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The Impact of Climate Change on Solar Radiation and Energy in Some Parts of Oyo State, South West, Nigeria

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Abstract - This study was carried out to investigate the impact of climate change on solar radiation and energy in South West Nigeria, using 10 years meteorological data of Ibadan (longitude 3.9° E, latitude 7.43° N), Iseyin (longitude 3.6 ° E, latitude 7.97° N) and Shaki (longitude 3.47° E, latitude 8.35° N) as a case study. Both the monthly and annual mean data for the three locations were analyzed statistically using excel spreadsheet and SPSS software. The analyses used to investigate the impact of climate change on solar radiation and energy includes trend, scenario, correlation, regression, comparative and impact analysis. The study suggests that when designing solar PV systems for these areas, at least 8%, 15% and 25% reduction in projected Solar PV output (for Ibadan, Iseyin and Shaki respectively) should be considered in addition to the usual provisions in designing such systems to provide for the future impact of climate change on the solar radiation and Solar PV output.

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1 INTRODUCTION

Solar radiation is presently considered by many energy experts as the world's most promising and prized source of alternative energy due to its abundance. Despite the huge potential in solar energy its effective utilization and cost competitiveness is threatened by climate change which is a global phenomenon. In recent years, there has been an increased concern related to the magnitude and the way in which climate change may impact the performance of existing and future energy production systems (IPCC, 2001).

The on-going climate change and its associated global warming are expected to cause distinctive climate patterns in different climatic zones, which will impact negatively on the ecosystem (Mshelia, 2005; Hengeveld et al., 2005; Ayuba, et al., 2007). The current available pieces of evidence show that Nigeria, like most parts of the world, is experiencing the basic features of climate change (Odjugo, 2010) which has resulted in variation in climate parameters.

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Renewable energy has a negligible effect on climate change, whereas climate change can have a serious effect on renewable energy technologies (Contreras-Lisperguer and de Cuba, 2008). Solar energy technology depends on meteorological and climatic variables such as temperature, humidity, cloudiness and solar radiation which tend to be very vulnerable to climate change and variability (Audun et al, 2006). Depending on the specific location and time of installation, changes in these meteorological and climatic variables may determine the viability of a specific solar energy projects, hence there is a need to determine the pattern or trend at which the variations occur in the past years for us to be able to ascertain the level of impact of climate change on the solar radiation and energy production in Nigeria.

Climate change can affect solar energy production in two major ways; (i) impact of the variation in climate parameters on solar radiation which is the most critical solar resource and major input in the solar energy production (ii) the impact of variation in climate parameters on the efficiency of solar cell.

Buonassisi (2008) also stated that atmospheric effects have several impacts on the solar radiation at the Earth's surface such as following;

- A reduction in the power of the solar radiation due to absorption, scattering and reflection in the atmosphere.

- A change in the spectral content of the solar radiation due to greater absorption or scattering of some wavelengths;
- The introduction of a diffuse or indirect component into the solar radiation.
- Local variations in the atmosphere (such as water vapor, clouds and pollution) which have additional effects on the incident power, spectrum and directionality.

Climate change can affect the performance of a solar cell in two main ways. Firstly, the current delivered by a solar cell is very dependent on the irradiance of the incoming sunlight. Secondly, solar cells are very sensitive to any changes in the temperature. These changes can either be caused by changes in the overall ambient temperature, the irradiance or in the amount of wind cooling the solar panel. (Audun Fidje. et al, 2006).

2 MATERIALS AND METHOD

Several research works on solar energy and its utilization have been done using simulations or models derived from various statistical analysis methods. This may be attributed to the fact that the output of solar energy system is site specific and data sensitive. Severally empirical formulae for predicting global solar radiation as a function of one or two readily measured climatic data have been derived (Bamiro, 1983; Fagbenle, 1992; Iqbal, 1983; Sayigh, 1977; Klien, 1977). The first empirical correlation using the idea of employing sunshine hours for the estimation of global solar radiation was proposed by Angstrom (1924) and Prescott and Page (1940) modified this correlation (Ahmad and Ulfat, 2004). Model 1 and 2 were derived by Bamiro (1983) and Fagbenle (1992) respectively were using statistical analysis.

