Modelling Accurate Global Solar Irradiation Based on Freely Available Satellite Remote Sensing Data

Dr. Iva Gašparović[1]

Assist. Prof. Dr. Mateo Gašparović[2]

[1] State Geodetic Administration, **Croatia**
[2] Faculty of Geodesy University of Zagreb, **Croatia**

ABSTRACT

The aim of this research was to determine the global horizontal irradiation (GHI) for Istria and Kvarner, two western regions in the Republic of Croatia with the GRASS GIS r.sun module and to compare it with the values of solar irradiation obtained from satellite images and ground measurements. Since the results obtained from the r.sun module have no quality control, the accuracy assessment was made on ground solar irradiation measurements obtained from Baseline Surface Radiation Network stations (BSRN). BSRN is a very commonly used network of surface reference stations designed in 2004 in the Global Climate Observing System (GCOS) program. BSRN currently has 63 stations in different climatic zones in the world. The main objective of the BSRN is to provide the best possible quality observation for shortwave and longwave solar radiation with high temporal resolution. The data used for accuracy assessment were shortwave global radiation data measured at the BSRN measuring station closest to Croatia, Carpentras in France. Solar irradiation can be also obtained from weather satellites, such as Meteosat Second Generation (MSG) for the Europe area. A comparison of the GHI values from different sources showed that the MSG and BSRN data correlate best with the data being measured, while r.sun was modelled. However, the data obtained by the r.sun module have better resolutions and thus are more suitable for determining optimal locations for solar energy utilization. Comparing the accuracy of modelled GHI with solar irradiation data obtained from satellite images and ground measurements it was concluded that they are accurate solar energy potential data that can be used to ensure quality energy planning.

Keywords: global solar irradiation, remote sensing, GIS, energy planning.

INTRODUCTION

In recent years, the world is increasingly turning to renewable energy sources due to increased consumption of fossil fuels, high CO^2 emissions and environmental pollution that irreversibly destroys nature. The purpose of using renewable energy is primarily to protect the environment, but it also brings socio-economic benefits for the Earth's population.

Every year there is an increasing number of newly installed photovoltaic systems and concentrated solar power plants, which is why solar energy today plays a significant role in the total electricity production and consumption. By the end of 2018, solar energy production reached a cumulative operational capacity of over 500 GW worldwide [1].

To use solar irradiation for energy production, it is necessary to select adequate locations for installing photovoltaic systems and concentrated solar power plants. The determination of solar energy potential is primarily based on solar irradiation data [2,3]. Depending on the surface position or the atmosphere influence, solar irradiation can be divided into different types of radiation, but the most commonly used parameter of solar energy potential is Global Horizontal Irradiation (GHI) [4,5,6].

Earth's solar irradiation data are collected at global [7,8], regional and national meteorological stations [9], but solar irradiation can also be measured by various satellite missions that collect meteorological data [10].

The goal of this research is modelling accurate solar irradiation based on freely available satellite remote sensing data. The solar energy potential was modelled using the GRASS GIS program, i.e., its r.sun module, developed by Hofierka and Šúri [11], and subsequently applied to many other authors [4,12].

The GHI results obtained with r.sun module were compared with data obtained from the satellite mission Meteosat, and with the ground measurements from meteorological stations.

MATERIALS AND METHODS

In this research, modelling of solar irradiation potential was made for Istria and Kvarner, two western regions in the Republic of Croatia. The study area is situated along the Adriatic Sea with warm Mediterranean climate and annual average of more than 2000 sunny hours. This research is going to explored if the study area is a good candidate for the exploitation of solar energy by modelling the solar energy potential.

