# An Assessment of Solar Radiation Patterns for Sustainable Implementation of Solar Home Systems in Nigeria

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## Abstract

*The need for new energy infrastructure in Nigeria has long been established due to poor and unstable power supply, resulting in decrease of energy consumed when compared with African and World average. Solar Home System (SHS) is one of the sustainable renewable energy sources adequate for domestic power supply. Perhaps, it is among the best options for Nigeria especially being in the tropics where there is so much sunshine to convert to energy. This study focused on assessing the availability (measure of readiness) of the source through field survey and experiments. In this work, historical trends of solar radiation pattern of some locations were collected, studied and analysed. The annual mean of monthly global solar radiation is 22.88MJ/m$^2$/day, 18.29MJ/m$^2$/day and 17.08MJ/m$^2$/day for high, medium and low zones respectively. While 12.06 Hrs/day, 12.04 Hrs/day and 12.03 Hrs/day were found to be the solar sunshine duration for high, medium and low zones respectively. It also shows that, by tracking the length of the sunny period for a day is about 13 hour, about 1½ hour longer when no tracking is used. This would provide potentials and valuable aid for sustainable development in design and installation of photovoltaic systems in Nigeria.*

**Key words:** Radiation Pattern, Solar Home System, Sustainability, Solar tracking

## *Introduction*

Erratic power supply by Power Holding Company of Nigeria (PHCN) has given cause for concern leading to the avalanche of generating sets for household and commercial uses all over the country. The use of these generating sets is responsible for sizeable amount of air, water, soil and noise pollutions which is particularly acute in urban areas.

Therefore, in terms of infrastructure, PHCN have not fared well in the discharge of its mandate. It has an installed generating capacity of 6,000MW, with peak national demand of 30,000MW and could provide maximum of 3,000MW with losses of 30-35% during transmission (Stanley, 2008; Hall, 2006). Summary of the Nigerian Electricity Industry Scorecard for the First Half of 2008 showed a little improvement 5,567,706MWH and 3,761,794MWH during the first and second quarter respectively, with losses of 10-20% during transmission. Also, per Capita energy consumed (toe/capita) in Nigeria has been, 0.153, 0.125, 0.089, and 0.079 for 2002, 2004, 2006 and 2007 respectively. This values when compared with the 1.78 and 0.68 toe/capita for World average and Africa respectively shows great differences calling for an urgent attention (NERC, 2008; Sambo, 2009).

It has been observed that there is an abundant renewable energy source across Nigeria which makes sustainable energy technologies (SETs) viable option for the country.

Sustainable energy refers to a way of generating and using energy that is more efficient and less harmful to the environment and without compromising the ability of future generations to meet their needs. The most successful SETs programs focus on new products and techniques that have multiple benefits. Solar energy in this context refers to energy that is collected from sunlight and used for generating electricity using photovoltaic (PV) solar cells. Photovoltaic technology is the direct conversion of sunlight to electricity using semi-conductor devices called solar cells, which are almost maintenance free and seem to have a long life span. The longevity, simplicity and minimal resources used to produce electricity via PV make this a highly sustainable technology (SBTM, 1996). Solar photovoltaic applications have wider installation in Nigeria, it include solar photovoltaic water pumping systems, solar-powered vaccine refrigerators as well as telecommunication repeater stations powered by solar photovoltaic system. There are also solar photovoltaic power plants that are providing electricity to entire villages and some specific projects such as rural health cantres and television-viewing cantres (Sambo, 2001).