$$H = K [C_o + C_1 T (n/N) + C_2 (RH)^{1/2} + C_3 (RH) T^{1/2}/K + C_4 (RH) (n/N)/K] \quad (1)$$

$$H/H_O = 0281+0.490 (n/N) - 0.188 (n/N)^2 \quad (2)$$

Where
H is the monthly mean daily global radiation falling on a horizontal surface (MJ/m^{2}day).
Ho = monthly mean daily extraterrestrial radiation on a horizontal surface at the same latitude (MJ/m^{2}day).
n = monthly mean daily hours of observed bright sunshine hours per day.
N = monthly mean daily hours per day of daylight between sunrise and sunset. The ratio n/N is often termed the percentage possible sunshine, or the relative sunshine.
T = mean temperature.
K = latitude and altitude factor as defined in the Reddy (1971) model.
C_o, C_1, C_2, C_3, and C_4 are regression coefficients determined for eight different 'seasons' of the year while the coefficients in model 2 are also climatologically determined regression coefficient.

In the recent times Wan (2008) and Chen et al (2006) correlate global solar radiation and sunshine hours to investigate the impacts of different climate on solar radiation modeling in China. Therefore it is suitable to use statistical analysis to investigate the impact of climate change on solar radiation and energy using available measured data for the selected locations.

The major data used for this work was collected from Ibadan office of Nigerian Meteorological Agency (NIMET), Federal Ministry of Aviation. To use the global solar radiation data collected from NIMET, Ibadan which was measured and recorded in (MJm^{-2} day^{-1}), it was converted to (Kwhm^{-2} day^{-1}) by dividing the measured values by 3.6 which is a factor proposed by Iqbal (1983) for such conversion. Monthly mean of data collected was computed for the ten year period and annual mean of data was computed for each year within the period except for rainfall where cumulative for each year was computed. These were the final figures used for statistical analysis, using excel for the graphical analysis and SPSS software for regression and correlation analysis. The analyses used to investigate the impact of climate change on solar radiation and energy includes trend, scenario, correlation, regression, comparative and impact analysis

The possible impacts of climate parameters on solar energy outputs was assessed by examining the impacts of variations in the parameters on the efficiency of solar panel. This was analyzed by a scenario analysis using specification of 135Kw$_p$ Kyocera Solar Panel. Audun Fidje, et al, (2006) stated that a 2% reduction in global solar radiation will reduce solar PV cell output by 6%. Going by this, the impact of climate change on the solar PV cell output was estimated.

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Fig. 1. The map of Nigeria showing location of Oyo state and the relative position of Ibadan, Iseyin and Shaki

3 RESULTS AND DISCUSSION

The trend analysis of the variations in climate parameters as shown in Figure 3a- 3d for the three locations followed the same trends; seasonal variations in monthly mean data, decreasing annual global solar radiation, increasing annual air temperature, rainfall, humidity and decreasing annual sunshine hours in all the three locations.

Scenario analysis showed a declining trend in annual energy output within the period while the impact analysis showed that the impact of climate change on the solar radiation resulted in the reduction in the output of Solar PV cell by 7.7%, 14.49% and 24.69% for Ibadan, Iseyin and Shaki respectively within the period investigated.

It was observed that the values for monthly mean global solar Radiation for different locations during the period under examination were relatively lowest for all the locations the same month relative humidity was the highest, sunshine hour the lowest, temperature the lowest and rainfall very high. This was month of August.

The regression analysis models as shown in table 3.1 are consistent with the trend and comparative analysis carried out.

