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Full Length Research Paper

Evaluation of solar energy budget within Cross River Estuary, Nigeria: implication for marine transportation

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The meteorological parameters obtained from weather station in Uyo (2009 - 2013) were analyzed using Angstrom model to estimate the solar energy budget available in the Cross River estuary. The daily data obtained over the period of five years were converted to monthly data. The regression coefficients for Angstrom model (used for estimating solar energy budget) were obtained using SPSS. The results showed that the value of extraterrestrial radiation (H_o) for the estuary was 526.191 MJm^{-2} day^{-1}. While the estimated solar irradiance (energy budget) for the study area was 167.94 MJm^{-2} day^{-1}. This amount of energy is large enough to complement 80 liters of diesel used by seagoing vessel for a round trip between Oron and Calabar. Also, the computed relative sunshine duration yielded 0.706. This shows that the local atmosphere was not clear over the period studied but cloudy. Despite the cloudy conditions of the atmosphere, nature has budgeted sufficient solar energy in the study area. Based on these, the study recommends that water vessels within the study area should be encouraged to use solar energy in their day to day activities, as this will not only reduce fossil fuel consumption, but ensures that water craft operates in a more environmental friendly way.

Key words: Extraterrestrial, sunshine, energy, marine transportation, cloudy.

INTRODUCTION

All sources of energy are grouped into two general categories, namely incoming energy (the energy reaching the earth from outer space) and capital energy. The incoming energy includes solar and lunar energy, while capital energy sources include fossil fuels, geothermal energy and nuclear energy (Gueymard, 2004; Suri et al., 2005; Janjai, 2010; Mellit and Pavan, 2010; Ruiz-Arias et al., 2010). Solar radiation finds many applications, such as: domestic lighting systems, architecture, agriculture, irrigation and cathodic protection system. Also, mesoscale analysis of meteorological data had been used to model tornado event in Northern Greece (Matsangouras and Pytharoulis, 2011).

Several studies, (Rigollier et al., 2000;Badescu, 2002; Ineichen and Perez, 2002; Perez and Ramos-Real, 2009; Janjai and Deeyai, 2009) have shown that solar energy is environmental friendly and provides cleaner source of energy without any form of pollution and greenhouse gas as well as being cost effective. Despite the significance of solar radiation, many developing countries cannot afford it due to the cost of maintenance, calibration requirements and its unavailability in some locations

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Table 1. Meteorological data for the year 2009.

Month	Mean mintemp(Tmin,°C)	Mean maxtemp(Tmax,°C)	Meanmonthlysolarradiation(SR)	Relativehumidity(RH)	Mean daily hrsofbrightsunshine(HBS)	AtmosphericPressure(AP)	Daily No. of possible sunshine (BS)
Jan.	23.5	33.2	3.0	75	8.6	1008.7	5.2
Feb.	23.2	34.7	5.2	50	8.4	1007.4	4.5
Mar.	24.2	33.4	3.9	74	9.7	1007.6	4.6
Apr.	24.0	32.4	2.5	82	8.6	1007.0	5.1
May	23.7	31.8	1.8	84	10.1	1009.4	8.8
Jun.	23.2	31.4	1.6	84	9.9	1010.3	10.1
Jul.	23.3	29.8	1.3	87	9.8	1010.6	10.4
Aug.	23.0	28.8	1.1	89	10.3	1010.2	9.0
Sept.	23.0	29.2	1.1	87	6.7	1010.8	9.4
Oct.	23.1	30.5	1.4	85	9.8	1011.1	9.7
Nov.	23.8	31.5	1.6	86	10.0	1011.3	9.7
Dec.	21.8	31.8	2.8	76	8.8	1011.5	8.5

Source: Meteorological station, Uyo.

(Almorox and Hontoria, 2004). Information on the local solar energy budget is of great relevance to planning an efficient alternative energy source to the use of hydrocarbon in powering water going vessels within a locality. Such information could be estimated from readily available meteorological data. Several empirical models for calculating solar radiation have been suggested in the literature (Kasten, 1980; Nunez, 1993; Lynch, 2008; Coiffier and Sutcliffe, 2012; Kumar et al., 2013; Gadiwala et al., 2013). Some of these models use variables like sun hours, air temperature, relative humidity, and cloudiness. The most widely used parameter to estimate solar radiation is sunshine duration, which can be easily and reliably measured (Kerr and Tabony, 2004; Mengese et al., 2006; Gadiwala et al., 2013).

