Suitability Analysis for Solar Photovoltaic Development in East Belitung Regency

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Abstract. The dependence on energy affects the development of a region. Small islands usually have energy dependence on the nearby big island. In order to meet the needs of electric energy, Belitung Island has operated steam power plant as a form of energy independence in Bangka Belitung, but to meet the energy needs of households and various industrial sectors, especially the tourism industry in East Belitung which continues to increase, the capacity of electrical energy power on the island needs to be increased. Solar energy is one of the potential energy sources contained in East Belitung which can be used as an alternative energy source that is environmentally friendly. Placement of location for the development of Solar Photovoltaic (PV) System can be done by utilizing Geographic Information System with Multi Criteria Analysis, determining location for PV placement requires region suitability analysis using GIS technology. Ground assessment is used for knowing the real condition of the ideal area, then the potential site for photovoltaic system development can be obtained.

1. Introduction
This study provides an analysis of areas suitability for potential Solar Photovoltaic (PV) system development in the East Belitung Regency. The objectives of this study is to determine the suitable areas for the implementation of solar PV system based on the geographical factors and constraints of the region, analyzed using Geographic Information System (GIS). The result of the suitability analysis can be then verified with field survey to get the potential site for system development. This analysis could provide an assistance for policy-decision making process for the development of East Belitung Regency. Small islands usually have energy dependence on the large island that is nearby. In meeting of electrical energy needs, Belitung Island already operates steam power plants as a form of energy independence in the Bangka Belitung region, but to meet the energy needs of households and various industrial sectors, especially in East Belitung Regency which continues to grow, the need for additional power electrical energy on the island is undeniable. The total installed capacity of electric power plants in the Province of Bangka Belitung Islands up to 2014 is around 208 Mega Watts (MW) consisting of Perusahaan Listrik Negara (PLN) generators of around 194 MW and Independent Power Producer (IPP) of around 13 MW [1]. As for the type, the installed capacity of the plant consists of coal plants around 30 MW, PLTU-Bi (Biomass) around 13 MW, PLTD (Diesel) around 164 MW, and PLTS (Solar) around 0.04 MW. Electricity consumption for the Province of Bangka Belitung Islands until the end of 2014 was around 818 Giga Watt hour (GWh) with the composition of consumption per user sector for households around 588 GWh (71.9%), businesses around 130 GWh (16%), industries around 45 GWh (5.5%), and public around 54 GWh (6.6%). The electrification ratio in 2014 was around 95.53%. The electrification ratio
in the Province of Bangka Belitung Islands is targeted to increase from around 97.00% in 2015 to around 100% by 2025. To achieve this, an increase in the number of electrical households is an average of about 8,641 households per year. Meanwhile, to maintain an electrification ratio of around 100% by 2034, it is necessary to increase the number of electricity households by an average of around 6,497 households per year. In 2014 to 2015, East Belitung Regency experienced a population growth of 2.02% from 117,026 to 119,394 [2]. This makes the need for energy in the household sector will certainly continue to increase. This increasing demand require an alternative for providing the electricity needs in the region.

One of the potential energy sources found in East Belitung Regency is solar energy which can be used as an alternative energy source that is environmentally friendly. Location placement for the development of Solar Photovoltaic System can be done by utilizing Spatial Multi Criteria Analysis Method (SMCA) which based on the physical factors as well as economic factors and also land use constraints to be analyzed [3]. These factors are essential to determine the suitable location for solar PV system, physical factors such as slope, hill shade, solar radiation, as well as the land cover, bodies of water and area of settlement of the region are considered in the analysis. Whereas the economic factors represented by accessibility variable are distance from settlement and distance from roads as the represents of the electricity network in the region.

2. Research Methods
Spatial Multi Criteria Analysis (SMCA) is one method in the decision-making process in regional planning that uses a simulation model with several spatial criteria and factors [4]. The SMCA serves to assist policy makers in choosing from several alternative results of the simulation model available based on priority scale. The suitability area is obtained by using Fuzzy Overlay Tools in the software of ArcGIS 10.5 as a method of Multi Criteria Analysis. Variables used in analysis include; slope, hill shade (shadow), solar radiation, distance to water body (lake and river), distance to road network, and area restrictions (water bodies and settlement). The flow chart to conduct this research is shown in the Figure 1. below. Annual solar radiation is obtained by using ArcGIS Solar Analyst from Digital Elevation Model (DEM) data that has been obtained which will then produce annual solar radiation maps with Wh/m² units [5].