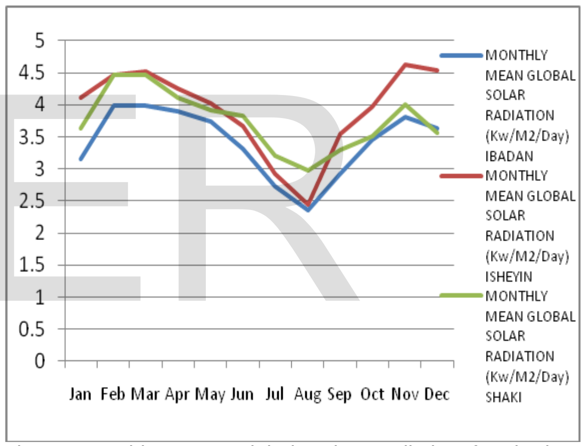

Fig. 2. Monthly Mean Global Solar Radiation for Ibadan, Iseyin and Shaki (2002-2011)

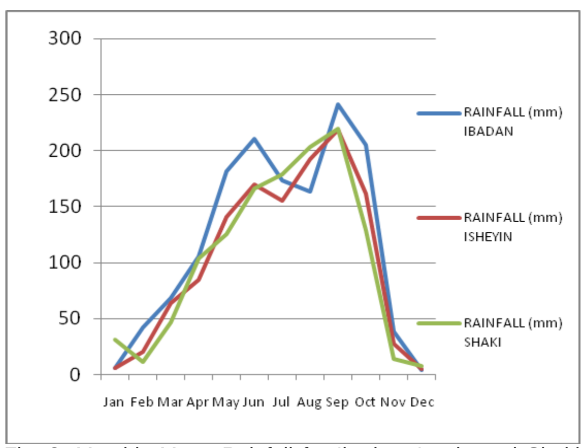

Fig. 3: Monthly Mean Rainfall for Ibadan, Iseyin and Shaki (2002-2011)

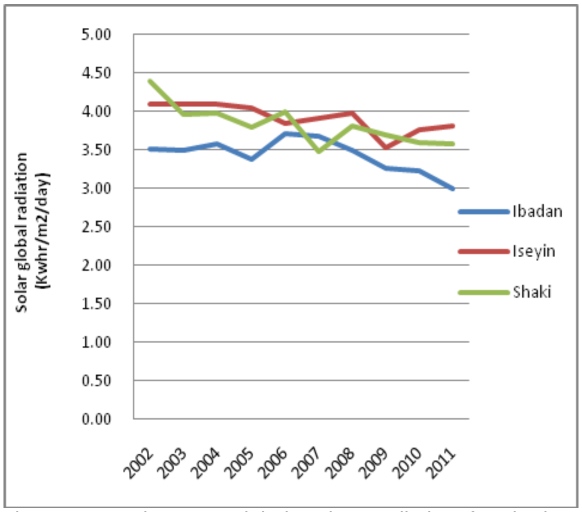

Fig. 4. Annual Mean Global Solar Radiation for Ibadan, Iseyin and Shaki (2002-2011)

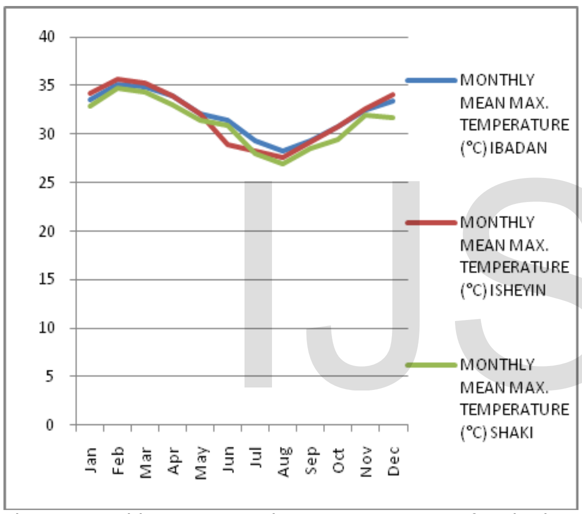

Fig. 5. Monthly Mean Maximum Temperature for Ibadan, Iseyin and Shaki (2002-2011)

