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Utilization of Solar Energy for Power Generation in Nigeria

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Abstract This study presents the viabilities for power generation in Nigeria through the utilization of the sun's energy. Solar-thermal and photovoltaic options were discussed. It highlights the basic science for the design and selection of components for successfully harnessing solar power. Requirements for solar panel placement and orientation were also highlighted. It emphasizes that the knowledge and experience gained in solar energy as an abundant and convenient energy source, can play a role in steering the nation toward a permanent and sustainable development. The energy demand in Nigeria far outweighs the supply which is epileptic in nature. The acute electricity supply hinders the country's development notwithstanding the availability of vast natural resources in the country. Our ability to continue the trend for affordable energy will be severely tested in the coming decades, as evidenced by the widening trade imbalance, collapse of big manufacturing companies, sharp increase in the cost of doing business just to mention but a few. It is the issue of utilizing the sun's silent, inexhaustible, and non-polluting resource for power generation in Nigeria that this work addresses; hence it is the long-range review of the energy problem.

Keywords Solar energy, solar-thermal conversion, solar electric (photovoltaic) conversion, panel placement and orientation

1. Introduction

The Earth as a resource system has a limited capacity for supporting a growing human population with an intensive exchange of materials and energy with its environment, hence the need for a growing awareness to achieve a more sustainable societal use of materials[1]. The earth receives energy directly from the sun. It is silent, inexhaustible, and non-polluting[2].

The utilization of solar energy depends on its availability and appropriate technology[3]. The idea of using the sun's power has held scientist in its grips for centuries[4]. Also, for most of its evolution, mankind relied for its sources of energy on constantly replenished materials. When the use of fire was discovered for the provision of heat and for the processing of food, the additional demand for energy was met by constantly renewed sources. Later still when water and wind powers were harnessed to the service of mankind, the new sources were also of a renewable nature. Thus throughout the early phase of human development, the availability of the readily renewable sources of energy was a key constraint and affected the size and distribution of popu-Lations[5,30].

The sun's power reaching the earth is typically about 1000W/m^2. The total amount of energy that the earth receives daily is 1353W/m^2[6]. Some 4million tons of the sun's matter will continue to be changed into energy every second[7].The sun is the most readily and widely available renewable energy source capable of meeting the energy needs of whole world. It can provide more power than any fossil fuel on the planet[8]. The solar radiation arrives at the earth at a maximum flux density of about 1kw/m^2 in wave length of band between 0.3 and 2.5μm.This is called short wave radiation and it includes visible spectrum. For habited areas fluxes received vary widely from about 3 to 30MJ/m^2/day, depending on place, time and weather. The quality of radiation is characterized by the photon energy of around 2eV as determined by 6000K surface temperature of the sun[9].

Solar panels are made up of solar cells which are an array of photovoltaic cells (PV). Any type of equipment used to convert sunlight into energy is considered solar cell or panels. The technology behind Solar panels has varied widely throughout the five or six decades and while Sola cells were the true origin of modern solar panels, today researchers are shifting to new platform and approaches to gathering energy from sunlight which including crafting solar cells from silicon semiconductor configured to trap and convert sun energy which are coated in an antireflective coating and contained

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under a glass cover plate to protect the cell from the elements[10].

In the 1950s General Pearson, Calvin Fuller and Daryl Chaplain (of Bells Laboratories) discovered how well silicon worked as a semi-conductor. Silicon is what solar cells and panels are generally made up of today[11]. An ambiguous study has been made of using a solar satellite which is continuously in direct sunlight to collect the energy, convert into electricity and direct a microwave beam to a receiver on earth where it would be reconverted to electricity[2]. However, the cost of such a scheme is likely to prohibit its realization.

