



Faculty of Engineering

**Solar Potential and Photovoltaic System Capacity Estimation for Sarawak
based on Empirical Model and *r.sun* Module in GRASS**

Seniorita Bandy Ak Kerungan @ Engkasan

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Solar Potential and Photovoltaic System Capacity Estimation for Sarawak based on Empirical Model and *r.sun* Module in GRASS

Seniorita Bandy Ak Kerungan @ Engkasan

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ABSTRACT

The study of solar radiation potential is crucial part in the solar energy technology development. In Sarawak, standalone solar PV system is widely used for rural area electrification. Long term and reliable data of solar radiation would be useful in the system energy capacity's estimation. However, the accessibility to the long term and reliable data is still limited in this developing country (i.e. Malaysia). Furthermore, the availability of meteorological stations in Sarawak is very sparse as the country has very wide area. The existing stations are insufficient to provide measured solar radiation of Sarawak thoroughly. Thus, this study focuses on estimating solar radiation potential and system capacity in Sarawak. The estimation of solar radiation potential is estimated locally for Bintulu, Kapit, Kuching, Miri, Limbang, Sibu, and Sri Aman and also for large areas where there are no meteorological stations. For the areas with meteorological stations, the solar radiation prediction is done by using empirical estimation models. Measured air temperature, relative humidity, cloud factor and solar radiation are obtained from Malaysian Meteorological Department (MMD) collected within a period of 2010-2015. Linear regression and multiple linear regressions method are developed based on the measured data and were compared with Hargreaves-Samani and Bristow-Campbell models. The performances of the empirical models are tested with statistical validation of mean bias error (MBE), root mean squared error (RMSE), t-test and correlation coefficient (R). Multiple linear regressions performed the best among the models. Meanwhile, solar radiation study for areas without meteorological station is done by using *r.sun* module of Geographical Resources Analysis Support System (GRASS). The maps of monthly solar radiation (global and overcast) and annual system

capacity are developed. During the month of June, the average solar radiation is the highest for both global solar radiation (6675.92W/m^2) and overcast solar radiation (5391W/m^2).

Keywords: Solar radiation, solar photovoltaic capacity, empirical model, *r.sun* module

Anggaran Potensi Radiasi Solar dan Kapasiti Sistem Fotovoltaik di Sarawak berdasarkan Kaedah Empirikal dan Modul r.sun GRASS

ABSTRAK

Kajian potensi radiasi solar adalah bahagian penting dalam penerapan teknologi tenaga solar. Sistem fotovoltaik digunakan untuk elektrifikasi di kawasan luar Bandar Sarawak. Data sinaran suria jangka panjang adalah berguna dalam anggaran kapasiti tenaga sistem. Namun, akses data tersebut adalah terhad di negara membangun seperti Malaysia disebabkan kerosakan dan kehilangan sebahagian data. Malah, ketersediaan stesen meteorologi di Sarawak amat jarang kerana kawasan yang luas. Stesen-stesen sedia ada di Sarawak tidak cukup untuk menyediakan data radiasi solar dengan teliti. Fokus kajian ini tertumpu kepada anggaran potensi radiasi solar dan kapasiti sistem di Sarawak. Anggaran potensi radiasi solar dilakukan secara tempatan di Bintulu, Kapit, Kuching, Limbang, Miri, Sibu dan Sri Aman dengan menggunakan model anggaran empirikal. Malahan, anggaran meliputi kawasan luas dan tiada stesen meteorologi turut dilakukan. Data yang diukur seperti suhu udara, kelembapan relatif, faktor awan dan radiasi solar bagi tempoh 2010-2015 telah diperolehi dari Jabatan Meteorologi Malaysia (MMD). Kaedah regresi linear dan kaedah regresi berganda linear dibangunkan berdasarkan data diperolehi dan dibandingkan dengan model Hargreaves-Samani dan Bristow-Campbell. Model empirikal tersebut diuji dengan pengesahan statistik seperti ralat min keliru (MBE), ralat kuadrat kuantiti akar (RMSE), ujian t dan koefisien korelasi (R). Hasil perbandingan model mendapati kaedah regresi berganda linear adalah terbaik. Manakala, kajian radiasi solar meliputi kawasan luas dan tiada stesen meteorologi dilakukan dengan menggunakan modul r.sun di Geographical Resources Analysis Support System (GRASS). Peta radiasi bulanan (global dan mendung)

dan kapasitas sistem tahunan telah dibangun. Hasil kajian mendapati radiasi solar pada bulan Jun adalah yang paling tinggi untuk global (6675.92W/m^2) dan mendung (5391W/m^2).

