THE REPERCUSSION OF THE SIMILARITY OF DISTRIBUTION PARAMETERS OF MODELLED AND MEASURED IRRADIANCE DATA SETS ON THE ACCURACY OF PERFORMANCE ESTIMATES FOR SOLAR ENERGY SYSTEMS

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1. Introduction

Within the framework of the IEA-SHC Task36 (see e.g. Renné 2009) a comprehensive scheme for the assessment of the quality of solar radiation products had been developed (see Espinar et al. 2009) . Besides the conventional measures for model quality as mean bias error MBE and root mean square error RMSE, second order measures motivated by the Kolmogorov-Smirnov test for the similarity of distribution functions are taken into account.

Applications of this scheme have been used for a scanning of different modeling procedures for global and direct irradiances. Both had been performed within the IEA Task 36 and e.g. the EU-project MESoR (see Hoyer-Klick et al 2010) and the German project SESK (see e.g. Meyer et al. 2009). They have revealed that today's procedures for the assessment of irradiance from satellite information are basically capable to produce bias free modelled sets. This holds for both, information on global and direct irradiance. Taking a look at the similarity of the distribution functions however, it has to be stated, that there is still a lack in representing the respective characteristics by the modelled data (Schumann et al. 2011 show work on reducing this discrepancies). Using the error measures as proposed by Espinar et al 2009, this shortcoming is e.g. reflected by elevated values of the parameter KSI (Kolmogorov-Smirnov integral, see below for a definition).

To judge profoundly about the consequences for the applicability of modelled data sets for the analysis of solar energy systems on the basis of these quality measures, information on the sensitivity of the system performance to the respective statistic properties of the input data is needed.

This is demonstrated here for systems, showing the basic response features of small scale solar thermal systems (nonlinear response to global irradiance) or large concentrating solar power (CSP) systems (nonlinear response to direct normal irradiance)..

2. Error measures for the quality of radiation products

In this paper, the error measures 'mean bias error' MBE, 'root mean square error' RMSE and 'Kolmogorov-Smirnov Integral' (KSI) are used for model characterization. MBE and RMSE are defined as follows:

$$MBE = \frac{1}{n}\sum_{i=1}^{n}\left(G_e(i) - G_m(i)\right)$$

n : number of data pairs

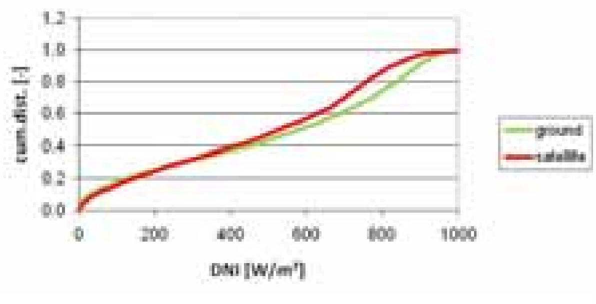
$G_e(i)$ = modelled (estimated) value (eqn. 1)

$G_m(i)$ = measured value

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(\ G_e(i) - G_m(i)\ )^2} \quad \text{(eqn. 2)}$$

The KSI is defined on the basis of the cumulative distribution functions of measured and modelled data,

Fig.1a gives an example for cumulative distribution functions (daytime data only) of ground measured and satellite derived direct normal irradiance DNI. The absolute deviations between these distributions are given in Fig. 1b.



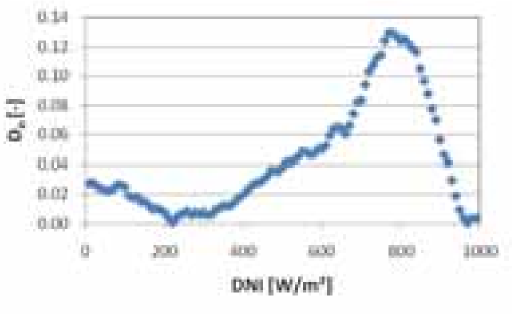


Fig. 1a: Cumulative distributions for ground measured and satellite derive data sets of direct normal irradiance (DNI). The data refer to one year of data (daytime only). Location is in Spain. The MBE amounts to 7% of the ground measured mean.

Fig. 1b: Absolute difference of the cumulative distributions as given in Fig. 1a. Data are analyzed for irradiance classes of width 10W/m². These data refer to a KSI of 43 W/m².

KSI gives an integral measure of the similarity of the distributions. In a discreet formulation, using irradiance classes of width ΔG, this is given by:

$$D_n = |F(G_n) - R(G_n)|$$
$$F(G_n) : \text{cummulative distribution of measured data}$$
$$R(G_n) :: \text{cummulative distribution of modeled data} \qquad \text{(eqn. 3)}$$

$$KSI = \sum_i D_n \Delta G$$
$$\Delta G = \text{class width}$$

For the example given, the KSI value is determined to be 43 W/m².