2. Energy Demand, Crisis, and Utilization in Nigeria

Nigeria is one of the tropical countries of the world which lies approximately between 4^o and 13^o with landmass of 9.24 x 105 km^2 enjoys an average daily sunshine of 6.25 hrs, ranging between about 3.5 hrs at the coastal areas and 9.0 hrs at the far northern boundary[12]. Her electrical energy consumption in the year 2001 is 15 x 10^{6}kWh. Its climate varies from tropical to subtropical. There are two main seasons; the dry season lasting from October to March and the rainy season lasting from April to October. In the north, it is hot and dry, rainy season extends between April and September. In the south, it is hot and wet, rainy season extends between March and December. From December to March there is a long dry season[13]. Temperature at the coast rarely rise above 32^{o}C. The north is drier with temperature range between 32 ^{o}C and 42 ^{o}C. Humidity is about 95%[14]. The terrestrial radiation on Nigeria's land area is 2.079 x 1015 kWh/year.

The Nigerian economy can be disaggregated into industry, transport, commercial, household, and agricultural sectors, with the household sector dominating energy consumption[15,16]. The energy consuming activities in the household sector still remain mainly cooking, lighting, and operations of electrical appliances (i.e., non-substitutable electricity). The percentage distribution of the total final consumption in 1989 in this sector and in terms of the major energy carriers is Kerosene (13%), Electricity (4%), LPG (1%), and Wood/others (82%)[16].

Nigeria's economy face deepening challenges: a widening trade imbalance, growing competition from developed countries, a collapse of big manufacturing companies, and a sharp increase in the cost of doing business, all owing basically to energy and its related infrastructural costs. Energy demand far outweighs the supply which is epileptic in nature. It is still pertinent to note that our energy consumption is projected to grow geometrically (Figure 1) while our ability to sustain our growth through energy generation, transmission and distribution continues to dwindle (Figure 2). Our capability to continue the trend for affordable energy will be severely tested in the coming decades.

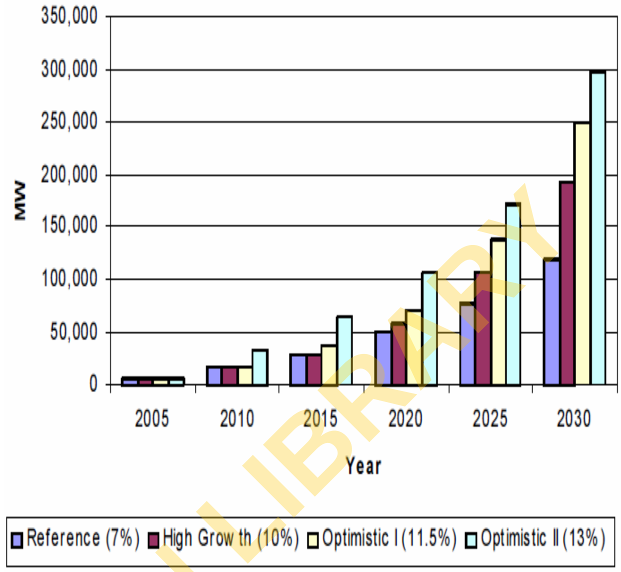

Figure 1. Electricity Demand Projection in Nigeria. Source:[18]

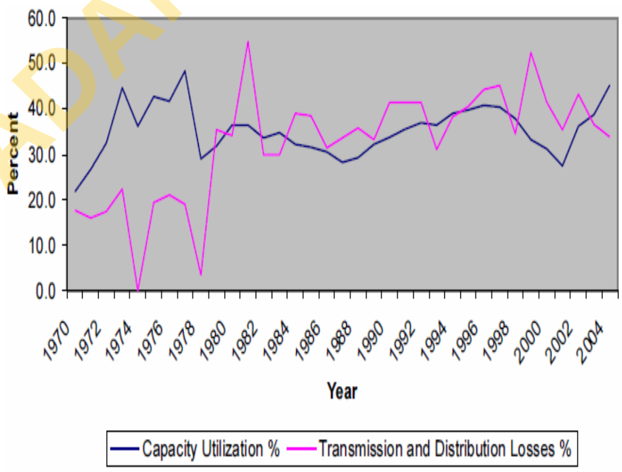

Figure 2. Indicator of Electricity Crisis in Nigeria 1970 to 2004 Source:[19]

Figure 3 shows the variation of the total radiation per square meter per day throughout the year in some cities of the country. The average total radiation received per day at the northern cities of Kano, Zaria, and Kaduna is more than that of the southern cities of Ibadan, Lagos and Nsukka. Furthermore, at each of these cities the total radiation varies significantly with the period of the year. Knowing that Nigeria has an annual average daily solar radiation of about 5.25 kWh/m²/day, varying between 3.5 kWh/m²/day at the coastal areas and 9.0 kWh/m²/day at the northern boundary, gives an impression that implementing solar energy strategy is a great opportunity for Nigeria to get renewable energy at low cost as well as minimize dependence from fossil fuels.

