GSJ: Volume 11, Issue 7, July 2023, Online: ISSN 2320-9186

www.globalscientificjournal.com

The relative comparison of different Models used for determining PV tilt angle in Anambra and Enugu state- Nigeria

G. E. Orizu[1], P. E. Ugwuoke[2], I. Humphrey[3], N. I. Obot[3], and S. U. Offiah[4]

[1]Department of Physics and Industrial Physics Nnamdi Azikiwe University, Awka, Anambra State, Nigeria (ge.orizu@unizik.edu.ng).

[2]University of Nigeria, Nsukka, Enugu State, Nigeria (paulinus.ugwuoke@unn.edu.ng, rita.akwolu@unn.edu.ng)

[3]Department of Physics, University of Lagos, Akoka, Lagos State, Nigeria

(ihumphrey@unilag.edu.ng, nobot@unilag.edu.ng).

[4]National Centre for Energy Research and Development, University of Nigeria Nsukka (offiahsolomon@gmail.com)

ABSTRACT

This study compared the seasonal-based isotropic and anisotropic models for mounting a solar panel in Anambra and Enugu State, both in South-Eastern Nigeria. The calculations were based on the monthly mean daily global solar radiation data of 10 years (January 2005 to December 2014). The annual optimum tilt angles for Anambra State (6°08'24"N, 6°46'48"E) and Enugu State (6°27'35.87"N, 7°32'56.22"E) were 11.9929° and 11.8053° respectively. When considering the seasonal-based optimum tilt angle for Anambra – making use of an isotropic model, the angle for the dry season was 21.8610° while that the rainy season was zero (0) degree. Again, making use of anisotropic model, the optimum tilt angle for the dry season gave 26.1110° while that of the rainy season still remained zero degrees. Similarly, making use of the isotropic model for Enugu, the optimum tilt angles for dry season and rainy season were 21.5090° and zero (0) degrees respectively. Whereas the anisotropic model gave 25.7120° for dry season and zero (0) degrees for the rainy season. All the correlation coefficients obtained by comparing isotropic models with anisotropic models were greater than 0.9, indicating a strong correlation between the models. As a result, there is no significant difference in the energy/Optimum tilt angle generated using any of the models. The percentage loss in the amount of annually collected energy using the isotropic model instead of the anisotropic model was 0.4557%. The prediction with the Badescu model less agreed with those of other models in both states.

Keywords*: Optimum tilt angle; zero degrees (horizontal placement); rainy season and dry season; Nigeria South Eastern States; Isotropic and Anisotropic Model.*

1. Introduction

A solar collector is a device that can be used to collect solar energy from the sun. Depending on how the system is designed, a collector can be a flat plate collector or photovoltaic (PV) panel. While a flat plate collector converts solar energy to thermal energy, a PV panel converts radiant energy from the sun to electrical energy. Nevertheless, the high cost of a PV system has made it challenging to use by an average household. Present research tends toward reducing the cost of producing solar panel or reducing the number of panels required for a project. To achieve the latter, we maximize the solar energy received by a panel and increase the panel power output.

A PV panel will perform optimally when the modules are perpendicular to the sunlight; the total solar power received by the surface is approximately equal to global solar radiation from the sun. The total extraterrestrial radiation from the sun is said to be equal to 1367 x $(R_{av} / R)^2$ W/m^2 (Duffie and Beckman, 2006). The position of the sun, as viewed from the Earth between 15^{o}N and 35^{o}N, is the region with the most solar energy (Keyhani, 2011). Since the position of the sun in the sky is always changing, the angle between a fixed panel and the sun changes as well. Conversely, the total solar power received by a fixed panel is not equal to that emitted by the sun. However, the total solar radiation received on a flat surface depends on some factors: the latitude of the site in question, the clearness index, the tilt angle of the surface, the day of the year, and the time of the day. Among all these factors, the only one we have control over is the tilt angle. Getting the optimum tilt angle for a site will result in the maximum power output of the panel. To do this, one should know the intensity of radiation falling upon the sloping surface and its variation over a period of a year (Tiwari and Ahmad, 2009)**.** The available solar radiation mostly within our reach is that of horizontal surfaces. The direct radiation on a horizontal surface is equal to the direct normal irradiance multiplied by the cosine of the zenith angle (Liu and Jordan, 1962). That of tilted surfaces can only be estimated using different models from the corresponding horizontal surfaces whereas the solar radiation on tilted surfaces is composed of direct (beam) radiation, diffused radiation, and ground-reflected radiation. The ground albedo value of 0.2 for poor reflecting surfaces like hot and humid tropical regions, 0.5 for dry tropical regions, and 0.9 value for highly reflecting surfaces like snow areas was assumed by Muneer, (2004).

In most existing studies, all the models use the same methods for calculating beam and ground reflected radiation, but different methods for diffuse radiation. While some models assume diffuse radiation to be the same in all directions over the sky dome (isotropic model), others see it as anisotropically distributed around the circumsolar region, and isotropically distributed from the rest of the sky dome (anisotropic model). Chiou and El-Naggar (1986) gave a method to calculate the optimum tilt angle of an equator-facing collector in the heating seasons. Kern and Harris (1975) calculated the optimum tilt angle for an equator-facing collector based on only beam radiation and concluded that the best angle is the latitude of the site**.** Nijmeh and Mamlook (2000) compared one isotropic model with an anisotropic model for estimating monthly mean hourly total radiation on tilted surfaces for Amman, Jordan and concluded that both isotropic and anisotropic models are equally accurate. Hay (1979) used the bright sunshine hours and surface albedo as the only required input data to calculate the monthly mean solar radiation for horizontal and inclined surfaces in Canada. His result showed that, despite the use of a daily time interval, the solar radiation incident on both horizontal and south-facing surfaces might be calculated with an accuracy generally associated with instrumental measurements. Ma and Iqbal (1983) tested the models of Liu and Jordan (1962) (isotropic model), Hay (1979), and Klucher (1979) (anisotropic models) and compared the results obtained from the three models with measurements from Canada. The Canadian results showed that Klucher (1979) and Hay (1979) models are more accurate than the isotropic model of Liu and Jordan**.** The selection of Liu and Jordan Model might be useful for the prediction of solar energy irradiance on a tilted surface in the tropical region, where the weather is mostly cloudy (Jakhrani *et al.*, 2012). Udoakah and Okpura (2015) determined the optimum tilt angle for a panel mounted in Enugu (latitude $6^{o}40'55.3''$N and Longitude $7^{o}27'42.42''$E), south Eastern Nigeria to be 6^{o} making use of estimated solar radiation instead of measured radiation. Their study did not consider seasonal optimum tilt angle for the state. Gulin *et al.*, (2013) used major inputs data of (i) solar irradiance components-direct (normal), diffuse (horizontal), ground reflected and/or global (horizontal) solar irradiance, (ii) sun position on the sky dome, (i.e., solar zenith and azimuth angles), and (iii) tilted surface orientation angles, (i.e., tilted surface tilt and azimuth angles). With these, they yield the model output which is the global solar irradiance incident with the tilted surface and verify the three neural network models used in predicting the global solar irradiance on a tilted surface.