To give more impressions of the range of KSI values attainable by state of the art modelled data sets together with the appearance of the disagreements of the distribution curves, in Fig.'s 2-4 another example for DNI-sets and two examples analyzing global irradiance data sets are given. For these examples, there is no bias.

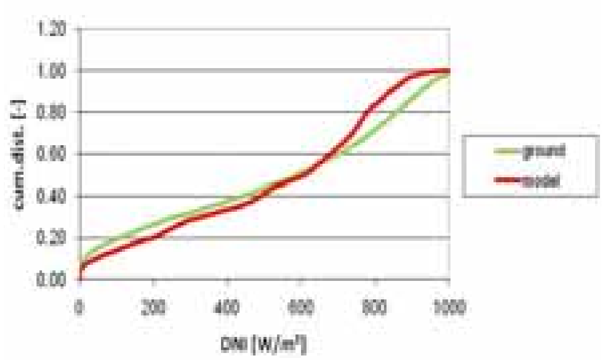


Fig. 2: Same presentation as Fig. 1a, but for other location and model used to derive DNI-values from satellite data. For this example there is no bias (MBE = 0). The KSI amounts to 51 W/m². Set is labeled C.

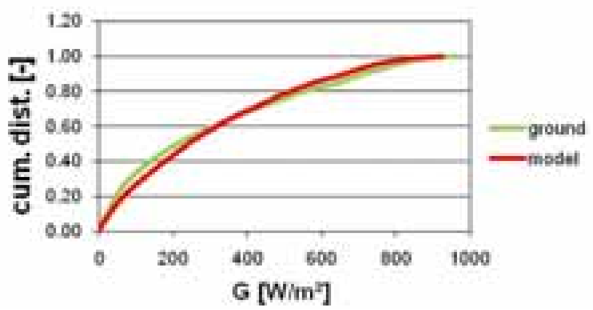


Fig. 3: Same presentation as Fig. 1a but for sets of global irradiance, location Switzerland. In this case, the modelled data are generated with a tool to derive the time series from given monthly means (WetSyn [Maier et al 2002]). This results in a modelled set with MBE = 0. The KSI amounts to 17 W/m². Set is labeled A.

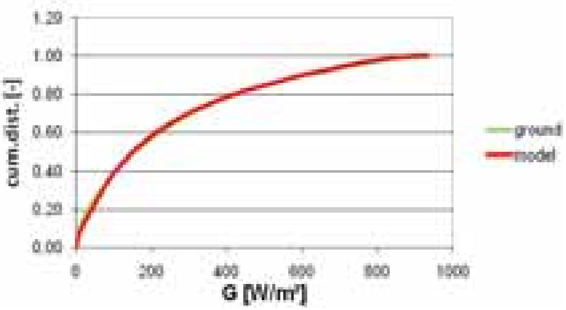


Fig. 4: Same presentation as Fig 1a but for sets of global irradiance, location UK. Model data are derived from satellite information. Bias of the deviations is 0, KSI amounts to 6 W/m². Set is labeled B.

3. System reaction

To analyze the influence of the characteristics of the difference data sets on system performance, simple generic models for the system reaction are applied here. Systems are assumed to have instantaneous reaction only, i.e. the sequential characteristic of the time series are not analyzed here.

Two types of (nonlinear) system reaction are discussed here. The first – motivated by the basic response characteristics of solar thermal collectors – shows a linear response to the difference of the irradiance to a threshold value. This characteristic is depicted in Fig. 5, indicated by 'lower limit' The second response characteristic – motivated by the typical response of concentrated solar power systems (CSP) – introduces an additional 'upper limit' (corresponding to the rated conditions of the system). For irradiance above the threshold value, the power output remains at the rated power (see curve 'lower/upper limit' in Fig. 5.

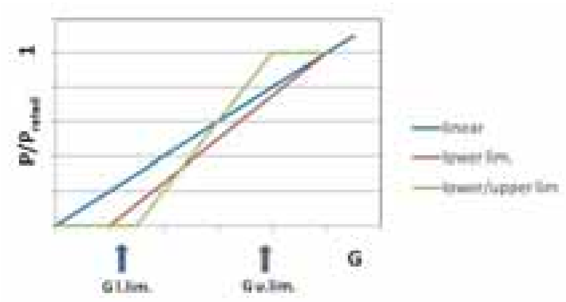


Fig. 5: Generic response characteristics of systems to irradiance. 'Lower limit' mimics the response of solar thermal collectors, 'lower/upper Limit' those of solar thermal power stations. The 'linear' response is given for comparison.

4. System performance under different irradiance distributions

Using the system characteristics given above, the mean power output of systems for irradiance conditions as given by different distribution characteristics can be evaluated.

