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Relationship between the solar radiation and surface temperature in Perlis

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Abstract. Statistical models for predicting the solar radiation have been developed. In any prediction of the solar radiation, an understanding of its characteristics is of fundamental importance. This study presents an investigation of a relationship between solar radiation and surface temperature in Perlis, Northern Malaysia for the year of 2006. To achieve this, the data are presented in daily averaged maximum and minimum surface temperature, and daily averaged solar radiation. Since the scatter plots represent the straight line, the linear regression model was selected to estimate the solar radiation. It was found that the linear correlation coefficient value is 0.7473 shows that a strong linear relationship between solar radiation and surface temperature. The analysis of variance R^2 is 0.5585 that is; about 56 percent of the variability in temperature is accounted for by the straight-line fit to solar radiation. Based on the results, the fitted model is adequate to represent the estimation of solar radiation.

Introduction

Solar energy has been gaining ground over the last few years and is now beginning to contribute to the global energy. Solar energy in the form of direct electricity conversion of photovoltaic is already popular in other countries including Malaysia. Solar radiation is the result of fusion of atoms inside the sun. When the solar radiation enters the earth's atmosphere as Figure 1, a part of the incident energy is removed by scattering or absorption by surface molecules, clouds and particulate matter usually referred to as aerosols. The radiation that is not reflected or scattered and reaches the surface directly in line from the PV module is called beam radiation. The scattered radiation which reaches the ground is called diffuse radiation. The albedo is a radiation that reaches a receiver after reflection from the ground. Global irradiance is the total solar radiation on a horizontal surface of PV module consisting of three components.

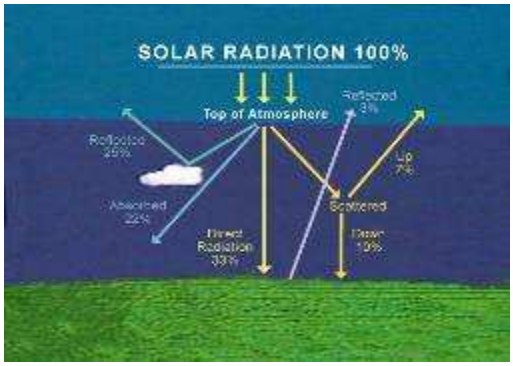

Fig. 1 Solar radiation in the earth's atmosphere [1]

When the skies are clear and the sun is directly in line from the PV module, the global irradiance is about 1000 W/m^2 [2]. The solar radiation data is the most important component to estimate output of photovoltaic systems [3, 4, 5]. Solar radiation is greater than 3 kWh/m^2 indicates that the sky is clear, its intensity very high and very good for PV application [6]. Temperature is an important consideration in the operation of PV module system [7]. At lower temperatures, PV module systems produce more power. For higher temperature, optimum operation requires modification of electrical load and removal of excess heat. The efficiency losses for PV systems can be minimized in the presence of temperature variations. This paper presents the relationship between the solar radiation and surface temperature in Perlis using Linear Regression model.

Climate and solar radiation in Perlis

Malaysia naturally has abundant sunshine and thus solar radiation. On the average, Malaysia receives about 6 hours of sunshine per day. As expected, the yearly average daily solar radiation is no significant different solar radiation intensity for both Peninsular and East Malaysia. The maximum solar radiation receive is 5.56 kWh/m^2 mostly in Northern region of Peninsular Malaysia and Southern region of East Malaysia. The Southern and Northeast region of Peninsular Malaysia as well as most parts in Sabah receives the lowest solar radiation as shown in Fig. 2 [8].

This research was obtained the solar radiation data from Meteorological Station, Chuping, Perlis (6^0 29' N , 100^0 16' E) (Fig. 3) has about 795 square kilometers land area, 0.24% of the total land area of Malaysia, with a population about 204450 people [9]. Perlis's climate is tropical monsoon. Its temperature is relatively uniform within the range of 21°C to 32°C throughout the year. During the months of January to April, the weather is generally dry and warm. Humidity is consistently high on the lowlands ranging between 82% to 86% per annum. The average rainfall per year is 2,032 mm to 2,540 mm and the wettest months are from May to December. In this research, the data are presented in daily averaged maximum and minimum temperature, and daily averaged solar radiation.

