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ISES SWC2015 –THE STATE OF SOLAR ENERGY RESOURCE ASSESSMENT IN COSTA RICA

Natalia Alvarado[1], Rodrigo A. Escobar[2], John Boland[3], and Evelyn Quiros[4]

1 Universidad de Costa Rica, Costa Rica

2 Pontificia Universidad Católica de Chile, Santiago, Chile

3University of South Australia, Australia

4 Instituto Costarricense de Electricidad, Costa Rica.

Abstract

It is traditionally assumed in Costa Rica that given its geographical location there must be a large potential for electricity generation from solar energy. However, this potential has not been properly assessed with measurements of high quality up to modern standards, and therefore the country still lacks the information needed to either establish public policies to promote solar energy utilization or support the development of commercial projects. The current trend of increasing energy consumption in the country and the existing interest on increasing solar energy utilization require an updated analysis of the available solar resource in order to generate meaningful data that can be used by government and private parties.

Costa Rica has been measuring global horizontal irradiation for over 20 years in several stations distributed throughout the country, although in most cases the measurements have been conducted without quality control checks and postprocessing. This network of radiometric measurement stations was set out to identify regions with adequate levels of average daily sunlight in order to define regions in which solar energy systems could find engineering applications.

Currently the measurement network is operated for the ICE group (Costa Rican Institute of Electricity), and consists of Second Class Pyranometers CHP3 and First Class Normal Incidence Pyrheliometer CHP1, both from Kipp and Zonen brand. The information is stored as minute-averages and spans a period of four years. No locally developed and validated satellite estimation models have yet been reported, and instead the country relies on commercial data. There are no measurements of either diffuse or direct normal irradiance. A more complete climatological characterization of the solar resource is possible by using the measured data of global horizontal irradiance coupled with the existing diffuse fraction models such as (Boland, Lauret, & Ridley, 2010) and (Jing, Boland, & Ridley, 2012), which allow decomposing the Global horizontal into its direct and diffuse components. This represents a significant improvement in the amount and quality of solar information that is available for solar engineering applications in Costa Rica and can be published for public access.

key-words: solar data, irradiance, radiation, solar energy, resource assessment & climate, solar potential, Central America

1. Introduction

Costa Rica is located in the southern part of Central America, between the coordinates 8° 15' – 11° 00' North and 83° 30' – 86° 00' West. This area is located within the tropical belt of the Northern Hemisphere. To the

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north, the country borders with Nicaragua, and in the south with Panama. To the east and west the country is surrounded by the Caribbean Sea and the Pacific Ocean, respectively. The country has a rich geography that is associated with higher levels of precipitations, humidity and temperature. Costa Rica has a surface area of 51,100 km² and a population of approximately 4.3 million people.

More than 60 % of the population lives around the capital San José, which is located in the center of the country. This area is called the "Gran Área Metropolitana" (GAM) in Spanish also called Central Valley. The area is surrounded by mountains and it concentrates most of Costa Rica´s industry. The rest of the country consists mainly of natural reserves and agricultural land.

Energy Consumption

Costa Rica has a 98.6% electrification rate, which is the highest in Central America, and a per capita power consumption of about a 1,611 kWh/year. On average, a middle-income Costa Rican family's electric bill takes up 2% of its income—one of the lowest rates in the region, thanks to Costa Rica's higher per capita income and lower power prices owing to the large utilization of hydropower for electricity generation that reaches 91% of the total installed capacity, making it very dependent and vulnerable to weather variability. Today it is known that climate and climate variability (such as for example events like El Niño Southern Oscillation ENSO) can cause unusual atmospheric patterns in the country thus affecting the energy generation and increasing use the energy from fossil fuels.

Electricity demand presents a clear pattern with growing consumption during the morning and two daily peaks, one in the early afternoon and the second at dusk. The forecasted demand growth rate for the next few years is 4% annually. Solar energy is considered as an important potential source to meet the growing energy demand of Costa Rica.

As of now, there have been several different reports trying to characterize the solar resource in the country including the following documents: *Non-Conventional Energy Sources* (Electrowatt Engineering Services ltd, 1983), *Radiación solar global de Costa Rica* (Castro, 1987), *Mapas de radiación solar en Costa Rica* (Wright, 2002), *Map of solar resource of SolarGIS from satellite data* (Weigl, 2014), *Determinación del potencial de energía solar para generación eléctrica en Costa Rica*. (ICE, 2014).