Shukla et al. (2015) compared the isotropic and anisotropic models and concluded in their work at Bhopal India that Badescu model (BA) gives a closer result to the measured value when compared to other isotropic and anisotropic models for the estimation of solar radiation on tilted surface in Bhopal. Aggarwal (2012) estimated the hourly total solar radiation on a tilted surface at different orientation in Delhi, Indian and compared the values with 15 years measured data of Delhi. He concluded that hourly total solar radiation can be estimated using correction factor without applying any meteorological parameters for the location having longitude range of ±70 to ±125.

David-Okoro *et al.* (2009) estimated the annual optimum tilt angle over tilted surfaces in Lagos to be 12°, using the method of photovoltaic geographical information system (PVGIS). Orizu *et al.* (2017) determined the annual optimum tilt angle for mounting a solar panel at Onitsha to be 12.74°, the seasonal optimal tilt angle to be 25.5° and 0° for dry season and wet season respectively combining both isotropic and anisotropic models.

Hanif *et al.* (2012) varied the tilt angles of various PV systems at different temperatures and discovered that at a low temperature of 15℃ and a tilt angle of 35° which is the latitude of the study area, the maximum power was achieved. In the northern hemisphere, the panel is optimal when facing south (Tiwari and Ahmad, 2009). El-Sebaii *et al.* (2010), in their study, stated that a solar panel not only will be tilted to face south if in the northern hemisphere but must be to the latitude angle of the location. Boxwell (2012) assumed a $90 - \phi - 15.6$ formula for calculating the optimum tilt angle if more energy is needed during the dry season and $90 - \phi + 15.6$ for the rainy season. Kamali *et al.* (2006) compared the results of eight widely used models for estimating solar radiation on tilted surfaces with measurements from Karaj, Iran, for south and west-facing surfaces inclined at angles 45° and 40°, respectively. Tiwari and Ahmad (2009) concluded that monthly based and seasonal based optimum tilt is different for different stations, while the annual based optimum tilt is approximately equal to the latitude of the station. Kamali *et al.* (2006) concluded that Reindl *et al.* (1990) model has the best agreement with the measured tilted data. Bugaje (2006) stated that we could meet the country's total energy demand if only 0.1% of the total solar radiant in the country is converted to electricity using suitable solar technology at an efficiency of 1%. Augustine and Nnabuchi (2009) stated that Nigeria has an average of 1.804 x 1015 KWh of incident solar energy annually based on Nigeria land area of 924 x 10^3 km^2 and an average of 5.535kwh/m^2/day.

2. Materials and Method

2.1. Data Evaluation and Analysis

The horizontal radiation data used for Enugu and Anambra states in Nigeria were obtained from the Nigerian Meteorological Agency, Abuja, for ten years (January 2005 – December 2014). The data were analysed by calculating the monthly average from the daily average. The total global solar radiation is made of direct, diffuse, and ground reflected solar radiations. Several models can be used for calculating solar radiation on tilted surfaces; all the models settle with the beam and reflected radiation while differing somewhat on diffused radiation.

Whereas some see it as isotropic, others see it as being anisotropic. To calculate the solar radiation on tilted surface, the following equations were used:

$$\hat{H}_T = \hat{H}_B + \hat{H}_D + \hat{H}_R \quad (1)$$

Miguel *et al.,* (2001) model was used to estimate the monthly average daily beam and diffused components on a horizontal surface from the measured monthly average daily global radiation as shown below.

$$\frac{\mathrm{Hd}}{\mathrm{H}} = 0.952 \qquad \text{If } K_T = 0.13$$

$$\frac{\mathrm{Hd}}{\mathrm{H}} = 0.868 + 1.335K_T - 5.782{K_T}^2 + 3.721{K_T}^3 \qquad \text{if } 0.13 < K_T \le 0.80 \quad (2)$$

$$\frac{\mathrm{Hd}}{\mathrm{H}} = 0.141 \qquad \text{If } K_T > 0.8$$

Where K_T ranges from 0 to 1. The value approaches 1 when the cloud is very clear in the noon day and tend to 0 (zero) when is totally dark.

H_b can be calculated as follows

$$H_b = H - H_d \quad (3)$$

The monthly average daily beam radiation received on a tilted surface can be expressed as

$$\hat{H}_B = (H - H_d)\hat{R}_b = H_b\hat{R}_b \quad (4)$$

For surfaces in the northern hemisphere sloped towards the equator, $\hat{R}_b$ is given by Liu and Jordan (1962) as

$$\hat{R}_b = \frac{\mathrm{Cos}(\emptyset-\beta)\mathrm{Cos}\delta\ \mathrm{Sin}\omega s + \left(\frac{\pi}{180}\right)\omega s\ \mathrm{Sin}(\emptyset-\beta)\mathrm{Sin}\delta}{\mathrm{Cos}\emptyset\ \mathrm{Cos}\delta\ \mathrm{Sin}\omega s + \left(\frac{\pi}{180}\right)\omega s\ \mathrm{Sin}\,\emptyset\ Sin\delta} \quad (5)$$

Where

$$\omega_s = \min\{\cos^{-1}(-\tan\emptyset\tan\delta), \cos^{-1}[-\tan(\emptyset-\beta)\tan\delta] \quad (6)$$

"min" means the smaller of the two terms in the bracket.

$$\delta = 23.45\sin\left[\frac{360}{365}(284 + n)\right]\ in\ degress \quad (7)$$

Where the value of n used is that of the middle of the month.

Assuming isotropic reflection, the daily ground reflected radiation is written as

$$\hat{H}_R = \hat{H}\rho\,(1 - cos\beta)/2 \quad (8)$$

Where ρ has a value of 0.2.

The sky-diffuse radiation on a tilted surface is

$$\hat{H}_d = H_d \hat{R}_d \tag{9}$$

To evaluate $\hat{R}_d$, the isotropic models used were Liu and Jordan (1962), Koronakis (1986) and Badescu (2002), while the anisotropic models were Hay (1979), Reindl *et al.*, (1990) and Skartvetit and Olseth (1986). Table 1 shows the mathematical arrangement for these models.

Table 1

List of isotropic and anisotropic models used in determination of optimum tilt angle.