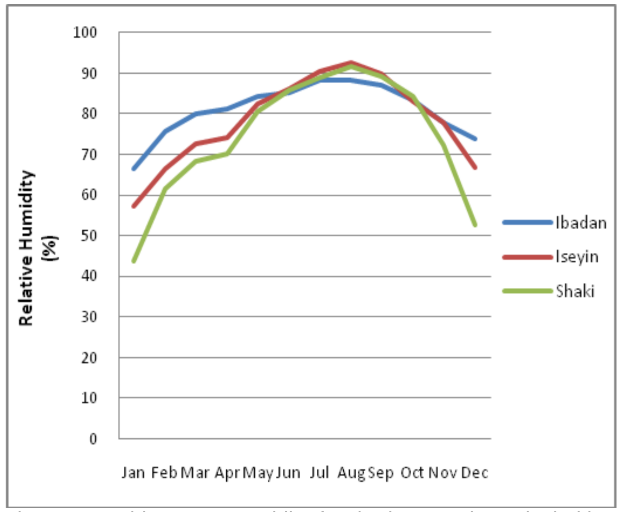

Fig. 7. Monthly Mean Humidity for Ibadan, Iseyin and Shaki (2002-2011)

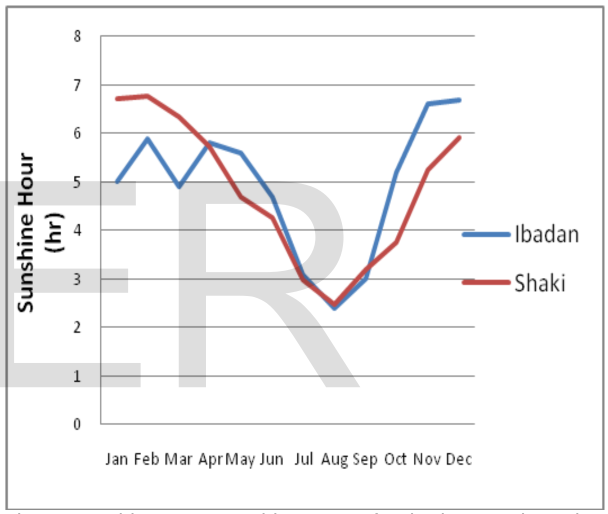

Fig. 6. Monthly Mean Sunshine Hours for Ibadan, Iseyin and Shaki (2002-2011)

FINDINGS

1. The climate change impacts resulted in significant annual and monthly variations in meteorological parameters that are fundamental to solar radiation and efficiency of solar energy production in the locations examined.
2. The seasonal variations and annual trends in the climate parameters differ from one location or the other hence solar energy system design must be site specific.
3. The variations in climate parameters; Air Temperature and Sunshine hours have a direct and statistically significant impact on the solar radiation which directly determines energy output.
4. The variations in climate parameters; Rainfall and Humidity have a direct and statistically significant impact on temperature and sunshine hours which in turn affect the solar radiation data.
5. Very significant reduction in sunshine hour is observed during the analysis of collected data.
6. The major impact of climate change on solar radiation is an annual decreasing trend and seasonal variation in its value over the time.
7. The impact of climate change on the solar radiation resulted in the reduction in the output of Solar PV cell by 7.7%, 14.49% and

24.69% for Ibadan, Iseyin and Shaki respectively.

8. If the climate issues remain the way it is now such that climate change is not curbed the decreasing trend and seasonal variation in solar radiation will continue.

TABLE 1

MINIMUM AND MAXIMUM GLOBAL SOLAR RADIATION FOR THE 3 LOCATIONS WITHIN THE PERIOD

Location	Maximum Monthly Mean Global Solar Radiation ($Kwhr/m^2/day$)	Month Maximum Solar Global Radiation Occurred	Minimum Monthly Mean Global Solar Radiation ($Kwhr/m^2/day$)	Month Minimum Solar Global Radiation occurred
Ibadan	3.98	November	2.36	August
Iseyin	4.61	March	2.45	August
Shaki	4.47	March	2.98	August