From satellite remote sensing data, solar irradiation value can be determined using physical, empirical or semi-empirical models [13]. Physical models use satellite imagery and other atmospheric data to calculate solar irradiation passing through the atmosphere. Physical models have been applied to determine the NASA SSE (Surface Meteorology and Solar Energy) solar databases that provide global solar data and Heliosat for Europe and Africa [14]. Using empirical models on visible satellite imagery bands the cloud coefficient can be determined, which is used to model GHI for clear skies. Semi-empirical models have been applied to determine solar databases SolarAnywhere and SolarGIS by using simple radiation transfer methods and measured data for determining solar irradiation [13].

The main goal of this paper is to determine GHI for Istra and Kvarner using the GRASS GIS (Version 7.2.1) r.sun module and freely available satellite remote sensing data.

The GRASS GIS r.sun module was developed by Hofierka and Šúri [11] for modelling the solar irradiation. R.sun module, models global horizontal irradiation without the atmospheric attenuation (clear sky – GHI_{CS}). To calculate the GHI with the r.sun module, the following input data is required: Digital Elevation Model for determining the aspect and slope raster matrices, Linke Turbidity factor (LT factor) and Effective Cloud Albedo (CAL).

Since r.sun module needs aspect and slope raster matrices as input data they were calculated from ASTER GDEM with a 30-m spatial resolution. Both aspect and slope raster matrices were calculated prior to GHI calculation to speed up the execution of r.sun module [12]. The Linke Turbidity factor was calculated using a program developed in Python based on the work of [12].

Using both aspect and slope raster matrices as well as Linke Turbidity factor, global horizontal irradiation for clear skies, GHI_{CS}, was determined. GHI_{CS} does not include atmospheric attenuation and thus needs to be corrected. The atmospheric attenuation correction of GHI_{CS} is done by using the clear sky coefficient, k_{CS}. The clear sky coefficient can be determined based on direct or diffuse radiation [5], data from terrestrial measuring stations [2] or different meteorological satellite data [10]. Therefore, the effective cloud albedo, which was derived from Meteosat Second Generation satellites and its Surface Solar Radiation Data Set – Heliosat (SARAH) was used to calculate the k_{CS} coefficient using the expression from Müller et al. [10]:

$$k_{CS} = \begin{cases} 1,05 & \text{for } CAL \leq -0,2 \\ 1-CAL & \text{for } -0,2 < CAL \leq 0,8 \\ 1,1661-1,781\cdot CAL+0,73\cdot CAL^2 & \text{for } 0,8 < CAL \leq 1,05 \\ 0,09 & \text{for } CAL > 1,05 \end{cases} \tag{1}$$

Based on the following expression, the actual GHI or GHI on Earth was also determined [12]:

$$GHI = k_{CS} \cdot GHI_{CS}\,. \tag{2}$$

Since the GHI calculated by r.sun module has no quality control, an accuracy assessment was made by comparing the results obtained by r.sun module with ground measurements of solar irradiation.

For the purpose of measuring solar irradiation on the Earth's surface, several global networks of meteorological stations have been developed. Baseline Surface Radiation Network (BSRN) is a very commonly used network of surface reference stations designed in 2004 in the Global Climate Observing System (GCOS) program. BSRN currently has 63 stations in different climatic zones in the world, covering a latitude range of 80 ° N to 90 ° N (Figure 1). Solar and atmospheric radiation are measured with instruments of the highest accuracy available and with a high temporal resolution of 1 to 3 minutes. The main objective of the BSRN is to provide the best possible quality observation for shortwave and longwave radiation with high temporal resolution [8].

