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# Estimating the global solar radiation in Putrajaya using the Angstrom-Prescott model

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**Abstract.** Global solar radiation (GSR) studies are essential in enhancing the use of solar PV systems especially for Building Integrated PV system (BIPV). Various studies on GSR had been carried out in Malaysia including Penang, Kuala Lumpur and Kota Bharu at the earlier stage. Afterward, data from the Malaysian Meteorological Department (MET) and the Malaysian National University were used to estimate the monthly average daily global radiation for various locations in Malaysia including Kuala Lumpur, Kuala Lumpur, Petaling Jaya, Bandar Baru Bangi, Kota Baru, Senai, Bayan Lepas, Kuching and Kota Kinabalu. GSR in Putrajaya, a location which has identified to implement Malaysian Building Integrated Photovoltaic (MBIPV) projects has yet to be estimated. The conventional method to obtain the amount of GSR at a location is to install a measuring device like a pyranometer at the site to observe and document its day-to-day recordings. However, this is a time-consuming and costly practice. The models used to estimate the GSR are usually based on astronomical factors, geometrical factors, physical factors and meteorological factors. There are numerous models used to predict GSR which can be categorized based on sunshine, cloud, temperature and other meteorological parameters. Additionally, the global solar energy models can be grouped by its modelling techniques such as linear, nonlinear, artificial intelligence and fuzzy logic modelling techniques. The reviews discovered that the models used to estimate GSR were mostly correlated to sunshine duration (SD), air temperature, relative humidity and geographical parameters like latitude, longitude and altitude. In this paper, the GSR in Putrajaya is estimated from the hourly solar radiation and daily sunshine hours data from the Malaysian Meteorological Department. The data, along with the calculated monthly average daily extraterrestrial radiation on a horizontal surface and monthly average maximum possible daily sunshine is used to plot a scatter graph that is linearly fitted. The gradient and vertical axis cut-off from the linear fit is used to obtain the coefficients in the Angstrom-Prescott (A-P) model. Subsequently, the coefficients were used to estimate the GSR in Putrajaya. In line with the government's initiative, this study will provide an estimation of the GSR in Putrajaya where the finding will be beneficial to the stakeholders, policy maker, developer and investor and energy authority. The average monthly GSR was obtained for nine out of twelve months with highest at 21.18 MJ/m<sup>2</sup> in March and lowest at 18.34 MJ/m<sup>2</sup> in June.

## 1. Introduction

The advent development and application of solar energy, a renewable energy source, can greatly impact a city's sustainability from the aspect of its social, economic and environmental influence. In order to be more eco-friendly, cities around the world have adopted various green technologies and strategies to ensure future generations are able to experience the same quality of living as the present. One such



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strategy currently developing in cities involves the use of building integrated photovoltaic systems (BIPV). BIPV systems refers to how photovoltaics can be integrated into the building design and structure. This can be achieved prior to construction by assimilating photovoltaics into the design of a building. Otherwise, the photovoltaics can be fitted onto existing structures. With BIPV, energy efficiency is improved while losses from electrical distribution is reduced due to the electricity produced in proximity to the demand area. This contributes to greater sustainability. The increasing application of BIPV in cities can be enhanced by studies in GSR. Such studies can help stakeholders assess the suitability of BIPV, which can influence the planning and policies of a city. Various stakeholders like policy makers, developers, investors and energy authorities may find the results of these studies to be valuable.

In the past, there were studies related to estimate the GSR in Penang, Kuala Lumpur, Kota Bharu, Petaling Jaya, Bandar Baru Bangi, Kota Baru, Senai, Bayan Lepas, Kuching and Kota Kinabalu [1, 2]. Currently, the GSR in Putrajaya, a location identified for implementing solar PV systems, has yet to be estimated. Putrajaya, the third and youngest designated federal territory of Malaysia, functions as the country's administrative centre and was developed as a "garden city" since 2001, has the potential to mature to an eco-friendly and sustainable city. There has been attempts in implementing solar PV systems which include two Malaysian Building Integrated Photovoltaic (MBIPV) projects. The first project was with bungalow houses in Precinct 16 and the second with the Putrajaya Perdana Headquarters building [3]. In line with these initiatives, research on GSR should be done to maximise the potential of BIPV in cities like Putrajaya.