For the purely linear response, the mean power output, or the energy gain, is proportional to the mean value of the irradiance. The mean bias deviation of irradiance is directly transferred to the deviation in energy gain without respect to details of the irradiance distribution. Using the nonlinear response characteristics, system response to sets with identical mean may split off according to different distribution characteristics.

This is first demonstrated for systems with the 'lower limit' response, reacting to the sets measured and modelled global irradiance given by A and B described above. Systems characterized by different values of the 'start up-irradiance' giving the lower limit are analyzed. It should be noted, that this type of calculation dates back to the utilizability concept developed in the mid of last century (see e.g. Whillier 1953)

Fig. 6 gives the relative differences in energy gain - labeled ΔE – from application of measured and modelled irradiance distributions. Data is given in dependence of the lower limit value.

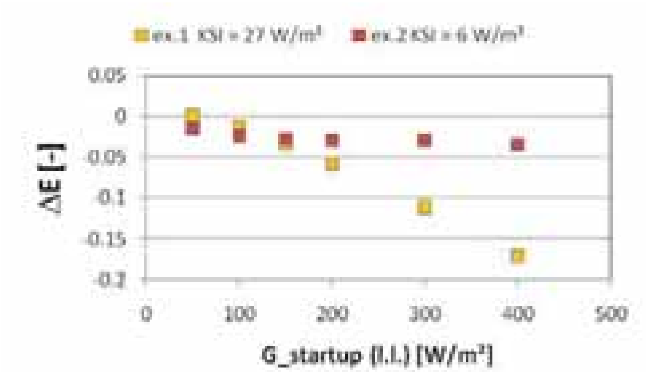


Fig. 6: Relative differences of energy gain ΔE as determined using the measured and modelled irradiance distributions from set A (ex.1) and B (ex.2). Energy gain is determined for systems with 'lower limit' response, using different values of the irradiance value for the lower limit.

These results prove that apparently small deviations of the cumulative distributions may cause significant differences in the system response. For higher values of the lower limit, the magnitudes of the deviations are well correlated to the KSI value (17 W/m² for set A, 8 W/m² for set B).

The estimation of the reaction of systems with the 'lower/upper limit' response to variations of the distribution characteristics is performed based on DNI data sets given ground measured and modelled by example C. For a more systematic evaluation of the influences of distribution variability, a scheme for an artificial distortion of the model distribution is used. The distortion is designed to keep the mean of the data set constant, but allowing for the creation of distributions showing different values of the KSI when compared to the measured data. Fig. 7 gives an example for a distortion function to be added to the basic cumulated distribution. Total area under the distortion function is 0 to assure the preservation of the mean. Fig. 8 gives the distribution of measured and the modelled sets and the artificially distorted distribution. By variation of the amplitude, the KSI values for the distorted distributions may be gained.

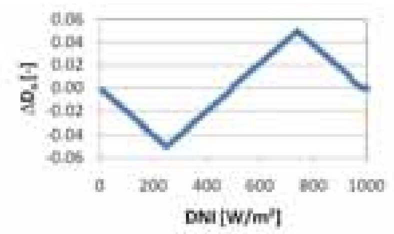


Fig. 6: Distortion function to create distribution functions with varying values of KSI form given distributions. The ΔD_n values given here have to be added to the distribution to be manipulated. Function is designed to keep the mean of the distribution constant.

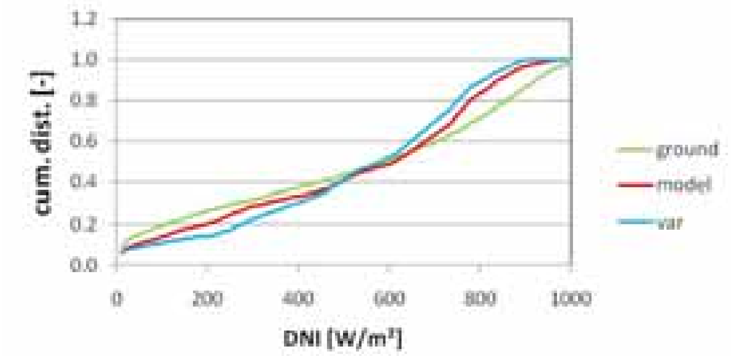


Fig.7: Same presentation as Fig. 2 (Set C) but with an artificially distorted distribution (var) added. In this case, the KSI is augment to 72W/m^2.

Using this scheme, a set of 5 artificial distributions is created with KSI values ranging from 34 – 97 W/m² relative to the measured set. This ensemble is given in Fig. 8. This range of KSI values is choosen according to the values as gained by the data analysis in the MESOR and SESK Projects.

