Determining Optimal Solar Power Plant Location in Melaka, Malaysia: A GIS-Based Solutions

Muhammad Iqbal Durrany Zulkifly¹, Mohd Shahmy Mohd Said¹

¹Centre of Studies for Surveying Science and Geomatics, Faculty of Architecture, Planning and Surveying, University Teknologi MARA, 40450 Shah Alam Selangor

*Email: durrany31@gmail.com, mohdshahmy@uitm.edu.my

Abstract. The energy demand has risen dramatically in recent years as a result of population growth and the fast expansion of the global economy. Due to rising carbon dioxide (CO2) emissions and increasing energy needs, Malaysia has recently intensified its efforts to encourage the development of renewable energy supplies. Despite the abundance of solar resources, the PV growth in underdeveloped countries such as Malaysia is moving slower. Malaysia has the advantage in solar energy generation since it is geographically close to the equator and has a significant solar generation potential due to its hot and sunny weather all year. Therefore the question here is, where is the most suitable place to build more solar power plants? What methods will we be using to find the most suitable place to build the solar power plant? In picking a place for such development, several factors must be examined, such as how effective the PV power station site is and how to decrease the overall cost of the project by minimising proximity to existing infrastructures while improving solar panel power production. A geographic information system (GIS) is a tool that can help to solve this challenge. In this case, we integrate economic, environmental, and technical variables such as solar radiation intensity, local physical terrain, environment, climate, and placement criteria such as distance from roads and rivers. As additional input factors, other geographical information data were used (solar radiation, digital elevation models (DEM), land cover, and temperature). Further analysis using the Analytic Hierarchy Process (AHP) based Multi-Criteria Decision Making (MCDM) was then applied to this study to get the suitable location based on the importance of the criteria. In order to build a cost-effective and high-performing solar project, a complete solar site assessment is required. The results of the study should give a decision support system model and map on determining the optimal locations of solar power plants in Melaka.

1. Introduction
Energy is an important element in economic growth and is a vital economic artery for countries all over the world. The demand for energy has risen dramatically in recent years as a result of population growth and the fast expansion of the global economy [1]. Solar energy has been identified as one of the alternative energy options in the world's transition from fossil fuels to carbon-free energy generation. The production of solar power is one of the most promising renewables since it is a consistent source of energy that is not influenced by seasonal weather patterns. Solar photovoltaic (PV) technology is one of the most rapidly expanding renewable energy technologies in the world. PV module prices have recently decreased by 80%, and they are expected to continue to reduce in the future years [2].
Furthermore, solar technologies' output efficiency has improved in recent years, and their flexibility to be used in a range of settings is highly appealing [3]. Solar energy demand is growing throughout the world as governments seek for sustainable development and lower carbon dioxide CO2 emissions. Due to rising carbon dioxide (CO2) emissions and rising energy needs, Malaysia has recently intensified its efforts to encourage the development of renewable energy supplies. According to reports from international and local environmental organisations, Malaysia alone released 226,988.90 kt of CO2 into the atmosphere in 2013 [4]. Solar radiation may be converted directly into electricity using photovoltaic (PV) technology, which feasible ways to deliver clean and sustainable energy. PV emits about 50 grammes per kilowatt-hour (kWh) as compared to CO2 emissions from coal combustion, which are 975 grammes per kWh. It provides free energy indefinitely, and solar goods can last up to 30 years [5].

Malaysia is rich with a diverse range of energy resources, including fossil fuels and different renewable energy sources. Malaysia has an advantage in solar energy generation since it is geographically close to the equator and has a large solar generation potential due to its hot and sunny weather all year. In the year 2012, the solar irradiation for Malaysia monthly is estimated at 400–600 MJ/m². Between November and March, the irradiation is greater due to the North-East monsoon. There is less irradiation between May and September due to the South-West monsoon [6]. As a result, rooftop solar and large-scale solar (LSS) are viable options for solar deployment in Malaysia. When compared to traditional energy sources, large-scale PV systems offer substantial environmental benefits.