The conventional method to obtain the amount of GSR at a location is to have a pyranometer installed at the site to observe and document its daily recordings. However, this is time-consuming and costly. Hence, the employment of models to estimate the GSR. There are generally numerous models used to predict GSR. These models are usually based on astronomical, geographical, geometrical, physical and meteorological factors [4]. In 2013, various models were identified based on the meteorological parameters used and were categorised base on sunshine, cloud, temperature and other meteorological parameters [4]. Additionally, in 2015, the global solar energy models were grouped by modelling techniques such as linear, nonlinear, artificial intelligence, etc. They discovered the models that were used in published works were mostly correlated to SD, air temperature, relative humidity and geographical parameters [5].

The prescribed model in this study, the A-P model, is most commonly used for estimating GSR. This is mainly because, firstly, there is readily available meteorological data for the sunshine based model. Secondly, the linear models derived from the A-P model are ranked high in global performance indicator (GPI) in comparison to other models in a review in 2015. Using ten statistical indicators, they introduced a global performance indicator (GPI) to rank the performance of the different models. Out of 101 models, their results showed that the linear model took first and third place while the polynomial model took second place. Within the top ten, 6 were linear models [6]. Thirdly, the A-P model is preferred due to its simplicity as a linear model and its reliability as a tool to estimate the GSR for practical applications like solar PV systems i.e. BIPV [7].

The A-P model is a sunshine-based linear model whereby the average daily GSR in a month at a particular geographical location can be predicted if the actual daily solar radiation and daily SD is available there. The A-P model is shown in equation (1).

$$\frac{H}{H_0} = a + b \left( \frac{S}{S_0} \right) \quad (1)$$

In equation (1),  $H$  is identified as the monthly average daily global radiation on a horizontal surface and it is measured in  $MJ\ m^{-2}\ day$ ,  $H_0$  is the monthly average daily extraterrestrial radiation on a horizontal surface and is also measured in  $MJ\ m^{-2}\ day$ ,  $S$  is the average daily SD within a month measured in  $h$ ,  $S_0$  is the average maximum daily SD possible within a month also measured in  $h$  and  $a$  and  $b$  are the linear coefficients of the A-P model.

In Malaysia, research in GSR mainly focuses on using established models to estimate the GSR in a specific place and measuring reliability of the results. Thus, the location is selected based on the availability of all required data needed by the model used. Although this method is suitable and ideal for generating new knowledge but obtaining all the required data from one location is not always practicable and thus, becomes a restricting factor for research. To ensure continuous research on GSR, new methods that can overcome the constraints of obtaining all relevant data from only a single location needs to be adopted.

Accordingly, this study aims to provide an estimation of the GSR in Putrajaya from the presently available hourly solar radiation and daily sunshine hours data obtained from the Malaysian Meteorological Department. This article will demonstrate a new and unconventional method of using data from two nearby locations rather the standard of using data from one location. Following that, both the AP model and the dual location method is validated by evaluating the results using statistics.

This study is organised as follows: Section 2 provides descriptions of the data used, the computational procedures to obtain the estimated GSR in Putrajaya and the statistics employed to evaluate the reliability of the estimated GSR; Section 3 will display and describe the results from the computation procedures and the statistics employed; Section 4 will discuss and evaluate the results and Section 5 will summarise the main findings and provide recommendations for future work.

## 2. Methodology

The data used in the study came from MET whereby a pyranometer is used to measure and monitor, both, the GSR on a horizontal surface and the daily SD [2]. The pyranometer consists of a thermocouple junction-sensing element. The thermocouple junction-sensing element is housed under two concentric fitting glass domes and a highly stable carbon based non organic coating with excellent spectral absorption and long-term stability characteristics is applied on the sensing element [10].

