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Research Article

General Models for Monthly Average Daily Global Solar Irradiation

Jacques Marie Ilboudo[1], Dominique Bonkoungou[2, *], Sosthene Tassembedo[3], Zacharie Koalaga[3]

[1]Institute of Research in Applied Sciences and Technologies, Ouagadougou, Burkina Faso
[2]Departement of Applied Science, University of Thomas Sankara, Ouagadougou, Burkina Faso
[3]Departement of Applied Science, University of Joseph Ki-Zerbo, Ouagadougou, Burkina Faso

Abstract

With the world's growing demand for electricity and the crucial need to reduce greenhouse gas emissions, it's more important than ever to develop renewable energies, particularly solar power. The study carried out in this document is in line with the same principle, i.e. to improve the exploitation of solar energy. Its aim is to develop a mathematical model for mean monthly daily global solar irradiation that is independent of measurement data and suitable for all sites worldwide. For this study, we used daily global solar irradiation data for a horizontal surface. These data are from 60 sites worldwide and cover the period from 2000 to 2023. To examine the quality of the models established in the document, we carried out an investigation into performance tools. We have presented two, including MAPE (Mean Absolute Percentage Error) and Pearson's correlation coefficient. Based on the daily global solar irradiance data from the 60 sites, the empirical model of extraterrestrial daily solar irradiance, and computational tools, we have formulated mathematical expressions of solar irradiance. It has the particularity of being independent of measurement data such as the duration of the day and temperature of the sites. It requires only the latitudes of the locations to estimate the solar potential values of the sites. A study of the performance of the established model showed that the model of monthly mean daily global solar irradiation values has fairly acceptable accuracy and fairly good correlation.

Keywords

Daily Global Solar Irradiation, Measurement Data, Maximum and Means Monthly, Models

1. Introduction

Spherical in shape, the Sun is a star made up mainly of hydrogen and helium. Inside this star, these main components undergo fusion reactions that produce heat and light. Once generated, this solar energy, or solar radiation, propagates through the planetary system, of which the Earth is a part, in the form of electromagnetic waves. On Earth, solar energy is harnessed directly to generate heat and electricity using PV technology. Fossil fuels are currently the most widely exploited energy sources. These types of energy sources are subject to depletion and are leading to global warming. Solar energy, because it is inexhaustible, clean, and renewable, is a better alternative to meet the planet's energy needs. On the Earth's surface, solar energy, reduced by the Earth's atmosphere, varies throughout the day, season, and in space.

*Corresponding author: dominique.bonkoung@gmail.com (Dominique Bonkoungou)

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However, according to reviews in the literature [1, 2], the performance of PV technologies evolves with the intensity of the solar potential. In these conditions, to get the best exploitation of solar PV, you need tools that can provide information on the solar potential of a given site. Research has shown that weather stations are effective ways of obtaining information about a site's solar potential, but require a financial investment that is not always within everyone's reach. Global solar irradiation modeling is a very interesting alternative that provides data on solar potential at virtually zero cost. However, most commonly used mathematical expressions require measurement data on temperature, humidity, or sunshine duration. These measurement data require the availability of measurement equipment, which also requires a financial investment. Additionally, the solar irradiation models currently available are site-specific and each time recommend calculations of coefficients to adapt them to other sites.

Current methods of obtaining daily global solar irradiation data still require a financial investment that not everyone can afford. Clearly, this can have an impact on the implementation of a solar energy project.

The aim of the work carried out in this document is to develop a mathematical model of daily global solar irradiation with zero user cost. This model will be independent of measurement data and will be adapted to all sites worldwide. The manuscript is structured in three parts, the first being devoted to methodology. The second part focuses on the results and the last part is devoted to the conclusion.

2. Materials and Methods

The study carried out in this section focuses on the analysis of some commonly used mathematical models, a presentation of the study's measurement data, and an analysis of performance indicator tools.

2.1. Models Used

In the captivating world of solar energy, solar irradiation modeling occupies a very important place. This tool not only digitizes a site's solar potential data using equations, but also makes it available for sites that do not have any.

Today, there are a multitude of mathematical models that provide data on solar irradiance. Of these models, we have those that require the availability of measurement data on day length and sun duration. The most recognized type of solar irradiation model is that of Angstrom [3-5], developed in 1923. With Angstrom's linear model, a large number of models have been developed, including the Angström-Prescott model [4-8]. The latter was developed by Prescott in 1940 and is an improved version of Angstrom's model. Like Prescott, others would follow this example and develop Angstrom-type solar irradiance models with a few differences.