Malaysia is a highly recommended place to build and gain solar power energy. Malaysia has these advantages as its position is near the equator, which resulted in Malaysia receiving more sunlight throughout the year and getting higher radiation light from the sun [7]. One of Malaysia's states that has a great aspiration to become a green technology city-state is Melaka. According to Melaka Green City Action Plan, one of the obstacles to reach Melaka’s vision of a green city is in locating suitable land for renewable energy plants in Melaka. Thus, this study aims to determine the optimal location for solar power plants in Melaka, Malaysia.

The question here is, where is the most suitable place to build more solar power in Melaka? What methods will we be using to find the most suitable place to build solar power? When picking a place for such an installation, several factors must be examined, such as how effective the PV power station site is and how to decrease the project's overall cost by minimising proximity to existing infrastructures while improving solar panel power production. In order to build a cost-effective and high-performing solar project, a complete solar site assessment is required. Thus, it mainly analyses and identifies the suitable place to build solar power for providing clean energy sources to provide electricity around the Melaka State.

2. Literature review

2.1. Solar Irradiance

The solar irradiance is the amount of light energy emitted by the whole sun disc as measured on Earth. Irradiance is defined as the quantity of light energy from one item impacting a square meter of another per second, according to National Aeronautics and Space Administration (NASA). Sunlight is the power per unit of the sun that is measured as electromagnetic radiation in the wavelength range of the measuring equipment. The brightness of a wavelength of light throughout the Sun is measured by spectral solar radiance. Solar radiance is a measure of instantaneous power density in kW/m². It is important to know the quantity of sunshine available at a given place at a given time when designing a photovoltaic system [8]. There are various types of solar irradiance that may be measured. Total Solar Irradiance (TSI) is a measurement of solar power per unit area incident on the Earth's upper atmosphere at all wavelengths. It is measured perpendicular to the direction of the incoming sunlight. The solar constant is a traditional measure of mean TSI at one astronomical unit distance (AU) [9]. Direct Normal Irradiance (DNI), also known as beam radiation, is measured at the Earth's surface at a specific spot using a surface element perpendicular to the Sun. It does not include diffuse sun radiation (radiation that is scattered or reflected by atmospheric components). The extra-terrestrial irradiance above the atmosphere is equal to direct
irradiance minus atmospheric losses due to absorption and scattering. Diffuse Horizontal Irradiance (DHI) is the radiation at the Earth’s surface caused by light scattered by the atmosphere. It is calculated on a horizontal surface using radiation from all points in the sky, except circumsolar radiation (radiation coming from the sun disk). In the absence of atmosphere, there would be essentially no DHI. The total irradiance from the sun on Earth’s horizontal surface is known as global horizontal irradiance (GHI). It is calculated as the sum of direct irradiance (SDI) and diffuse horizontal irradiance (DHI). The total radiation received on a surface with defined tilt and azimuth, whether fixed or sun-tracking, is referred to as global tilted irradiance (GTI). GTI can be calculated or calculated from GHI, DNI, and DHI [10-12]. It is frequently used as a reference for solar power plants, with photovoltaic modules mounted on fixed or tracked structures. The total irradiance from the sun at the Earth’s surface at a specific point with a surface element perpendicular to the Sun is known as global normal irradiance (GNI).

2.2. MCDM for Site Selection

Multiple-Criteria Decision-Making (MCDM), also known as Multiple-Criteria Decision Analysis (MCDA), is a branch of operations research that evaluates multiple competing decision-making criteria. In the estimation of cost or price options, which is usually one of the major criteria, conflicting criteria are prevalent, and some quality calculation is usually another criterion, readily in conflict with cost. Several previous studies have used MCDM tools and applications to solve field issues such as electricity, climate, sustainability, etc [21]. Methods of MCDM have been designed to define a preferred option, classify alternatives in a limited number of categories, and/or classify alternatives in a subjective order of preference. In cases where there is more than one competing criterion, MCDM is a general term for all approaches that exist to help people make decisions according to their preferences. Modern MCDM methods allow decision-makers to address all of the above-mentioned types of information. The choice of the aggregation method for solving the decision problem is one of the issues encountered during the MCDM process [29].

