Comparison and assessment of circumsolar ratio models for Évora, Portugal

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1. Introduction

The sun rays are scattered due to molecules, aerosols and some cloud types, such as cirrus clouds, and a region near to the vicinity of the sun disk, known as circumsolar region, with relatively high diffuse sky radiance is formed [1]. Consequently, this diffuse radiation is called circumsolar normal irradiance (CSNI). Modelling the CSNI is important because pyrheliometers (the instruments that are used to measure direct normal irradiance – DNI), have an aperture angle wider than the circumsolar region, and thus DNI measurements obtained with these instruments cannot resolve the distribution of solar radiance in that region [2]. Moreover, since concentrated solar power (CSP) systems only capture solar radiation from this region but with a narrower aperture angle than that of the pyrheliometers, this leads to an overestimation of the energy reaching the receiver of the CSP systems [1]. This can result in misleading power output estimations, which can harm the bankability of CSP projects. Information on CSNI is also crucial when designing, sizing and operating CSP powerplants.

2. Literature review and model development

CSR modelling is usually performed using radiative transfer models. However, these models are difficult to use for rapid calculations of the CSR due to the quantity and availability of input parameters as well as high computation times. To address this issue, simpler models using more common input parameters such as Global Horizontal Irradiance (GHI) or DNI are available in the literature, namely, the Neumann et al. model [3], the Ivanova model [4] and the Ejssa et al. model [2].

In clear sky conditions, the CSNI is directly proportional to the diffuse horizontal irradiance (DHI), that is, if the DHI is higher, then the CSNI is also higher. This relationship can be extended to the relationship between the circumsolar ratio (CSR = CSNI / DNI) and diffuse fraction index (K_d, the ratio between DHI and GHI). On the other hand, an increase of DNI in respect to the extra-terrestrial irradiance (K_b) represents a cleaner atmosphere and therefore, a low value of CSR. In a similar way, this relationship can also be represented through the clearness index (K_t, the ratio between GHI and extra-terrestrial irradiance). Combining the relationships described above, and adding some fitting coefficients to better determine the relationship between these parameters, the following equation to describe the CSR at Évora was used:

$$CSR(1-K_d) = \frac{0{,}04}{0{,}52 + (K_t K_b / K_d)^{1{,}65}}$$

3. Statistical analysis

The comparison and assessment of both the CSR model presented in this work as well as the models available in the literature was addressed using the global performance index (GPI) [5]. The GPI is a statistical tool which combines several statistical indicators allowing for easy comparison of the models, and is given by:

$$GPI = \sum_{j=1}^{5} \alpha_j (\bar{y}_j - y_{ij})$$

where $\bar{y}_j$ is the median of the scaled values of the statistical indicator j, y_{ij} is the scaled value of the statistical indicator j for the model i and α_j equals 1 for all the statistical indicators except the correlation coefficient, in which α_j equals to -1. The statistical indicators used in this work that were combined into the GPI were the following: mean bias error (MBE), the root mean square error (RMSE), the uncertainty at 95% (U95), the t-statistics (t-stat) and the correlation coefficient (R).

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4. Results

The performance of the models analysed here was assessed through a dataset of CSNI values for Évora, Portugal, which was created using the radiative transfer model libRadtran and AERONET data. Taking this dataset as reference, the several statistical indicators were calculated and the model with better performance (higher GPI value) was found to be the model proposed in this work, followed by the model proposed by Eissa et al. [2], as presented in Table 1, in which the values in bold represent the best model according to each statistical indicator.

Table 1. Statistical analysis of the CSR models at Évora.

Model	MBE (W/m^2)	RMSE (W/m^2)	t-stat	U95 (W/m^2)	R	GPI
Neumann et al. [3]	**9.90**	28.25	**35.02**	75.88	0.57	-0.64
Ivanova [4]	19.50	26.61	100.80	63.07	0.73	-1.22
Eissa et al. [2]	12.57	17.06	101.95	40.36	0.65	0.46
This work	12.26	**16.51**	103.71	**38.95**	**0.75**	**1.11**

From Table 1, one can see the importance of using the GPI, since the other five statistical indicators are not able to consistently select the best performing model. Despite being selected as the best performing model according to the MBE and t-stat, the Neumann et al. model [3] was ranked as the third best performing model, showing that the combined effect of the statistical indicators represents a more in-dept performance assessment.

5. Conclusions and Future work

This work presents and assesses the performance of a newly developed CSR model for Évora against a reference dataset as well as other models available in the literature. The proposed model relies on the relationship between indexes that are associated with the sky/atmosphere conditions and it was found to perform better than the models from the literature at Évora, according to the GPI.

References

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