Thus, Ögelman et al. [9, 10], Samuel [10, 11], Ampratwum and Dorvlo [10, 12] and Almorox and Hontoria [10, 13, 14] developed quadratic, cubic, logarithmic, and exponential models, respectively. It is clear that solar irradiance modeling is making an enormous contribution to improving solar energy exploitation. Therefore, in addition to models that are expressed as a function of day length and sun duration, other types are developed. This is the case of solar irradiation models expressed as a function of maximum and minimum ambient temperature. Of this type of solar irradiation model, we have those formulated by Hargreaves and Samani [10, 15], Chen et al. [10, 16], Pandey and Katiyar [17, 18] and BRISTOW and CAMPBELL [17, 19]. There are also solar irradiation models in the literature that depend on relative humidity, day length, and duration of sunshine, such as those formulated by Swartman and Ogunlade [10, 20], El-Sebaii et al. [10, 21]. There are also some models of daily solar irradiance that are expressed as a function of maximum and minimum ambient temperature, day length and sunshine duration, such as those developed by Chen et al. [10, 16], El-Sebaii et al. [10, 21] and Ododo et al. [10, 22]. Virtually all existing global daily solar irradiance models are expressed as a function of other variables, which require the availability of data to exploit the models in question. For solar irradiation models that depend on the duration of the sun, a sensor is required to measure the values of the duration of the sun. This is also the case for models expressed as a function of relative humidity and maximum and minimum ambient temperature. The applicability of all these solar irradiation models requires prior measurement data, which requires a financial investment that is often difficult to obtain. However, there are very few studies in the literature that provide models of daily global solar irradiance that are independent of these variables, which require the availability of measurable data. The aim of this study is to propose universal models of daily global solar irradiance that do not require measurable data but depend only on-site, latitude and that will be useful to the solar energy industry.

2.2. Model Performance Indicator

At present, there are several statistical methods to determine the performance of established or empirical models. We have grouped them into two types. Statistical methods for assessing the accuracy of models in relation to the measurement results. These statistical methods include the Root Mean Square Error (RMSE), the Mean Error (ME), the Mean Percentage Error (PME), the Mean Absolute Percentage Error (MAPE) and the Mean Absolute Error (MAE) [4-6, 10, 14]. The second type of statistical method highlights the quality of the correlation between the model and the measurement results. From this type of statistical method, we have the Pearson's correlation coefficient (r) and the coefficient of determination R^2 [10, 14]. In the case of the study we are conducting in this manuscript, we use the statistical method relating to the Mean Absolute Percentage Error (MAPE) to assess the deviation or precision of the results produced by the model exploited.

We also use the Pearson correlation coefficient r to determine the quality of the correlation between the model and the measurement results.

The choice of (MAPE) and (r) in the paper over the others is explained by the fact that these performance indicators allow to obtain better test results on the precision and correlation of the processed models.

The mean absolute percentage error (MAPE) is determined using relationship (1), and the Pearson correlation coefficient (r) is calculated using relationship (2).

$$MAPE = \frac{1}{n} \times \sum_{i=1}^{n} \left(\frac{|H_{i,c} - H_{i,m}|}{H_{i,m}} \times 100 \right) \quad (1)$$

Where $H_{i,c}$ and $H_{i,m}$ are, respectively the ith calculated and measured values of global daily solar irradiation on a horizontal surface.

The Table 1 displays MAPE values as a function of model accuracy.

Table 1. *MAPE indicator.*

Values of MAPE (%)	Levels of precision
0 to 5	Very good
5 to 10	Good
10 to 20	Fairly good
20 to 30	Average
30 to 100	Low

$$r = \frac{\sum_{i=1}^{n} (H_{i,c} - H_{avg,c}) \times (H_{i,m} - H_{avg,m})}{\sqrt{\sum_{i=1}^{n} (H_{i,c} - H_{avg,c})^2 \times \sum_{i=1}^{n} (H_{i,m} - H_{avg,m})^2}} \quad (2)$$

Where $H_{avg,c}$ and $H_{avg,m}$ are, respectively, the mean calculated and measured values of global daily solar irradiation on a horizontal surface.

The Table 2 shows the (r) values as a function of the model correlation quality.

Table 2. *Pearson correlation coefficient indicator.*

Pearson correlation coefficient values	Correlation Quality
0 to 0.1	No correlation
0.1 to 0.3	Low correlation
0.3 to 0.5	Average correlation
0.5 to 0.7	High correlation
0.7 to 1	Very high correlation

2.3. Study Sites and Data

In the necessity of the study of this article, we have exploited data of the solar potential of several sites. The selected sites are those that we consider to have an ideal location and that we have access to the solar potential data.

By proceeding with a selection study, we chose to exploit the solar potential data from 60 sites listed in Table 4. The solar potential data exploited for these sites is that of global daily solar irradiation on a horizontal surface.

At each site, we considered daily solar irradiation data from 2000 to 2023. These data are from NASA.

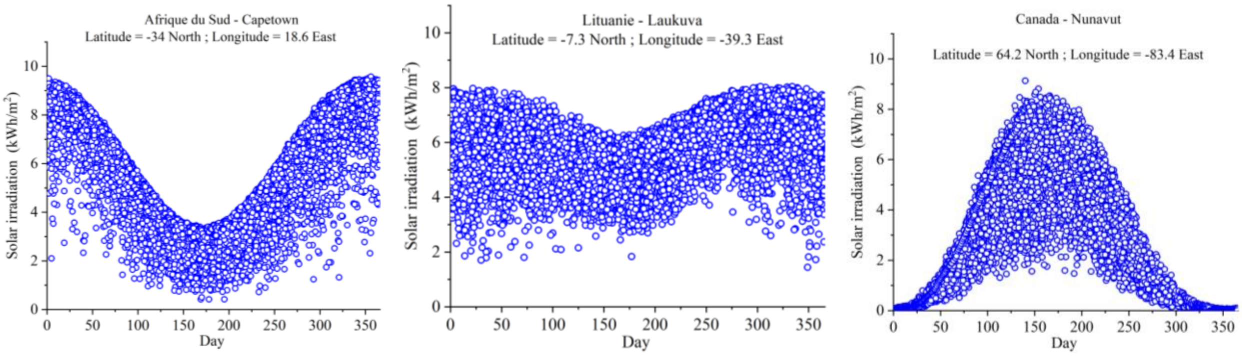
NASA data were processed and validated using data from ANAM (National Meteorological Agency of Burkina Faso) and ground measurement data from documents [3-22].