![Figure 1. Flowchart of Suitability Analysis](image-url)
### 2.1 Data Collection

There are two types of data needed in this study, primary data and secondary data. Before conducting data collection in the field for verification purpose, secondary data analysis for suitability analysis is needed first to support data collection in the field. These secondary data are in the form of a basic map which can be seen in the following table:

| Data                        | Sources                          | Data type | Year |
|-----------------------------|----------------------------------|-----------|------|
| Digital Elevation Model (DEM)| ASTER GDEM [https://earthexplorer.usgs.gov/](https://earthexplorer.usgs.gov/) | Raster 90m | 2015 |
| Administration maps         | BIG [http://tanahair.indonesia.go.id](http://tanahair.indonesia.go.id) | Shapefile | 2016 |
| Land use maps               | BIG [http://tanahair.indonesia.go.id](http://tanahair.indonesia.go.id) | Shapefile | 2016 |
| Road network maps           | BIG [http://tanahair.indonesia.go.id](http://tanahair.indonesia.go.id) | Shapefile | 2016 |
| River maps                  | BIG [http://tanahair.indonesia.go.id](http://tanahair.indonesia.go.id) | Shapefile | 2016 |

From the secondary data above, a suitability maps will be created that will be used for verification of the potential site in the field. To assess the potential site, the methods used is to observe the physical condition of the region (area, accessibility and land use). Three sub-districts were chosen as sample region for the potential site survey which are Damar, Manggar, and Gantong sub-districts of East Belitung Regency.

### 2.2 Data Processing and Analysis

The amount of solar radiation that comes in with attention to the shadow effect, is the main indicator of the calculation of solar energy for development in this study. An annual solar radiation map that has been processed from DEM data, then used for site selection for solar panel installation. Technical, economic and environmental constraints are considered in the analysis. Spatial Multi Criteria Analysis using **Fuzzy Overlay** approach is applied to produce a map of suitability areas for the development of a solar photovoltaic system installation site. The **Fuzzy Overlay** tool allows the analysis of the possibility of a phenomenon belonging to multiple sets in a multicriteria overlay analysis. Not only does Fuzzy Overlay determine what sets the phenomenon is possibly a member of, it also analyzes the relationships between the membership of the multiple sets.

The spatial variability of solar radiation at a regional scale is mainly determined by surface topographic characteristics [6]. On the other hand, on a smaller scale such as building roofs, this spatial variability is mainly due to the surface of objects and building structures. In both cases, solar radiation analysis in ArcGIS software allows calculating solar radiation in a geographical area to be mapped for a certain period of time using high resolution elevation data [7]. After making a solar radiation map, the processing of other secondary data is then combined and processed to obtain the suitability of the land where the installation of solar photovoltaic systems in East Belitung Regency. All of the spatial data is used to make derived maps for each variable, then a criteria is specified for each variables before processing it to become suitability maps. The classification and criteria for each variable are shown on the **Table 2.**
Table 2. Classification and criteria of each variable

| No. | Variable          | Standard criteria                                      | References                  |
|-----|-------------------|--------------------------------------------------------|-----------------------------|
| 1   | Solar Radiation   | The higher incoming solar radiation the better (>= 1.15 MWh/m²/yr) | [8]; Pletka et al. (2007); [6]; [9] |
| 2   | Slope             | Slope < some slope limit (< 4%)                         |                             |
| 3   | Aspect (shade)    | North facing orientation only                          |                             |
| 4   | Water sources     | Not too far to water sources (<= 200 m) but not water bodies |                             |
| 5   | Road networks     | Not too far from road networks (<= 200 m)               |                             |
| 6   | Land suitability  | Not on reserved or in-use areas (settlements)           |                             |
| 7   | Constraints       | Not on water bodies                                    |                             |