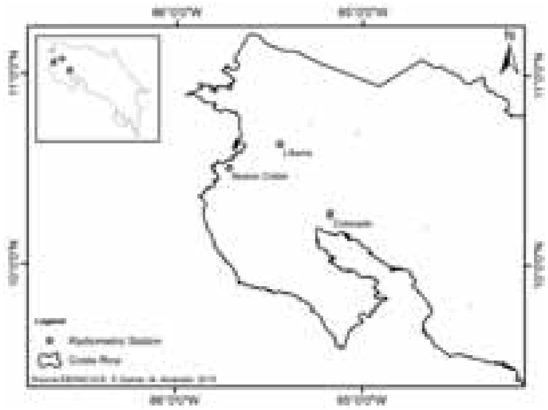
Some of these reports were performed the ground data, but with low quality, because had a systematic errors. Due to this low quality of the data arises the need for modeling as a method of quality control and analysis of solar resource available in the country for its subsequent use as an energy source. In the Electrowatt document the information considered included 22 actinographs and 26 heliometers with data previous to 1982. The results indicated that the majority of the irradiation data was affected by systematic and random errors due to poor sensor operation and maintenence. Castro´s work (1987) reviewed all actinography and heliometer data available in the country and achieved similar conclusions, that the uncertainty levels on average of 10% with maximum of 25%. Wright´s work (2002) concluded that the density of measurement points was adequate although the data quality was low as it displays high uncertainty, short measurement periods, uncalibrated sensors, and substandard maintenance. Considering this, it is clear that a larger effort must be made to properly evaluate the available solar resource in Costa Rica.

2. Available Data

The data we choose to use with a model is data from three locations over same climate region, the north pacific region in Costa Rica (Liberia, Colorado and Nueva Colon). These data were collected as a response of campaign of measurement the national electricity company in Costa Rica.

Each station was equipped with a pyranometer (CMP3) and a pyrheliometer (CHP1) manufactured by Kipp and Zonen with Campbell-Stokes datalogger. The measurements include globaland direct normal irradiance values with sampling rate and minutal averaged storing rate. Every dataset has been reviewed using a quality control (QC) procedure based on the BSRN guidelines (McArthur, 2005).

Liberia and Colorado locations used have time series of measured irradiance since a 2009.In the following analysis only a full year of data (2014) is considered. Figure 1 present the location of the three stations considered here. These radiometric stations have similar geographical and climatological characteristics as the elevation and climate of the stations differ from 85 m to less 1000 m. These three stations are located in relative proximity as it was previously determined that the region has a large potential for solar energy utilization.



Station	**Lat (deg.)**	**Lon (deg.)**	**Elev. (m)**
Liberia	10.6	-85.4	990.7
Colorado	10.3	-85.2	999.2
Nuevo Colón	10.5	-85.7	85.0

Figure 1: Measurement stations location

3. The Boland-Ridley-Lauret (BRL) Model

However, for this paper, we have global and direct radiation is measured, for modelling solar energy applications, the amount of radiation on a surface is needed. Different models for estimating the diffuse fraction and correlating it to the clearness index, such as Orgill and Hollands, Erbs et al, Reindl et al (Duffie & Beckman, 1980). Also, Boland et al. (2010) presented a model based on predictors for finding the diffuse fraction from GHI data. The model utilizes the hourly clearness index, solar altitude, apparent solar time and a measure of persistence of global radiation level as predictors and allows estimating the diffuse fraction for measured datasets. The diffuse fraction is defined as the ratio between diffuse horizontal irradiation and global horizontal irradiation:

$$d = \frac{I_{diffuse}}{I_{global}} \quad (1)$$

According to Boland et al (2010), the diffuse fration can be also represented as:

$$d = \frac{1}{1 + e^{-5.38 + 6.63 k_t + 0.006 AST - 0.007\alpha + 1.75 K_t + 1.31\psi}} \quad (2)$$

Where k_t is hourly clearness index, *AST* the solar time, α the solar angle in degrees, K_t the daily clearness index, and ψ is the persistence.

4. Methodology

For this paper, it had been used at hourly data from 365 days of Liberia Station, 398 days of Colorado Station and 88 days of Nueva Colon Station.

The information obtained from the model (BRL), is compared with the diffuse fraction from the Orgill and

Hollands model (Duffie & Beckman, 1980) and the diffuse fraction obtained from DNI data. The diffuse fraction of the Orgill and Hollands model is:

$$d = \begin{cases} 1.0 - 2.49k_t & for\ k_t < 0.35 \\ 1.557 - 1.84k_t & for\ 0.35 \le k_t \le 0.75 \\ 0.177 & for\ k_t > 0.75 \end{cases} \quad (3)$$

For this work the minutal data was initially to convert to hourly data. With the calculated of k_t-hourly clearness index we applies an Orgill and Hollands model, the equation 3.