3. Results

3.1. Forms of Daily Global Solar Irradiance Evolution Over the Course of a Year Worldwide

Daily global solar irradiance is a measurable quantity that presents different values depending on the location of the measurement site and over time.

In the case of a modeling study of this quantity of solar energy, it is interesting to know how this quantity can evolve over the course of a year. This information can then be used to find an ideal suitable model. Thus, based on NASA solar irradiation data from the period 2000 to 2023 of 60 sites, we have deduced the different types of evolution forms over the course of a year of daily global solar irradiation in the world. The results obtained are presented in Figure 1.



a) Capetown site in South Africa b) Laukuva site in Lituanie c) Nunavut site in Canada

Figure 1. *Scatter plot of daily global solar irradiation data for different countries.*

The results presented above are for sites in South Africa, Lithuania, and Canada. Each curve represents one type of daily solar irradiation evolution formed over the course of a year, identified from a set. Sites located in the southern hemisphere of the globe with a latitude greater than 10° generally present annual daily solar irradiation evolution forms similar to those shown in Figure 1a. At these sites, daily global solar irradiation values are high at the beginning and end of the year, and low or zero in the middle of the year. In the case of sites located near the equator, they commonly show annual solar irradiation evolution forms corresponding to Figure 1b. Daily global solar irradiance values at these sites are lower in the middle of the year. On the whole, global daily solar irradiance in the sites near the equator shows almost an evolution forms constant trend over the year. In the Northern Hemisphere, sites with a superior latitude 20° present global daily solar irradiations that evolve like that of Figure 1c. At the beginning and end of the year, daily global solar irradiance values are practically low or zero, and very high in the middle of the year.

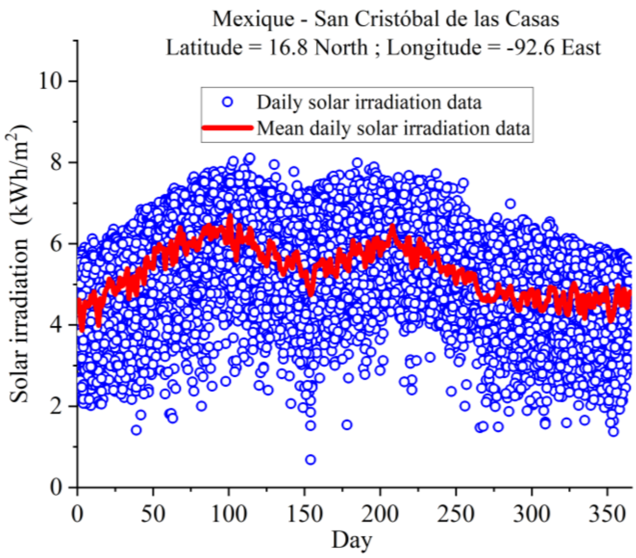


Figure 2. *Daily global solar irradiation and average values for the period 2000 to 2023.*

3.2 Example of Mean Monthly Data of Daily Global Solar Irradiation for the Period 2000-2023

In the modeling work that is undertaken in this document, we present in this section a description of the daily monthly mean global solar irradiation data.

For each of the 60 sites listed in Table 4 below, we have daily global solar irradiation data for the period 2000 to 2023, i.e., 24 years of data.

We obtained monthly mean values of daily global solar irradiance for each site, by first calculating the daily mean values of the data obtained for each of the 365 days in the period from 2000 to 2023. We then determined the monthly mean values from the daily mean values. Figures 2 to 4 show an example of a case of the determination of monthly average daily global solar irradiation values for the San Cristobal de las Casas site in Mexico.

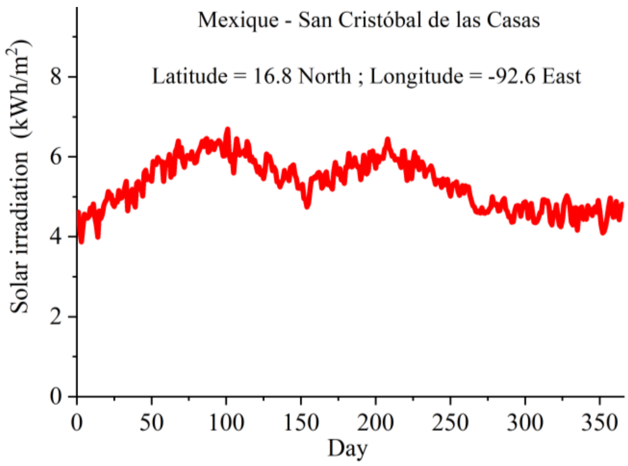


Figure 3. *Curve of the average daily global solar irradiation values for the period 2000 to 2023.*