Measurements of SD were taken in accordance to the World Meteorological Organisation; whereby the SD throughout a specified timeframe is defined as “the sum of that sub-period for which the direct solar irradiance exceeds  $120\ W\ m^{-2}$ ”. The GSR and SD measurements are recorded hourly and daily. The data covered a duration of 5 years, beginning from 2011 and ending at 2015. Data from 2011 to 2014 was used to obtain the GSR estimates while the 2015 data was used as a comparison for statistical analysis to evaluate the estimates.

Due to the fact that there are no radiation measurements available in Putrajaya, the data had to be obtained from other locations. In choosing suitable data to be used, two selection criteria was utilized. Firstly, availability of data and, secondly, proximity of the source of data from Putrajaya. Consequently, the daily GSR data came from Kuala Lumpur International Airport (KLIA) in Sepang (latitude  $2.7333^\circ$ ) while the daily sunshine hour data came from MARDI in Klang (latitude  $2.9833^\circ$ ). Ideally, both sets of data should come from the same location but because the SD data was unavailable in KLIA, thus, MARDI was the next location closest to Putrajaya that had available SD data.

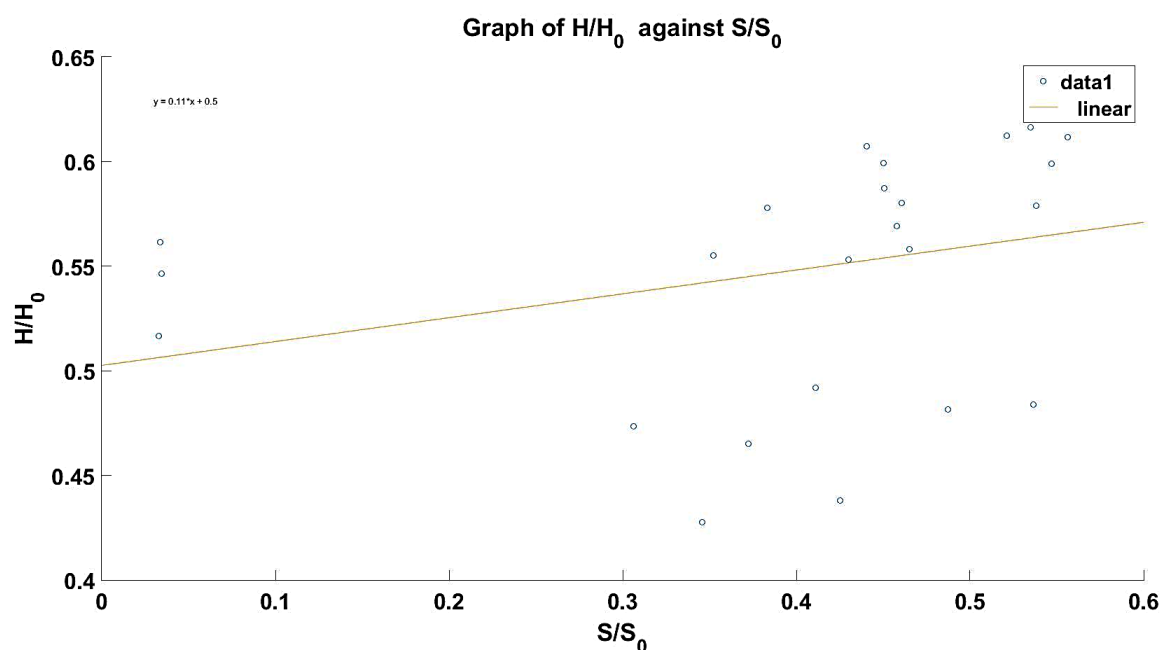
Additionally, the data was screened in order to avoid defective values due to the malfunction of the pyranometer. Firstly, the daily data was omitted if there was missing data, in either one of the GSR or

daily SD, or in both. Secondly, the data was omitted if the ratios of  $\frac{H}{H_0}$  and  $\frac{S}{S_0}$  were greater than one. Finally, the monthly data was omitted if 10 or more daily data were missing in that month [8, 9, 10].