For example, the total radiation received per day on a 1m^2 surface at Ibadan varies from 16MJ in January to 22MJ in May. Under the same period at Kano the total radiation received varies from 33MJ to 37MJ per day on the same surface. Using this as a benchmark, it can be seen that even the minimum harnessible power in any part of the country is more than that required for powering an average 3- bed room flat and 2-room apartment using low-power consuming appliances (Table 1 and Table 2). The need for harnessing this renewable energy supply is apparent as fossil fuels (especially oil) become increasingly expensive, depleting reserves, population increase, and individual press for a higher standard of living in terms of material goods, especially in rural and developing regions.

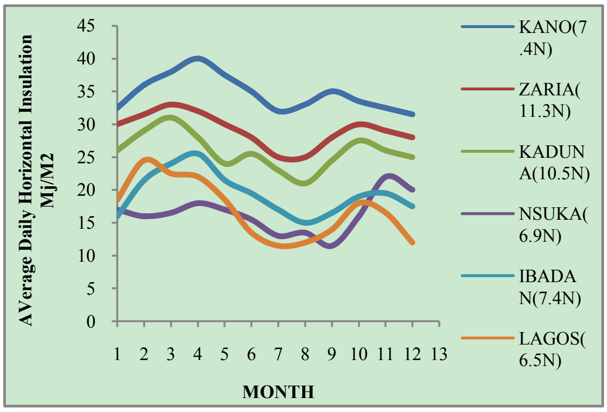

Figure 3. Variation of daily total radiation in some Nigerian cities Source:[17]

Table 1. Power estimate for an average 3-bedroom apartment in Nigeria

S/N	APPLIANCE	POWER (W-h)	QTY	TOTAL POWER (W-h)
1	Light	20	10	200
2	Fan	100	4	400
3	TV	58	2	116
4	Home theatre	95	1	95
5	Fridge	850	1	850
6	Air conditioner	750	1	750
8	Miscellaneous	100	-	100
TOTAL POWER REQUIRED 2511W-h or 2.511KWh Note: 1J/sec=1 Watts				

Table 2. Power estimate for an average 2-bedroom apartment in Nigeria

S/N	APPLIANCE	POWER (W-h)	QTY	TOTAL POWER (W-h)
1	Light	20	4	80
2	Fan	80	2	160
3	TV	58	2	116
4	Fridge	500	1	500
6	Miscellaneous	100	-	100
TOTAL POWER REQUIRED 956W-h or 0.956KWh Note: 1J/sec=1 Watts				

2.1. Techno-Economics of Solar Energy in present rural Nigeria

At present, a litre of premium motor spirit (PMS) for running a generator (commonly called petrol) is sold at 97 per litre. Bearing this cost in mind and the fact that 70% of the Nigerian population live in rural settlements, a cost estimate for solar powering a 3-bedroom and 2-bedroom is presented in table 3 and 4. From the table it can be shown that cost estimate for powering a 2-bedroom and 3-bedroom apartment with generator for 1 year in a rural area not connected to the national grid is put at 126,506 and 349,016 respectively.[28] in a recent paper has opined that the total cost for solar powering a 3-bedroom flat apartment is estimated to be 738,375.30 while that of a 1-bedroom apartment, comprising of 4 lighting points, 1 Television set, 1 Fan and a VCD, is 172, 349. From the above it can be deduced that in three years the individual utilizing solar energy will break-even for his energy needs. This is not even taking cognizance of efficiency of the generators which are on the downward trend as utilization increases. The foregoing is in consonance with the assertions of[20] and[21] that there is the major impediment militating against the widespread use solar energy and its related technologies is the Initial Capital Outlay (ICA).

