energy due to its higher transmissible power, its ability to readily transform to other forms of energy and the human capability to facilitate its storage. Electricity features everywhere in our lives. It lights up our homes, cooks our meals, powers our computers and other electronic devices and ultimately, electricity from battery keeps our cars running. For these reasons energy consumption worldwide depends on the quantum of electricity generated.

For Nigeria to meet up with the Vision 20:2020; Nigeria requires per capital power capacity of 1000 Watts per person or power generating/handling capacity of 170,000 MW as against the current capacity of 3,920 MW. This will put Nigeria slightly below South Africa with per capita power capacity of 1047Watts, UK with per capita power capacity of 1266 Watts and above Brazil with per capita power capacity of 480 Watts, China with per capita power capacity of 260 Watts. Currently Nigeria has per capita power capacity of 23.06 Watts and this is grossly inadequate even for domestic consumption. To the much-desired millennium goal, a strong energy sector is essential for a vibrant and competitive economy. Figure 1 shows the comparative statistics of current power capacity of selected countries vis-à-vis the population served as at year 2002. The situation has not improved in Nigeria [3].

Nigeria's unreliability of supply and decline in traditional fossil fuel production, combined with very grave environmental matters and continued uncharted economic and population growth makes it imperative to search for alternative forms of energy. It is imperative to proceed with increasing the country's power generation capacity. However, the issues associated with transmission and distribution of existing energy is germane and must be pursued vigorously by developing energy conservation and efficiency systems supported by realistic government policies. It becomes expedient to expedite action on alternatives to the traditional energy sources which among other things is capital intensive and the technology required becomes obsolete within a short space of time thereby requiring intensive overhauling of the machineries or better still a complete replacement of the existing technology with a newer innovation leading to colossal waste of fund. However, the answer to the present imbroglio may be found in sustainable but renewable energy forms both for rural and urban areas of the country [4].

Table 1: Biometry of current power capacity of selected countries (Year 2002)

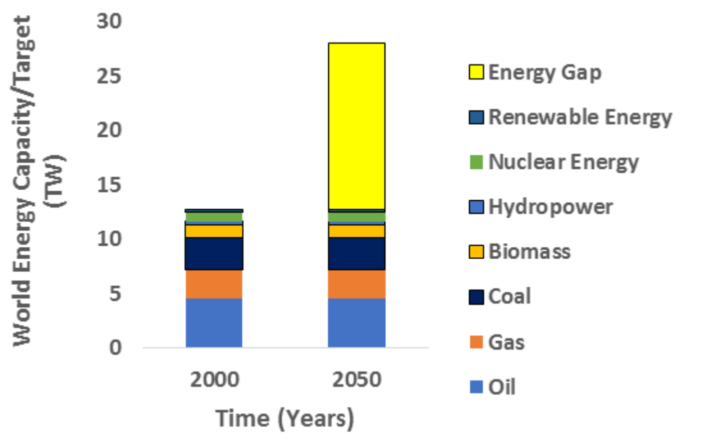
Country	Population served ('000)	Power generating capacity (MW)
USA	293,600	848,300
Germany	82,600	115,000
U.K	59,700	76,300
S.A	42,700	44,650
Brazil	179,100	86,020
China	1,300,100	338,300
Ghana	20,700	1,762
Nigeria	170,000	4,000

1.1 Renewable Energy versus Non-renewable Energy

The word renewable emanated from renew which implies "to give new strength to something" or restore to original state, [3, 5]. Renewable energy (RE) thus mean: energy derivable from a source that can be given new strength to. REs are derivable from the natural movements and environment such as: sunshine, wind, the heat of the earth, the movement of seas and rivers and the growth/movement of plants and animals. Basically, a RE system transforms incoming solar energy and its primary alternate forms such as wind and river flow, usually without pollution-causing combustion into readily usable form of energy such as electricity [6]. Some renewable energy forms are: Solar, Wind, Micro-Hydro, Fuel Cells, Biomass and Geothermal Energy. However, some energy forms are non-renewable. Major non-renewable energy forms are the Fossil Fuels. These are the traditional sources of energy such as coal, oil and natural gas. Fossil Fuels are non-renewable since they cannot be recycled. Once they are spent they cannot be recovered again. A comparative analysis of renewable and non-renewable energy is summarized as follows:

- REs from wind, solar, and hydroelectric power emit no pollution or carbon dioxide (although the building of the components does)
- Even though Biomass is a form of RE, Biomass combustion emits CO_2 and other pollutants
- RE is sustainable indefinitely, unlike long-stored energy from fossil fuels
- Fossil-fuel energy will deplete in the future; took millions of years to create that much fuel (rate of depletion >> rate of creation)
- US oil production peaked about 1974; world energy will peak about 2004-9 or so
- Nuclear energy is not renewable, but sometimes it is treated as though it were because of the long period of depletion

In view of the comparisons above, REs will eventually become mandatory, and our lifestyles may change. It is our sincere hope that transition to renewable energy will occur in Nigeria well before energy crisis occurs. Figure 1 is the inventory of global energy in our immediate past and the not too far future.



Source: Universe 4th Edition
Figure 1: Global Energy Inventory

2.1 Solar Energy

The use of energy from the sun by man and plant alike is as old as human/plant existence itself. Plants use energy of the sun to produce their foods through photosynthesis. Animals eat plants for food. Fossil fuels such as coal, oil and natural gas are sunlight that have been stored for millions of years ago since they emanated from decaying plants hundreds of millions of years ago [7, 8]. Indirectly, the sun is responsible for most of our energy. Moreover, solar energy can also be used to make electricity. This is due to the fact that solar energy is derived from the one-fifth of the sun's ray that falls on land and that can produce more than 2,000 times the current global energy demand; the balance four-fifth of the sun range falls on oceans and drives the hydrologic cycle which is a major global hydropower resource. According to Steward and Penev (2010), the sun gives off 3.90×1026 Watts. The energy of the sun is intercepted by the earth on a disk radius being the radius of the earth is 3,393,000 meters (World Geodetic System 1984 value is 6,378,137/2m). The earth solar interception area is (3.14)(3,393,000)^2 while the amount of power crossing earth's orbit is 1388 watts/m^2. Therefore, the earth intercepts energy may be put at 5.02×1016 watts, an indication that the earth intercepts about 50 quadrillion watts of solar power on daily basis. Making electricity from solar energy could be achieved in two major ways namely: the solar thermal electricity such as the parabolic disks thermal plant in the California's Mojave Desert and the solar photovoltaic (or solar cells) technologies. The solar thermal technology has been used to provide electricity that powers more than 350,000 homes in California Mojave Desert [10]. This is the size of a modest state capital in the northern part of Nigeria [6]. However, the solar thermal technology is cumbersome and may not be sustainable in Nigeria since maintenance is a major problem in Africa.

Of concern in this paper is the application of the solar photovoltaic technology to provide sustainable energy for Nigerian rural dwellers. Sunlight is convertible into electricity using photovoltaic cells (PVCs), Concentrating Solar Power (CSP), and other viable experimental technologies [11]. Particularly, PVC has been used to power small and medium-sized applications ranging from calculator powered by a single solar cell to off-grid homes powered by a photovoltaic array.