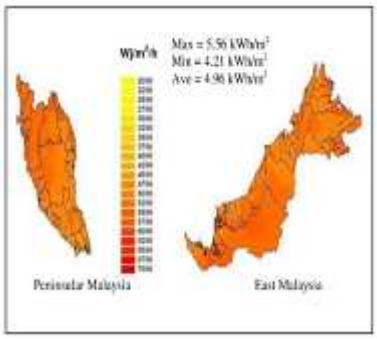

Fig. 2 Annual average daily solar radiation of Malaysia [8]

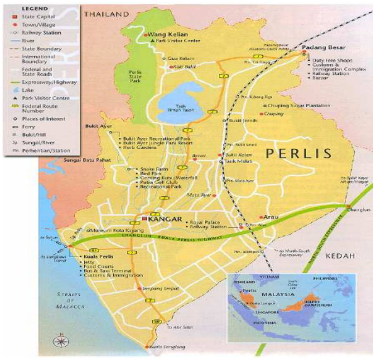

Fig. 2 Map of Perlis

Simple Linear Regression Model

Regression analysis is a statistical technique for investigating and modelling the relationship between variables [10] and it is the most widely used statistical technique. The simple linear regression model (SLR) used is a model with a single independent variable x that has a relationship with a response variable y that is a straight line. This SLR model is given by

$$y_i = \beta_0 + \beta_1 x_i + \varepsilon_i, \qquad i=1, 2, ..., n \tag{1}$$

where the intercept β_0 and the slope β_1 are unknown constant and ε is a random error. The errors are assumed to have mean zero and unknown variance σ^2. The parameters β_0 and β_1 are unknown and must be estimated using sample data. The simple linear regression equation is also called the *least*

squares regression equation. It tells the criterion used to select the best fitting line, namely the sum of the *squares* of the residuals should be *least*. That is, the least squares regression equation is the line for which the sum of squared residuals $\sum_{i=1}^{n}(y_i - \hat{y}_i)^2$ is a minimum.

The coefficients that minimize the square of the distance between the line end the points are given by

$$\hat{\beta}_0 = \bar{y} - \hat{\beta}_1 \bar{x} \quad \text{and} \quad \beta_1 = \frac{\sum_{i=1}^{n} y_i x_i - \frac{\left(\sum_{i=1}^{n} y_i\right)\left(\sum_{i=1}^{n} x_i\right)}{n}}{\sum_{i=1}^{n} x_i^{\,2} - \frac{\left(\sum_{i=1}^{n} x_i\right)^2}{n}} \tag{2}$$

where

$$\bar{y} = \frac{1}{n}\sum_{i=1}^{n} y_i \quad \text{and} \quad \bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$$

are the averages of y_i and x_i, respectively. Therefore, β_0 and β_1 are the least squares estimators of the intercept and slope. The residuals ε are the differences between the observed and the predicted values $y_i - \hat{y}_i$, i=1, 2, ..., n. The fitted simple linear regression model is given by

$$\hat{y} = \hat{\beta}_0 + \hat{\beta}_1 x_i \tag{3}$$

The correlation coefficient r evaluates the goodness of the fitting of data considered and the standard error measures, s is calculated. The correlation coefficient value can vary in the range –1 and +1, for the strong correlation between the two variables x and y. If the value is zero there is not any linear correlation between the two variables. The calculation of r as follow

$$r = \frac{n\sum_{i=1}^{n} x_i y_i - \left(\sum_{i=1}^{n} x_i\right)\left(\sum_{i=1}^{n} y_i\right)}{\sqrt{\left[n\sum_{i=1}^{n} x_i^{\,2} - \left(\sum_{i=1}^{n} x_i\right)^2\right]\left[n\sum_{i=1}^{n} y_i^{\,2} - \left(\sum_{i=1}^{n} y_i\right)^2\right]}} \tag{4}$$

The coefficient of determination, R^2 is given by

$$R^2 = \frac{\sum_{i=1}^{n}(\hat{y}_i - \bar{y})^2}{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2} \tag{5}$$

where $0 \le R^2 \le 1$. R^2 is called the proportion of variation explained by the regressor x. Value of R^2 that are closed to 1 imply that most of the variability in y is explained by the regression model [10].