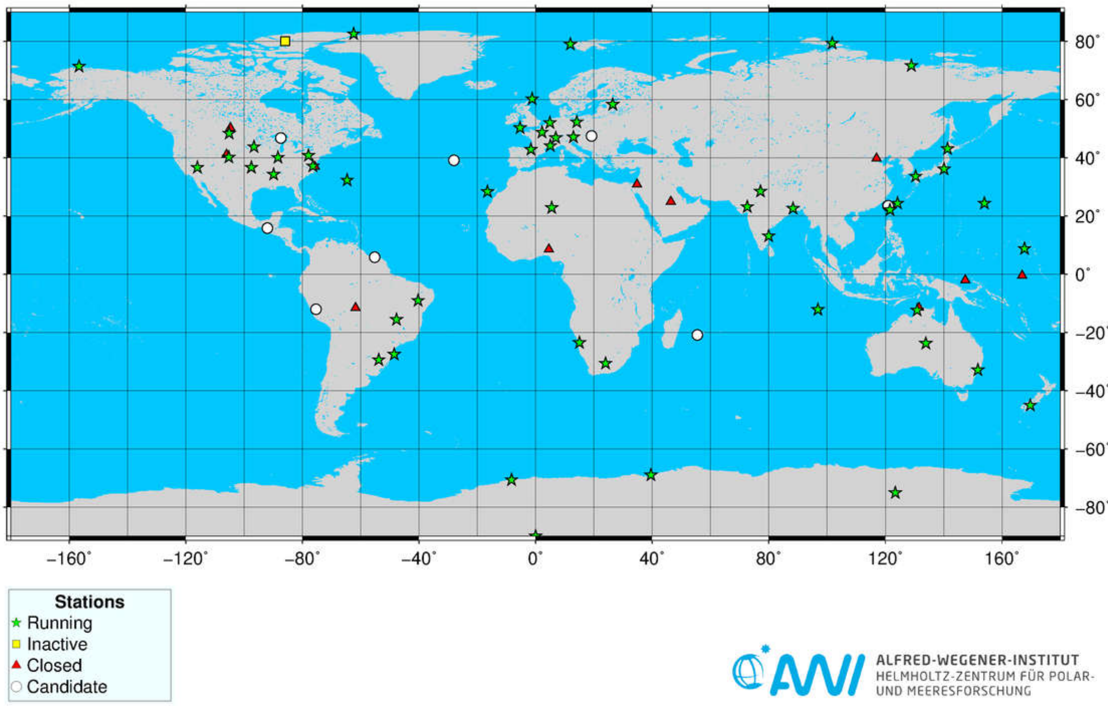

Figure 1. Runnin, inactive, planned and closed BSRN stations, August 2019.

Solar irradiation can be also obtained from weather satellites, such as Meteosat Second Generation (MSG) for Europe area. Data obtained from MSG version SARAH ed. 1.0 are accessible for the period from 1983–2013 with a 0.05° × 0.05° spatial resolution [10].

RESULTS

Researching different sources of solar radiation data, it was concluded that each has certain limitations, either access and fees for use, or limitations of spatial resolution [6]. Solar radiation data obtained on meteorological stations are the most accurate data for determining solar potential, but due to their excessive dispersion, i.e., small spatial resolution, they are not suitable for analysis in a wider area. Furthermore, solar radiation data generated from satellite observations have low spatial resolution, which is not sufficient for energy planning purposes. For this reason, it is recommended to model higher resolution solar radiation for energy planning purposes.

The purpose of comparing the modelled GHI calculated by the r.sun module with the data obtained from the MSG satellite was accuracy assessment of the results obtained and the possibility of using the modelling data for energy planning purposes (Figure 2). For comparison, both data were transformed into the same system and mapping projection HTRS96/TM and reduced to the spatial resolution of 30 m x 30 m. For this purpose, the r.resamp.interp module and the bilinear interpolation method were applied [12]. Also, the data used for accuracy assessment were shortwave global radiation data measured at the BSRN measuring station closest to Croatia, Carpentras (CAR) in France. Figure 3a shows the daily variation of GHI from different sources (BSRN, MSG, and r.sun) for 2013 and the variation of GHI for August 2013 (Figure 3b).

Previous analyzes of GHI variation and research clearly show a large correlation of all GHI sources [6,12]. Given that BSRN data are measured on Earth and the most accurate solar radiation data, we took them as a reference. In this case, it should be noted that MSG correlates most with BSRN data, then r.sun.