Table 3. Cost estimate of powering a 3-bedroom apartment with generator for 1 year in a rural area not connected to the national grid

Particular	Description	Amount ()
Cost price		55,000
Fueling	8 hours/day @ 8 litres/day	284,016
Servicing	15,000.00/year.	15,000
TOTAL		**354,016**

Table 4. Cost estimate of powering a 2-bedroom apartment with generator for 1 year in a rural area not connected to the national grid

Particular	Description	Amount ()
Cost price		15,000
Fueling	8 hours/day @ 3 litres/day	106,506
Servicing	5,000.00/year.	5,000
TOTAL		**126,506**

3. Power Generation Technologies

Power generation is the process of converting energy from an available source to electrical energy in a form that is suitable for distribution, consumption and storage. Solar energy can be used to generate power in two ways; solar-thermal conversion and solar electric (photovoltaic) conversion.

3.1. Solar-thermal Conversion

Solar-thermal is the heating of fluids to produce steam to drive turbines for large-scale centralized generation (figure 4). Like solar cells, solar thermal systems, also called concentrated solar power (CSP), use solar energy to produce electricity, but in a different way. Most solar thermal systems use a solar collector with a mirrored surface to focus sunlight onto a receiver that heats a liquid. The super-heated liquid is used to make steam to produce electricity in the same way that coal plants do. Albeit, the Renewable Electricity Action Program (REAP) of the Federal Ministry of Power and Steel (2006) published by the International Centre for Energy, Environment and Development did not cover this aspect of power generation[22].

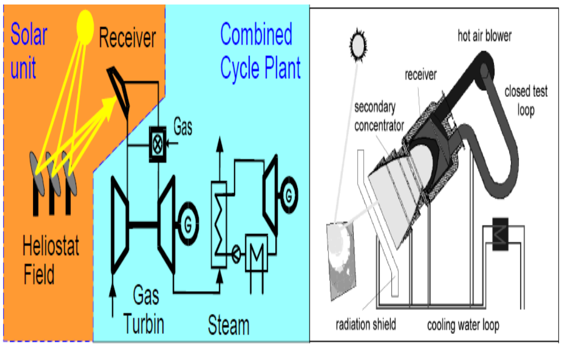

Figure 4. The REFOS-receiver for testing at the Plataforma Solar de Almería. Source:[23]

3.2. Solar Electric (Photovoltaic) Conversion

Solar-electric (photovoltaic) conversion is the direct conversion of sunlight in to electricity through a photocell. This could be in a centralized or decentralized fashion. Solar-electric (Photovoltaic) technologies convert sunlight directly into electrical power. Photovoltaic system is made up of a balance of system (BOS), which consists of mounting structures for modules, power conditioning equipment, tracking structures, concentrator systems and storage devices. Photovoltaic conversion could be small scale for stand-alone systems or large scale connected to national grid (figure 5).

Solar cell also referred to as photovoltaic (PV) cells, which as the name implies (Photo meaning “light” and voltaic meaning “electricity”), convert sunlight directly into electricity. Panel stands for a group of modules connected mechanically and electrically. A module is a group of cells connected electrically and packaged into a frame (more commonly known as a solar panel), which can then be grouped into larger solar arrays.

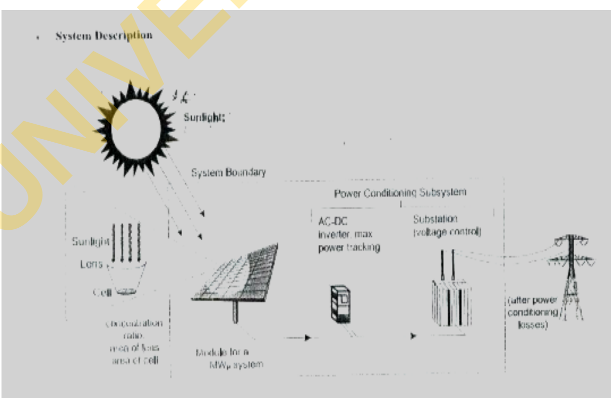

Figure 5. Schematic of a large-scale photovoltaic system. Source:[24]

Photovoltaic cells are made of special materials called semiconductors such as silicon, which is most commonly used. Basically, when light strikes the cell, a certain portion of it is absorbed within the semiconductor material. This means that the energy of the absorbed light is transferred to the semiconductor. The energy knocks electrons loose, allowing them to flow freely.

