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ScienceDirect
Energy Procedia 49 (2014) 2290 – 2296
Energy Procedia

SolarPACES 2013

Beam solar irradiation assessment for Sonora, Mexico

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Abstract

Located in north western Mexico, the State of Sonora has an excellent quality solar resource, with the highest solar irradiation levels in the country. In less than 1% of its vast arid territory, it receives enough solar power to satisfy the energy demand of the entire country. In spite of its huge solar potential, there has been little work on the measurement of solar radiation in this area. At a few locations, global solar radiation has been measured for some years. Also there have been some works reporting evaluation of solar irradiation based on empirical models or satellite images. Because of the very small amount of precipitation on most of its territory, Sonora is ideal for the implementation of concentrated solar power (CSP). Beam solar radiation data is necessary for the sizing and assessment of CSP plants. Unfortunately, very little information is available on this solar radiation component for Sonora. The present work reports on the results of recent measurements of beam and solar global radiation for the area of the city of Hermosillo, in the center of the state. The obtained results are compared with other available information obtained by indirect methods, such as satellite based or empirical climate data based models. The yearly available energy as well as the utilizable energy for certain irradiance levels is evaluated.

Selection and peer review by the scientific conference committee of SolarPACES 2013 under responsibility of PSE AG.
Final manuscript published as received without editorial corrections.
Keywords:Beam solar radiation; solar radiation; solar resource.

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Selection and peer review by the scientific conference committee of SolarPACES 2013 under responsibility of PSE AG.
Final manuscript published as received without editorial corrections.
doi:10.1016/j.egypro.2014.03.242

1. Introduction

Mexico receives important amounts of solar radiation over its whole territory. Therefore, the country has a big potential for solar energy applications. However, this solar resource is far from being adequately evaluated. In particular, high quality beam solar radiation is available mainly, but not exclusively, in the northwest states: Sonora, Baja California, Sonora, and Chihuahua, but there are also other parts of the territory. The state of Sonora, with its large desert areas has the highest potential. Nevertheless, beam solar radiation measurements are very scarce.

Different authors [1-4] have carried out indirect solar resource evaluation for Mexico and have published different maps. For instance the work of Galindo, Castro and Valdez [3], reported global radiation isolines for average solar insolation for each month of the year, and also provided values for specific locations corresponding to important cities. The methodology of that work was based on satellite estimations from VISSR radiometer data with a detection range between 550 and 750 nm wavelength, on board in geostationary satellites SMS-2 and GOES-2. The files used consist of seven daily images with a resolution of one degree by one degree (latitude and longitude), and are translated into irradiance according to Tarpley method, modified by Galindo et al in 1991 [4]. The more recent work by Estrada-Cajigal and Almanza [5] used the model validated by Reddy [6] for different locations in India, which is based in climatological data to estimate solar radiation empirically. This work also uses a correlation by Page [7] to obtain the diffuse component from the global irradiance and from this, the DNI. It was published together with a software program to evaluate the different components of solar irradiance for any location in Mexico, based on the implemented models.

This paper reports some measured beam solar radiation data for the city of Hermosillo, located in the Sonoran desert. Also, global solar radiation data is presented for other locations in the state, and a simple model, based on well-known correlations [7,8,9] is used to estimate beam solar radiation form this information. The results obtained are also compared with the above quoted works [3,5].

2. Methodology

The present work is intended as a preliminary assessment of beam solar radiation resource for the state of Sonora. Data for this work was taken from different stations as listed in Table 1. Also in Fig. 1, the location of the stations in the state of Sonora is shown.

Table 1. Measurement stations for data used in the present work.