In order to conduct the study, various computational procedures were required. These procedures were as follows: determining the average daily global radiation on a horizontal surface within a month ( $H$ ); determining the average daily SD within a month ( $S$ ); determining the average daily extraterrestrial radiation on a horizontal surface within a month ( $H_0$ ); determining the average maximum possible daily sunshine within a month ( $S_0$ ); determining the coefficients in the linear A-P Model; conducting an error analysis on the estimates using statistics like mean percentage error (MPE), mean bias error (MBE), root mean square error (RMSE), and mean absolute error (MAE) and, finally, estimating the average daily extraterrestrial radiation on a horizontal surface within a month in Putrajaya (latitude  $2.9264^\circ$ ).

### 3. Results

Firstly, results from the computation of  $H_0$  and  $S_0$  were used in plotting a scatter diagram and linearly fitted as shown in figure 1. The coefficients obtained from the gradient and vertical axis cut-off were  $b = 0.11$  and  $a = 0.5$  respectively.



**Figure 1.** Results of the scatter diagram and linear fitting of  $\frac{H}{H_0}$  and  $\frac{S}{S_0}$ .

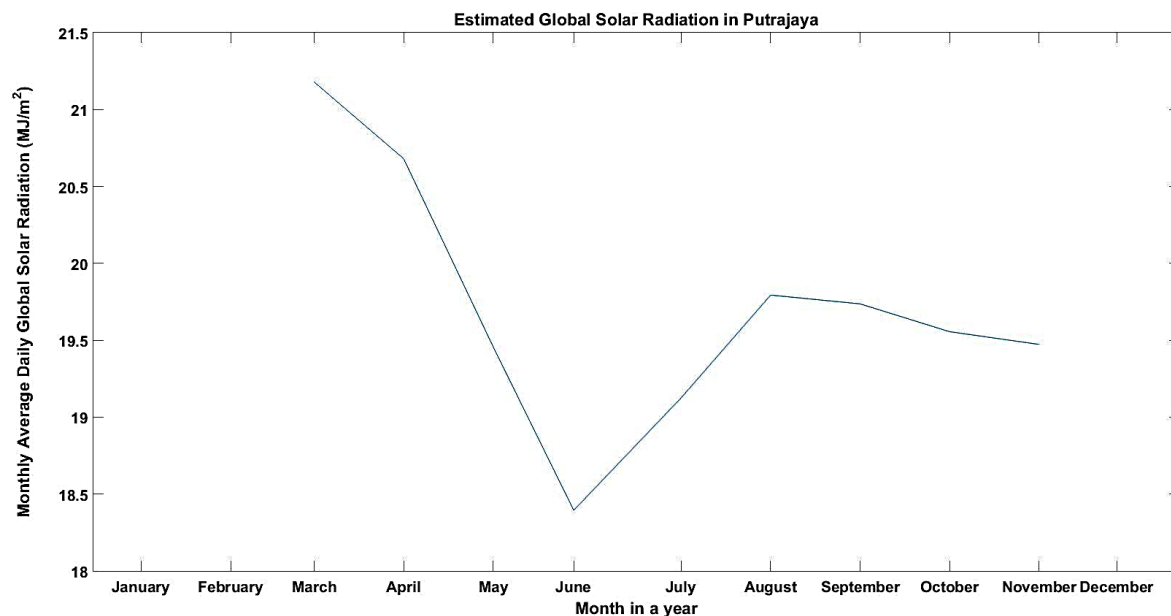
Secondly, results of the statistics used to validate the estimates of the monthly average daily GSR are shown in table 1.

**Table 1.** Results of the MBE, MAE, RMSE and MPE values obtained from the estimated and measured GSR.

MBE	MAE	RMSE	MPE
0.85	1.8	1.9	3.4

Ultimately, results of the estimation of the monthly average daily GSR for Putrajaya in 2015 were displayed using a linked plot diagram as shown in figure 2. It shows that out of 12 months, this study was able to estimate the monthly average daily GSR for 9 months, from March to November, while

unable to for 3 months i.e. January, February and December due to unavailability of data. Also, the largest monthly average daily GSR was estimated to be  $21.18 \text{ MJ/m}^2$  which occurs in the month of March and the least was  $18.34 \text{ MJ/m}^2$  which occurred in the month of June.