GIS integration with MCDM has recently been increasingly popular in different location applications, including the selection of waste sites, urban design and planning of RES sites. Many industrial enterprises have started concentrating on selecting a plant or the ideal location in order to withstand the global competition of the 21st century. The optimal situation is that, via increasing production and a solid distribution network, leads to more financial gains. MCDM approaches help decision-makers in choosing the optimum choice for the coexistence of several criteria among numerous possibilities [13]. These strategies are often used in planning, particularly in the selection of sites based on environmental, technological and economic aspects. Moreover, various decision-makers might vary on the exact criteria or options which the decision framework should entail. There are a lot of MCDM applications widely used for site selection planning. AHP, ANP, Boolean logic, weighted linear combination (WLC), and fuzzy logic are some approaches for multi-criteria analysis. These techniques have been used to find the best locations for solar PV installations. The AHP approach is the most often used method for calculating weight analysis [14].

Hierarchical structures in the AHP describe an issue and make decisions based on expert judgements to create priority scales. A pair-wise comparison matrix is used to determine the overall weights and significance of each input parameter. AHP is one of the most complete multi-criteria decision-making systems available. The key feature of AHP is that it is based on paired comparisons. Multiple criteria issues can be divided into one-to-one comparisons. Several studies have been conducted to evaluate suitable locations for CSP or PV power plant installations utilising AHP. According to [15], this technique may be used to construct issues in a hierarchical manner. Solar radiation, transmission lines, water bodies, slope, land use, potential energy output, and a number of economic and technical factors can all be evaluated as part of the AHP process [13]. As a result, multi-criteria decision-making (MCDM) approaches have been discovered to be an effective tool for resolving these location selection issues.
3. Materials and methods

3.1. Identification Criteria of Site Selection

In order to choose suitable sites for solar energy consumption in the study region, it is important to establish effective geographical criteria and factors on the feasibility of solar power plants. The criteria used in this study were gathered from a variety of previous investigations [15], [16], [17], [18], [19]. There are three types of criteria in this study: economic, environmental, and technological. The criteria will be downloaded and processed as well.

![Criteria of Site Selection](image)

**Figure 1.** Criteria of Site Selection

i. Economic Criteria

Distance roads, elevation, and slope were chosen as economic factors for this study. Because the transfer of personnel and equipment, as well as the construction of SPPs, becomes more difficult as altitude above sea level increases thus, project costs rise. As a result, building SPPs at high elevations is not suggested. Access to the transportation network, on the other hand, reduces the operating costs of SPPs since power plants' transportation costs are reduced when they are close to highways. Other economic factors include slope. The gradient of the Earth's surface is depicted by slope, which can be a crucial factor in civil concerns about solar plant construction and deployment. Slope consideration can also help SPPs save money on their civil costs. Flat ground is essential for large-scale PV. Valleys and steep terrain on higher slopes should be avoided. The survey area's aspects have been created using the DEM [13].

ii. Environmental Criteria

The Land Use Land Cover (LULC) and the distance to rivers were two of the environmental factors evaluated in this study. Baldomero, according [17]. The availability of land is an essential factor to consider while choosing a location. PV power plants sometimes require a large amount of land, which can have a detrimental influence on the environment and the communities around them. Some locations, including as protected regions and water resources such as rivers and lakes, are not suitable for the building of SPPs. Land use maps should be used to manage and modify natural environments such as urban settlements, power plants, industrial zones, and other constructed environments in a sustainable manner.

iii. Technical Criteria

For SPP site selection, a number of technical parameters, mostly related to climatic conditions include things like temperature and sunshine hours (Solar Radiation), could be considered, according to [13]. The temperature effect should be included into the site evaluation process for SPPs to enhance the reliability and maximise the performance efficiency of large-scale PV power plants. The major technical element used in this study's geographical analysis is sunlight hours, also known as solar radiance. The amount of sunlight hours is the most important factor in determining whether sites will get adequate solar radiation for a power plant [19]. The yearly distribution of sunlight hours and average sunshine
hours is depicted on the interpolated map. This map may be used to find areas that receive more sunlight throughout the year. A large amount of solar power generates a large amount of electricity.