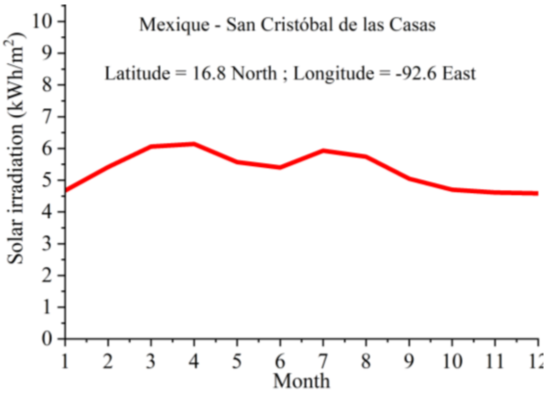


Figure 4. *Curve of monthly mean values of daily global solar irradiation for the period 2000 to 2023.*

3.3. Development of Monthly Mean Global Daily Solar Irradiance Models

By analyzing the different daily global solar irradiance prediction models presented in the literature [5, 6], we found that the extraterrestrial daily global solar irradiance model is more widely exploited. This model is expressed as a function of latitude, which is an easily determinable parameter and does not require a measurement sensor. This model is simple to handle. In this document, we will use this model to determine the general model monthly mean daily global solar irradiance on the ground. The expression for the H_0 extraterrestrial daily global solar irradiance model is given in equation (3) below.

$$H_0 = \frac{24\times I_0}{\pi}\times\left(1+0.033\times\cos(\frac{360}{365}\times J)\right)\times\left(\cos(\varphi)\times\cos(\delta)\times\sin(\omega_s)+\frac{\pi\times\omega_s}{180}\times\sin(\varphi)\times\sin(\delta)\right) \quad (3)$$

Expression (3) is expressed in kWh/m^2.

(I_0) is the solar constant whose value is 1.367 kW/m^2. (δ) is the solar declination angle. (ω_s), the sunset hour angle. (φ), represents the site latitude. And (J) is the day number for a 365 days year.

With (ω_s) determined from relation (4).

$$\cos(\omega_s) = -\tan(\delta)\times\tan(\varphi) \quad (4)$$

(δ) is calculated with formula (5).

$$\delta = 23.45\times\sin\left(360\times\frac{284+J}{365}\right) \quad (5)$$

With computer tools, the empirical model of extraterrestrial irradiance from formula (3) and data from the monthly mean values of daily global solar irradiance from the 60 sites in Table 4. We have obtained an adapted expression for the monthly mean daily global solar irradiation, which is expressed as follows:

$$H_{mean} = A\times\left(1+0.033\times\cos(\frac{-184.8+360\times m}{12})\right)\times\left(B\times\cos(\varphi)\times\cos(\delta_{mean})\times\sin(\omega_s)+C\times\frac{\pi\times\omega_s}{180}\times\sin(\varphi)\times\sin(\delta_{mean})\right)\times F_2 \quad (6)$$

H_{mean} is the monthly mean daily global solar irradiation. (m) is the month number for a year. With F_2 and δ mean defined as follows:

$$F_2 = \left(D\times Ln(1+|\varphi|)+E\times\cos(\varphi)\right) \quad (7)$$

$$\delta_{mean} = 23.45\times\sin\left(360\times\frac{-3.2+m}{12}\right) \quad (8)$$

A, B, C, D and E are coefficients whose values are given in Table 3.

Table 3. *Values of coefficients of equation 6.*

Coefficient	-60 °≤ φ < 0 °and 25 °< φ ≤ 67 °	0 °< φ ≤ 25 °
A	1.96	1.71
B	1.44	1.72
C	1.56	0.97
D	1.12	0
E	1.89	2.12

3.4. Performance of Established Model

In this section, the results obtained from the performance study of the equation (6) model for monthly mean values of daily global solar irradiation are given.

In this study, we have determined the values of performance tools, such as the Mean Absolute Percentage Error (MAPE) and the Pearson correlation coefficient (r). This work was carried out with data from 60 sites. The results show that 5% of the sites have MAPE values less than 5%. 18% of the sites have MAPE values between 5% and 10%. 65% of the sites have MAPE values between 10% and 20%. And 11% of the sites have MAPE values of more than 20%. According to the data in Table 1, the model presents a moderately interesting level of precision. In the case of the correlation of the model results of the equation (6), 90 % of the study sites have a Pearson coefficient (r) of over 0.7. On the other hand, 10% of study sites have a Pearson coefficient (r) between 0 and 0.7. Overall, this model of the equation (6) presents a fairly good correlation as shown in Figure 6 which gives all the results of the 60 sites on the correlation of the model. We present in Figure 5 a sample of the results obtained. Table 4 also presents all the MAPE and (r) values of the 60 sites.