Location	Latitude	Longitude	Elevation	Global	Beam	Sensors	Years	Operator
Hermosillo, Son.	29.028	-111.145	200 m	Yes	Yes	Eppley PSP, Kipp & Zonen CM11	Apr 2012-Mar 2013	UNAM/ UNISON
Temixco, Mor.	18.840	-99.236	1270 m	Yes	Yes	Eppley PSP, Eppley B&W	2010-2012	UNAM
Nogales, Son.	31.298	-110.914	1275 m	Yes	No	Kipp & Zonen CM11	2004- 2006	SMN
Alamos, Son.	27.022	-108.938	409 m	Yes	No	Kipp & Zonen CM11	1999-2002	SMN
Bahia de Kino, Son.	29.013	-111.137	160 m	Yes	No	Kipp & Zonen CMP11	2008-2011	SMN

First of all, data from two stations were both beam and global solar radiation are measured on a routine basis, were used as references to check the implemented models. These stations are among the very few measuring beam solar radiation in the country: the station recently installed at the Heliostat Test Field, operated by Universidad Nacional Autónoma de México (UNAM) and Universidad de Sonora; and the station of UNAM's Instituto de Energías Renovables (Renewable Energy Institute) located in Temixco, in the state of Morelos. The latter is not located at the region of interest but is used as a reference because it has been measuring beam solar radiation for a longer period.

Fig. 1. Location of the stations considered in the State of Sonora.

After the models are checked against the available beam solar radiation data, they are implemented for the other stations in the State of Sonora, wich measure Global radiation only. These are stations from Servicio Meteorológico Nacional (National Meteorological Service). There are 6 stations from this authority in Sonora, the data from those listed in Table 1 has been validated, while the others are still in progress.

From the values of monthly averaged global insolations the diffuse component can be obtained by means of a series of correlations published by different authors. In particular we use that from Page [6]

$$H_d = H(1.0 - 1.13\,K_T) \tag{1}$$

where the clearness index is the ration form the monthly averaged daily insolation to the extraterrestrial global insolation.

$$K_T = H/H_0 \tag{2}$$

Also the correlation from Erbs et al. [7]

$$H_d = H(1.391 - 3.560\,K_T + 4.189\,K_T^2 - 2.137\,K_T^3) \tag{3a}$$

for $\omega_s \leq 81.4°$ and

$$H_d = H(1.311 - 3.022\,K_T + 3.427\,K_T^2 - 2.821\,K_T^3) \tag{3b}$$

for $\omega_s > 81.4°$. Where ω_s is the sunset hour angle. Finally the one from Collares-Pereira and Rabl [8]

$$H_d = H\{0.775 + 0.00606\,(\omega_s - 90°) - [0.505 + 0.00455\,(\omega_s - 90°)]\cos(115K_T - 103)\} \tag{4}$$

From the obtained diffuse radiation and the global one the monthly averaged direct normal insolation is obtained as

$$H_{bn} = \left(H - H_d\right)\left\langle \cos\theta_z \right\rangle^{-1} \quad (5)$$

where the term in angular brackets is the monthly averaged cosine of the zenith angle.

The beam solar radiation obtained from eq. (5) is calculated first, with the different diffuse radiation models, for the two sites with measured beam solar radiation. From this comparison one model is chosen to carry out further calculations for the sites with no measurements of this component.

3. Results

Fig. 2 presents graphs of monthly averaged global insolation for the selected sites in Sonora, based on measurements taken at the stations of Table 1.

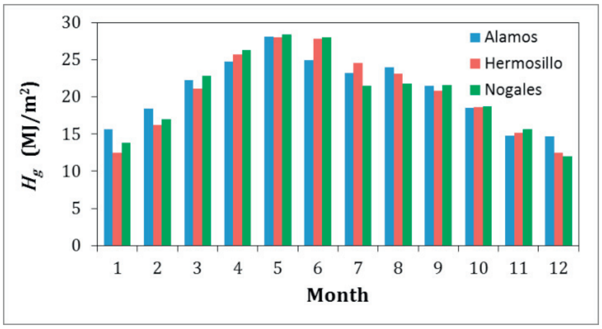

Fig. 2. Monthly averaged global insolation for different locations in Sonora.