Equation number	Model	Year	Abbreviation	$\hat{R}_d$
10.	Liu and Jordan	1962	*L&J*	$=\frac{1+cos\beta}{2}$
11.	Koronakis	1986	*Kn*	$=\frac{2+cos\beta}{3}$
12.	Badescu	2002	BA	$=\frac{3+cos2\beta}{4}$
13.	Hay	1979	*Ha*	$=\frac{\hat{H}_b}{\hat{H}_o}\hat{R}_b+\left(1-\frac{\hat{H}_b}{\hat{H}_o}\right)\left[\frac{(1+cos\beta)}{2}\right]$
14.	Skartvetit and Olseth	1986	*S&O*	$=\frac{\hat{H}_b}{\hat{H}_o}\hat{R}_b+\Omega cos\beta+\left(1-\frac{\hat{H}_b}{\hat{H}_o}-\Omega\right)\left[\frac{(1+cos\beta)}{2}\right]$ Where $\Omega=\left\{max\left[0,\left(0.3-2\frac{\hat{H}_b}{\hat{H}_o}\right)\right]\right\}$
15.	Reindl *et al.,*	1990	*Re*	$=\frac{\hat{H}_b}{\hat{H}_o}\hat{R}_b+\left(1-\frac{\hat{H}_b}{\hat{H}_o}\right)\left[\frac{(1+cos\beta)}{2}\right]\left[1+\sqrt{\frac{\hat{H}_b}{\hat{H}}}sin^3\left(\frac{\beta}{2}\right)\right]$

The total global solar radiation on a tilted surface is then,

$$\hat{H}_T = (H - H_d)R_b + H\rho(1 - cos\beta)/2 + H_d R_d \tag{16}$$

Equations 1 to 16 with the values of $\hat{R}_d$ in Table 1 were used to determine the total global solar radiation for each model on various tilt angles for every month. A second-order polynomial equation was developed to fit the curves generated. However, the turning point of the curve gives the maximum solar radiation with the corresponding tilt angle for the month (optimum tilt angle). Thus, the optimum tilt angle for each month was computed for each isotropic and anisotropic model. The average result of optimum tilt angle for each month of the year was calculated for both the isotropic and anisotropic model, and the graph plotted and compared. In addition, the seasonal optimal based tilt angle was calculated for both isotropic and anisotropic models by finding the average value of the tilt angles for each season (dry and wet seasons). The annual based optimal tilt angle for both isotropic and anisotropic models was as well calculated by finding the average value of the tilt angles for all months of the year. In the end, a statistical method was used to compare each model with the other.

The general polynomial equation for different models is

$$Y = AX^2 + BX + C \tag{17}$$

Where A, B and C assumed different values for different models at different months of the year.

Y = Global solar radiation

X = Tilt angle

2.2. Statistical Measure

The results of different models used in determination of optimum tilt angles were evaluated making use of correlation coefficient to determine how each of the models relates with one another and with the expected average results of isotropic and anisotropic models.

The correlation coefficient, R was used to measure the strength and direction of relationship between a model's predicted values with the others and the expected values. R is expressed as:

$$R = \frac{n\sum H.H_p - (\sum H)(H_p)}{\left(\sqrt{n(\sum H)^2 - (\sum H)^2}\ \sqrt{n\left(\sum H_p\right)^2 - \left(\sum H_p\right)^2}\right)} \tag{18}$$

Where H_p =predicted value

H = Expected values

n = number of observations

The value of R can range between -1 and +1. The values equal to minus one (-1) indicates a negative correlation, while a value of R equal to plus one (+1) indicates a perfect positive correlation. The value of R equal zero (0) or near zero indicates there is no or very little correlation between the two variables. The correlation coefficient value of 0.9 and above is considered a very strong positive correlation between the two variables.

3. Results and Discussion

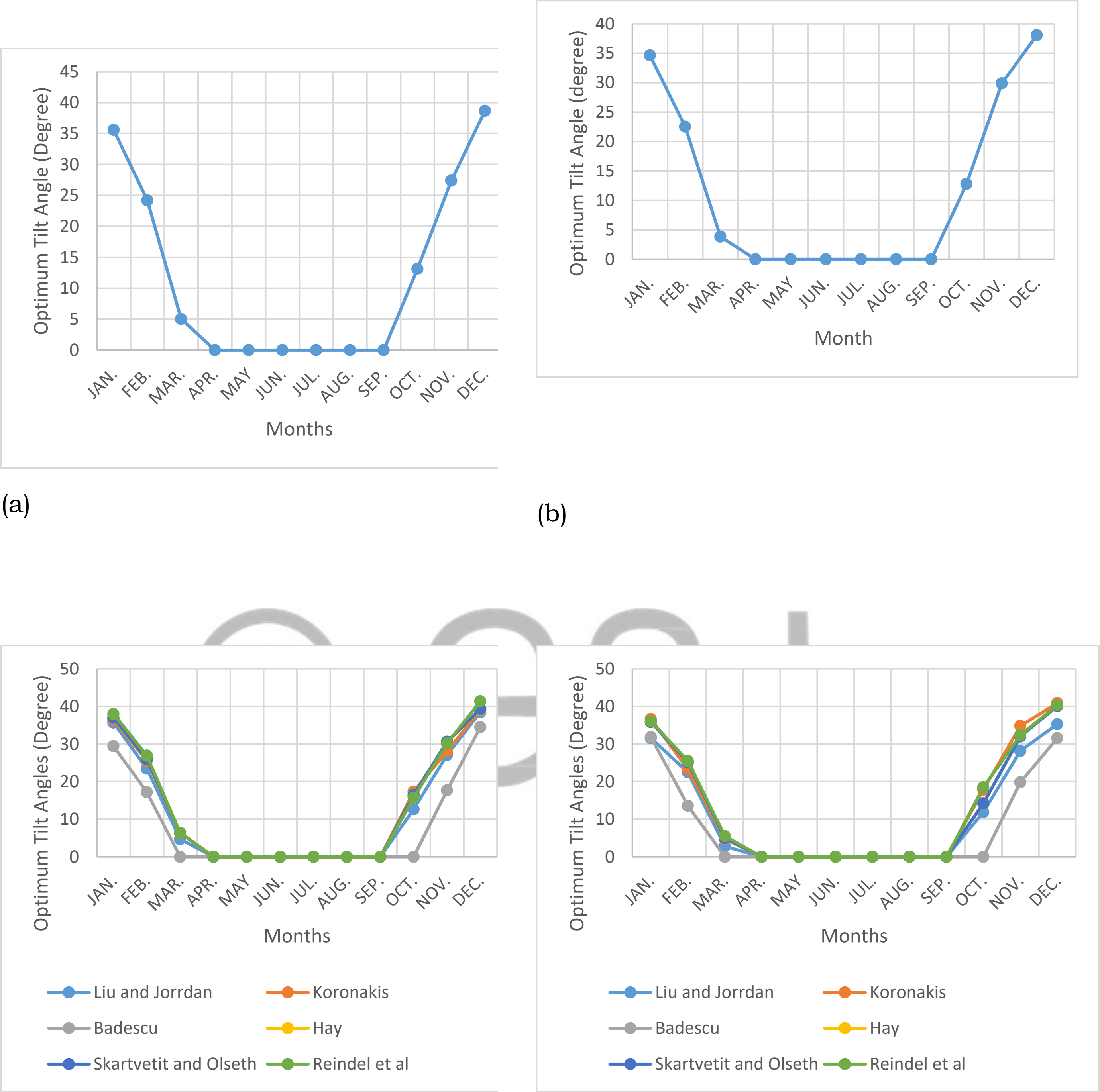
3.1. Monthly and annual optimum tilt angle

The monthly and annual optimum tilt angle was analysed making use of Table 2 and Fig. 1. The said Figure helped to compare the optimum tilt angle of a model with another.