![Flow Chart of Determine Optimal Solar Power Plant Location](image)

**Figure 2.** Flow Chart of Determine Optimal Solar Power Plant Location

### 3.2. Spatial Data and Software

In this project, Landsat 8 OLI satellite images with a resolution 30m was used. This data has been downloaded from United States Geological Survey (USGS) Earth Explorer. Land use data refers to data that is a result of classifying raw satellite data into land use categories based on the return value of the satellite image. Next, data that will be used in this study is the Primary Road Network Data of Melaka. This data has been downloaded from OpenStreetMap (OSM). Function of this data is to proximity the road to get the suitable site location of the PV. To get the elevation and slope data, DEM data is needed.
This data has been downloaded from USGS. Digital elevation data are sets of elevation measurements for locations distributed over the land surface. The parameter for this DEM is 30m resolution. For the waterway data of the study area, the data has been downloaded from OpenStreetMap (OSM). Function of this data is to proximity the waterway to get the suitable site location of the PV away from flood. Lastly, the solar radiation data in this study. This data has been downloaded from Global Solar Atlas. This type of solar radiation data is GHI. GHI is the most important parameter for energy yield calculation and performance assessment of flat-plate photovoltaic (PV) technologies. It is mainly used for studies on PV plants [14]. For picture processing and geographical analysis, several software programmes were employed in this investigation. For image processing and classification, ERDAS Imagine was utilized. In a geo-database package, ArcGIS was utilized to store and manage geographic data. In addition, for the solar radiation potential evaluation, GIS data were generated and analyzed in both vector and raster formats. In order to calculate criterion weight, Microsoft Excel will be used. Aside from that, ArcGIS was utilized for weighing criteria decision assistance and uncertainty management, as well as a large number of criteria aggregation processes based on a weighted linear combination. For cartographic visualization software on mapping the result, ArcGIS will be used to edit the map result.

### Table 1. Data Used For This Study

| GIS Data Layer  | Description          | Sources                  | Projection |
|-----------------|----------------------|--------------------------|------------|
| Vector (Line)   | Road                 | OSM                      | WGS 84     |
| Vector (Line)   | Waterway             | OSM                      | WGS 84     |
| Raster          | Slope and Elevation  | DEM 30m, USGS            | WGS 84     |
| Raster          | Land Use/ Land Cover | Landsat 8 OLI, 2020 USGS | WGS 84     |
| Raster          | GHI                  | Solar Atlas              | WGS 84     |

### 3.3 Data Processing

#### 3.3.1 Satellite Image

For image processing, firstly add the image data that had been downloaded from USGS on ERDAS IMAGINE. Then, subset the image through the study area. A radio metric correction (haze and noise reduction) is needed to eliminate the haze and noise. On getting the LULC of the image, a classification process is needed. On this processing, Supervised Classification is used to get the land cover of the image. Firstly, sample is needed to make the software read the histogram of image. About 98 sampling had been taken and 5 class of land cover had been classified from the process. Among the 5 classes are Waterbodies, Vegetation, Forest, Urban and Baresoil. The result for the land classification as shown on Fig. 4.

#### 3.3.2 Euclidean Distance

For this processing part, there is 2 data needed to be proximity. Among these 2 data are Road and Waterway (River). To produce a Euclidean distance, firstly it needed to change projection to UTM (Kertau_48N) so that the distance (meter) can be calculated and represented in ArcGIS accurately. By using Euclidean distance tool in the software, the proximity distance can be obtain. The result for the Euclidean Distance of Road as shown on Fig. 5 (c) and The result for the Euclidean Distance of River as shown on Fig. 6 (d).

#### 3.3.3 Slope

For this processing part, it needed a data DEM of study area to produce a slope. The projection of DEM data that had been downloaded from the USGS must be in UTM (Kertau_48N) so that the distance (meter) can be calculated and can be represented in ArcGIS accurately. To produce a slope, firstly go to 3D Analyst tools > Raster Surface > Slope. For this study, the output measurement should be degree and z factor is 1. The result for the slope as shown on Fig. 5 (b).
3.3.4 Temperature. A LST processing method should be used to obtain the temperature of the study area. To process LST, the Top of Atmospheric was first calculated. The TOA should then be converted to Brightness Temperature. The NDVI of the research area is then calculated. The NDVI must be computed because the proportion of vegetation (Pv), which is heavily related to the NDVI, and emissivity, which is related to the Pv, must also be determined. Finally, use the LST equation to get a surface temperature map. All of this processing involves their own formula and its application with a raster calculator.