3.1. Comparison of the models

The results of the application of the different models to obtain the beam solar component from the global radiation data, for the reference stations is compared with the measured monthly averaged beam insolation for the reference sites.

As seen in Fig. 4 all the models tend to overestimate the beam solar component, but the model that best approaches the measured results is the one that uses the Collares-Pereira and Rabl correlation [8]. Moreover it is notorious that this model fits much better the results from Hermosillo, than those from Temixco (8.5% and average deviation). This may have to do with the fact that the quoted model was validated for measurements carried out in the United States; the latitude and climate of Hermosillo are much closer to that country than those of Temixco. Actually this latter site is in the inter-tropical region. According to this, and due to the relative similarity of the behavior of the different stations from Sonora, we chose to use the correlation from Collares-Pereira and Rabl to evaluate diffuse radiation.

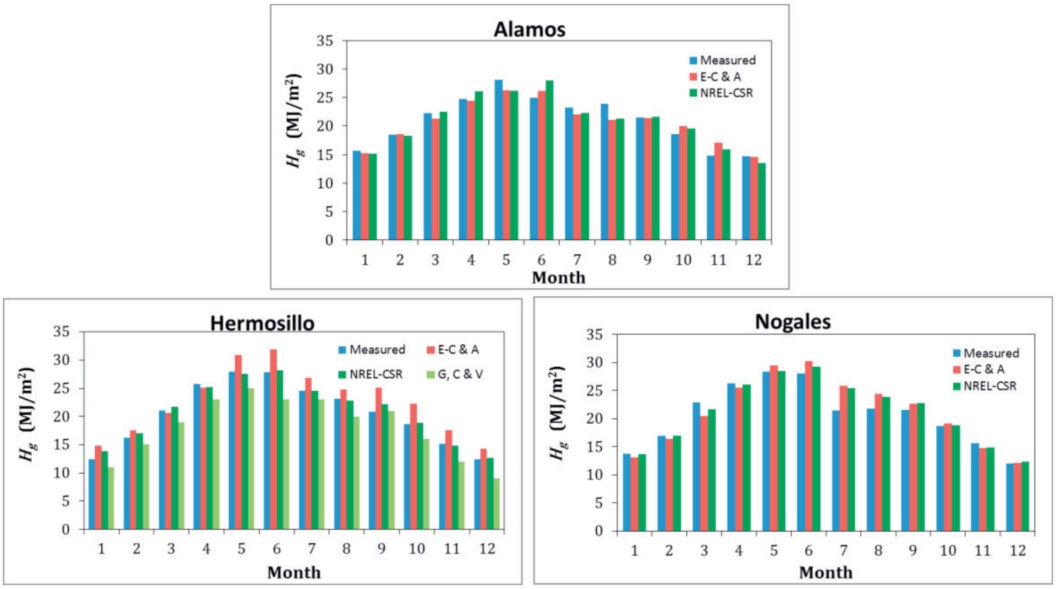

Fig.3. Comparison of measured data with different models.

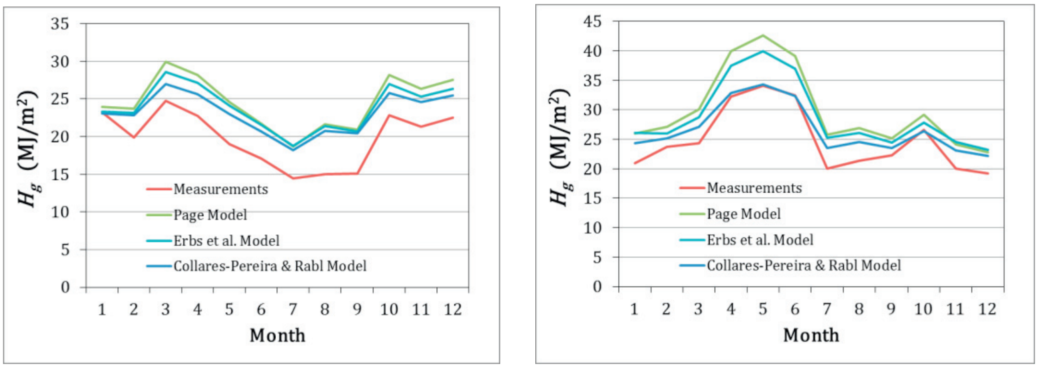

Fig. 4. Monthy averaged beam insolation data for Hermosillo (left) and Temixco (right), as compared to the different models.