Table 2

Summary of the Optimum Tilt Angles and Maximum Global Solar Radiation for (both models combined together) each month.

Month	Average Optimum Tilt Angle for all the models in Anambra, β_{opt} (°)	Average Optimum Tilt Angle for all the models in Enugu, β_{opt} (°)	Average Maximum Global, Solar Radiaton, for all the models H_{Tmax} in Anambra (KWh/m^2/day)	Average Maximum Global, Solar Radiaton, for all the models H_{Tmax} in Enugu (KWh/m^2/day)
January	35.5716	34.6268	7.0499	6.9797
February	24.1837	22.5226	6.5471	6.5088
March	5.0241	3.8417	5.7529	5.7441
April	0	0	5.2900	5.2900
May	0	0	4.9700	4.9700
June	0	0	4.5900	4.5900
July	0	0	4.2000	4.2000
August	0	0	3.9700	3.9700
September	0	0	4.2300	4.2300
October	13.1248	12.7681	4.6993	4.6811
November	27.3668	29.8540	5.6665	5.6188
December	38.644	38.0509	6.7978	6.7264
Average	**11.9929**	**11.8053**	**5.3136**	**5.2924**



(a)

(b)

(c)

(d)

Fig. 1. Graph of Optimum Tilt Angle β (º) versus Months of the year, (a) Average value of all the models, Anambra State, (b) Average value of all the models, Enugu State, (c) All the six models, Anambra State, and (d) All the six models, Enugu State; in Nigeria.

Table 2 shows the average optimum tilt angle values for each month of the year and the corresponding solar radiation. It was used to obtain the graph of average optimum tilt angle versus month for all the models in both states. The graph shows the monthly variation of the optimum tilt angles when all the models (isotropic and anisotropic) were combined. From Table 2, the optimum tilt angle for Anambra state in January is 35.57^o, 24.18^o for February and 5.02^o for March. These values remain zero from April till September before increasing to 13.12, 27.37 and 38.64 degrees for October, November, and December. In comparison, Enugu state is 34.63^o in January, 22.52^o in February, and 3.84^o in March. Again, the value remained zero from April to September and increases to 12.77^o, 29.85^o and 38.05^o for October, November and December, respectively. The optimum tilt angle for both states is zero from April to September but varied from October to March. The yearly optimum tilt angle for Anambra state is 11.99^o and 11.81^o for Enugu State.

3.2. Seasonal Optimum tilt angle

The rainy season for the two states (Anambra and Enugu State) in the south-eastern part of Nigeria is between April and September, while the dry season is from October to March. The seasonal optimum tilt angles as given in Tables 3 (making use of both models) shows that the optimum tilt angle for the dry season in Anambra State is 32.99^o and zero (0) degree in the rainy season. In contrast, Enugu State is 23.61^o in the dry season and zero (0) degree in the rainy season. Comparing the isotropic and anisotropic model, the optimum tilt angle for the dry season in Anambra state using the isotropic model is 21.86^o and zero (0) degree for the rainy season. Using anisotropic models to determine the optimum tilt angle in Anambra state, the optimum tilt angle for the dry season is 26.11^o and zero (0) degree for the rainy season. It was observed that both models gave the same tilt angle for the rainy season and differed a little with a value of 4.25^o in the months of the dry season.

Table 3

Optimum tilt angle of different models for different seasons and year.

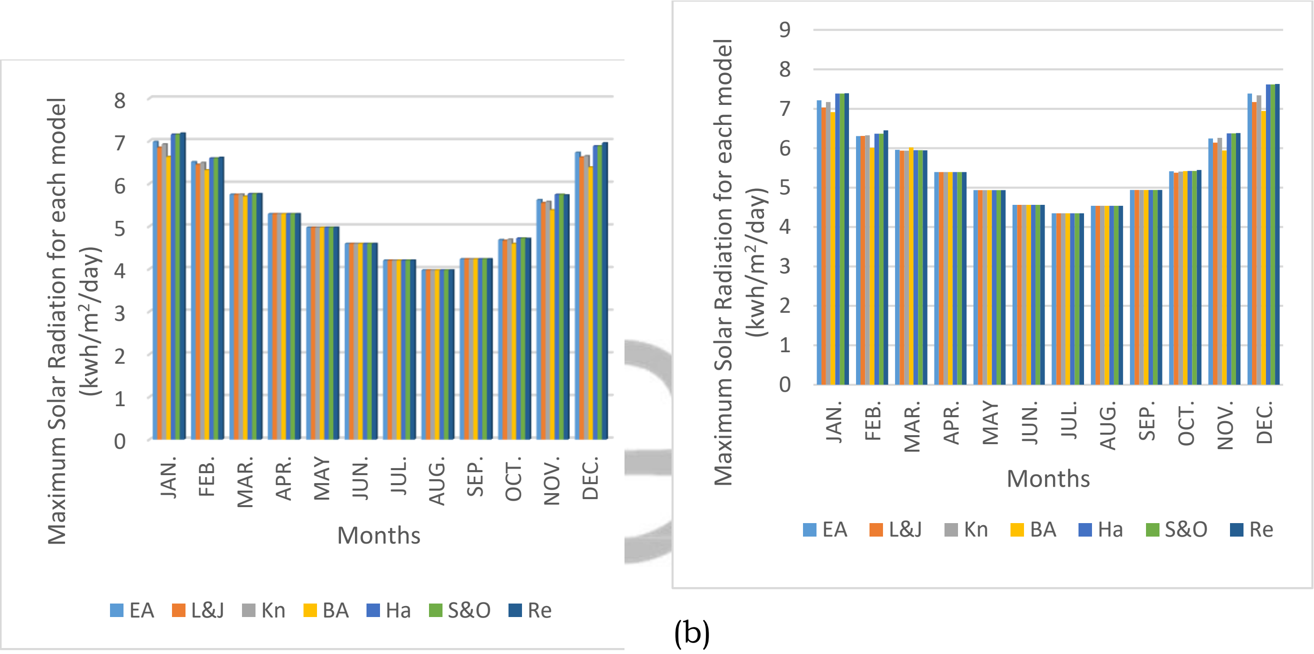
Location	Model	Optimum Tilt Angle for Dry Season (°)	Optimum Tilt Angle for Wet Season (°)	Optimum Tilt Angle for a Year (°)
Anambra	Isotropic Models	21.86	0.00	10.93
	Anisotropic Models	26.11	0.00	13.06
	Total Average	**23.99**	**0.00**	**11.99**
Enugu	Isotropic Models	21.51	0.00	10.75
	Anisotropic Models	25.71	0.00	12.86
	Total Average	**23.61**	**0.00**	**11.81**

In the same manner, both models predicted 0 as the optimum tilt angle for the rainy season. Whereas for the dry season, the values differ by 4.20° in Enugu state.