When we analyze the performance results of existing models in the literature [3-22], we find that most of these models perform better than the model described in this document. This is due to the fact that these models are expressed according of measurement data, and the coefficients of most of these models have been recalculated according to the sites. Whereas the model established in this document is a mathematical relationship independent of measurement data, requiring only the value of site latitude to be taken into account in determining solar irradiance values.

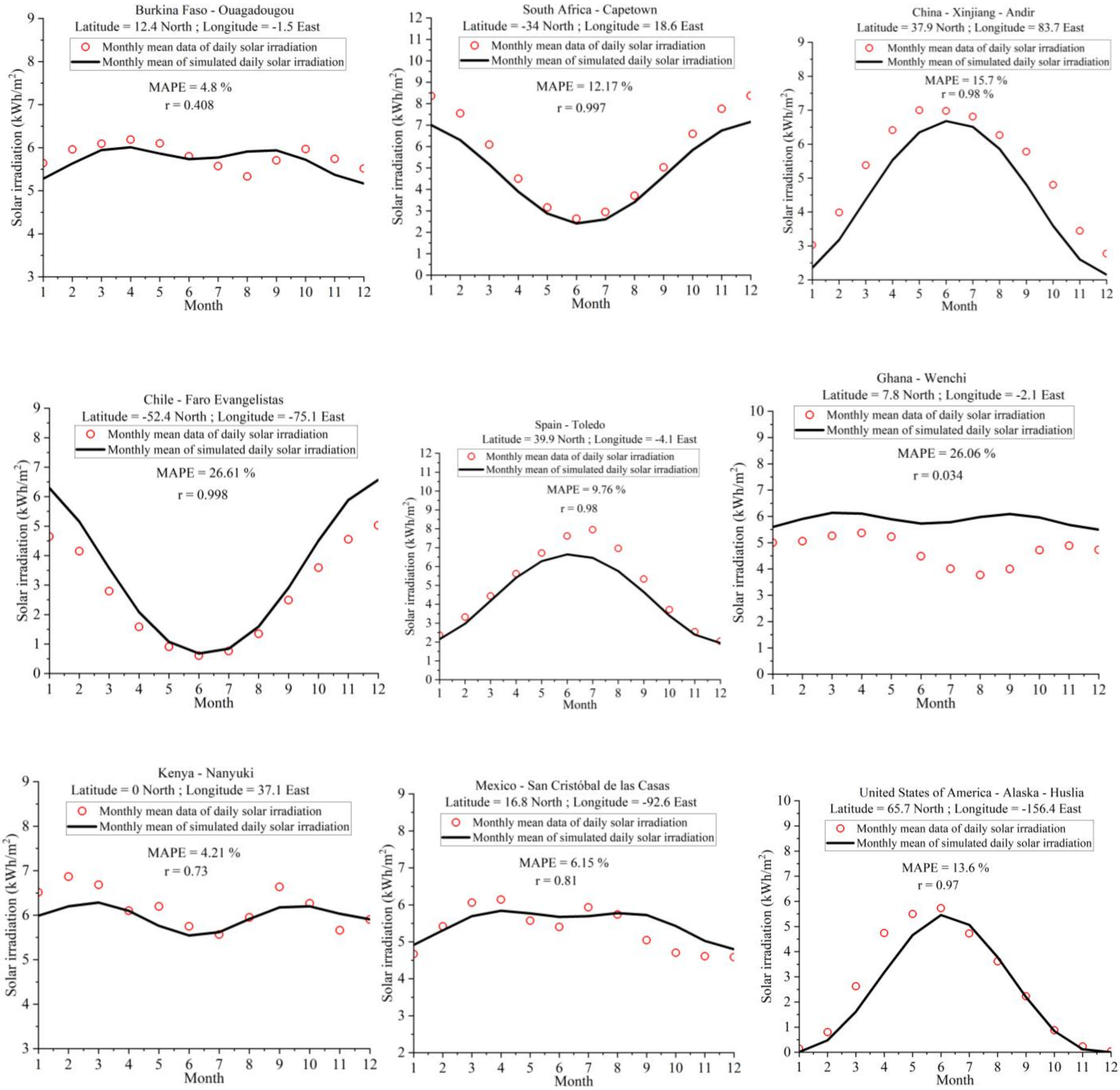


***Figure 5**. Estimated and measured of monthly mean daily global solar irradiation at different sites.*

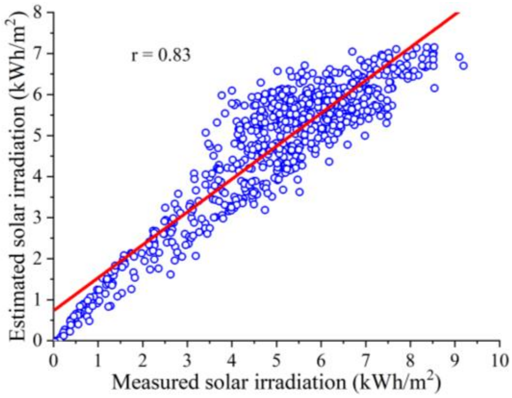


Figure 6. *Scatter plot of all data from the sites of the estimated and measured monthly mean values.*