The solar energy striking the earth's surface at any one time depends on weather conditions, as well as location and orientation of the surface. Thus, one of the most important requirements in the design of any solar energy conversion system is the information on the intensity of solar radiation at a given location**.** Such data are required in many applications ranging from design of photovoltaic systems, solar collector system and other building science. Solar collectors harvest solar energy in the form of heat while solar PV panels harvest solar energy in the form of electricity and are manufactured with varying electrical outputs ranging from a few watts to more than 100 watts of direct current (DC) electricity. For the developing countries (such as Nigeria) where there is an acute shortage of conventional source of energy, solar radiation data is still very scarce. However, many attempts have been made to develop models that can predict the amount of solar radiation available at a given place from a few input parameters (Gulma and Bajpai, 1983, Abah and Ochagwuba, 2001; Apabio et al, 2005; NASEF, 2007; RISE, 2010)

To this effect, NERC is currently exploring the resources available for sustainable power generation in Nigeria. They estimated an annual average of daily solar radiation to vary from as high as 7KW/m$^2$/day in the northern border regions to as low as 3.5KW/m$^2$/day in the coastal regions of south, and an annual average daily sunshine hours to vary from as high as greater than 8hrs/day in the northern border regions to as low as less than 6hrs/day in the coastal regions of south. It then classified the country with respect to availability of sunshine for Solar energy in to three classes; low, medium and high region (Iloeje, 2004, NERC, 2008).

Therefore, sustainability is essential in the systems that fundamentally rely on natural sources (Concise Encyclopedia of Engineering, 2002). Sambo (2009) opined the fact that, solar home system is one of such sustainable renewable energy system; perhaps, the best for Nigeria especially being in the tropics where there is so much sunshine begging for conversion. He then called government to develop policies and strategies for continuous active support of research and development activities as well as support of demonstration and pilot projects to ensure the public awareness of the potential of the technology. Nigeria has energy resource from solar radiation as given in the Renewable Energy Master plan (REMP) Table 1.

**Table 1: Solar Radiation**

| Reserves (Natural Units) | Production Level (Natural Units) | Utilization (Natural Units) |
|---|---|---|
| 3.5 – 7.0 KWh/m$^2$/day (485.1 million MWh/day using 0.1% Nigeria land area) | Excess of 240 KWp of solar PV or 0.01 million MWh/day | Excess of 0.01 million MWph/day of solar PV |

**Source: REMP, (2005)**

Limitations exist mainly due to variation of solar radiation over one day and over a year. In the high latitude countries for example, it is not viable to apply these systems (even at the present state of a solar technology). Cloud, limited visibility and weather patterns vary and attenuate the solar radiation in traversing the atmosphere. Regions that generally have cloud-free weather, such as dry regions receive greater solar energy. Additionally, water vapour, haze, dust and other atmospheric contaminants tend to decrease the solar energy available at the earth's surface. Hence, geographical location, climate and local conditions are the most important factors that determine the possibilities of applying solar energy and other renewable methods of energy conversion (Gulma and Bajpai, 1983, Chwieduk, 2004, Akpabio et al, 2005, RISE, 2010).

The availability of more comprehensive solar radiation data is invaluable for the design and evaluation of solar based conversion systems and is not available in many places of the world, particularly the developing countries. Hence, photovoltaic modules are typically installed as arrays of modules with a fixed orientation depending on the site characteristics and cost constraints. Solar tracking is a widely-applied proven technology that increases solar park production by directing photovoltaic or concentrated photovoltaic to follow the sun along its path from dawn until dusk and so capturing the maximum solar radiation for the longest time possible. It also make a positive impact on the total gain of the whole system, causing the inverter to work as much time as possible at a better level of performance and minimise problems associated with susceptibility to dust and dirt that may cause drift in solar alignment (Gulma and Bajpai, 1983, Chwieduk, 2004, Akpabio et al, 2005, Iloeje, 2007, Li et al, 2008).