The requirement here is that the panel's tilt angle should be adjusted twice a year, first to zero degree in the rainy season months and later to different angles in the months of the dry season, depending on the state. Since both states are located in the northern hemisphere, the December optimum tilt angle gave the highest value. This is expected because the December 22 (December solstice) declination angle is -23.45°, which is the farthest in both states. The monthly optimum tilt angle must not be less than the sum of the latitude angle of the site and the absolute value of the declination angle for the month. As the declination angle tends towards zero degree (March 22 equinox), Fig. 1 shows that the optimum tilt angle became approximately equal to the latitude of the site and then zero for any value equal to or above the latitude of the site (since the panel must be flat or tilted towards the south if the site is in the northern hemisphere). The optimum tilt angle remains zero throughout the rainy season when the declination angle is positive but increases from October when the declination angle becomes negative. Additionally, the sun goes below the equator, as indicated in Fig. 1. Figs. 1(c and d) indicate that all the models follow the same adjustment pattern from January to December.

3.3. Energy generation and optimum tilt angles

The energy generated making use of each model helps to determine how best and closely related a model is with the other. From Fig. 2, it was observed that the same amount of solar radiation was generated making use of any of the models from the month of April to September. The Badescu Model (BA) gives a lesser amount of energy in the months of dry season when compared with that of expected average (EA) and that generated making use of other models. It was observed that the only noticeable different in the energy generated using different models was in the month of dry season, the months of the rainy season gives exactly the same value in both states.



(a)

(b)

Fig. 2. Comparing the estimated solar radiation for each of the models, (a) Anambra state and (b) Enugu State; in Nigeria.

Table 4

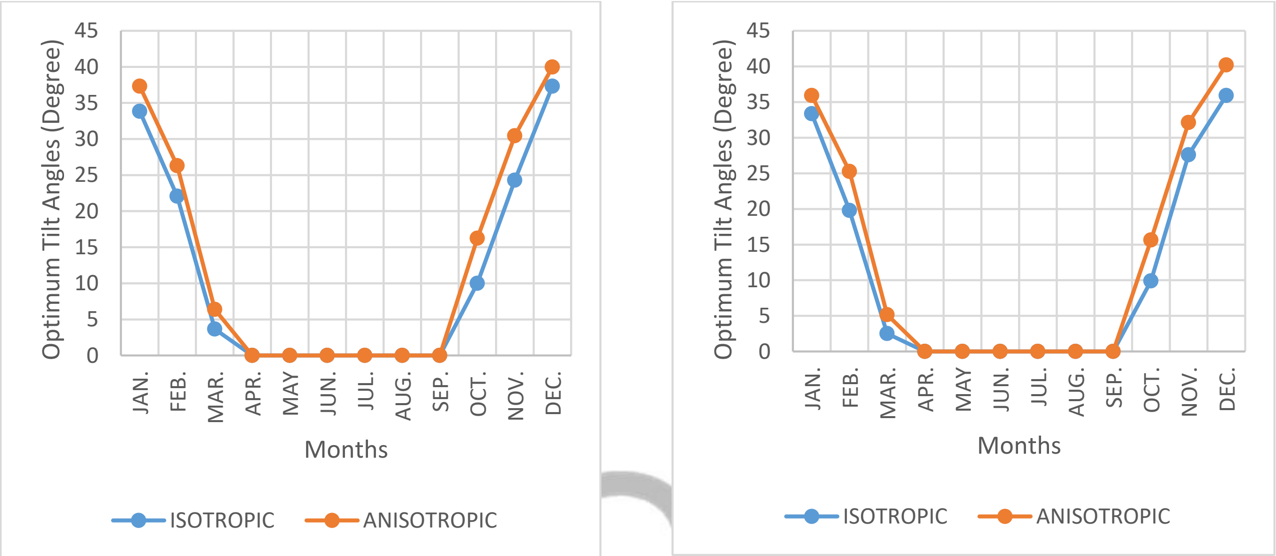
Average optimal tilt angle in each month of the year for both isotropic and anisotropic models.

Location	Model	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.
Anambra	Isotropic Models	36.03	24.49	5.50	0.00	0.00	0.00	0.00	0.00	0.00	15.00	27.60	38.73
	Anisotropic Models	37.31	26.31	6.38	0.00	0.00	0.00	0.00	0.00	0.00	16.25	30.44	39.97
	Absolute diff. btw the optimal tilt angle for the two models.(Degree)	1.28	1.82	0.88	0.00	0.00	0.00	0.00	0.00	0.00	1.25	2.84	1.24
Enugu	Isotropic Models	34.10	22.88	3.78	0.00	0.00	0.00	0.00	0.00	0.00	14.85	31.48	38.09
	Anisotropic Models	35.91	25.26	5.17	0.00	0.00	0.00	0.00	0.00	0.00	15.63	32.12	40.19
	Absolute diff. btw the optimal tilt angle for the two models.(Degree)	1.81	2.38	1.39	0.00	0.00	0.00	0.00	0.00	0.00	0.78	0.64	2.10

Table 4 indicates that the difference between the optimum tilt angle obtained making use of isotropic and anisotropic model in the rainy season is zero in both state. The difference in the optimum tilt angles in the months of dry season for Anambra state are 1.28, 1.82, 0.88, 1.25, 2.84 and 1.24 degrees for the months of January, February, March, October, November and December respectively. While the difference in the optimum tilt angle obtained in the month of dry season making use of isotropic and anisotropic models in Enugu state are 1.81, 2.38, 1.39, 0.78, 0.64 and 2.10 degrees for January, February, March, October, November and December respectively. The most noticeable difference (2.38°) occurred in the month of February for Enugu state and in the month of November (2.84°) for Anambra state. In the same manner, the least difference (0.64°) occurred in the month of November for Enugu and in the month of March (0.88°) for Anambra state.