PV cells also have one or more electric field that acts to force electrons freed by light absorption to flow in a certain direction. This flow of electrons is the current, and by placing metal contacts on the top and bottom of the PV cell, we can draw that current off for external use say, to power a calculator. This current, together with the cell’s voltage (which is a result of its built-in electric fields), defines the power (or wattage) that the solar cell can produce[25].

PV modules are integrated into systems designed for specific applications. The components added to the module constitute the “balance of system” or BOS. Balance of system components can be classified into four categories[26].

3.2.1. Deep Cycle Battery

store electricity to provide energy on demand at night or on overcast days. They are designed to be discharged and then re-charged hundreds or thousands of times. These batteries are rated in amp hours usually at 20 hours and 100 hours. Like solar panels, batteries are wired in series and/or parallel to increase voltage to the desired level and increase amp hours;

3.2.2. Inverters

Required to convert the direct current (DC) power produced by the PV module into Alternating current (AC) power. Most solar power systems generate Dc current which is stored in batteries while nearly all lighting, appliances, motors and so on, are designed to use AC power, so it takes an inverter to make the switch from battery-stored DC to standard power (120VAC, 60Hz);

3.2.3. Charge Controller

A charge controller monitors the battery’s state-of-charge to insure that when the battery needs charge current it gets it, and also insures the battery isn’t over charged. Connecting a solar panel to a battery without a regulator seriously risks damaging the battery and potentially causing a safety concern;

3.2.4. Structure

Required to mount or install the PV modules and other components. Not all systems will require all these components. For example in systems where no AC load is present an inverter is not required. For on-grid systems, the utility grid acts as the storage medium and batteries are not required. Batteries are typically not required for PV water pumping systems, where a water reservoir “buffers” short-term demand and supply differences. Some systems also require other components which are not strictly related to photovoltaics[27].

3.3. Solar Panel Placement and Orientation

Solar panels should also be inclined at an angle as close to the area's latitude as possible to absorb the maximum amount of energy year-round. Mounting angles for fixed solar collectors is shown in figure 6.

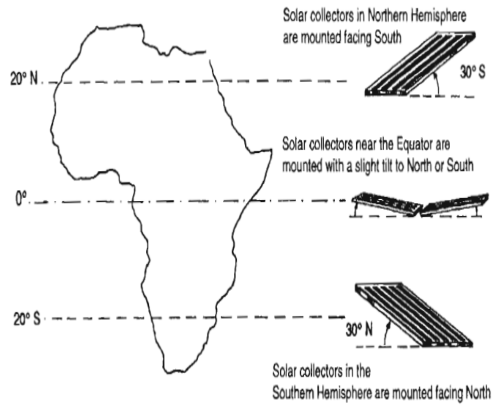

Figure 6. Mounting angles for fixed solar collectors (Source:[28])

A different orientation and/or inclination could be used if you want to maximize energy production for the morning or afternoon, and/or the summer or winter. The modules should never be shaded by near trees or buildings, no matter the time of day or the time of year. In a PV module, if even just one of its cells is shaded, power production can be significantly reduced.

Optimally, the angle of the panels is set to provide the most exposure to direct sunlight. The caveat is that the optimum angle which depends on latitude, as the sun's height in the daytime sky will be different for all. To determine the optimum angle for solar panel, the following instructions are generally adhered to.

1. Calculate latitude using a global positioning system, GPS, map an Atlas or even from Google Earth. An easy to read sun map with key information such as the number of hours of sunshine, its intensity and so on is created. This will be used to calculate the optimum angle
2. Add 15 to the calculated latitude (This is the rule of thumb for even production throughout the year).
3. Ratchet systems can be installed to raise or lower the angle or panel can be adjusted manually.

4. Challenges

According to[29], some of the factors militating against the growth of the Solar – PV and concurrently solar thermal Industry in Nigeria include:

(a) **Financial constraints**: A basic barrier to the development of solar energy technology in Nigeria as a developing country lies in high initial costs and long payback times.