Angstrom regression model is the most commonly used method, which is a linear correlation between the average daily global radiation to the corresponding value on a completely clear day and the ratio of average daily sunshine duration to the maximum possible sunshine duration. Prescott suggested replacing the clear sky global radiation with the extraterrestrial radiation, producing a more convenient form of Angstrom equation called Angstrom - Prescott regression model (Angstrom, 1924; Prescott, 1940; Gadiwala et al., 2013). Against this background, this study is aimed at estimating the solar radiation budget for the study area as well as contributing to the global reduction in greenhouse gases emission. A comprehensive knowledge of the solar energy available in a location not only means its characterization by the total value, but also its temporal repartition, spectral distribution, and nature (direct or diffuse).

METEOROLOGICAL PARAMETERS AND DATA AVAILABLE

To estimate the solar radiation budget in the Cross River estuary, daily weather data for the local area latitude 04°56′N and longitude 07°56′E and elevation of 80.0 m were obtained from the Nigerian Meteorological Agency in Uyo. The data obtained (Tables 1 - 4) includes: mean daily solar radiation (SR), daily maximum temperature (Tmax,°c), daily minimum temperature (Tmin,°c), relative humidity (RH), mean daily hours of bright sunshine (BSH), mean daily number of bright sunshine (BS) and atmospheric pressure (AP) for an observation period of five (2009-2013) years.

Solar radiation (SR)

This is the amount of solar energy (electromagnetic radiation emitted by the sun) that arrives at a specific area of a surface during a specific time interval (radiant flux density). It is measured in W/m^2 or MJm^{-2}. However, not all of the solar energy from the Earth's outer atmosphere reaches the surface of the Earth. Some of this energy is reflected back out into space and some are absorbed by the atmosphere. A solarimeter isused to measure the combined direct and diffuse solar radiation.

Daily maximum temperature (Tmax°C)

This is the Maximum temperature obtained in the course

Table 2. Meteorological data for the year 2010.

Month	Mean mintemp(Tmin,°C)	Mean maxtemp(Tmax,°C)	Meanmnthlysolarradiation(SR)	Relativehumidity(RH)		C AtmospheriPressure(AP)	Daily No. of possible sunshine (BS)
Jan.	21.9	32.9	3.3	61	6.2	1010.1	7.6
Feb.	23.5	35.0	4.8	57	9.0	1009.9	9.9
Mar.	23.9	33.0	2.4	81	9.3	1010.4	10.3
Apr.	23.8	32.4	2.2	83	10.2	1011.1	6.7
May	23.8	31.8	1.9	82	10.9	1011.3	9.8
Jun.	23.1	30.3	1.4	85	9.4	1011.7	10.0
Jul.	22.8	29.3	1.3	87	7.4	1011.5	8.8
Aug.	22.8	28.9	1.0	90	7.5	1011.8	9.9
Sept.	22.9	30.4	1.1	85	9.4	1010.9	10.3
Oct.	23.3	29.5	1.3	86	9.8	1011.1	7.4
Nov.	23.8	32.0	1.7	83	9.7	1011.4	7.5
Dec.	23.9	32.5	2.5	77	9.0	1011.2	9.4

Source: Meteorological station, Uyo.

Table 3. Meteorological data for the year 2011.

Month	Mean mintemp(Tmin,°C)	Mean maxtemp(Tmax,°C)	Mean mnthlysolarradiation(SR)	Relativehumidity(RH)	Mean daily hrsof bright sunshine(HBS)	AtmosphericPressure(AP)	Daily No. of possible sunshine (BS)
Jan.	22.1	33.2	3.7	58	9.1	1080.1	6.5
Feb.	23.7	34.3	4.6	59	9.0	1074.2	5.5
Mar.	24.8	33.3	2.4	84	10.4	1076.1	7.5
Apr.	23.7	32.5	2.2	81	10.0	1066.7	8.0
May	23.4	32.1	1.8	86	10.1	1065.4	8.5
Jun.	23.3	30.1	1.3	85	10.8	1056.1	8.6
Jul.	23.5	30.0	1.2	87	9.7	1057.1	8.9
Aug.	23.1	29.1	1.0	89	4.3	1045.3	9.5
Sept.	23.1	29.8	1.5	88	8.4	1040.2	9.3
Oct.	23.1	31.2	1.5	83	9.7	1038.2	8.9
Nov.	23.9	31.0	2.0	83	8.5	1033.1	8.1
Dec.	22.9	33.0	2.4	74	8.3	1030.5	7.1

Source: Meteorological station, Uyo.

of a continuous time interval of 24 h (usually midnight to midnight local time). It is the highest temperature reported for a given location during a given period. The time at which the daily maximum temperature can be obtained is usually 3-4 pm; this is after the time of max insulation because the ground reflects heat energy in the late afternoon and this makes an energy surplus (Zeppenfeld et al., 2012). On the contrast, the minimum temperature (lowest temperature attained during a specific period) is usually recorded after sunrise (about 9 am).