**Figure 2.** Estimate of the monthly average daily GSR for Putrajaya in 2015.

#### 4. Discussion

The results from table 1 shows how well the estimated GSR values perform in comparison to the measured values in KLIA for 2015. This is an indication of the reliability of the A-P model. The value of the MBE is close to zero which is looked-for. The MAE is computed to show the size of the mean difference between the estimated and measured GSR values. The RMSE value of 1.9 can be considered low since it was as high as 6.24 in another research using another model with temperature parameters [11]. A low RMSE value is preferred as it reflects a better estimate. The MPE is the percentage deviation between the estimated and measured GSR values and its value is desired to be low. A MPE of 3.4% is reasonably low. MPE is commonly considered acceptable for values below that of 10% [8]. The MPE in this study shows better results than a previous study on GSR in Malaysia done in 1997 which showed results with MPE between 4.486 % to 15.41 % [12]. These statistics indicate that the results are reliable. Hence, the A-P model is reliable to give an estimate of the GSR in Putrajaya as various other studies have indicated [7, 6].

#### 5. Conclusion

By using data from two nearby locations, a reliable estimate of the GSR in Putrajaya was provided for the benefit of various stakeholders, policy maker, developers and investors and energy authorities. Thus, the A-P model is an uncomplicated, economical and pragmatic method to estimate the GSR at a geographical location but is dependent on the availability and reliability of the meteorological data obtained. The average monthly GSR was obtained for nine out of twelve months with highest at  $21.18 \text{ MJ/m}^2$  in March and lowest at  $18.34 \text{ MJ/m}^2$  in June. MPE of 3.4% was adequately low, indicating the model and method used is reliable.

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## References

- [1] Chuah D G and Lee S 1981 Solar radiation estimates in Malaysia *Solar Energy* **26** 33-40
- [2] Sopian K and Othman M Y H 1992 Estimates of monthly average daily global solar radiation in Malaysia *Renewable Energy* **2** 319-25
- [3] Mekhilef S Safari A Mustaffa W E S Saidur R Omar R and Younis M A A 2012 Solar energy in Malaysia: current state and prospects *Renewable and Sustainable Energy Reviews* 386– 96
- [4] Besharat F, Dehghan A A and Faghil A R 2013 Empirical models for estimating global solar radiation: a review *Renewable and Sustainable Energy Reviews* **21** 798–821
- [5] Teke A Yıldırım H and Celik O 2015, Evaluation and performance comparison of different models for the estimation of solar radiation *Renewable and Sustainable Energy Reviews* **50** 1097–107
- [6] Despotovic M, Nedic V, Despotovic D and Cvetanovic S 2015 Review and statistical analysis of different global solar radiation sunshine models *Renewable and Sustainable Energy Reviews* **52** 1869–80
- [7] Paulescu M, Stefu N, Calinoiu D, Paulescu E, Pop N, Boata R and Mares O 2016 Angstrom–prescott equation: physical basis, empirical models and sensitivity analysis *Renewable and Sustainable Energy Reviews* 495–506
- [8] Manzano A, Martín M, Valero F and Armenta C 2015 A single method to estimate the daily global solar radiation from monthly data *Atmospheric Research* 70-82
- [9] Liu X, Mei X, Li Y, Zhang Y, Wang Q, Jensen J R and Porter J R 2009 Calibration of the Angstrom-Prescott coefficients (a, b) under different time scales and their impacts in estimating global solar radiation in the Yellow River basin *Agricultural and Forest Meteorology* 697-710
- [10] X. Liu, X. Mei, Y. Li, J. R. Porter, Q. Wang and Y. Zhang, "Choice of the Ångström–Prescott coefficients: Are time-dependent ones better than fixed ones in modeling global solar irradiance?," *Energy Conversion and Management*, no. 51, p. 2565–2574, 2010.
- [11] Li M F, Liu H B, Guo P T and Wu W 2010 Estimation of daily solar radiation from routinely observed meteorological data in Chongqing, China *Energy Conversion and Management*, 2575–9
- [12] Rehman S and Halawani T O 1997 Global solar radiation estimation *Renewable Energy*, **12** 369-85