3.4 GIS Based Multi Criteria Analysis
In this study, Multi Criteria Decision Making (MCDM) has been be used to determine the optimal solar power plant location. Several criteria were chosen based on previous study. All these criteria have been applied in the map. The criterion has been ranked by the experts before further processing. Questionnaire has been done conducted and distributed to the experts in order to get the weightage of each criterion. The experts evaluated and ranked each criterion in the range of 1 to 5 and decided which criteria is more important or less important than the other criteria. After that, calculated criterion weights and priorities by using the Analytical Hierarchy Process (AHP). A decision matrix is created as a result of pairwise comparisons in the context of the AHP technique. As a result of these calculations, criterion weights are determined. After calculate weightage of main criteria and sub criteria, then it can proceed to second step which is calculating priorities. The total sum of the priorities must be 1. Insert the value of the priorities into the influence (%) at weighted overlay table. In this study, Microsoft Excel had been used to calculate the criterion weight. Then, the consistency test is performed after the normalized weights of the criteria, which are determined by the level of importance. In the pairwise comparison procedure, a consistency ratio (CR) is used to screen out inconsistent judgments of decisions. Equations based on Figure 3 are used to calculate the Consistency Index (CI) and Consistency Ratio (CR). The random consistency index (RI) changes with the number of criteria in a comparison (n). The number of criterion (n) in this study is 3, and the RI value is 0.52. If CR ⩽ 0.10, the degree of consistency is considered acceptable or otherwise, the pairwise comparison contains major errors. As a result, the AHP may not produce relevant results. As overall, the CR that get in this study is below 0.10 and it is acceptable.

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CI = \frac{\lambda_{\text{max}} - n}{n - 1}
\]

\[
CR = \frac{CI}{RI}
\]

Figure 3. Formula of Consistency Index & Consistency Ratio

4. Result and discussion

4.1. Suitability Criteria
In order of priority, all known criteria that may influence PV solar farm site selection were reviewed. The criteria are Land Use, Slope, Elevation, Temperature, GHI, River Proximity, and Road Proximity. Using this criterion, each factor and constraint for selecting potential sites for large PV plant installation were examined. These conditions and constraints are based on past research undertaken in several areas [13], [19-26]. The condition and constraint of site selection are shown in the table below. The data criteria needed to be reclassify based on the condition and constrain of site selection. The criteria factors will be reclassify on scale from 1 to 3. Based on the scale, we will know where is the suitable and unsuitable area based on the condition/constrain of every criteria factor. The reclassify scale of 1 is not suitable, 2 is intermediate and 3 is suitable.
Table 2. The Suitability Criteria of Site Selection

| Criteria               | 1 (Not Suitable) | 2 (Intermediate) | 3 (Suitable) | Weight (%) |
|------------------------|------------------|------------------|--------------|------------|
| Land Used              | Water Bodies,    | Urban & Forest   | Bare Soil &  |            |
|                        | Urban & Forest   | Vegetation       |              | 16.0       |
| Slope                  | > 15°            | 5° - 15°         | < 5°         | 8.8        |
| Elevation              | > 150m           | 60m - 150m       | < 60m        | 4.7        |
| Temperature            | > 25°C           | < 18°C           | 18°C – 25°C  | 15.0       |
| Solar Radiation, GHI   | < 4.6 kW/m²      | > 4.6 kW/m²      |              | 45.0       |
| River                  | < 1 km           | > 5 km           | 1 km – 5 km  | 4.0        |
| Road                   | < 0.5 km         | > 3000m          | 0.5 km – 3 km| 6.4        |