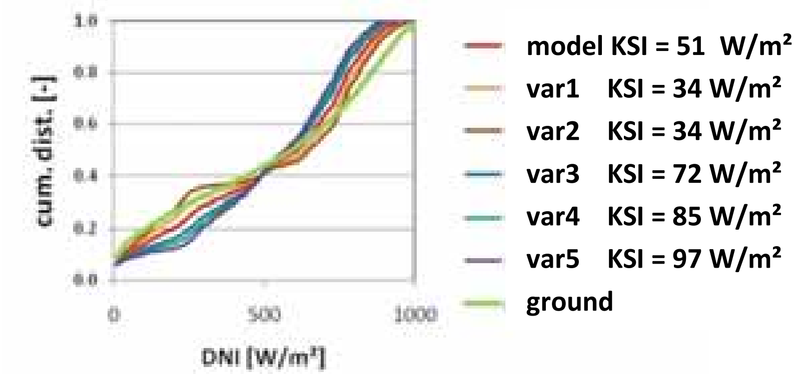


Fig. 8: Ensemble of different distribution functions giving the mean bias of 0 as compared to the distribution of the ground measured set (green curve). The respective KSI values are indicated.

The system response to these distributions is analyzed here for systems with a fixed lower limit (start up irradiance) of 200 W/m² and an upper limit varying from 900 - 700 W/m². The resulting relative errors are given in Fig. 9 as function of the KSI values of the modelled/modified sets,

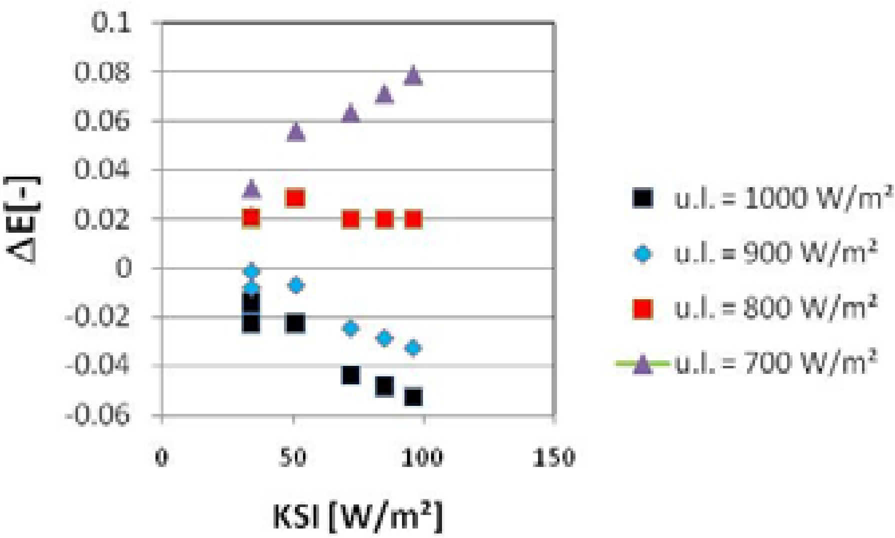


Fig. 9: Relative differences in energy gain when various modelled/modified DNI distribution functions as compared to the application of the distribution function of the measured data, given as function of the KSI values of the sets. The system response used is the 'lower/upper limit' model (see Fig. 5). For the lower limit, a fixed value of 200 W/m² is used, the upper limit varies from 1000 – 700 W/m².

It can be remarked that for given value of the upper limit, the errors are well correlated to the KSI data. For the interpretation of the differences in the resulting error for systems with various values of the upper limit, the relative position of the threshold values on the distribution curves – which also effects efficiency curve of the system, the location and the initial sign of the dominant contributions to the KSI - have to be taken into account. Thus, a precise determination of the performance errors, caused by deviations in the distribution characteristics has to rely on a system specific calculation.

5. Conclusions

The nonlinear response of most solar energy systems to the irradiance causes sensitivity to irradiance distribution beyond the obvious influence of the data mean. Thus, schemes for modelling irradiance data have to be checked for both, ability to represent correct means and sufficiently similar distribution characteristics. Non-perfect matching of the modelled distributions my cause errors in estimated performance figures a compared to the figures derived from measured data. Examples for these deviations in a simple performance figure - the energy gain of solar thermal systems as calculated by a static nonlinear response - have been given here. Differences in energy gain in the range of up to 10-20% may be caused by the deviations in the distribution function as given by state of the art data modelling tools. The differences in performance of systems with given configuration and system parameters in general show – for modelled data sets giving the correct mean – clear correlations to the error measure KSI, which tests the similarity of the cumulative distribution function of measured and modelled data. As however, the deviations in performance are to a high degree influenced by details of the system response, as demonstrated here for the influence of threshold values, a unique simple link of KSI and performance error cannot be given. As a consequence, working with modelled data showing elevated values of KSI for analyzing systems with complex response, requires special attention to the respective error propagation.

6. References

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