Table 4. *(r) and MAPE values obtained according to sites.*

Site	Latitude (°)	Longitude (°)	r	MAPE (%)
Argentina - Ushuaia Aero	-54.8 N	-68.3 E	0.99	15.28
Chile - Faro Evangelistas	-52.4 N	-75.1 E	0.99	26.61
Argentina - Rio Gallegos Arpt	-51.6 N	-69.3 E	0.99	4.13
Chile - Puerto Montt Tepual	-41.4 N	-73.1 E	0.99	13.32
Chile - Temuco Maquehue	-38.8 N	-72.6 E	0.98	10.89
Chile - Concepcion Carriel	-36.8 N	-73.1 E	0.99	7.63
South Africa - Capetown	-34 N	18.6 E	0.99	12.16
Chile - Quelentaro	-34 N	-71.6 E	0.99	10.22
Australia - Northern Territory	-25 N	128.3 E	0.98	13.75
Australia - Northern Territory	-23.8 N	133.9 E	0.98	15.34
Chile - Antofagasta Cerro	-23.4 N	-70.4 E	0.99	12.83
Namibia - Walvis Bay (LH)	-22.9 N	14.4 E	0.99	8.87
Chile - Calama	-22.5 N	-68.9 E	0.98	26.15
Australia - Northern Territory	-19.6 N	134.2 E	0.96	14.11
Australia - Australie-Occidentale - Wyndham	-15.5 N	128.1 E	0.73	13
Zambia - Kabwe	-14.4 N	28.5 E	0.56	13.24
Brazil - Acre - Rio Branco Medici	-10 N	-67.8 E	0.9	13
Brazil - Ceará - Barbalha	-7.3 N	-39.3 E	0.74	7.27
Brazil - Amazonas - Tefe	-3.4 N	-64.7 E	0.41	12.64
Gabon - Lambaréné	-0.7 N	10.2 E	0.66	21.7
Congo, Rép. Démocratique du - Boende	-0.2 N	20.9 E	0.72	10.2
Kenya - Nanyuki	0 N	37.1 E	0.72	4.21
Somalia - Mogadisho	2 N	45.3 E	0.7	5.6
Ghana - Wenchi	7.8 N	-2.1 E	0.03	26.06
Somalia - Garōwe	8.4 N	48.5 E	0.8	11.11
Burkina Faso - Gaoua	10.3 N	-3.2 E	0.02	6.54

Site	Latitude (°)	Longitude (°)	r	MAPE (%)
Costa Rica - Puerto Limon	10 N	-83.1 E	0.75	23.12
India - Kerala - Kozhikode	11.3 N	75.8 E	0.14	16.07
Sudan - Niyālā	12.1 N	24.9 E	0.27	11
Burkina Faso - Ouagadougou (Mil)	12.4 N	-1.5 E	0.4	4.8
Burkina Faso - Dori	14 N	0 E	0.85	7.44
Honduras - Tegucigalpa Toncont	14.1 N	-87.2 E	0.91	10.24
Mexico - San Cristóbal de las Casas	16.8 N	-92.6 E	0.81	6.15
Niger - Arlit	18.8 N	7.3 E	0.98	16.87
Mauritania - Šingati	20 N	-12.4 E	0.97	12.85
Algéria - Tamanrasset	22.8 N	5.4 E	0.98	19.74
Japan - Minamitorishima	24.3 N	154 E	0.96	11.05
India - Bihar - Patna	25.6 N	85.1 E	0.82	12.07
Mexico - Monclova	26.9 N	-101.4 E	0.97	9.2
Algéria - Tindūf	27.7 N	8.2 E	0.99	18.18
Soudi Arabia - Tabuk	28.4 N	36.6 E	0.99	19.64
Soudi Arabia - Al-Jouf	29.8 N	40.1 E	0.99	17.75
Mexico - Puerto Peñasco	31.3 N	-113.5 E	0.98	18.11
China - Henan - Nanyang	33 N	112.6 E	0.98	14.4
United States of America - California	34.3 N	-116.2 E	0.99	19.56
United States of America - Nevada - Mercury	36.6 N	-116 E	0.99	19.87
China - Xinjiang - Andir	37.9 N	83.7 E	0.98	15.7
Spain - Toledo	39.9 N	-4.1 E	0.98	9.76
China - Xinjiang - Urumqi	43.8N	87.7E	0.99	10.29
Canada - Nouvelle-Écosse - Kejimkujik	44.4 N	-65.2E	0.99	16.68
French - Paris Orly	48.7 N	2.4E	0.99	12.72
Kazakhstan - Turgaj	49.6 N	63.5E	0.99	12.61
Netherlands	54.9 N	4.7E	0.99	7.98
United States of America - Alaska - Hydaburg Seaplane	55.2 N	-132.8 E	0.99	25.31
Lituania - Laukuva	55.6 N	22.2 E	0.99	9.44
Canada - Québec - Inukjuak	58.5 N	-78.1 E	0.98	13
Groenland - Narssarssuaq	61.1 N	-45.4 E	0.99	26.43
Russia - Khanty-Mansi - Surgut	61.3 N	73.5 E	0.97	13.44
Canada - Nunavut -	64.2 N	-83.4 E	0.98	12.44
United States of America - Alaska - Huslia	65.7 N	-156.4 E	0.96	13.6

3.5. Evolution of the Monthly Mean Daily Global Solar Irradiance as a Function of Latitude from Established Model

In the previous study, we have shown that established model has acceptable performances. In this section, we present the simulation results for the model, which are shown in the Figure 7 below.