Recently, multi-megawatt PV plants are becoming common for large-scale electric power generation. The 14 MW power station in Clark County, Nevada and the 20 MW site in Beneixama, Spain both completed in 2007 are characteristic of the new trend towards larger power stations in the US and Europe [12, 13]. A solar cell is a device that converts light into direct current using the photoelectric effect. The first of the prototype selenium solar cell which converts less than 1% of incident light into electricity, was constructed by Charles Fritts in 1880s. Following the work of Russell Ohl in the 1940s, Gerald Pearson, Calvin Fuller and Darl Chapin created the silicon solar cell in 1954. The early solar cells cost 286 USD/watt and reached efficiencies of 4.5–6% [14]. The earliest significant application of solar cells was as a back-up power source to the Vanguard I satellite, which allowed it to continue transmitting for over a year after its chemical battery was exhausted. The successful operation of solar cells on this mission was duplicated in many other Soviet and American satellites, and by the late 1960s, PVC had become the established source of power for them [15]. PVCs went on to play an essential part in the success of early commercial satellites such as Telstar, and they remain vital to the telecommunications infrastructure to date.

The high cost of solar cells limited terrestrial uses throughout the 1960s. This changed in the early 1970s when prices reached levels that made PV generation competitive in remote areas without grid access [16]. Early terrestrial uses included powering telecommunication stations, offshore oil rigs, navigational buoys and railroad crossings. These off-grid applications have proven very successful and accounted for over half of worldwide installed capacity until 2004 [17].

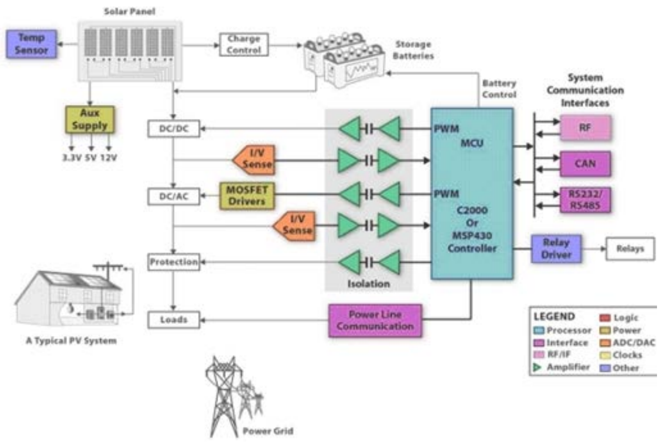
The 1973 oil-crisis stimulated a rapid rise in the production of PV and this trend continued into early 1980s. Economies of scales which resulted from increasing production along with improvements in system performance brought the price of PV down from 100 USD/watt in 1971 to 7 USD/watt in 1985. Steadily falling oil prices during the early 1980s led to a reduction in funding for photovoltaic research and development (R&D) and a discontinuation of the tax credits associated with the energy tax act of 1978. These factors moderated growth to approximately 15% per year from 1984 through 1996. Since the mid-1990s, leadership in the PV sector has shifted from the US to Japan and Germany. Between 1992 and 1994 Japan increased R&D funding, established net metering guidelines, and introduced a subsidy program to encourage the installation of residential PV systems. As a result, PV installations in the country climbed from 31.2 MW in 1994 to 318 MW in 1999, and worldwide production growth increased to 30% in the late 1990s. Germany has become the leading PV market worldwide since revising its Feed-in tariff system as part of the Renewable Energy Sources Act. Installed PV capacity has risen from 100 MW in 2000 to approximately 4,150 MW at the end of 2007. Spain has become the third largest PV market after adopting a similar feed-in tariff structure in 2004, while France, Italy, South Korea and the US have seen rapid growth recently due to various incentive programs and local market conditions.

www.innovation-vilage.com
Figure 2: Building-integrated PV cover for homes

In Nigeria where epileptic supply of power has plagued the economy, it will be encouraging if the federal government will follow the Germany's example by formulating a Renewable Energy Sources Act which will make similar provisions for varieties of incentives that will almost annihilate importation of the traditional Fossil fuel devices such as the gasoline power generators and pave way for viable RE options especially the Solar PC energy technologies. A system whereby government deploys 18.5 billion dollars ($18.5bn) to arrest epileptic power supply in the country with huge failure due to lack of commitment. PVs have proven to be most successful as they are usually incorporated with a battery-bank to cater for the cloudy days and the night. Figure 2 is a typical rural community model where PVC technology has been deployed for energy sufficiency.