For the BRL model, equation 2, first step it to calculate the parameters is hourly clearness index, *AST* the solar time, α the solar angle in degrees, K_t the daily clearness index, and ψ is the persistence detailed is in Boland et al. (2010)

Finally to determine the diffuse fraction from the minutes variables of GHI and DNI, it calculated the hourly averages, diffuse radiation is determined with the differential of the global radiation (GHI) and the horizontal component of direct radiation (DNI cos (θ_z)), the diffuse fraction was determined by applying the equation 1.

After include the information, we obtained the next figures 2 to figure 4.

5. Results

The diffuse fraction was obtained by a BRL model, have a right behavior curves expected by a data in the three locations. These patterns we associate with a good performance of this model in a north pacific Costa Rica region.

After a graphical comparison for the three points of data of the fit of the BRL model overlaid against Orgill and Holland model is shown in Figure 2 and Figure 4 where we can observe a very good fit to most of that data set of Liberia and Colorado. We observe seems to fit the data reasonably well but does not fit enough into the high clearness index region.

In a case of a Nuevo Colón, Figure 4 shows the fit between the two models where we see that both does not extend fit enough into the high clearness to low diffuse values, but this station has less quantity of data.

We need move onto formal error analysis, because we need to know if BRL model is performing better than other models.

Besides in a Figure 2 to 4, the result of used DNI fraction to calculate diffuse, but the result show very complex patterns, in the three points if possible that we have errors resulting from the operational problems, easily noticed by this type of plot. We recognized that any serious departure of data from the normally expected value is thus identified.

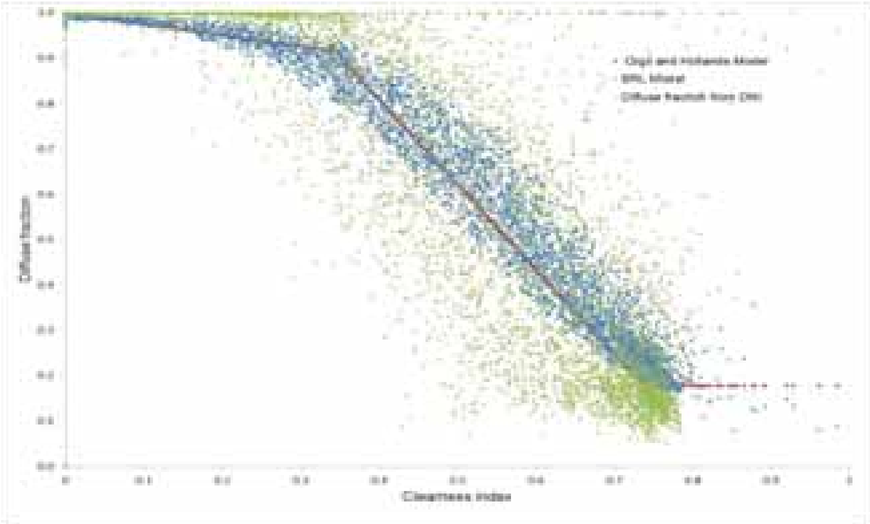


Figure 2. Liberia Data with BRL model, Orgill and Hollands model and Diffuse Fraction from DNI

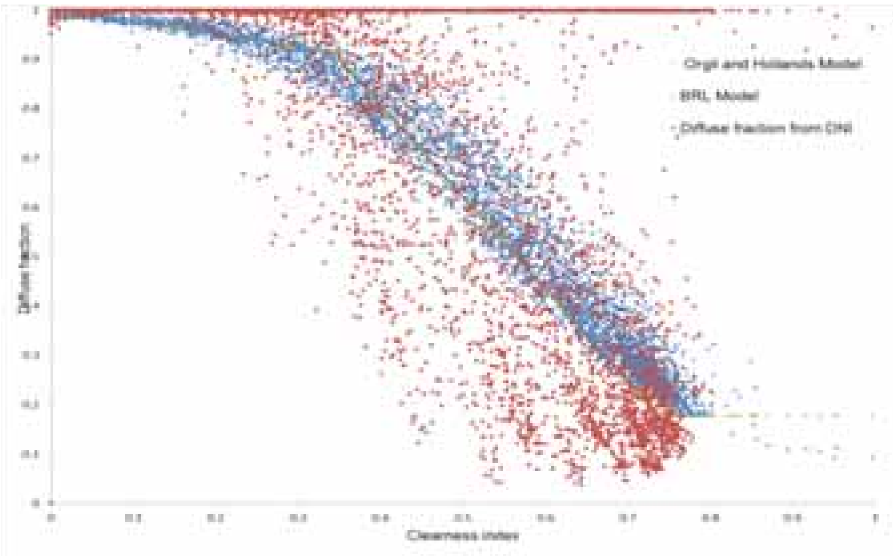


Figure 3. Colorado Data with BRL model, Orgill and Hollands model and Diffuse Fraction from DNI

