Annual Average Value of Solar Radiation and its Variability in Portugal

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***Abstract* – Solar resource assessment is essential for the different phases of solar energy projects, such as preliminary design engineering, financing including due diligence and, later, insurance phases. An important aspect is the long term resource estimation. This kind of estimation can only be obtained through the statistical analysis of long-term data series of solar radiation measurements, preferably ground measurements. This paper is a first step in this direction, with an initial statistical analysis performed over the radiation data from a national measurement network, consisting of eighty-nine meteorological stations. These preliminary results are presented in figures that represent the annual average values of Global Horizontal Irradiation (GHI) and its Variability in the Portuguese continental territory. These results show that the South of Portugal is the most suitable area for the implementation of medium to large scale solar plants.**

***Resumo* – A avaliação de recurso solar é essencial para diferentes fases de projectos de energia solar, como as fases de engenharia, financiamento e *due diligence.* Dada a importância do conhecimento do recurso solar disponível, torna-se necessário efectuar estimativas de longo prazo. Este artigo sumariza a análise estatística preliminar já efectuada sobre as séries temporais de dados de oitenta e nove estações meteorológicas. Os resultados obtidos são apresentados em figuras que ilustram os valores médios anuais da irradiação solar global e da sua variabilidade, em Portugal Continental. Estas figuras evidenciam que o Sul de Portugal é a região mais adequada para a implementação de centrais solares de média a grande escala.**

Key words – Solar Energy, Assessment and Variability, GHI, Measurements, Solar Plants, Statistical Analysis.

INTRODUCTION

When seeking financing for medium to large solar energy applications, the characterization of the solar resource at a given site is essential for different phases of solar energy projects. In the early stages only a rough estimation of yearly values of solar radiation is needed, but the depth of solar radiation estimation availability increases as the projects advance. At a certain point a long-term estimation is needed and it can only be obtained through a statistical analysis of long-term solar radiation data series. For a reliable statistical characterization of solar resource, a minimum of ten years of data is required. Some Researchers propose different periods for analysis, from six to thirty years of data [1]. This kind of assessment is usually based on the supposition that the long-term average annual solar radiation from the past can provide an accurate estimation, without significant variability, for the availability of solar resources in the future [2] [3]. Discrepancies resulting from this assumption are often not considered or considered to be negligible in comparison to other uncertainties [4].

When simulating solar energy performance, a continuous series of solar radiation data is desirable. However, it is usual to find data gaps in the available recorded series, and, thus, there is a need to design and apply a sound gap filling procedure. A common procedure to estimate monthly and annual values data series with gaps is to fill the missing days with the average values of the available days of the same month. This procedure may result in inaccurate estimates, depending on the number of missing days [5]. Other authors suggest a simple linear interpolation when gaps are up to three hours and filling gap with neighbor data or data of the same day from other years for greater gaps [5]. There are other studies that suggest the use of correlations with the solar radiation data from nearby weather stations as the best option [6].

In Portugal there are ground measured solar radiation data series and average values reported from those, dating back to the fifties, sixties and seventies of the 20th century. These data were obtained with different instruments and calibration procedures not exactly as accurate as other more recent ones. Besides, the total radiation available at the ground level can change with solar activity and with climatic changes. For today's usage it is important to use more recent data when assessing radiation availability at a given site, provided long enough recent series are available [7]. This work presents a thorough analysis performed to assess solar radiation in Portugal, providing also information about its annual variability. The results obtained are presented in terms of annual average values and are presented in a map format showing the Global Horizontal Irradiation (GHI) availability and its variability in the Portuguese continental territory.

EXPERIMENTAL DATA

The data analyzed in this study have been recorded by IPMA – Instituto Português do Mar e da Atmosfera (Portuguese Institute for Sea and Atmosphere) during the period 2001-2015, at eighty-nine stations in the Portuguese continental territory as shown in Figure 1. The global horizontal irradiance is measured in 30-s intervals with Kipp & Zonen CM11 and Hukseflux LP02 pyranometers, with the CM11 model being used in most of the stations. Both pyranometers are secondary standard instruments according to ISO standards.

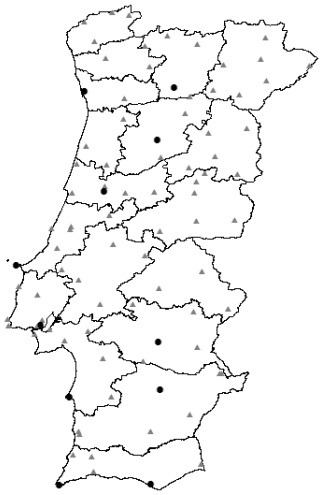

FIGURE 1
IPMA'S METEOROLOGICAL STATIONS. (BLACK DOTS - PRINCIPAL STATIONS, GREY TRIANGLES - SECONDARY STATIONS).