Relative humidity (RH)

Relative humidity is the ratio of the partial pressure of water vapor in an air-water mixture to the saturated vapor pressure of water at a prescribed temperature. The

Table 4. Meteorological data for the year 2012.

Month	Meanmintemp(Tmin,°C)	Meanmaxtemp(Tmax, °C)	Mean mnthlysolarradiation(SR)	Relativehumidity(RH)	Mean dailyhrsofbrightsunshine(HBS)	AtmosphericPressure(AP)	Daily No. ofpossiblesunshine(BS)
Jan.	21.7	31.9	2.2	51	5.2	1001.1	6.6
Feb.	22.5	34.0	3.4	47	8.0	1008.1	8.9
Mar.	22.9	32.0	2.4	71	8.3	1010.1	9.3
Apr.	22.8	31.4	2.2	73	9.2	1011.2	5.7
May	22.9	30.8	1.8	72	10.9	1011.1	8.8
Jun.	22.1	30.3	1.5	75	10.2	1011.4	9.0
Jul.	22.8	28.9	1.3	77	7.4	1011.5	7.8
Aug.	22.8	30.5	1.1	80	9.8	1011.7	8.9
Sept.	22.8	28.4	1.0	75	9.7	1010.4	9.3
Oct.	22.5	29.3	1.3	76	10.9	1011.8	6.4
Nov.	22.1	30.4	1.7	73	9.8	1011.4	8.4
Dec.	22.6	29.5	2.6	88	9.0	1011.3	7.5

Source: Meteorological station, Uyo.

Table 5. Meteorological data for the year 2013.

Month	Mean mintemp(Tmin,°C)	Mean maxtemp(Tmax,°C)		Relativehumidity(RH)		AtmosphericPressure(AP)	Daily No.ofpossiblesunshine(BS)
Jan.	22.7	31.9	2.1	59	4.2	1010.1	5.6
Feb.	21.5	31.4	2.4	44	7.0	1011.1	7.9
Mar.	21.9	32.6	2.2	69	7.3	1011.3	8.3
Apr.	21.1	32.1	1.5	73	8.2	1010.2	4.7
May	21.8	34.0	1.7	70	9.9	1011.4	7.7
Jun.	21.8	30.3	1.9	77	9.2	1001.1	6.4
Jul.	21.5	28.8	1.2	85	6.4	1008.1	8.8
Aug.	21.6	29.5	1.1	80	8.8	1010.4	8.4
Sept.	21.5	30.4	1.3	75	8.7	1011.8	7.5
Oct.	21.2	32.0	1.0	77	8.8	1011.7	9.9
Nov.	21.9	30.5	1.7	88	9.9	1005.4	9.3
Dec.	21.8	32.3	2.9	80	10.9	1010.7	8.9

Source: Meteorological station, Uyo.

humidity of air-water vapor mixture is determined by the use of psychrometric charts when both the dry bulb temperature (T) and the wet bulb temperature (T_W) of the mixture are known (Perry and Green, 1997).

Mean daily hours of bright sunshine (HBS)

This is the average number of hours of bright sunshine each day in a calendar month or year, calculated over the period of record. Hours of bright sunshine is measured from midnight to midnight. It is generally recorded with a Campbell-Stokes recorder. This device only measures the duration of “bright” sunshine, which is less than the amount of “visible” sunshine. For example, sunshine immediately after sunrise and just before sunset is visible, but would not be bright enough to register on the Campbell-Stokes recorder (Sunshine Recorders – Manual,

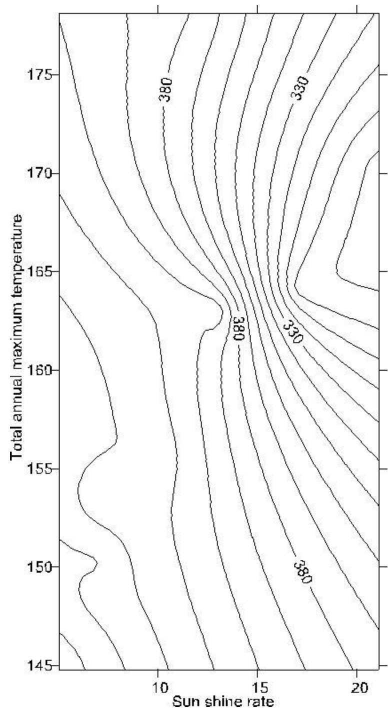

Figure 1. Meteorological parameter for the study area over the period of observation.

1966).