Result and Discussion

Data Analysis and Parameter estimation

The daily averaged maximum and minimum surface temperature and daily averaged solar radiation throughout the year of 2007 in Perlis are shown in Fig. 3 and 4, respectively. Then, the analysis part is to assess whether or not there appears to be a strong relationship between solar radiation (y) and surface temperature (x), a scatter plot is plotted as shown in Fig. 5. The scatter plot consists of the data points, where there is a positive and roughly linear relationship between solar

radiation and the increase in surface temperature. The three exceptional data points (observations no. 1, 22 and 198) are well isolated from the remainder of the data. These data points are called outliers. The linear correlation coefficient value is 0.7473, shows that a strong linear relationship between solar radiation and surface temperature. This is because the solar radiation and surface temperature is directly proportional.

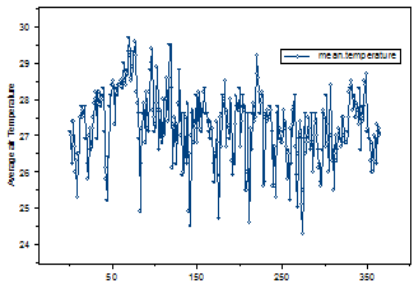

Fig. 3 The graph of average surface temperature

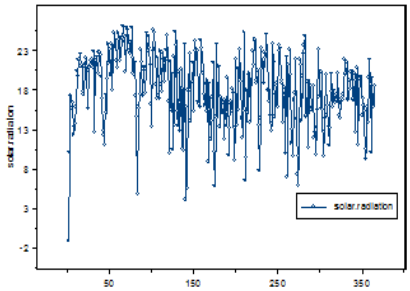

Fig. 4 The graph of solar radiation

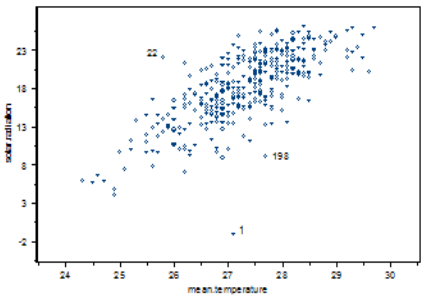

Fig. 5 The scatter plot of solar radiation versus surface temperature

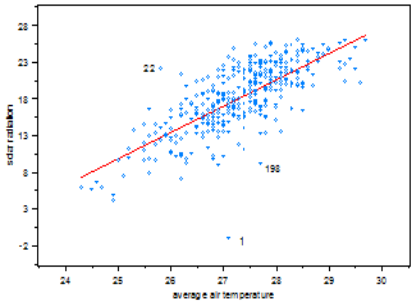

Fig. 6 The scatter plot with the fitted line of surface temperature versus solar radiation

A SLR model is assumed, and the estimation of parameters in the regression model is calculated using least squares method as given in Eq. 2. The value of $\hat{\beta}_0$ and $\hat{\beta}_1$ is -80.4560 and 3.6100 respectively. The least squares fit to the solar radiation data is

$$\hat{y} = -80.4560 + 3.6100x$$

where $\hat{y}$ is the estimated value of solar radiation corresponding to the surface temperature of x cases. The fitted equation is plotted in Fig. 6. The analysis of variance for this model $R^2 = 0.5585$. It is explained about 56 percent of the variability in temperature is accounted for by the straight-line.

Measure of Model Adequacy

To diagnostic and checking the adequacy of the model, the assumption of the regression analysis are studied such as the normal probability plot. Analysis of residuals is an effective method for discovering several types of model deficiencies. The normal probability plot represented that the errors (residuals) are normally distributed and shown in Fig. 7 since the points lie approximately along the straight line. Here, a common defect that shows up the occurrence of three large residuals, indicated that the corresponding observations as outliers [10, 11].

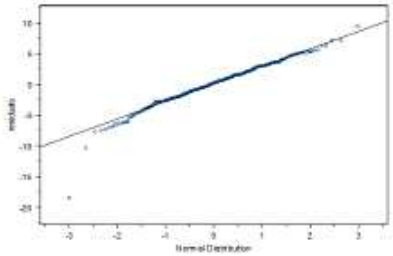

Fig. 7 The graph of the normal probability plot of residuals

Summary

The SLR model can be used to estimate the solar radiation in Perlis, Northern Malaysia. The relationship between average surface temperature and solar radiation is linear. The linear correlation coefficient value between surface temperature and solar radiation is 0.7473 shows strong linear relationship between variables. This indicated that exist a relationship between solar radiation and surface temperature.

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