Estimation of Solar Irradiance for the Maltese Islands

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Abstract Solar energy is a promising renewable resource. Solar radiation modelling is essential for optimising its potential. This study replicates an existing model, namely, SOLAR, originally implemented in Fortran, and adapts it using MATLAB. The model estimates the hourly average solar irradiance under all-sky conditions, incorporating two cloud cover estimation methods, i.e., sub-models, labelled as Model 1, based on the daily total solar flux, and Model 2, which uses daily total sunshine hours. The new implementation of the model was evaluated using an extensive data set collected at two monitoring sites in Malta. Results indicate that both sub-models perform well under moderate to high solar irradiance conditions, in keeping with findings of previous studies. Higher correlation between the modelled and corresponding measurements were observed for clearer conditions, suggesting better model performance when the cloud cover is minimal. However, the discrepancy increased for low solar irradiance, indicating challenges when it comes to cloud cover estimation. In this study, modelled and observed data correlated better as compared to previous studies, implying that the model suits better the Mediterranean conditions. This study demonstrates that a straightforward, yet effective solar modelling approach can be successfully adapted to different geographical contexts with minimal modifications. The findings highlight the model's reliability for solar energy applications in regions with varying atmospheric conditions, making it a valuable tool for solar radiation forecasting and energy assessments where high computational complexity cannot be afforded.

Keywords: solar radiation; model evaluation; Maltese Islands

1. Introduction

Solar energy is a renewable, clean and an 'inexhaustible' source of energy, making it one of the most promising alternatives to the traditional source, i.e., fossil fuels. Due to Malta's prolonged periods of sunshine, solar energy remains an option for Malta. Solar radiation modelling is essential for understanding the associated energy potential. It is also important in understanding atmospheric conditions. Locally collected data plays an important role in developing and evaluating models that reflect the region's unique meteorological and climatic characteristics, ensuring more precise estimations of solar irradiance (Yousif et al., 2012).

Various methods have been employed to estimate solar irradiance, ranging from empirical models to advanced machine learning techniques. The approach by Micallef (2023) involves a physics-based phenomenological model that calculates the total solar irradiance at the Earth's surface under clear-sky conditions. This model, dubbed SOLAR, uses fundamental equations that incorporate factors such as the solar constant, the Earth's orbital parameters, geographical latitude, solar declination and atmospheric transmissivity. Additionally, the model accounts for cloud cover by adjusting both direct and diffuse irradiance components, providing a comprehensive estimation of total solar irradiance under various sky conditions.

Preliminary evaluation of SOLAR by Micallef (2023) was accomplished through linear regression analysis. The model results correlated well with the measured data. The latter were collected at rural and semi-rural areas in the East Midlands, UK. The said linear regression yielded an average correlation coefficient of approximately 0.6 and slopes between 0.80 and 0.93 when comparing modelled and observed solar irradiance. SOLAR was also successfully integrated into an urban air quality model to assess vehicle-derived particulate matter concentrations in street canyons, demonstrating its applicability (Micallef, 2023).

2. Materials and Methods

This study made use of the methodological framework established by Micallef (2023). The original approach utilised Fortran for the coding of SOLAR. The latter was converted to MATLAB for more efficient data processing and analysis. SOLAR estimates the hourly average solar irradiance under all-sky conditions and has two variations: Model 1 (a sub-model of SOLAR), estimates cloud cover based on daily total solar flux, and Model 2 (the other sub-model) estimates cloud cover using daily total sunshine hours. The goal of this study was to replicate SOLAR with its sub-models (Model 1 and Model 2) in MATLAB and evaluate it utilising measurements. Hourly averages of solar irradiance were derived from the raw data. This pre-processing step was essential for ensuring consistency in the subsequent analysis.