In this Figure 7, we see that in areas close to the North Pole, the curves of monthly mean values of daily global solar irradiance have a bell-shaped evolution, with a peak in value in the middle of the year. From the northern hemisphere southwards, via the equator, we see a gradual change in the shape of global daily solar irradiance. Toward the equator, this evolution resembles a straight line with curvatures in the middle. In areas near the South Pole, solar irradiance values are high at the beginning and end of each year. They are lower in the middle of the year.

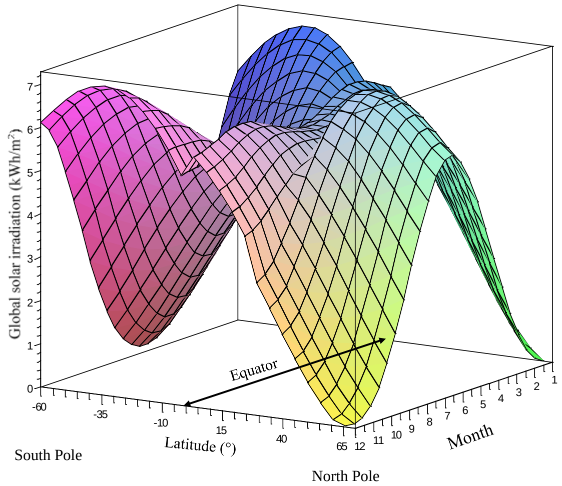


Figure 7. Monthly mean daily global solar irradiation as a function of latitude.

4. Discussion

Today, solar energy is appreciated for being renewable and non-polluting. It is harnessed directly from its heat, which allows life on earth, and through devices such as photovoltaic technology, which allows electricity to be produced. In this day and age, electricity is an essential element in the development of any country. Solar power is therefore becoming an effective means which not only allows to promote the economic and industrial development of countries, but also guaranteeing environmental protection. However, in some parts of the world, the problem of availability of solar potential data is a reality that hinders the development of solar energy. This problem is partly due to the considerable cost of weather stations, and partly to the inaccessibility of the regions concerned. Global daily solar irradiation models are one method of obtaining solar potential data. However, most existing models are expressed according of measurement data such as sunshine duration, temperature, humidity, etc [3-22]. The use of these models requires measurement data, that requires a financial investment. The model established in this manuscript enables us to estimate the global daily solar irradiance of the world's regions. It depends only on latitude and requires no financial investment. In addition, it is not necessary to recalculate the model's coefficients to adapt it to a particular site, as is the case with some models. With the interesting performance results obtained in the paper, this model represents a good method for solving the problem of solar deposit data in regions that do not have weather stations.

5. Conclusion

The study carried out in this document has made a contribution to the development of universal model of daily global solar irradiance. To obtain the results of the study in this paper, we exploited the empirical model of extraterrestrial daily global solar irradiance, data from 60 sites, and computer software. For each site, we used daily global solar irradiation data for the period 2000 to 2023, i.e. 24 years. The model established is relatively for monthly mean values of daily global solar irradiance.

The performance study carried out on the established model showed it to have moderately acceptable accuracy and fairly good correlation. This study will help solve the problem of the availability of solar potential data on the sites that do not have it.

Abbreviations

RMSE	Root Mean Square Error
ME	Mean Error
PME	Mean Percentage Error
MAPE	Mean Absolute Percentage Error
MAE	Mean Absolute Error
r	Pearson’s Correlation Coefficient
R^2	Coefficient of Determination
NASA	National Aeronautics and Space Administration
ANAM	National Meteorological Agency of Burkina Faso
ω_s	Sunset Hour Angle
δ	Solar Declination Angle
I_0	Solar Constant
φ	Latitude

Author Contributions

Jacques Marie Ilboudo: Conceptualization, Writing – original draft, Investigation, Validation, Methodology, Investigation, Data curation, Software

Dominique Bonkoungou: Conceptualization, Project administration Writing – review & editing, Investigation, Validation

Sosthène Tassembedo: Project administration, Formal Analysis, Visualization

Zacharie Koalaga: Supervision, Validation

Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] D. Bonkoungou, J. M. Ilboudo, A. Kabre, Z. Koalaga, «Monitoring and Effectiveness Analysis of a Hybrid PV Battery System in Real Conditions», International Journal of Energy and Power Engineering, 2023; 12(6): 75-83, https://doi.org/10.11648/j.ijepe.20231206.11

[2] J. M. Ilboudo, D. Bonkoungou, Z. Koalaga, «A New Approach to Sizing PV Modules While Accounting the Effect of Temperature», American Journal of Energy Engineering, 2023; 11(4): 127-133, https://doi.org/10.11648/j.ajee.20231104.14

[3] A. Angström, «Solar and Terrestrial Radiation», Quarterly Journal of the Royal Meteorological Society, Vol. 50, No. 210, 1924, pp. 121-126. https://doi.org/10.1002/qj.49705021008