DATA QUALITY

The authors do not have accurate information about the proper operation of the instruments, thus the measurements could be affected by problems such as lack of calibration or malfunction and possible data acquisition failures. However, for the study of GHI annual variability it was considered that an eventual lower data quality of the analyzed series would not be much relevant since the consequences of calibration and data acquisition problems should not significantly affect the variability around an average value, regardless of whether it is reliable or not.

Due to the lack of information about the quality of the IPMA data series, a comparison between IPMA's and ICT - Instituto de Ciências da Terra (Institute of Earth Sciences, former CGE/UE - Geophysics Centre of Évora at the University of Évora) stations was performed for 2003-2015, Figure 2, since the distance between both stations is quite short, about 4.5 km. Data from the ICT (CGE/UE) station has been independently obtained with a good quality control and for a long period (13 years) [8]. The least square relation between the data series is high, R^2=0.98, which shows a small difference between both stations. This is reinforced by a slope close to one, m=1.0067.

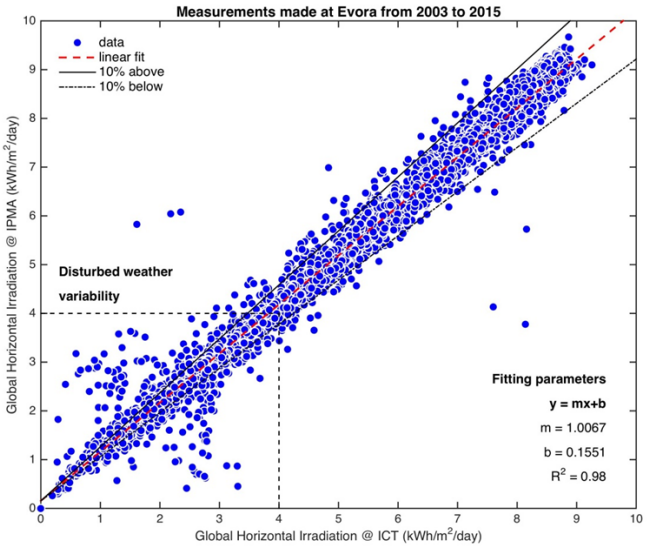

FIGURE 2
COMPARISON OF GHI DATA FOR IPMA'S AND ICT (CGE/UE) METEOROLOGICAL STATIONS IN ÉVORA.

Since the ICT (CGE/UE) meteorological station is rigorously maintained (periodic clean up, maintenance and calibration of instruments), it can be assumed that the quality of data measured by IPMA's stations is acceptable.

Once the data series were analyzed another quality data comparison was performed. The annual average GHI for Faro, Évora, Lisboa, Coimbra, Porto and Bragança were compared with series measured in the seventies. The results show an overall increase of annual GHI availability of 3.5% to 6.0%, which can be explained, as already referred by the fact that present day instrumentation can be considered more accurate and perhaps better calibrated than before. Another explanation is the transition from a period of solar dimming to a one of brightening. Some studies have shown an inflection point in the eighties, which would be consistent with the fact that the higher values recorded are accordant with the possibility of a present period of brightening [7]. Yet another explanation is the modification of the atmospheric conditions due to climatic dynamics, compatible with the fact that Portugal could likely be moving towards a warmer and drier climate [9]. However the quality and length of the available data series cannot be used to decide among these possibilities.

METHODOLOGY

In order to obtain reliable results it was necessary to perform quality data analysis and gap filling, after the pre-analysis, the annual values of GHI and its variability were determined. The applied criteria were:

1) Years that lack more that 5% of the total records are not considered for analysis;
2) For days that lack more than two records for more than two hours, between sunrise and sunset are

rejected and daily GHI availability for those days is estimated through the mean daily value of the same period for the other years of the data series;

3) For days that lack less than two hours, the corresponding gaps are interpolated from the values of the neighboring hours;
4) GHI average annual availability was determined by averaging the annual averages of GHI;
5) GHI annual variability was determined through the standard deviation of the annual averages of GHI;

RESULTS

With the results obtained through the application of the described methodology, the annual average values were processed in order to map the GHI availability in Portugal, Figure 3, and the relative variability of GHI, Figure 4. To produce Figure 4 and Figure 5 only meteorological stations with at least five years of valid data were used, resulting in the use of sixty-six out of the initial eighty-nine meteorological stations, as shown in Figure 3.