2. MATERIALS AND METHOD

The material requirement for the project include: 6 Nos. 140 watts solar panel, 1 No. solar charger, 2 Nos. 200 Ah deep cycle batteries, 2.4 KVA inverter (DC/DC converter, DC/AC inverter, MOSFET, signal sensors, etc.), 10mm multi-strand copper cable, 4mm single-strand copper cable and cable clips. All these components are connected in accordance with Figure 3.



www.embedded.com
Figure 3: Schematics for PV-Battery-Inverter System

The rural setting in Nigeria consists of people who are mainly peasant farmers. Therefore their major preoccupation is farming. The lifestyle of rural dwellers is regimental. They spend most of their time in the farm retiring into the village only in the evening at about 6.00pm daily. Sometimes, they even retreat to the farm for about three months during the time of planting or harvesting. To this end, their energy requirement is abysmally low. For instance, a study carried out at Itoko-Ajegunle village in Odeda Local Government of Ogun State attested to this fact. Itoko-Ajegunle is a modest village of about one hundred (100) houses with no cottage industry except the gari grating mills that can be found in every home requiring no electricity to operate. An average home in the village has six rooms. And there is no presence of modern day civilization except for very few homes with power generators. Table 2 shows the typical power consumption pattern of a typical household at Itoko-Ajegunle rural community. The essential electrical equipment for a single household are: 12 energy saving bulbs, 1 electric fan, 1 radio and 1 television set. Table 2 summarizes energy requirements of a typical household in the village.

Table 2: Typical Household Electricity Consumption Pattern in a Village Setting

Electrical Devices	**Power Rating** (W)	**Unit**	**Operating Hours**	**Energy** (WH)
Electric bulbs	5	12	6	360
Mini Sound System	50	1	4	200
Electric Fan	50	1	4	200
Television	150	1	4	600
Load	**255**		**Total**	**1360**

2.1 Solar Panels Requirement

Solar panels required for the daily energy consumption is calculated as follows:

$$\text{Solar Power} = \frac{\text{Total Daily Energy Consumption}}{\text{Sunshine Hours}}$$

$$= \frac{1360}{6} = 226.67\,W$$

$$\text{Cable Losses} + \text{Solar Panel Degradation Factor}$$

$$= 10\% \times 226.67 = 22.67\,W$$

Total Solar Power Required = 249.34 W

Since the rating of our solar panel is 140 W, then 2 Nos. of solar panels are required for each household, thus a total installation capacity of solar panels is 280 W.

2.2 Battery Requirement

It will not be out of place to determine total energy requirement for our chosen community so as to determine the quantum of energy to be generated in this study for the communities' energy need.

Total energy storage with 50% discharge capacity = 2×1360 Watt-Hour = 2720 WH

$$\text{Battery Capacity} = \frac{\text{Total Energy Storage}}{Operating Voltage} = \frac{2720}{12} = 226.67\,AH$$

Thus, 1 No. of battery with capacity of 230 AH is adequate.

Table 3: Statistics of energy consumption for the pilot household at Magboro, Ogun State

Electrical Devices	**Power Rating** (W)	**Unit**	**Operating Hours**	**Energy** (WH)
Electric bulbs	10	7	5	350
Mini Sound System	80	1	1	80
Laptop	75	1	4	300
Ceiling Fan	60	2	12	1440
Deep Freezer	180	1	6	1080
Television	150	1	8	1200
Load	**555**		**Total**	**4450**

2.3 Inverter

The rating of the inverter depends on the load, and the batteries combined rating. In this instance, since only one battery is required, then the voltage rating of the inverter can only be 12 V. The capacity is as determined in Equation 6. Thus:

$$\text{Inverter Capacity} = \frac{\text{Instantaneous Load}}{Power Factor} = \frac{255W}{0.7} = 364.29VA$$

Installation capacity of inverter is 500VA or 0.5KVA.