Model data inputs such as solar flux, daily total sunshine hours, Julian day, latitude and atmospheric pressure were formatted for MATLAB. Zenith angle, air mass and clear-sky irradiance were computed using equations from Micallef (2023). The direct and diffuse components were adjusted for cloud cover using the estimated factors (through the application of Model 1 and Model 2) and combined to calculate the total solar irradiance given by $S_{total} = S_{diff}^{c} + (1 + C)(1 - 0.75C)S_{dir}^{c}$, where S_{dir}^{c} is the direct solar irradiance at the Earth's surface, under clear-sky conditions, S_{diff}^{c} is the diffuse solar irradiance at the Earth's surface for a turbid, cloudless atmosphere, which was derived from Aida and Gotoh (1982) and C represents the fractional cloud cover.

The model output was compared to the observed data through scatter plots and time series analysis. Observed data spanning from 2011 to 2024 were sourced from the meteorological stations that are owned and managed by the Department of Geosciences, University of Malta. The stations are located at Birżebbuġa (specifically, Għar Dalam) and Msida. These locations were selected to assess the performance of SOLAR for different environmental settings, with Msida representing an urban area and Birżebbuġa, a semi-rural coastal site. Furthermore, solar irradiance and photovoltaic potential data for the years 2015 to 2017 were retrieved from the Joint Research Centre (JRC) Photovoltaic (PV) Tools website as done by Huld et al., 2012.

3. Results and Discussion

The analysis/evaluation discussed hereunder compares modelled and observed solar irradiance values, examining model performance under varying atmospheric conditions over a 12-year period.

SOLAR demonstrates consistently good performance irrespective of the sub-model that is used for the estimation of the cloud cover (referring to Model 1 and Model 2), as indicated by the values of the correlation coefficient (R^2), as shown in Table 1. Birżebbuġa and Msida exhibit high R^2 values, indicating a satisfactory agreement between modelled results and observations. In Birżebbuġa (2017), Model 1 and Model 2 had identical results for the correlation coefficient, namely, $R^2 = 0.85$. Msida (2014) exhibited the best model performance with Model 1 ($R^2 = 0.88$) and Model 2 ($R^2 = 0.89$) closely matching the observations. However, Msida (2020) showed a slight decline in model performance with lower R^2 values (0.79 for Model 1 and Model 2), likely due to changes in atmospheric conditions, cloud cover estimation uncertainties or/and uncertainties in other input data, e.g., daily sunshine duration. Overall, Model 2 consistently produced slightly better correlations, suggesting that using daily total sunshine hours for cloud cover estimation is favoured.

Performance was better for high solar irradiance, consistent with the fact that for these ranges there is less uncertainty in the computation of cloud cover. Micallef (2023), in his initial evaluation of SOLAR, arrived at the same conclusion. At lower solar irradiance values, especially in the lower-middle range, there was more data scatter and deviation from the 1:1 plot. This suggests that the model struggles the most in partly cloudy conditions, when cloud cover fluctuates and is harder to estimate. Nevertheless, the R^2 values obtained in this evaluation exercise are generally higher than those reported by Micallef (2023), suggesting better overall agreement between estimations and observations.

	Model 1		
	Msida 2014	**Msida 2020**	**Birżebbuġa 2017**
Slope	0.85	0.79	0.75
R^2	0.88	0.79	0.85

	Model 2		
	Msida 2014	**Msida 2020**	**Birżebbuġa 2017**
Slope	0.85	0.78	0.75
R^2	0.89	0.79	0.85

Table 1. Modelled solar irradiance data were plotted against measurements. The subsequent results of the linear regression analysis (zero intercept) for Birżebbuġa and Msida are tabulated for the two sub-models of SOLAR (Model 1 and Model 2), separately, at the specified years (2014, 2017 and 2020).

4. Conclusion

A modelling framework originally developed for the East Midlands, UK, to estimate hourly average solar irradiance, dubbed SOLAR, was adapted successfully for the Maltese Islands. The output of SOLAR agreed with actual solar irradiance measurements collected at different locations on the Maltese Islands. This underscores the versatility and reliability of the model, suggesting that it can be a valuable tool in relevant studies. Even simple models, when properly tested and calibrated with local data, can yield good results.

References

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