In view of the fact that, there are multiple power cuts during the day, businesses that rely on electricity become less efficient and lose profits as result of power losses. Indian government has no short-term plans rather, a small scale biogas generator was developed, and it run on different forms of biomass and serves a household in localized situation. It is reliable, cheap and sustainable alternative for electricity generation (Biogas Generator, 2008). Thus, there is a growing national and international interest in sustainability, there is also likely to be a greater focus on decoupling environmental pressures from economic growth through smatter consumption and greater resource efficiency in energy utilization, distribution and transmission management. Technology Research Institute (TRI) under the Renewable Energy Technology in Asia (RETs) installed one Battery Charging Station (BCS) and five Solar Home Systems (SHS) in a village about 30km from the nearest grid electricity. This demonstrated use and benefit of the technology among the potential users, with improvement in quality of life, children education, income generation, and awareness of the technology among the rural people (TRI, 2001). Therefore, research efforts to develop these alternative sources of energy should be intensified in the area of domestic power supply of electricity to a cluster of households and shops for both urban and rural homes in Nigeria.

NASEF (2007) outlined in its communiqué that, high initial capital investment, low public awareness, lack of appropriate institutional framework, regulatory and technical standard and local manufacturing of solar system components-solar PV panels are some of the challenges. Institutionalisation of the National Energy Policy and the Master-plans, promotion of public-private partnerships involving local and international energy institutions, donors and development partners, and strategies development of strategies for local processing/manufacturing of components; were recommended. This paper aims at exploring the need for sustainable solar home systems development and its essential requirements. Solar radiation data was considered as prerequisite to the sustainable power supply through solar energy. In addition, hypotheses tested contributed to the identification of the ingredient data for rapid advancement of the SHS. Finally, conclusions were drawn on the intentions for SHS through availability of solar radiation and design criteria.

## Research Methodology

Historical trends of solar radiation data were collected from Nigerian Metrological Agency (NIMET). The data were processed and analysed to predict the pattern of solar radiation of nine cities in Nigeria and were grouped to the three solar radiations zoning of ECN as in Table 1.

**Table 1: Solar sunshine durations and radiation of ten years long term average**

| S/N | Maiduguri 11.85$^o$ Lat. | | Yola 09.14$^o$ Lat. | | Sokoto 13.07$^o$ Lat. | |
|---|---|---|---|---|---|---|
| | Duration (hrs/day) | Radiation kWh/day | Duration (hrs/day) | Radiation kWh/day | Duration (hrs/day) | Radiation kWh/day |
| 1 | 12.08 | 7.93 | 11.47 | 7.75 | 12.11 | 4.53 |
| 2 | 12.07 | 8.12 | 11.47 | 7.53 | 12.10 | 4.64 |
| 3 | 12.06 | 8.11 | 11.48 | 8.31 | 12.08 | 4.67 |
| 4 | 12.05 | 7.94 | 11.48 | 7.33 | 12.07 | 4.64 |
| 5 | 12.04 | 7.95 | 11.48 | 7.14 | 12.10 | 4.41 |
| 6 | 12.03 | 7.40 | 11.48 | 7.72 | 12.05 | 4.91 |
| 7 | 12.03 | 6.35 | 11.49 | 6.67 | 12.03 | 5.21 |
| 8 | 12.02 | 5.10 | 11.49 | 5.64 | 12.02 | 5.85 |
| 9 | 12.01 | 5.89 | 11.49 | 6.47 | 12.01 | 5.25 |
| 10 | 12.00 | 6.60 | 11.50 | 6.97 | 12.00 | 5.34 |

| S/N | Jos 09.52$^o$ Lat. | | Zaria 11.06$^o$ Lat. | | Abuja 09.15$^o$ Lat. | |
|---|---|---|---|---|---|---|
| | Duration (hrs/day) | Radiation kWh/day | Duration (hrs/day) | Radiation kWh/day | Duration (hrs/day) | Radiation kWh/day |
| 1 | 12.10 | 5.19 | 12.10 | 5.95 | 12.07 | 4.82 |
| 2 | 12.07 | 5.31 | 12.08 | 4.80 | 12.07 | 4.89 |
| 3 | 12.06 | 5.01 | 12.07 | 5.43 | 12.06 | 4.83 |
| 4 | 12.05 | 4.32 | 12.06 | 5.12 | 12.05 | 4.43 |
| 5 | 12.04 | 4.29 | 12.05 | 4.81 | 12.04 | 4.14 |
| 6 | 12.03 | 5.06 | 12.04 | 4.62 | 12.03 | 5.16 |
| p7 | 12.06 | 5.50 | 12.03 | 5.53 | 12.02 | 5.43 |
| 8 | 12.02 | 5.59 | 12.02 | 5.86 | 12.01 | 5.43 |
| 9 | 12.01 | 5.51 | 12.01 | 5.13 | 12.01 | 4.89 |
| 10 | 12.00 | 5.32 | 12.00 | 5.82 | 12.00 | 4.45 |