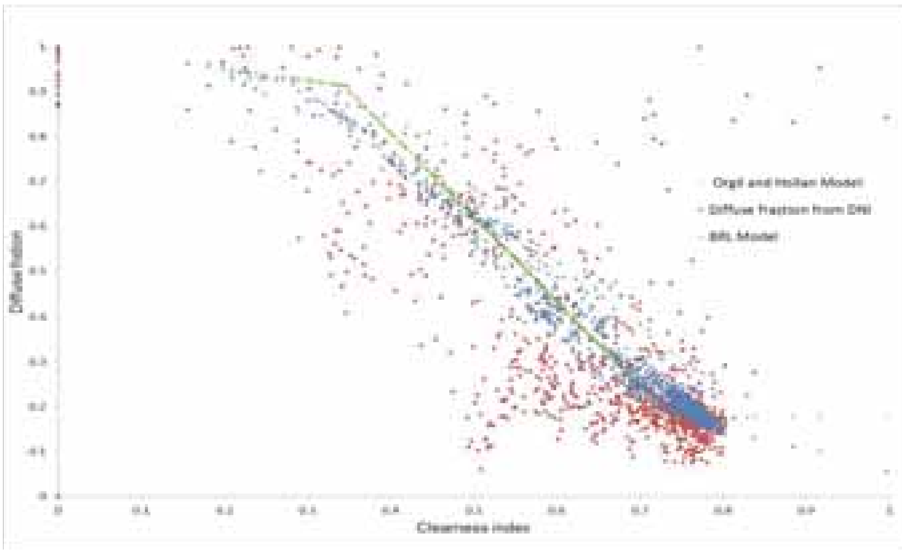


Figure 4. Nueva Colon Data with BRL model, Orgill and Hollands model and Diffuse Fraction from DNI

The points in the top right of the graphic can be caused for misalignment of the sensor CHP1, the data modeled with BRL and as obtained from measured data present conglomerate with low fraction of diffuse, so the DNI component is significant.

La información disponible actual es insuficiente, para su comparación con diferentes modelos. Adicionalmente, permitirá analizar la afectación de los patrones atmosféricos de la región ante el recurso solare. Costa rica debe generar bases de dato de calidad, que genere información requerida para su comparación con diferentes modelos

The available information is insufficient for comparison with various models applied. In addition, it did not allow analyzing the affectation of the weather patterns of the region on the solar resource.

6. Conclusions

The all figure we observe that BRL model and Orgill and Hollands models have the right behavior curves but the information from de DNI presents an involute acceptable some data out of it. Some reason of this because the measures have many errors.

We need move onto formal error analysis, because we need to know if BRL model is performing better than other models.

Costa Rica must generate reliable and high quality databases, with sufficient information for the use and verification of different solar models in order to determinate of the solar resource and its subsequent conversion to energy.

7. References:

Boland, J., Lauret, P., & Ridley, B. (2010). Modelling of diffuse solar fraction with multiple predictors. *Renewable Energy*(35), 478–483.

Castro, V. (1987). *Radiación Solar Global en Costa Rica.* San José, Costa Rica: Instituto Meteorologico Nacional.

Duffie, J., & Beckman, W. (1980). *Solar Engeneering of Thermal Processes.* Madison-Wisconsin: Wiley Interscience Publication.
Electrowatt Engineering Services ltd. (1983). *Non- Conventional Energy Sources.* San José: Instituto Costarricense de Electricidad.
ICE. (2014). *Determinación del potencial de energía solar para generación eléctrica en Costa Rica* . San José: ICE.
Jing, H., Boland, J., & Ridley, B. (2012). *Decomposing Global Solar Radiation into its Direct and Diffuse Components.* South Australia: School of Mathematics and Statistics, Barbara Hardy Institute, University of South Australia.
McArthur, L. J. (2005). *Operation Manual, Version 2.1.* Canada: BSRN.
Weigl, T. H. (2014). *Analysis of the Technical Potential and Profitability of Photovoltaic in Costa Rica*. Recuperado el 30 de 06 de 2015, de Acesolar: http://www.acesolar.org/ckfinder/userfiles/files/Master%20Thesis%20Toni%20Weigl%2C%20Solar%20Energy%20in%20Costa%20Rica.pdf
Wright, J. (2002). *Mapas de radiación solar en Costa Rica.* Heredia, Costa Rica: Universidad Nacional.