[4] M. Paulescu, N. Stefu, D. Calinoiu, E. Paulescu, N. Pop, R. Boata, O. Mares, «Ångström–Prescott equation: Physical basis, empirical models and sensitivity analysis», Renewable and Sustainable Energy Reviews 62 (2016) 495–506, http://dx.doi.org/10.1016/j.rser.2016.04.012

[5] Mohamed Salah Mecibah, Taqiy Eddine Boukelia, Reda Tahtah, Kacem Gairaa, «Introducing the best model for estimation the monthly mean daily global solar radiation on a horizontal surface (Case study: Algeria)», Renewable and Sustainable Energy Reviews 36 (2014) 194–202, http://dx.doi.org/10.1016/j.rser.2014.04.054

[6] C. Iradukunda, K. Chiteka, «Angstrom-Prescott Type Models for Predicting Solar Irradiation for Different Locations in Zimbabwe», Journal of Mechanical Engineering 69(2023)1-2, 32-48, https://doi.org/10.5545/sv-jme.2022.331

[7] H. Morf, «A stochastic solar irradiance model adjusted on the Angström–Prescott regression», Solar Energy 87 (2013) 1–21, http://dx.doi.org/10.1016/j.solener.2012.10.005.

[8] Muhammad Jamilu Ya'u, Muhammad Abdullahi Gele, Yerima Yusif Ali, Abdulkarim Mika'il Alhaji, «Global Solar Radiation Models: A Review», Journal of Photonic Materials and Technology, 2018, 4(1): 26-32, https://doi.org/10.11648/j.jmpt.20180401.15

[9] H. Ögelman, A. Ecevit, E. Tasdemiroglu, «A new method for estimating solar radiation from bright sunshine data», Solar Energy 1984; 33: 619–25, https://doi.org/10.1016/0038-092X(84)90018-5

[10] F. Besharat, A. A. Dehghan, A. R. Faghih, «Empirical models for estimating global solar radiation: A review and case study», Renewable and Sustainable Energy Reviews 21 (2013) 798–821, http://dx.doi.org/10.1016/j.rser.2012.12.043

[11] T. D. M. A. SAMUEL, «ESTIMATION OF GLOBAL RADIATION FOR SRI LANKA», Solar Energy Vol. 47, No. 5, pp. 333-337, 1991, https://doi.org/10.1016/0038-092X(91)90026-S

[12] D. B. Ampratwum, A. S. S. Dorvlo, «Estimation of solar radiation from the number of sunshine hours», Applied Energy 63 (1999) 161-167, https://doi.org/10.1016/S0306-2619(99)00025-2

[13] J. Almorox, C. Hontoria, «Global solar radiation estimation using sunshine duration in Spain», Energy Conversion and Management 45 (2004) 1529–1535, https://doi.org/10.1016/j.enconman.2003.08.022

[14] K. Bakirci, «Correlations for estimation of daily global solar radiation with hours of bright sunshine in Turkey», Energy 34 (2009) 485–501, https://doi.org/10.1016/j.energy.2009.02.005

[15] Hargreaves GH, Samani ZA, «Estimating potential evapotranspiration. Journal of Irrigation and Drainage Engineering», 1982; 108(IR3): 223–230, https://doi.org/10.1061/JRCEA4.0001390

[16] R. Chen, K. Ersi, J. Yang, S. Lu, W. Zhao, «Validation of five global radiation models with measured daily data in China», Energy Conversion and Management 2004; 45: 1759–69, https://doi.org/10.1016/j.enconman.2003.09.019

[17] C. K. Pandey, A. K. Katiyar, «Temperature base correlation for the estimation of global solar radiation on horizontal surface», IJEE. 2010; 1: 737–44.

[18] B. Benamrou, O. Mustapha, I. Allaouzi, M. B. Ahmed «Empirical models for estimating the global solar radiation based on air temperature and sunshine duration», 2018 Association for Computing Machinery, ACM ISBN 978-1-4503-6562-8/18/10, https://doi.org/10.1145/3286606.3286856

[19] K. BRISTOW and G. S. CAMPBELL, «On the relationship between incoming solar radiation and daily maximum and minimum temperature», Agricultural and Forest Meteorology, 31 (1984) 159-166, https://doi.org/10.1016/0168-1923(84)90017-0

[20] R. K. Swartman and O. Ogunlade, «Solar Radiation Estimates from Common Parameters», Presented at the Solar Energy Conference, Tempe, Arizona, March 20-22, 1967, https://doi.org/10.1016/0038-092X(67)90026-6

[21] A. A. El-Sebaii, A. A. Al-Ghamdi, F. S. Al-Hazmi, A. S. Faidah, «Estimation of global solar radiation on horizontal surfaces in Jeddah, Saudi Arabia», Energy Policy 37 (2009) 3645–3649, https://doi.org/10.1016/j.enpol.2009.04.038

[22] J. C. Ododo, A. T. Sulaiman, J. Aidan, M. M. Yuguda, F. A. Ogbu, «The importance of maximum air temperature in the parameterisation of solar radiation in Nigeria», Renewable Energy, Vol. 6, No. 7, pp. 751 763, 1995, https://doi.org/10.101016/0960-1481(94)00097-P