**Table 1 (cont)**

| S/N | Benin 06.19$^o$ Lat. | | Ondo 07.10$^o$ Lat. | | Lagos 06.35$^o$ Lat. | |
|---|---|---|---|---|---|---|
| | Duration (hrs/day) | Radiation kWh/day | Duration (hrs/day) | Radiation kWh/day | Duration (hrs/day) | Radiation kWh/day |
| 1 | 12.05 | 5.63 | 12.06 | 4.51 | 12.05 | 3.07 |
| 2 | 12.04 | 5.35 | 12.05 | 4.22 | 12.05 | 4.69 |
| 3 | 12.04 | 5.39 | 12.05 | 4.48 | 12.04 | 4.34 |
| 4 | 12.03 | 4.99 | 12.04 | 3.88 | 12.04 | 4.35 |
| 5 | 12.03 | 5.28 | 12.02 | 4.46 | 12.03 | 3.98 |
| 6 | 12.02 | 5.34 | 12.02 | 5.12 | 12.02 | 4.71 |
| 7 | 12.02 | 5.69 | 12.02 | 4.87 | 12.02 | 5.34 |
| 8 | 12.01 | 5.38 | 12.01 | 4.36 | 12.01 | 4.36 |
| 9 | 12.00 | 4.95 | 12.01 | 4.88 | 12.00 | 3.99 |
| 10 | 12.00 | 5.50 | 12.00 | 4.47 | 12.00 | 4.72 |

Secondary data were also sourced and sorted for comparison of incident solar radiation of tracking and non tracking PV panels as in Table 2. Finally, energy conversion efficiency of a PV panel was outlined. Statistical Package for Social Sciences (SPSS) was used for the following tests in the work.

**Table 2: Solar tracking radiation and a fixed inclined module radiation (12.5$^o$) [8.30am- 5.00pm]**

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tracking (KW/m$^2$) | 0.45 | 0.55 | 0.60 | 0.70 | 0.73 | 0.75 | 0.78 | 0.83 | 0.85 | 0.85 | 0.83 | 0.78 | 0.78 | 0.68 | 0.60 | 0.53 | 0.45 | 0.30 |
| Non tracking (KW/m$^2$) | 0.26 | 0.33 | 0.40 | 0.45 | 0.56 | 0.68 | 0.73 | 0.80 | 0.83 | 0.85 | 0.80 | 0.70 | 0.66 | 0.60 | 0.50 | 0.35 | 0.28 | 0.15 |

Note: Readings at interval of 30minutes Source: Gulma and Bajpai (1983)

1. One-way analysis of variance (ANOVA) test, to test the null hypotheses that the annual average of solar sunshine duration and radiation in all the nine cities are the same. That is; $H_0: \mu_{c1} = \mu_{c2} = \mu_{c3} \ldots = \mu_{c9}$

   $H_1: \mu_{c1} \neq \mu_{c2} \neq \mu_{c3} \ldots \neq \mu_{c9}$

   Criterion: Reject the null hypotheses if $F > F_{0.05}$

2. Student t-statistics to determine whether the difference in the annual averages of solar sunshine duration and radiation of each of the three zones is comparatively significant.

   Criterion: Reject the t-test result if $t > t_{0.025}$

3. Paired sample t-statistics to determine whether the difference in the tracking module radiation and a fixed inclined module radiation is significant.