The mean daily meteorological data for five years (2009-2013) obtained from meteorological station in Uyo was converted to mean monthly parameters (Tables 1-4). This was used in conjunction with the established Angstrom type correlation equations (Equation 1) to estimate solar radiation (energy) budget for the study area.

$$\frac{H_{est}}{H_0} = a_0 + a_1 \frac{n}{N} \quad (1)$$

Where H_{est} is the estimated solar radiation, a_0 and a_1 are empirical coefficients, $\frac{n}{N}$ is the relative sunshine duration and H_0 is extraterrestrial solar radiation for the given area. The monthly average daily extraterrestrial solar radiation (H_0), measured on horizontal surface according to Duffie and Beckham (1991) is given as:

$$H_0 = \frac{24 I_{sc} E_0 \pi}{\pi 180} \left(W_s \sin\phi \sin\delta + \cos\phi \cos\delta \cos W_s \right) (2)$$

Where I_{SC} is solar constant in MJm^{-1}, E_0 is the eccentricity correction factor of the earth's orbit given by Liou (1980) and computed as:

$$E_o = 1 + .0033 \left(\frac{360J}{365} \right) = 5.9315 \quad (3)$$

Where J is the number of year considered. For this study, J was five years. From Equation 2, ϕ and δ are the latitude of observation and declination angle respectively. The value of declination was calculated for the study area from the equation of Cooper (1969).

$$\delta = 23.45\ 360 \left[\left(\frac{J + 284}{368} \right) \right] = 48.79 \quad (4)$$

W_S is the sunrise sunset hour angle given by Fayegh and Ghazi (1983) and was determined for the study area as:

$$W_S = Cos^{-1} (-\tan\phi \tan\delta) = 95.53 \quad (5)$$

The relative sunshine duration also known as the cloudiness of the atmosphere was determined using the average monthly actual duration of sunshine (n) and the maximum possible duration of sunshine or dayline hour (N) to be 0.706. The value of N was estimated using an expression by Igbal (1983) given as:

$$N = 2/15 W_S \quad (6)$$

For the study area, the value of N was determined to be 12.093. The extraterrestrial radiation (H_0) obtained for the study area using Equation (2) was 526.191 MJm^{-2} day^{-1}. The relevant values computed as well as the regression coefficients for Angstrom model (a_0 = 22.314; a_1= -11.936) obtained for the study were employed to estimate the solar energy that can be deposited on a plane surface (such as solar panel) in the local area studied. Figure 1 shows the inter relationship of some meteorological parameters for the study area.

RESULTS AND DISCUSSION

From Angstrom model, the estimated solar energy budget of 167.94 MJm^{-2} day^{-1} was obtained for the study area. This represents the amount of solar energy that any solar panel can absorb per unit area per day. The sum of the regression constants (10.378), which represents fractions of the extraterrestrial radiation on an over cast day is relatively high was determined. Also, the relative sunshine duration (0.706) obtained from the study area, is an indication that the atmosphere of study was cloudy over the period. This is in support of Goody and Yung (1989).They noted that regression models can be used to describe the clearness index of the atmosphere.

The extraterrestrial radiation (ETR) computed for the study area yielded 526.191 MJm^{-2} day^{-1}. However, Bakkirciet al. (2009) had reported that, ETR fluctuates at about 6.9% within a year (1412.0 Wm^{-2} in January to 1321.0 Wm^{-2} in July) due to the Earth's varying distance from the Sun.

In the absence of any cloud, the actual duration of sunshine is equal to the daylight hours and the ratio should be unity. It is an indication that the atmospheric condition of the study area was humid and dusty. It also gives information on the pollution level of the area by aerosols.

The amount of radiation reaching any horizontal plane estimated using the Angstrom model yielded a reasonable estimated solar energy of 167.94 MJm^{-2} day^{-1} is greater than the energy produced by of gasoline (36 MJl^{-1}). This estimated solar energy budget is large enough to power seagoing vessels in the study area. Recent advances in solar cell and photovoltaic module technologies have led to solar power becoming a cost effective fuel reduction option on pleasure boats, ferries and tourist vessels.

Conclusion

The solar energy received in the coastal area of Oron had been estimated using local meteorological data and three sunshine models. The constants in the models were determined using regression analysis and the results were used to compute the local solar energy available in the study area.

The Angstrom model yielded a value of 167.94 MJm^{-2} day^{-1}. This value was considered significant compared to 36 MJl^{-3}produced by fossil fuel. Also, the use of solar energy will help tackle the issues of air pollution, energy security and climate change. The value of the relative sunshine duration (0.706) shows that the atmospheric condition of the study area was cloudy. This indicates that, on a clear weather, the energy budget could be far above the value estimated by this study. Therefore, water going vessels within the study area should take advantage of the abundant solar energy in the study area for their daily transportation.

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