Kata kunci: Radiasi solar, kapasitas sistem fotovoltaik, model empirikal, modul r.sun

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LIST OF ABBREVIATION

E_0	Eccentricity coefficient
CF	Cloud factor
DEM	Digital Elevation Model
GRASS	Geographical Resources Support System
H	Terrestrial radiation
H_B	Beam radiation
H_D	Diffuse radiation
H_0	Extraterrestrial radiation during a day
I_0	Extraterrestrial radiation during a given hour
$I_{0,H}$	Solar radiation on Earth horizontal plane
I_{SC}	Solar Constant
K_C	Clearness Index (computed from cloud factor)
K_{COMP}	Computed Clearness Index
K_{MEAS}	Measured Clearness Index
K_T	Clearness Index
MAD	Monthly Average Daily
MBE	Mean Bias Error
MMD	Malaysian Meteorological Department
MPE	Mean Percentage Error
MRM	Multiple Regression Method
N	Number of day
NTE	Nominal Terrestrial Environment

RH	Relative Humidity
RMSE	Root Mean Square Error
SoDA	European Solar Radiation Data2
SRTM	Shuttle Radar Topographic Mission
T_{LK}	Linke Turbidity Index
δ	Earth Declination
ΔT	Air temperature difference
Θ_z	Solar zenith
ϕ	Latitude
ω_s	Sunrise hour

CHAPTER 1

INTRODUCTION

1.1 Research Background

In the urban-industrial areas of developing nations, the availability of fossil fuels has increased for expansion of economic production and personal consumption. However, the fossil fuel distribution is unevenly distributed throughout the world. Currently, the world uses a lot of energy. It is accounted that average energy usage is 17 terawatt (2.5 kW per person) with world energy market of \$3 trillion/year [1] which commonly generated from non-renewable resources. Malaysia is one of developing country that relies on fossil fuel where the electricity supply made up of 74% of natural gas and 88% of coal [1–3]. To meet the growing demand, the environment and sustainability of energy sources are at tolls [4].

Global energy demand will increase at the rate of 1.6% and 65% increases will be due to developing countries by 2030 [1, 5, 6]. As a consequence, global warming which gives negatives impact (i.e. glacier receding, biodiversity loss) occurs [7]. In addition, fossil fuel is non-renewable energy which will deplete in future. These two factors, threat of global warming and fossil fuels depletion, have become the driving forces towards renewable energy development.

Development of renewable energy is important to reduce the greenhouse gases (GHG) while accommodating electrification to urban areas and remote areas. Every country's economic and environmental well-being is highly dependent on the shift of sustainable, reliable, abundant and relatively clean energy resources. Solar energy technology, for instance,

has high potential to substitute conventional energy sources as it is able to generate electricity without emitting global warming pollutants and have no risk of fuel price spikes.

1.2 Statement of Problem

The solar technology field uses detailed information concerning meteorology and solar radiation to optimize the technology selection (e.g. solar photovoltaic system, concentrated solar power and solar heating system) and performance, hence, secure financing. Sarawak is a tropical country that has significant solar resources but curtailed radiation monitoring network and analyses of the meteorological data [8–10]. Furthermore, availability of long term and reliable solar radiation data (e.g. sunshine duration and daily global solar radiation) is very scarce and often limited due to the absence of measurement or maintenance issues. The missing data may occur for some parameters in meteorological data set while other parameters are complete. Therefore, estimation using suitable solar radiation estimation models, which have been developed using historical data from the weather station, is needed to fill the missing data.