(b) **Technological incapability**: Though the technologies for harnessing solar energy are being developed in Nigeria, most components have to be imported which further pushes the investment costs higher.

(c) **Absence of a Comprehensive National Energy Policy**: There was virtually no comprehensive energy policy in Nigeria until very recently. Only sub-sectorial policies relating to energy exist.

(d) **Low level of Public Awareness**: The level of awareness about the immense socio-economic and environmental benefits derivable from solar energy is very low in Nigeria. The current flow of information about the development, various applications, dissemination and diffusion of solar energy resource and technologies is inadequate.

5. Recommendations

For effective and efficient utilization of solar electricity in Nigeria, the following recommendations will be useful-

a) More research into the techno-economies involving the initial and subsequent costs of solar plants and their power efficiencies is encouraged.

b) Government should subsidize the cost of importation of Renewable Energy Technologies (RET) most especially solar PV to bring down the high cost in Nigeria.

c) Private individuals and organisations should be encouraged by appropriate authorities to invest in solar technologies in the country.

d) Consequently, the wide chasm between research bodies (universities, polytechnics and research institutes) and manufacturing industries must be bridged.

e) Government should create more awareness on the advantages derivable from Renewable Energy Technologies (RET) such as solar technologies.

f) Government can also consider placing restrictions on the importation of diesel and petrol engine generators because of its adverse effects on the environment even as the global community gear towards clean (green) energies.

g) Funding of solar technology researches and development initiatives in Nigerian Universities, Polytechnics and Research Institutes so as to develop solar PVs with increased efficiency that will be adaptable to our environment is advocated as is obtainable in developed countries. Such pilot schemes are seriously undertaken at the National Agency for Science and Engineering Infrastructure, NASENI, FCT Abuja and the Prototype Engineering Development Institute Ilesa, Osun State. The National Energy Research Centres at the University of Nigeria, Nsukka, the Obafemi Awolowo University, Ile-Ife and Usmanu Danfodiyo University, Sokoto, also provide a valuable source of solar radiation and other climatic information. Less consistently collected are data from some tertiary institutions nationwide, where individual energy researchers work on various energy projects.

6. Conclusions

This paper focuses on the maximization of the sun's energy supply for generating optimum power. It has presented the viabilities for power generation in Nigeria by the utilization of the sun's energy through solar-thermal or photovoltaic technologies. The basic science for the design and selection of solar components as well as panel placement and orientation were highlighted. The future of solar electricity is brighter than before. Solar energy is free- it needs no fuel and produces no waste or pollution. It is only recently that mankind turned to the large scale exploitation of new, and non renewable sources of energy and those sources have made possible the advance of industrial revolution and large increase in populations. It is clear however, that because of the finite magnitude of these sources, this phase of human development is transitory and the era of extensive dependence on finite fossil energy resources will appear as a brief episode.

REFERENCES

[1] Karlsson, S., “Closing the Technospheric Flows of Toxic Metals: Modeling Lead Losses from a Lead-Acid Battery System for Sweden., Massachusset Institute of Technology,” Journal of Industrial Ecology, Vol 3, 1999.

[2] Eastop T.D., McConkey A., “Applied Thermodynamics for Engineering Technologists.”, Fifth Edition Pearson Education (Singapore) Pte. Ltd., Indian Branch, Patparganj, India. P 697, 2002.

[3] Nasir, A., “A Technology for Helping to Alleviate the Energy Problems; Solar Energy for Cooking and Power generation.” paper presented at the 3rd annual Engineering Conference of Federal University of Technology, Minna, Nigeria, 2001.

[4] Bradley, D., “Plants point the way to renewable energy. “ New Sci.121: 8, 1995.

[5] Sambo, A.S., Renewable Energy Technology for National Development: Status, Prospects and Policy Directions”. Proceedings of the Annual General Meeting of the Nigerian Society of Engineers. Bauchi branch, Bauchi State, Nigeria, 2001.

[6] Hoff, E. and Cheney, M., “The Idea of Low Cost Photovoltaic”. Energy Journal. 93: 17, 2000.