Now for a community of one hundred households. The instantaneous load is 30,000 Watts (30KiloWatts), the chiefs' households will require refrigerators. If there are six refrigerators in the community and each is rated 180 Watts. The total instantaneous load will be 31080 Watts (31.08kiloWatts). The total daily energy consumption of the community taking into consideration of six operating hours for the refrigerators is 122480 Watts-Hour. A house located at Magboro community, a suburb of Lagos, Nigeria, which rely solely on solar PV systems for energy needs was used as pilot project. The house was equipped modestly with state of the art household equipment. The logic employed in the project is unambiguous. If the systems works for a sub-urban setting such as Magboro, it will work at reduced scale for a more localized setting like Itoko-Ajegunle.

Figure 4: The solar panels being fixed

Figure 5: Batteries and inverter connected

The energy sustenance for the household whose energy consumption statistics is as shown in Table 3 above is derived from six solar photovoltaic cells each with 140 Watts power rating and two sealed maintenance free 12V, 200A deep cycle batteries. The two batteries are connected in series to double the voltage to 24V with 200AH capacity rating. The use of six solar panels is informed by the scaling factor of 4450/1360 (or 3.27) based on the total daily consumption of the Magboro compared to a typical Itoko-Ajegunle facilities. The scale of 3 to 1 has been used for the battery capacity and other such materials.

3. RESULTS

The results of the study are as displayed in Figures 6 and 7. Energy consumption pattern of weekdays may not be of major concern since the occupants of the house may be at work outside the home for a substantial part of the day. The weekday scenario is also comparable to the predominantly farming livelihood of the rural communities who are not likely to be at home on weekdays but rest only on Sundays. However, all the utilities are put to use during the weekends. The readings of the batteries' potential difference is taken at equal interval of 1 Hour from 12 am on Friday to 11:00pm on Saturday. These readings are captured in Figure 6.

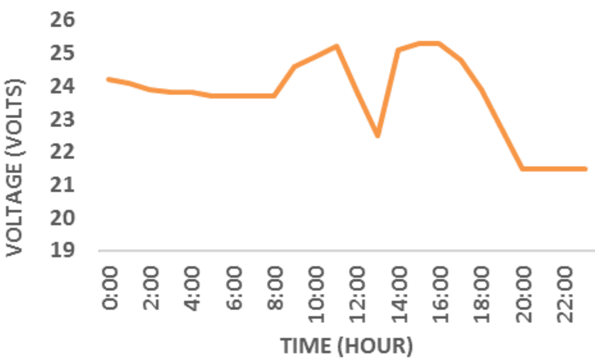


Figure 6: The Usage Trend of Stored Energy from Solar PV at the Pilot Household in Magboro Community

In Figure 6 however, we have carefully done an audit of load on hourly basis with the intent of acquiring data which will serve as a basis for determining the most efficient means of conserving energy to ascertain uninterrupted supply of energy to a household with strong likelihood for sustainability. Sustainability has been confirmed because we have monitored the project for forty four (44) months. The national grid was extended to the area under consideration in August 2017 even though it has not been installed in the facility at the time of writing this report

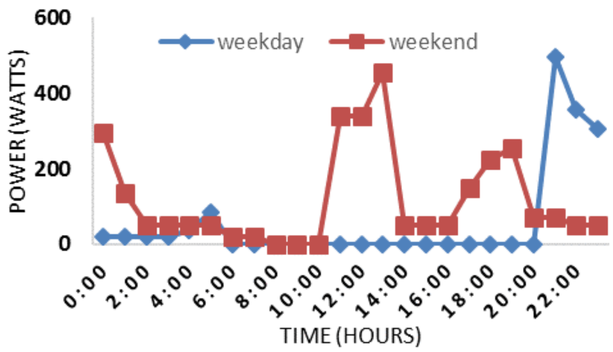


Figure 7: Energy consuming pattern of modest family at the pilot household in Magboro Community

4. DISCUSSION

Every human endeavour requires energy since energy is directly related to work done. Even the state of human health is a function of the energy level a man possesses [18]. There is no kind of activity that does not require energy [19, 20]. Nigeria is regarded as a failed project by a school of thought because of her inability to provide the energy requirement of the citizenry. Figure 1 revealed the place of renewable energy in the global energy inventory. The combined contribution of all forms of renewable energy is 14.1% of world total energy.