The amount of the solar radiation energy depends on the location, time of the year and atmospheric conditions. Several solar radiation models have been developed based on the meteorological data obtained from weather station or satellite measurements. However, the solar radiation estimation is too local since they rely on the weather stations and unable to estimate the radiation over a wide area [11–13]. The estimation of solar radiation over wide area enables the study of solar radiation at locations where the solar monitoring networks is unavailable.

The implication of estimating the solar radiation over a wide region allows to a better assessment of PV system development. Planning of optimal exploitation of solar energy is

required before sitting of solar panel units. The potential obstacle that prevents optimal exploitation of solar energy is intermittency. Solar power at any location is intermittent: it varies over times that are imperfectly predictable [14]. Geographical mismatches (e.g. terrains, elevation, land cover) between sunlight are creating trade-offs in solar panel system sitting decisions. Estimation of solar irradiation potential with its capacity in a geographical area can be mapped out via Geographical Information System (GIS) for better assessments of the renewable energy. Hence, prediction of solar irradiation to exploit the source should be done.

1.3 Research Question

A study on sun-earth relation is required to understand solar potential estimation. A variety of studies on global solar radiation (or known as solar radiation received on earth surface) has been carried out over the time. However, long-term solar radiation measurements on specific areas are relatively scarce due to equipment maintenance cost or malfunction. The earliest study is done in Kuala Lumpur [15] yet no specific study has been conducted in Sarawak. The issues that become questions in this research are:

- i. How does the existing meteorological data incorporated with the solar radiation estimated?
- ii. What is the best empirical model used to estimate the solar radiation at each meteorological stations? How will the estimation model performs?
- iii. What is the intensity of incoming solar radiation at the locations without weather monitoring network?
- iv. How the local environment does affect the incoming solar radiation?

- v. What is solar photovoltaic system capacity generated within a year based on the solar radiation received?

1.4 Research Objectives

The challenges faced as discussed in the statements of problems become focus of this research work. Therefore, this work will present the solar radiation map which, later, allows the assessments of the solar PV system. The research area of this project will be focus mainly in Sarawak, Malaysia. The objectives of this research project are:

- i. To investigate the current solar radiation estimation model.
- ii. To estimate solar radiation potential and solar system capacity using mathematical model approach.
- iii. To develop GIS mapping for solar radiation potential map and PV system capacity assessment for Sarawak.

1.5 Research Significance and Expected Outcomes

The primary motivation of this research work is to estimate solar radiation and solar PV assessments using GIS approach. The estimation of solar potential is based on existing knowledge of sun-earth relation and meteorological data from selected region. The significance of this research work is presented as following:

- i. Estimation of missing solar radiation data using existing meteorological data in solar radiation model.
- ii. Calibration and evaluation of empirical coefficient of solar radiation model.
- iii. Estimation of solar radiation at areas that are not covered by meteorological stations.

- iv. Development of GIS to estimate solar potential and its capacity in Sarawak using open software, Geographical Resources Analysis Support System (GRASS) GIS software.

At the end of this project, the expected outcomes are:

- i. Mathematical approaches for solar irradiation estimation.
- ii. GIS maps of solar radiation potential and its capacity maps.

1.6 Thesis Outlines and Research Scope

This research focuses on investigating solar radiation potential and its capacity in Sarawak. The outlines of this work are provided as following:

- i. Chapter 1 Introduction provides the introduction of this study background, research statements of problem, objectives and expected outcomes of this research.
- ii. Chapter 2 Literature Review focuses on the works that has been done by other researchers besides brief theoretical background concerning the solar radiation characteristics and solar radiation attenuation factors. In this topic, prospectus of solar energy technology and its potential are discussed based on the current findings and views of researchers.
- iii. Chapter 3 Methodology covers the methods, based on information in Chapter 2, employed in this research work, data collection, missing solar radiation data estimation at the local meteorological stations and development of monthly solar radiation potential and annual solar capacity maps.
- iv. Chapter 4 Result and Discussion gives the result obtained from the analysis and presented in tabular and graphical forms. The solar radiation potential of the study area was determined by analyzing availability and characteristics of the solar