3.2. Evaluation of beam insolation

Using eqs. (4) and (5) and the data of global radiation form the different sites, beam solar insolation is evaluated. The results are shown in Fig. 5.

As can be observed the behavior of beam solar radiation for the different sites is very similar. Even though precipitation is small in the most of the state of Sonora, it is interesting to observe a clear diminution of beam normal solar radiation in the months of July, August, and September, which correspond to the rainy season. This is due to the increased cloudiness during this time of the year, in spite of the lack of important precipitations.

3.3. Distribution of hours according to irradiance level

The cumulative distribution of hourly average beam solar irradiance was calculated for Hermosillo from the measured data. This distribution gives the average number of hours in a day with average irradiance above fixed radiation levels, and is presented in Fig. 6. Here it can be seen that there are for instance

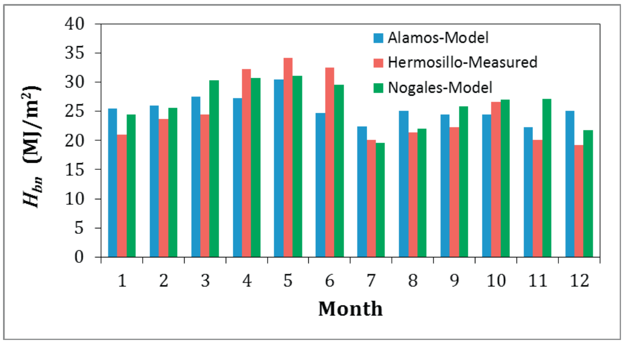

Fig. 5. Monthly averaged beam solar insolation for locations in Sonora.

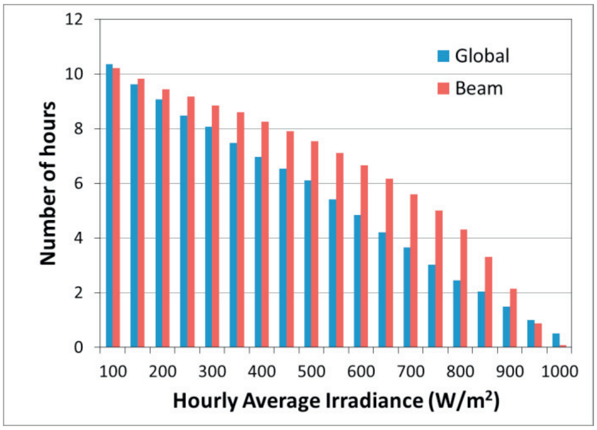

Fig. 6. Average number of hours in a day with hourly average irradiation above given levels for Hermosillo.

4. Conclusions

Quite high yearly average global insolation values have been measured for the locations in Sonora, ranging from 5.6 to 5.8 kWh/m^2/day. Also high values have been estimated for the beam component of radiation around 7 kWh/m^2/day. Of course, these latter values are not definitive, but subject to further improvement of the models. The exception is Hermosillo, where beam normal solar radiation has been actually measured, giving the result of 7.8 kWh/m^2/day, which is an excellent value for concentrating solar energy aplicaciones. This amounts to 10249 MJ/m^2 a year.

Acknowledgements

The authors gratefully acknowledge Cuitlahuac Iriarte, Pablo Sosa, and Julio Mont for technical support with solar radiation measurements. This work has been partially supported by CONACYT trough grant 123767.

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