3.4. Comparison of Optimum tilt Angles

To see how closely related the optimum tilt angle of a mode is with another, the average optimum tilt angle of isotropic models was plotted with that of anisotropic models



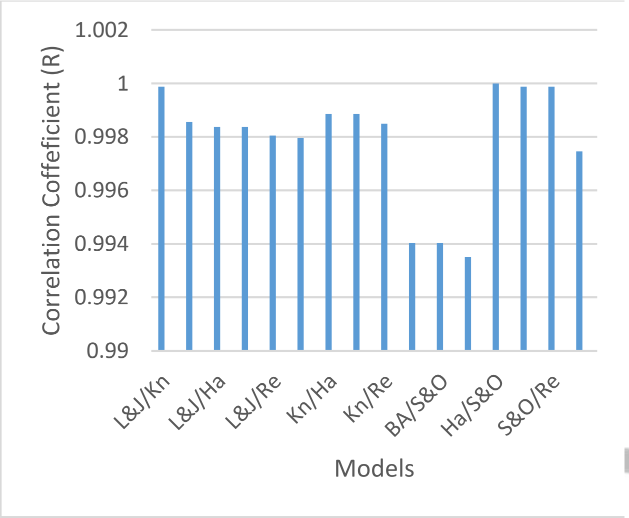
(a) (b)

Fig. 3. Graph of optimum tilt angle versus each month of the year for both isotropic and anisotropic models, (a) Anambra state and (b) Enugu State, in Nigeria.

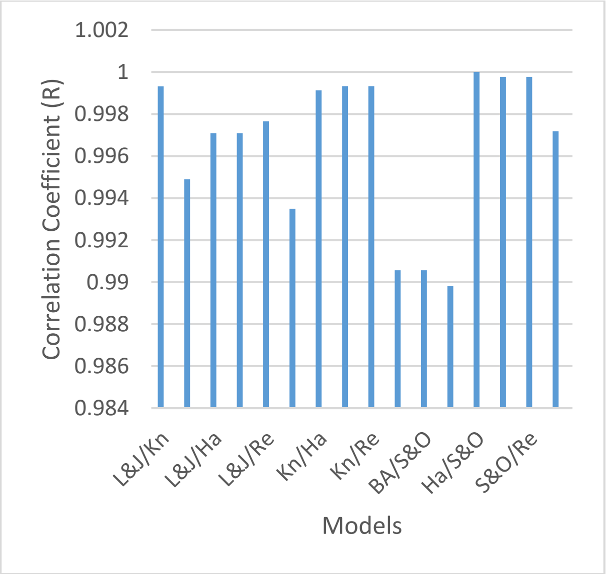
Fig. 3 shows that the monthly optimal tilt angle from isotropic models is very close to the monthly optimal tilt angle obtained from anisotropic models. It was observed from the graphs that both models show a steady declined in the first three months of the year (January, February and March), which is the first segment of the graph for both states. This segment indicates a very relative value in the optimum tilt angles for both models in the three months. The second segment indicates flat overlapping curves, which signified the same optimum tilt angle for both models from April to September (rainy season). The third segment, which represents the beginning of the dry season, indicates a steady increase in the optimum tilt angle from September to December. It shows that the optimum tilt angle increases for both models as the dry season begins. This segment also observed that both models give approximately the optimum tilt angle for mounting a solar panel. Fig. 3 also indicates that both models have their peak of optimum tilt angle in December, possibly signifying the dry season's weather peak.

3.5. Statistical comparison

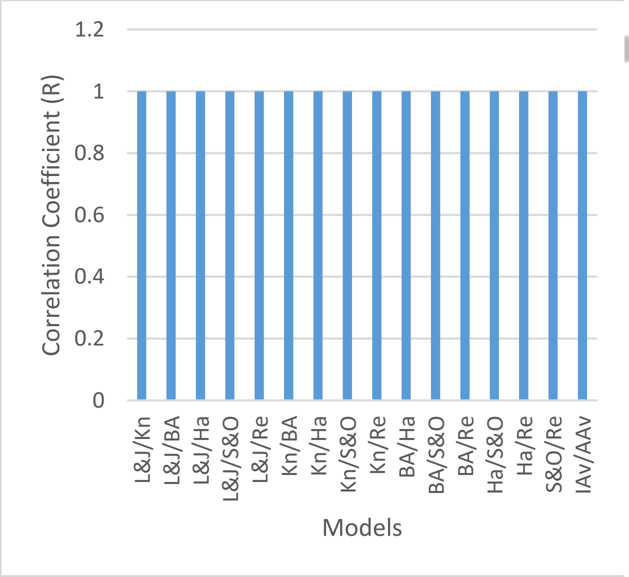
The results of optimum tilt angle and energy generated making use of different models was compared using a statistical method. The correlation coefficient indicates how closely related the result of a particular model is to the others.



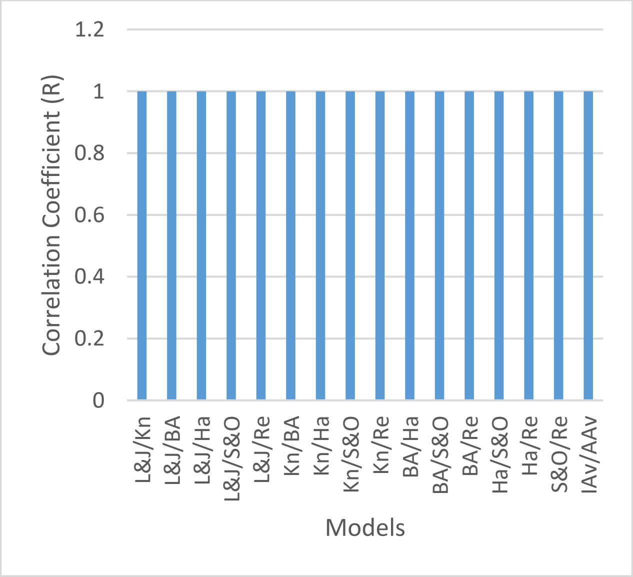
(a)