The availability of land is a significant factor in implementing optimal site evaluations. The availability of various land-use categories may differ. Certain land-use types are not appropriate for PV installation. Water bodies, environmentally sensitive land, and developed urban regions are examples of these. In a rough topography similar to Malaysia, the elevation must be less than or equal to 60m, and the slope must be less than 5° throughout the entire spatial aspect, for a land area to be considered ideal. When temperatures fall below 25 ° C, the efficiency of PV systems rises [27]. As a result, places with lower mean temperature are more advantageous in terms of improving PV system performance and, as a result, must be granted the highest grading level. The Global Horizontal Irradiation, or GHI, is the main determining factor in locating and identifying the optimal location to deploy solar farms. Where it is recognized that the use of solar energy resources is economically possible or profitable, particularly in areas with a GHI average of 4.6 kW/m² [28]. The proximity of solar PV facilities to existing highways will be advantageous and may reduce project costs. In the current study, the distance to the main road was categorized into three categories: suitable (0.5-3 km), and intermediate (>3 km). It is not suitable to be so close to the road, 0.5km. Finally, the river and flood plains are considered constraints; consequently, it is not recommended to deploy solar farms within or near river flood plains. It is suitable for a distance of more than 1 kilometer.
Figure 4. Condition Land Used Map of Melaka.
Figure 5. Condition Elevation (a), Condition Slope (b) and (c) Condition Distance Road.
Figure 6. Condition Distance River (d), Condition LST (e) and (f) Condition Solar Irradiance.
4.2. Site Selection Result
After reclassify every criteria factors, it is time to overlay it to get the optimal location of solar power plant of the study area. To do that, a weighted overlay tools is needed. On weighted overlay tools, we can see the influence percentage and the value number. Values are rounded down to the nearest integer. The sum of influences must equal 100. The scale value is for the criterion, as specified by the important of the criteria based on expert result. With this weighted overlay, the ArcGIS will process the output of the optimal location of solar power plant as shown on Fig. 7. The goal of this map is to show the most suitable place for a solar power plant to be built. This result is obtained by removing all of the study area's unsuitability criteria conditions. Then overlay it with the priorities of the AHP result to get the final location area. The map also showed the existing location of the power plant in Melaka which is located in the center area of Melaka. It seems that the existing solar power location is within and near the area of optimal site location. Melaka was divided into five states, according to the map. The results revealed that the majority of the best locations were in Jasin. This suggests that Jasin state has a great potential to build another solar power plant in the future.

![Figure 7. Map of Optimal Solar Power Plant Location in Melaka.](image-url)
5. Conclusion

This study evaluated numerous published works on GIS-based methodologies and applications for solar power system planning and design. This study proposes a method for establishing criterion layers that include solar irradiation and temperature in the siting of utility-scale PV power facilities. The solar radiation applied in this research is Global Horizontal Irradiance (GHI), which is excellent for determining optimal PV power plant location. Solar radiation is the key factor in most site evaluation studies, and it is gathered in a variety of ways depending on the existence or absence of data. The integration of GIS and MCDM methods has developed as a highly effective methodology for dealing systematically with rich geographical information data as well as manipulating important variables for establishing best sites for solar power plants. The AHP technique is used in MCDM to assess the value of each decision criterion in determining the best location for utility scale solar PV power projects. The amount of solar irradiation (GHI), land surface temperature, land use cover, slope, elevation, and proximity to a river and a road are all technical and economic considerations. The process successfully creates a site suitability condition for potential sites where all requirements are met. Site evaluation using a GIS, in particular, is important for supporting regional decision making, and it is necessary to evaluate economic, environmental, and technical factors in conjunction to solar radiation.

Through weighted overlay, these criteria could be used to exclude inappropriate places. According to the findings for the Melaka case, the most suitable areas may very well be found in Jasin, which is located to the east of the study area. These strategies can assist Melaka and other Malaysian states in achieving their solar power plant locations and SDG targets for a more sustainable energy future. As a recommendation for future study, it should improve and progress in the future by using high-resolution geospatial data, advancing spatial data analytic methodologies, and integrating GIS technology. This could include applying new tactics as well as doing a comparison analysis of such techniques to acquire a comprehensive understanding of the ideal methods. Furthermore, it would be interesting to incorporate more other choice factors, such as distance to grid line power, heritage sites, rocky surface, aspect, and visual impact, to broaden the suggested model. Incorporating population density, terrain orientation, and solar energy policies could provide anticipate more accurate, optimal sites, which will benefit in energy potential analysis.

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