[7] David, K., Hare, G., “Applied Solar energy.” Butterworths Litho Preparation Department.Primted by Cambridge University Press, Cambridge, England, 1983.

[8] Rochell, M.S., “The History of Solar power today.”[Online], available: http://enzinearticles.com, 2010.

[9] John W. T., Anthony D. W., “Renewable energy resources." University Press , Cambridge, England, 1987.

[10] Jonathan, G., “A brief History of Solar Power.”[Online], available: http://ezinearticles.com, 2010.

[11] Clark, A., “The history of solar energy-It is longer than you may think.”[Online] available: http://ezinearticles.com, 2010.

[12] Bala, E.J., Ojosu, J.O., and Umar, I.H., “Government Policies and Programmes on the Development of Solar PV Sub-sector in Nigeria”. Nigeria Journal of Renewable Energy. 8(1&2): 1-6, 2000.

[13] Ojo, O., “Fundamentals of Physical and Dynamic Climatology.” 1st ed., SEDEC Publ., Lagos, Nigeria, 2000.

[14] Falade, T.S., “Solving Housing Problems in Lokoja.” B.Sc. Research Report. Department of Architecture, A.B.U. Zaria, 1995.

[15] Akinbami, J.F.K., “Renewable Energy Resources and Technologies in Nigeria: Present Situation, Future Prospects and Policy Framework. Mitigation and Adaptation Strategies for Global Change, Kluwer Academic Publishers: Holland, The Netherlands, 6:155-181, 2001.

[16] Oladosu, G.A. and Adegbuluge, A.O., “Nigeria’s Energy Sector: Issues and Supply/Demand Frontiers.” Energy Policy, 22(6): 538-549, 1994.

[17] Bamiro, O.A., “Introductory Technology for Schools and Colleges.” Book 3, Evans Brothers (Nigerian Publishers) limited, 1999.

[18] Sambo, A.S., “Matching Electricity Supply with Demand in Nigeria.” International Association for Energy Economics, 2008.

[19] Iwayemi, A., “Nigeria’s Dual Energy Problems: Policy Issues and Challenges.” International Association for Energy Economics, pp 17-21, 2008.

[20] Sambo A.S., “Sustainable energy development in Nigeria”. Available at www.isesco.org, 2005.

[21] Adeyemo S.B, “Estimation of Direct solar radiation Intensities” Nigerian Society of Engineers (NSE) Technical Transactions. Vol.32, No.1. Pg 1-9, 1997.

[22] Federal Ministry of Power and Steel, “Renewable Electricity Action Program (REAP).” Published by the International Centre for Energy, Environment and Development,[Online], available: http://www.iceednigeria.org, 2006,

[23] Becker., “Solar Thermal Power Plants.” Prepared for the EUREC-Agency drafted version with status of May 03, 2000.

[24] Green, M.A., “Solar Cells Operating Principles, Technology and Systems Application.” Prentice Hall, Eaglewood Cliff, NJ, USA, 1982.

[25] Agrafiotis, C., “Solar water splitting for hydrogen production with monolithic reactors.” Solar Energy 79 (4): 409–421, 2005.

[26] Owolabi I.E., “Solar Photovoltaic power technology: Prospects and challenges for socioeconomic empowerment in Nigeria.” Technical Paper presented to the Nigerian Society of Engineers (NSE) Ado-Ekiti branch. Pg 3-5, 2008.

[27] Ogunleye, I.O., Awogbemi, O., “Constraints to the use of solar photovoltaic as a sustainable power source in Nigeria.” American Journal of Scientific and Industrial Research Vol. 2(1): 11-16, 2010.

[28] Hankins, M., “Solar Electric systems for Africa.” Commonwealth Science Council. Marlborough house, Pall mall, London, 1995.

[29] Chendo, M.A.C., “Factors Militating Against the Growth of the Solar – PV Industry in Nigeria and their Removal.” Nigeria Journal of Renewable Energy. 10(1&2):151 – 158, 2002.

[30] Sambo, A.S., “Renewable Energy Technology for National Development: Energy Crisis in Nigeria. The Way Forward.” Proceedings of the Annual General Meeting of the Nigerian Society of Engineers. Bauchi branch, Bauchi State,Nigeria. 2001.