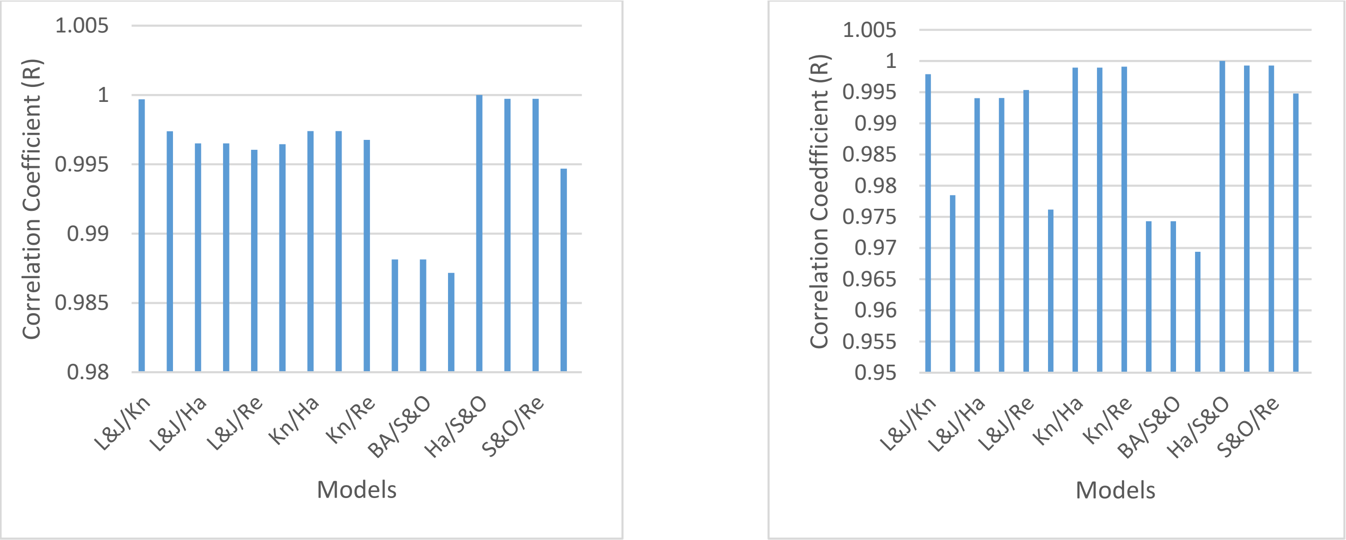
(b)



(c)



(d)



(e)

(f)

Fig. 4. Comparing the isotropic models with anisotropic models using correlation coefficient, (a) Solar Radiation, Anambra State, (b) Solar Radiation, Enugu State (c) Optimum Tilt Angle in the rainy season, Anambra State, (d) Optimum Tilt Angle in the rainy season, Enugu State, (e) Optimum tilt angle in the dry season, Anambra State, and (f) Optimum tilt angle in the dry season, Enugu State; in Nigeria.

Fig. 4, indicates that all the models gave a close value of optimum tilt angle, with all having a correlation coefficient that is above 0.90. The correlation coefficients indicates that Hay model's agreed more with Skartvetit and Olseth model's with a correlation coefficient of one (1). This is an indication that both models gave the same value of optimum tilt angle and generated solar energy. No model has a correlation coefficient less than 0.90 with the other, the least is when compared the Badescu model with Reindl *et al.* (1990) model which gave a correlation coefficient of 0.9935 for Anambra and 0.9898 for Enugu State. This indicates that the difference between the result of one model and the other is not much. All the Anisotropic models gave more close value with each other when compared with how close is the value of the Isotropic models in both states. It was observed that Badescu model agreed less with all the anisotropic models when compared with other Isotropic models. For the rainy season, all the models gave the same optimum tilt angle (zero (0)) and solar energy generated is equally the same using each model. The correlation coefficient between each model and another is one (1) in all the models. This is an indication that all the models perfectly agreed with each other. The correlation coefficient for the dry season still indicates that all the models gave a close value of optimum tilt angle and energy generated in the same order, with a correlation coefficient value that is greater than 0.9 in all. The least is the correlation coefficient between Badescu model and Reindl *et al* model which gives a correlation coefficient of 0.9872 for Anambra State and 0.9694 for Enugu state. The correlation coefficient between Hay model and Skartvetit and Olseth model still remain the strongest with a correlation coefficient of one (1). The correlation coefficient between the Isotropic average solar radiation (IAv) and anisotropic average solar radiation (AAv) for a year in Anambra State is 0.9975 and 0.9972 for Enugu State. For the months of the rainy season, the correlation coefficient between IAv and AAv for both states is one (1). This is a strong indication that both models (isotropic and anisotropic) gave exactly the same value of optimum tilt angle and generated energy for the months in the rainy season. In the dry season, the correlation coefficient between IAv and AAv is 0.9947 for Anambra state and 0.9948 for Enugu state. This is an indication that there is no much different between the isotropic and anisotropic models.

4. Conclusions

Determination of how the result of optimum tilt angle and energy generated making use of isotropic and anisotropic models relates with each other. The concluding result was drawn from two south eastern states in Nigeria (Anambra and Enugu state). The work compared how the result of six models varied from each other and the following conclusion was drawn.

- The average based annual optimum tilt angle for Anambra State is 11.99° while that of Enugu State is 11.81°. The seasonal optimal tilt angle for rainy season is zero (0) degree for both Anambra and Enugu State, while that of dry season is 23.99° for Anambra State and 23.61° for Enugu State.
- Comparing the isotropic and anisotropic models, the seasonal based optimum tilt angle for Anambra state making use of isotropic models is 21.86° for the dry season and zero (0) degree for the rainy season. Making use of anisotropic models, the optimum tilt angle for the dry season is 26.11° and zero (0) degree for the rainy season. Again, considering the seasonal optimum tilt angle for Enugu state, the isotropic models gave 21.51° for the dry season and zero (0) degree for the rainy season, while anisotropic models gave 25.71 degrees for the dry season and zero (0) degree for the rainy season.

- The monthly optimum tilt angle for both isotropic and anisotropic model in both states decreased from January to April, but the value remained zero for the month of rainy season (April to September) and increased from October to December.
- The optimum tilt angle is approximately equal to the latitude of the site as the declination angle tends towards zero degree (March 22 equinox) and then becomes zero for any value equal or above the latitude of the site in both state.
- The panel must be flat or tilted towards the south if the site is in the northern hemisphere.
- All the models offer the same solar energy and optimum tilt angle for the months of the rainy season, but differ a little for the months of dry season.
- The solar energy generated making use of anisotropic models is a little greater than that generated making use of isotropic models in both states.
- The statistical analysis showed that the result of Badescu model agreed less with other models in predicting the average solar radiation for a month in both states.
- Any of the isotropic model or the anisotropic model can be used to predict the optimum tilt angle of any state in the federation for easy installation of PV panels.
- The Hay Model predict exactly the same optimum tilt angle and solar energy with the Skartvetit and Olseth Models in both state with a correlation coefficient of one.
- No model has a correlation coefficient less than 0.90 with the other in both state; that is a strong indication that there is no mush different between the isotropic and anisotropic models.
- In comparing the isotropic average energy (IAv) with the anisotropic average (AAv) indicates that both has a correlation coefficient of 0.9947 for Anambra state and 0.9948 for Enugu state. This indicates that there is no much different between the isotropic models and the anisotropic models.