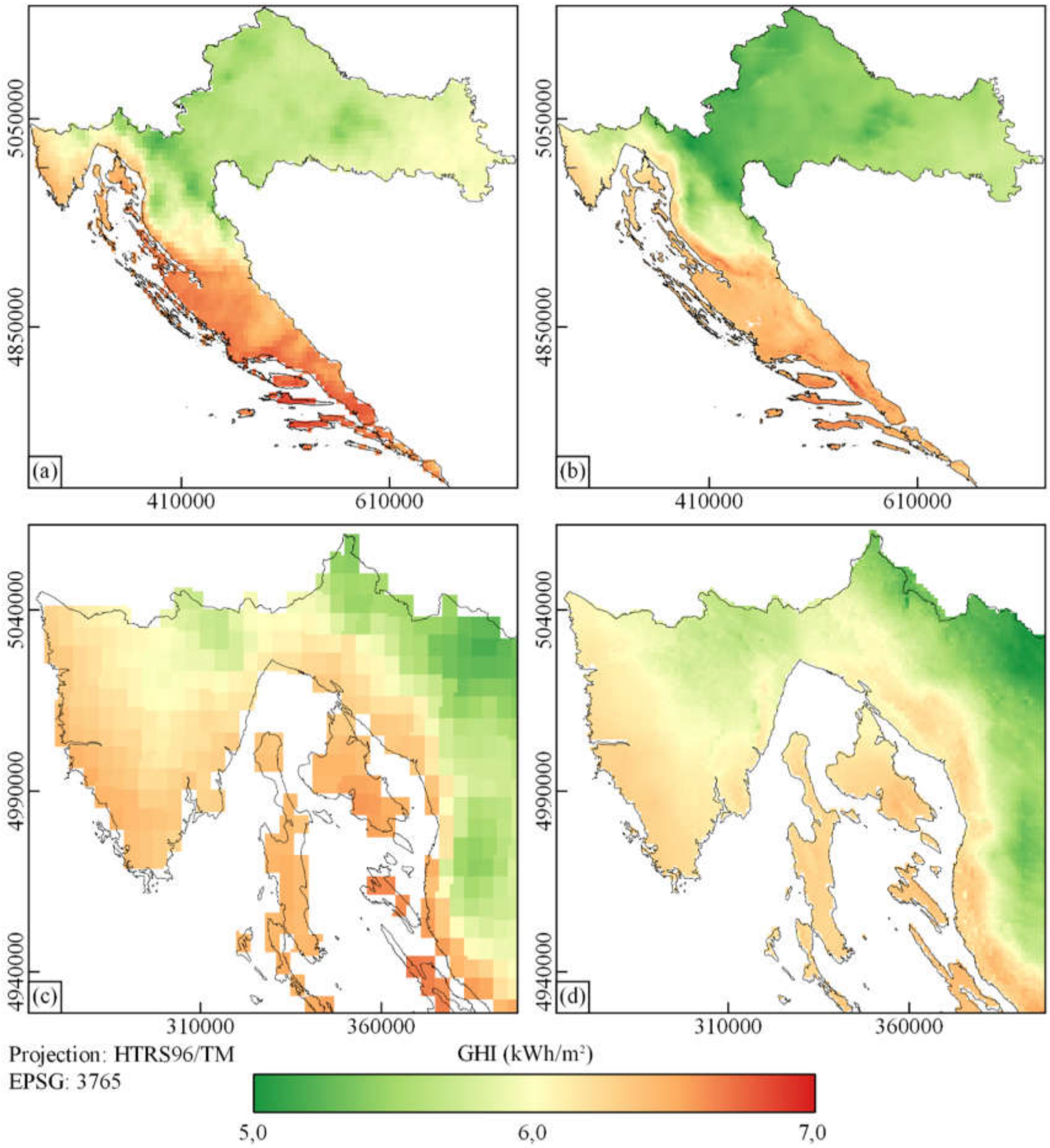

Figure 2. GHI for August 2013 in Croatia (a, c) obtained based on MSG satellite, (b, d) modelled in GRASS GIS.