The cleanest and the surest way of achieving energy for all is to harness the energy from the sun. The best we have achieved from the sun is the erection of umbrella to shield us from our destiny, the sun. The earlier we realize and exploit the abundance of the enrichment in the sun rays that we shield from ourselves the better for us. Figures 2 attests to ability of solar energy to solve the energy crisis in Nigeria. The example of the household at Magboro near Lagos where national grid is not present as analysed in Figures 4 and 5 is a testimony that when deployed in a rural community, solar system can be self-sufficient for the rural populace. Table 2 is the enumeration of the energy requirement of a household in Itoko-Ajegunle also in Ogun State. A close examination of Table 3 reveals that a rural household requires less than half of the energy requirement of the Magboro Community household and so the affordability of the installation of solar system in such a household is not in doubt. All we need do is to adapt the same facility at the Magboro household to the Itoko-Ajegunle by scaling down the solar system to meet the energy requirement of each house. However, government may subsidize procurement since the financial requirement is far less than the cost of erecting the national grid into those communities especially when no maintenance cost is required over a reasonably long period of time. In addition to providing energy needs for affected communities, it will also open a new trend in commerce since there will be need for maintenance and repairs of the solar system. The choice of the facility in Magboro was informed by the need for effective monitoring. One other key factor is the education of the end users about conservation and efficient use of energy.

However, being one of the world's best generators of garbage, Nigeria may become a world leader in biomass technology if the potentials of the garbage generated is harnessed. The current practice where people pay refuse collectors from their hard-earned financial resources may be reversed. The dirtiest family may them become the richest since their activities would have translated to more raw materials for power generation. It is an aberration that a country which stands on trillions of cubic metric tons of gas is one of the poorest nations of the world. It might simply mean that our destiny is not tied to oil but garbage. Qatar is a world envy for its abundance of petroleum resources, Nigeria could become the world envy for its abundance in garbage, solar energy, green vegetation which are veritable source of renewable energy, and for its water resources among other endowments. Nigeria must wake-up from its slumber and the time is now because the need for energy is so enormous, current technologies are not enough and there is therefore the need to develop new science to take care of the missing 6B person energy demand. It is imperative to note that the combination of solar (direct) and water (indirect) sources of energy has the capacity to meet future energy needs but large expanse of fundamental science needs to be discovered. Renewable energy research should be pursued with vigour and tackled as a basic science problem and not as an engineering problem [14, 21]. Currently, materials, catalysis and many new modes of reactivity awaits discovery [9]. Nigeria is not ready for the vision 20:2020 without solving her energy crisis. Chemistry is the central science of energy because it involves light capture and conversion with materials and storage in bonds. If it is a fifty year problem, the basic science needs to be solved now [6, 22].

5. CONCLUSION

In this work, headway had been channelled towards a renewable energy development for rural power sufficiency with the ultimate aim of achieving Nigeria's millennium goals. The current practice where policy makers in the country set agenda without well laid foundation will only end in jeopardy. Nigeria has reached a stage where proper pedestal must be laid before setting agenda. The pedestal for vision 20:2020 is development of viable renewable energy option to drive the vision. It is our belief that if renewable energy especially the solar system supplies the rural populace with sufficient power, the national grid can be concentrated in industrial areas. This paper will contribute in no small measure to the aspiration of Nigeria to overcome the epileptic power supply that has plagued the economy of the nation for a long time now.

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