TABLE 2
REGRESSION ANALYSIS OF MONTHLY MEAN CLIMATE PARAMETERS MEASURED AT IBADAN, ISEYIN AND SHAKI

Term	Result	Interpretation
R-Square	Ibadan = 0.973 Iseyin = 0.789 Shaki = 0.977	The results for the three locations suggests a positive relationship among the dependent variable (Global Solar Radiation) and Independent variables (Sunshine Hour, Temperature, Rainfall and Humidity) when considered together.
Adjusted R-Square	Ibadan 0.957 Iseyin 0.710 Shaki 0.963	It shows that 95.7% and 96.3% of total change in the dependent variable (Global Solar Radiation) can be attributed to variation in the independent variables (Temperature, Rainfall, Humidity and Sunshine Hours) in the case of Ibadan and Iseyin respectively. For Iseyin 71% of total change in the dependent variable (Global Solar Radiation) can be attributed to variation in the independent variable (Temperature, Rainfall and Humidity)
F-Statistics	Ibadan 61.889 Iseyin 9.986 Shaki 68.0634	At value 61.889, 9.986 and 68.0634, p values are less than 0.05 .This shows that the regression **model 1, 2 and 3** are statistically significant. Variation in Solar Radiation can reliably be predicted by variation in the independent variables as contained in the models.
Models	$G = -6.758 + 0.197\,T + 0.001\,R + 0.033\,H + 0.216\,S$ (3) $G = -5.010 + 0.239\,T - 0.001R + 0.19\,H$ (4) $G = -4.851 + 0.228\,T - 0.01\,R + 0.2\,H + 0.026\,S$ (5)	

Where G= Monthly Mean Global Solar Radiation, T=Temperature, R=Rainfall, H= Humidity, S= Sunshine

TABLE 3

THE AVERAGE ANNUAL CHANGE IN METEOROLOGICAL DATA WITHIN THE PERIOD UNDER INVESTIGATION (2002-2011)

Parameter	Ibadan	Iseyin	Shaki
Global Solar Radiation	-2.59%	-4.83%	-8.23%
Sunshine	-17.52%	-	-8.65%
Rainfall	16.04%	26.05%	13.06%
Temperature	1.06%	-1.50%	8.41%
Humidity	4.95%	10.16%	2.15%

TABLE 4
PERCENTAGE REDUCTION IN THE PV CELL OUTPUT FOR THE THREE LOCATIONS

Parameter	Ibadan	Iseyin	Shaki
% Average Change in Global Solar Radiation	-2.59%	-4.83%	-8.23%
% Reduction in the PV Cell output	-7.77%	-14.49%	-24.69%

4 CONCLUSIONS AND RECOMMENDATIONS

- The study shows that Global Solar Radiation will continue to decrease in value annually if the trend in climate change continues. The implication of this is that the efficiency of a Solar PV system will also have a declining trend except an adequate provision is made to accommodate the annual reduction in Global Solar Radiation.

- This research also concluded that the likely impacts of climate change on the energy output of Solar PV cell within the period under review were reduction by 7.77%, 14.49% and 24.69% for Ibadan, Iseyin and Shaki respectively, therefore if the trend of climate change continues efficiency of Solar panels will also be declining by the year hence need to put climate change factor into consideration in addition to other provision presently made in the design of Solar PV system especially in the south west where the research was conducted.

The study recommends as follows:

- Using the similar methodology and approach adopted in this project to assess the impact of climate change on solar radiation and energy, projected future climate parameters for a longer period (e.g 2000- 2100) should be used to replace the old data used in this research to project likely future impacts.

- In designing solar PV systems a factor due to possible impact of climate change, in percentage should be put into consideration in addition to the current provisions usually considered.

- For the sites examined in this study at least 8%, 15% and 25% reduction in projected Solar PV output (for Ibadan, Iseyin and Shaki respectively) due to the impact of climate change is recommended when designing solar PV system for these areas.
- As suggested by Contreras-Lisperguer and Cuba (2008) solar energy modeling tools that integrate climate change factors should be utilized in project design, appraisal and implementation.

- The research into nanotechnology to increase the efficiency and cost effectiveness of solar energy solutions especially in the areas of solar panel production and energy storage should be intensified to make up for the impacts of climate change of the reduction of solar PV system efficiency.

- It is also recommended that a similar study should be carried out to evaluate the impact of climate change on other renewable energy resources such as wind and water in various locations in the country.

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