Nomenclature

SYMBOL	DESCRIPTION
$\hat{H}_T$	Monthly average daily total radiation on a tilted surface
$\hat{H}_B$	Monthly average daily beam radiation on a tilted surface
$\hat{H}_D$	Monthly average daily diffuse radiation on a tilted surface
$\hat{H}_R$	Ground reflected radiation on a tilted surface
K_T	The monthly clearness index
H	Monthly average daily global radiation on a horizontal surface
H_d	Monthly average daily diffuse radiation on a horizontal surface

H_b	Monthly average daily beam radiation on a horizontal surface
$\hat{R}_b$	Ratio of the monthly average daily beam radiation on a tilted surface to that on a horizontal surface
ω_s	The sunset hour angle (in degrees) for the tilted surface for the mean day of the month.
Ø	The latitude of the location
δ	The declination angle
β	Tilt angle
$\hat{R}_d$	The ratio of the average daily diffused radiation on a tilted surface to that on horizontal surface
ρ	The ground albedo

ACKNOWLEDGMENT

The corresponding author sincerely expresses his profound gratitude to Dr. Onuchukwu of Physics Department, of Chukwuemeka Odumegwu Ojukwu University, Uli for his assistance in making this work a reality. Mr. Umoke Ikechukwu Daniel of Royal Exchange Prudential Life PLC technical Department (individual life) for his assistant in English editing of the manuscript.

REFERENCES

Aggarwal, K. (2012). Precise estimation of total solar radiation on tilted surface. *African Journal of Environmental Science and Technology*, *6*(9), 365–370. https://doi.org/10.5897/ajest12.090

Augustine, C., & Nnabuchi, M. N. (2009). Relationship between global solar radiation and sunshine hours for Calabar, Port Harcourt and Enugu, Nigeria. *International Journal of Physical Sciences*, *4*(4), 182–188.

Boxwell, M. (2012). Solar Electricity Handbook 2012 edition. Greenstream Publishing 12 Poplar Grove Ryton on Dunsmore Warwickshire CV8 3QE United Kingdom.

Bugaje, I. (2006). Renewable Energy for Sustainable Development in Africa: A review. *Renewable and Sustainable energy reviews,* 10(6), 603-612.

Chiou, J.P. & EL-Naggar, M.M. (1986). Optimum slope for solar insolation on a flat surface tilted towards the Equator in heating season. *Solar energy*, 36(5), 381-479.

David-Okoro, I.L., Chineke, T.C., Ihemmadu, V.E., Onyeuwaoma, N.D. & Dike, V.N. (2009). Solar electricity potentials and optimal angles for mounting solar panels in the six geopolitical zones of Nigeria. *Nigeria Journal of Physics,* 21(1), 144-153.

Duffie, J.A & Beckman, W.A (2006). Solar Engineering of thermal processes (fourth Edition). John Wiley & Sons, Inc., Hoboken, New Jersey.

El-Sebaii, A., Al-Hazmi, F., Al-Ghamdi, A., & Yaghmour, S. (2010). Global, direct and diffuse solar radiation on horizontal and tilted surfaces in Jeddah, Saudi Arabia. *Applied Energy,* 87, 568-576.

Gulin, M., Vasak, M., & Baotic, M. (2013). Estimation of the global solar irradiance on tilted surfaces. *17th International Conference on Electrical Drives and Power Electronics (EDPE 2013)*, (i), 6.

Hanif, M., Ramzan, M., Rahman, M., Khan, M., Amin, M. and Aamir, M. (2012). Studying power output of PV solar panels at different temperatures and tilt angles. ISESCO *Journal of science and technology,* 8(14), 9-12.

Hay, J.E. (1979). Calculation of monthly mean solar radiation for horizontal and inclined surfaces. *Solar Energy*, 23, 301-307.

Jakhrani, A. Q., Othman, A., Rigit, A. R. H., Samo, S. R., & Ahmed, S. (2012). Estimation of Incident Solar Radiation on Tilted Surface by Different Empirical Models. *International Journal of Scientific and Research Publications*, *2*(12), 15–20.

Kamali, G. A., Moradi, I., & Khalili, A. (2006). Estimating solar radiation on tilted surfaces with various orientations: A study case in Karaj (Iran). *Theoretical and Applied Climatology*, *84*(4), 235–241. https://doi.org/10.1007/s00704-005-0171-y

Kern, J. & Harris, L. (1975). On the optimum tilt of a solar collector. *Solar Energy*, 17, 97-102.

Keyhani, A. L. I. (2011). *Design of* smart power grid renewable energy systems. *John Wiley & Sons, Inc., New Jersey*.

Koronakis, P.S. (1986). On the choice of the angle of tilt for south facing solar collectors in the Athens Basin area. *Solar Energy*, 36, 217-225.

Liu, B.Y.H. & Jordan, R.C. (1962). Daily insolation on surface tilted towards the Equator. *Trans ASHRAE*, 67, 526-541.

Klucher, T.M. (1979). Evaluation of models to predict insolation on tilted surfaces. *Solar Energy*, 23, 111-114.

Ma, C. and Iqbal, M. (1983). Statistical comparison of models for estimating solar radiation on inclined surface. *Solar Energy,* 31, 313-317.

Miguel, A., Bilbao, J., Aguiar, R., Kambezidis, H. & Negro, E. (2001). Diffuse solar radiation model evaluation in the north Mediterranean Belt area. *Solar Energy*, 70, 143-153.

Muneer, T., (2004). Solar Radiation and Day Light models. Elsevier, Oxford

Nijmeh, S. and Mamlook, R. (2000). Testing of two models for computing global solar radiation on tilted surfaces. *Renewable Energy* 20(1), 75-81.

Orizu, G. E., Okpala, U. V, Onuchukwu, C. C., & Nnaemeka, C. U. (2017). *OPTIMUM TILT ANGLE FOR MOUNTING A SOLAR PANEL IN ONITSHA AND ITS ENVIRONMENT*. (Fapscon), 13–21.

Reindl, D.T., Beckman, W.A. & Duffie, J.A. (1990). Evaluation of hourly tilted surface radiation models. *Solar Energy*, 45(1), 9-17.

Shukla, K. N., Rangnekar, S., & Sudhakar, K. (2015). Comparative study of isotropic and anisotropic sky models to estimate solar radiation incident on tilted surface: A case study for Bhopal, India. *Energy Reports*, *1*, 96–103. https://doi.org/10.1016/j.egyr.2015.03.003

Skartveit, A. & Olseth, J.A. (1986). Modeling slope irradiance at high Latitudes. *Solar Energy*, 36(4), 333-344.

Tiwari, G. N., & Ahmad, M. J. (2009). Optimization of Tilt Angle for Solar Collector to Receive Maximum Radiation. *The Open Renewable Energy Journal*, *2*(1), 19–24. https://doi.org/10.2174/1876387100902010019

Udoakah, Y., & Okpura, N. (2015). Determination of Optimal Tilt Angle for Maximum Solar Insolation for PV Systems in Enugu-Southern Nigeria. *Nigerian Journal of Technology*, *34*(4), 838. https://doi.org/10.4314/njt.v34i4.24