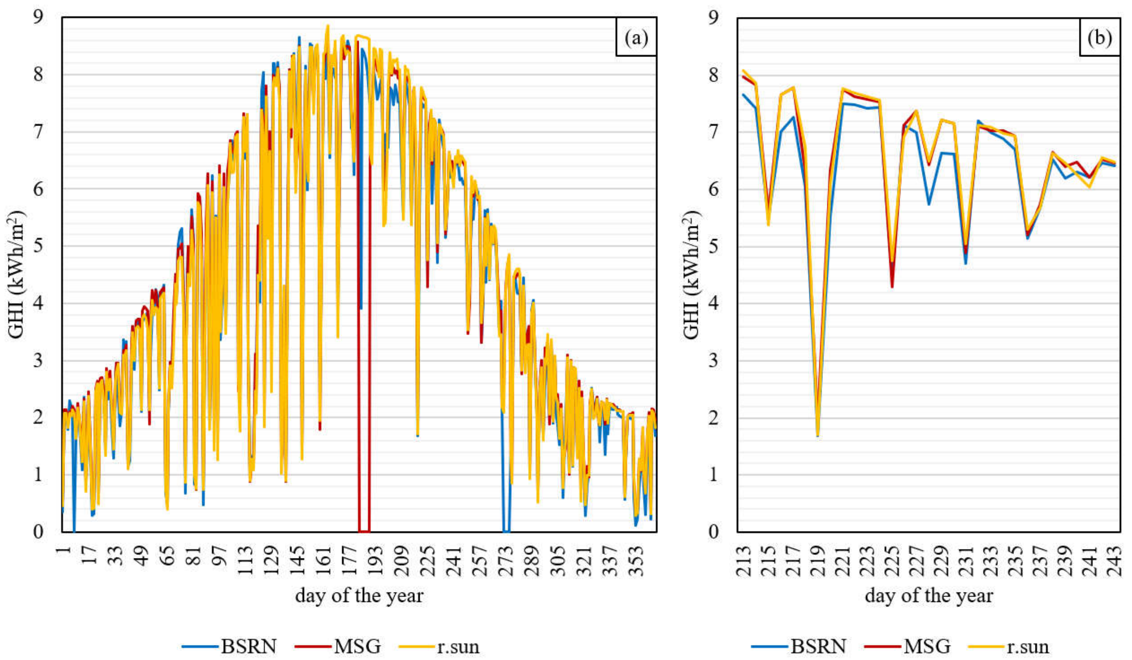

Figure 3. The daily variation of GHI for (a) 2013 and (b) August of 2013.

CONCLUSION

In the research of solar potential data sources for the Republic of Croatia, it was found that none of the available, non-commercial sources of solar potential data meets the criterion of high spatial resolution. Therefore, modelling of solar potential is recommended. The research used an algorithm for calculating the solar potential in the Istra and Kvarner in high resolution, based on the module r.sun of the open-source GRASS GIS program. The calculated clear-sky solar irradiation potential is reduced for atmospheric attenuation based on actual data collected from meteorological satellites.

In order to assess the correlation of the calculated solar potential, a comparison was made with actual measurements on Earth, at a selected BSRN meteorological station closest to the study area, Carpentras in France, and with MSG data. A comparison of the GHI values from different sources showed that the MSG and BSRN data correlate best with the data being measured, while r.sun was modelled. However, the data obtained by the r.sun module have better resolutions and thus are more suitable for determining optimal locations for solar energy utilization.

Comparing the accuracy of modelled GHI with solar irradiation data obtained from satellite images and ground measurements it was concluded that they are accurate solar energy potential data that can be used to ensure quality energy planning. The research is entirely based on freely available data and open-source software.

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