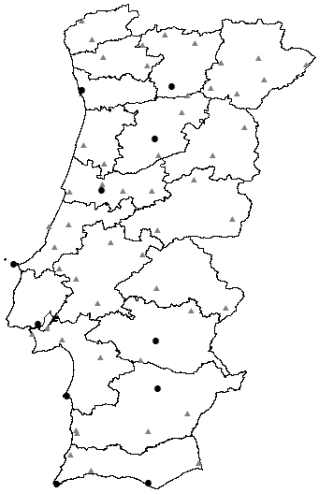

FIGURE 3
IPMA'S METEOROLOGICAL STATIONS USED FOR GHI MAPPING IN PORTUGAL (BLACK DOTS - PRINCIPAL STATIONS, GREY TRIANGLES - SECONDARY STATIONS)

As shown in Figure 4, GHI availability is higher from North to South due to the latitude effect and the higher average cloudiness in the North region of Portugal. On the other hand, GHI availability also increases from West to East, especially in the North and Center regions most probably due to the frequent formation of fogs in seaside (because of earth-sea interactions). Both effects are also evident in Figure 5, where the GHI relative variability is higher in the zones where GHI availability is smaller [10].

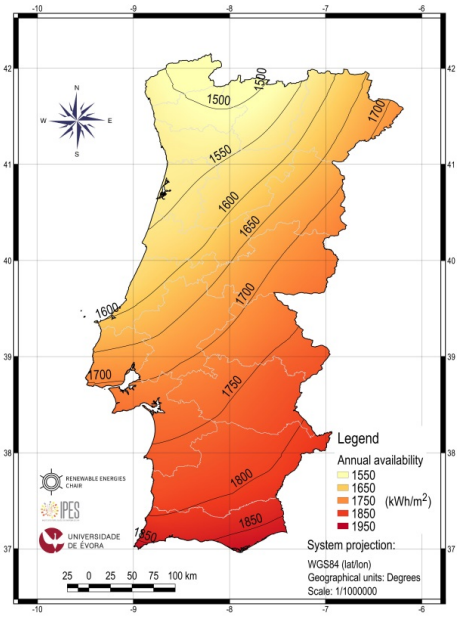

FIGURE 4
GHI AVERAGE ANNUAL AVAILABILITY IN PORTUGAL CONTINENTAL TERRITORY (kWh/m^2/year).

The average annual values of GHI availability and its variability are important for the definition of sites for the implementation of solar plants, i.e. medium to large scale solar Plants. The smaller the GHI annual variability the more reliable are the predictions of GHI estimations at a given place and, consequently, more reliable are the simulation outputs of solar applications performance.

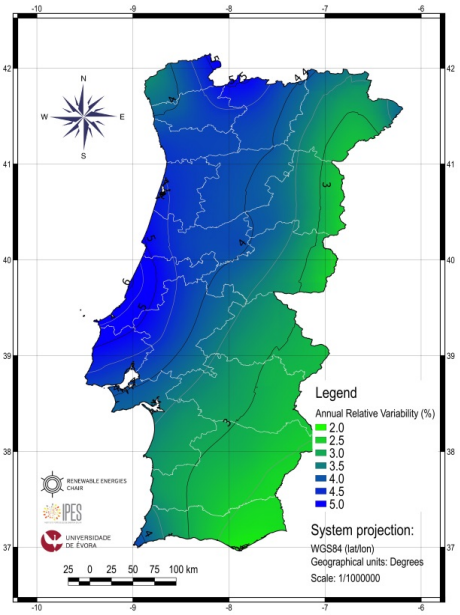

FIGURE 5
RELATIVE ANNUAL VARIABILITY OF GHI (%/YEAR).

Figure 4 and Figure 5 evidence Alentejo and Algarve, South of Portugal, as the most suitable areas for the implementation of solar energy projects due to the combination of high GHI annual availability and its lower annual variability.

CONCLUSIONS

The knowledge of GHI availability is essential for viability analysis of solar projects. The existence of long term statistical analysis is fundamental to estimate the real availability and variability of solar resource in Portugal. This study provides the best present insight over the Portuguese GHI annual variability and it constitutes fundamental knowledge when projecting medium to large scale solar plants.

Even though the overall data quality could not be determined with a high certainty level, variability analysis of GHI should not be too much affected since it is not dependent on the absolute accuracy of the annual GHI average value. However, a data quality comparison was performed, which allowed the assumption that the quality of the data measured by IPMA's stations is acceptable.

This study shows that GHI annual variability in Portugal is small, from 1.6% to 3.0%, for the locations with higher GHI availability (typically the region south of the river Tejo) and only 3.5% to 5.0% for the remaining locations. Another conclusion is that low GHI annual variability areas correspond to high GHI annual availability areas, making these areas quite interesting for the implementation of future solar plants.

In the future this kind of studies will be performed for Direct Normal Irradiance (DNI) measurements since the University of Évora and IPES – Portuguese Solar Energy Institute together with other institutions (LNEG, Logica, INEGI, AREANATejo, and Capwatt) are managing a DNI measurement Network with focus in the South of Portugal, a known area for having higher DNI availability [11]. IPMA will join this network with a recently acquired system that is able to measure DNI in order to join the effort to characterize the DNI annual availability and variability in the South of Portugal.

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