   Criterion: Reject the t-test result if $t > t_{0.025}$

## Results and Discussions

### Solar sunshine duration and radiation

Historical data collected from NIMET (Table 1) shows the solar sunshine hours/day and solar radiation (MJ/M$^2$/day) for nine cities across Nigeria for the month of January, 1971 to 1980. The solar sunshine hours/day and the radiation studied seem to be the same for almost all the cities. Therefore, the result of the ANOVA test on the solar sunshine duration (Table 1) indicates that F = 533.344 > $F_{0.05}$ and similarly Solar intensity (Table 1) indicates that F = 32.08 > $F_{0.05}$. In both cases, the null hypothesis of equality was rejected and it was concluded that there is a significant difference in the annual solar sunshine duration and radiation. The result shows that, the annual mean of monthly global solar radiation in each of the zones is 22.88MJ/m$^2$/day, 18.29MJ/m$^2$/day and 17.08MJ/m$^2$/day for high, medium and low zones respectively. While 12.06 Hrs/day, 12.04 Hrs/day and 12.03 Hrs/day were the solar sunshine duration for high, medium and low zones respectively. It is then possible to examine further the differences based on the three zoning (high, medium and low).

The difference in solar sunshine duration and radiation between the zones for the three cases high Vs medium, high VS low and medium VS low and the result of the t-tests on the level of significance of the variations are presented in Table 3. The result shows that the difference between the zones is significant in all the cases tested; therefore each zone would be treated independently in the design and installation of SHS for sustainable development.

**Table 3: Difference in solar sunshine duration and radiation between the zones**

| solar sunshine duration (hours/day) | | | |
|---|---|---|---|
| | Two-tail t-statistic result | Degree of freedom | Remark |
| High VS Medium Zone | t = 3.655 > $t_{0.025}$ | 58 | Significant |
| High VS Low Zone | t = 3.255 > $t_{0.025}$ | 56 | Significant |
| Medium VS Low Zone | t = 2.3585 > $t_{0.025}$ | 56 | Significant |
| solar sunshine radiation (MJ/m$^2$/day) | | | |
| | Two-tail t-statistic result | Degree of freedom | Remark |
| High VS Medium Zone | t = 5.308 > $t_{0.025}$ | 58 | Significant |
| High VS Low Zone | t = 6.354 > $t_{0.025}$ | 58 | Significant |
| Medium VS Low Zone | t = 2.511 > $t_{0.025}$ | 58 | Significant |

### Comparison of tracking and non tracking on incident solar radiation

Secondary data on the tracking and non tracking on incident solar radiation was sorted and analyses to determine whether the difference in the tracking module radiation and a fixed inclined module radiation is significant. The data was based on the use of Metrosol measuring instrument that record the maximum reading of solar energy density. (See Table 2). The result shows that the difference in the tracking module radiation and a fixed inclined module radiation is significant based on the paired sample test with t = 6.145 > $t_{0.025}$. Results shows that by tracking, some solar radiation could be measured almost 100% above either in the morning or late in the evening as in Appendix 2. However, by tracking the length of the sunny period for a day is about 13 hour which is about 1½ hour longer than that when no tracking is used. The energy conversion efficiency of the PV module used was also measured to be 10.2 % and is quite normal for the type of silicon cells used in the module. The efficiency depends to a great extent on the manufacturing process, materials used and the spectral distribution of the incident solar radiation (Gulma and Bajpai, 1983).

## Conclusions

The present source systems and level of electrical energy generation and supply in Nigeria are in adequate and have created the need for a search into new ones. Renewable energy technologies, solar energy in particular, are favorable alternatives/complements by reason of availability of abundant resources (e.g sunshine) in the country.

Sunshine Duration and solar radiation data from selected cities in Nigeria show that zoning is necessary in the country for efficient design and installation of SHS and other PV system application. Solar tracking is also necessary for good performance of the systems despite cost constrain. Further studies should address:

I. Reliable way for predicting monthly solar radiation.
II. Development of design and implementation criteria for sustainable SHS application in Nigeria.

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