The amount of solar radiation which used in the suitability analysis is using the maximum amount of number calculated by Solar analyst tools in ArcGIS 10.5. Slope is derived from the DEM data using slope tools in ArcGIS 10.5, in this classification the slope used is 4% which is considered as land with flat conditions [8]. It turns out that up to 70% of land in East Belitung regency is flat land with slope gradients below 4%. The next aspect is shade or shadow (hill shade) which derived from aspect tools in ArcGIS 10.5. East Belitung Regency is located in the southern part of the equator, this makes the land facing north tends to have a higher level of sun exposure [9] so that the north-facing area is classified accordingly. The distance of land with roads and water sources is calculated using Euclidian tools and Fuzzy Membership. Judging from the ability of the PV system, the distance used is a criterion so that PV can be easily accessed and managed by 200m from the road (Pletka et al., 2007). The road used by includes local road and path, this is because it also takes into account the possibility of developing East Belitung Regency in the future which makes access to these areas are easy to access. Water bodies as technical factor used as variables in this suitability analysis include lake and river in the region, this because for solar PV to keep working the use of water as cooling and maintenance mechanism is needed [6]. For the distance from the water body is also used 200m buffer to make the PV system which can be managed properly. Restrictions for the construction of this PV system are in the form of water bodies and settlements, the solar PV cannot be deployed in existing water and already built environment. Because land use in East Belitung Regency can still be said to be small and is still dominated by natural land cover, the assumption here is that land other than the aforementioned restrictions are considered to be appropriate. Land cover such as plantations, cropland, mining land, and other land managed by humans has not become a separate restriction.

These seven variables are then analyzed using Fuzzy Membership to classify each pixel in each raster data that has been processed to have a value between 1 which means it is suitable and 0 which means it is not suitable. After doing this stage, then the data that has been obtained is analyzed using Fuzzy Overlay.

3. Result and Discussion

The maps presented in the Figure 2 were the reclassified maps of the variables. These maps are generated using Fuzzy membership to get the suitability score of each variables, 1 represent the suitable area whereas, 0 represent non-suitable area.
Figure 2. Reclassified maps of the suitability variables

After doing Fuzzy Overlay using ArcGIS 10.5, the suitability area is obtained for the development of photovoltaic systems. The area focused for suitability analysis and field assessment are Damar, Manggar, and Gantung Subdistricts, which has highest population in East Belitung Regency and also because the analysis carried out is a macro-scale analysis and the results of the region obtained are quite large to be surveyed thoroughly. From what can be seen in the following figure, there are many areas that are suitable as PV locations in aforementioned Sub-districts.
Figure 3. Suitability area for solar PV in East Belitung Regency and Figure 4. Suitability area for solar PV in Damar, Manggar, and Gantung sub-districts.

Furthermore, not all areas of suitability in Damar, Manggar, and Gantung Subdistrict will be analyzed in more depth. To find out the suitability area that really has the potential as a PV system development site, there are selected areas that have easy access (near main road) and allow it to be surveyed as a suitability area assessment sample. The area chosen is an area close to the main road or collector road located along East Belitung Regency, precisely which crosses the Damar Subdistrict, Manggar District and Gantung District. There are six areas selected as samples to see how the characteristics of these region and the site assessment is based on observations. In Figure 4., the distribution of suitability areas in the three related sub-districts and regions that have been selected as observations point in the field is displayed.

Figure 4. Selected potential site in Damar, Manggar, and Gantung districts
3.1 Field Survey

Field surveys are intended to find out the actual conditions of the area that have the potential for PV systems site. Each suitability area that has been chosen before is then observed one by one. The factors observed as the basis for assessing the suitability area are; the physical aspects of the area in the form of slope and land cover, and the economic aspects in the form of distance from the main road as accessibility assessment. Figure 5. Shows the photographs of every surveyed potential site.

![Potential Site A (Damna)](image1)
![Potential Site B (Damna)](image2)
![Potential Site C (Manung)](image3)
![Potential Site D (Manung)](image4)
![Potential Site E (Manung)](image5)
![Potential Site F (Manung)](image6)

Figure 5. The photographs taken from observations of land use of each potential site

Based on the results of the field survey, every potential area observed has its own advantages and disadvantages. Each region has an average potential to get 1.78 Wh/m² of solar radiation, however not all regions can be fully operated as PV installations, a summary of the results of calculations and observations for each region is shown in the following table.

| Selected Area | Advantages | Disadvantages | Area (m²) | Solar Radiation (Wh/m²) | Electricity potential (kWh) |
|---------------|------------|---------------|-----------|-------------------------|-----------------------------|
| Site A        | Wide area  | Hard to access| 913.247,91| 1.79                    | 1.625,581                   |
|               | Flat area  |               |           |                         |                             |
|               | Flat area  |               |           |                         |                             |
|               | Flat area  |               |           |                         |                             |
|               | Flat area  |               |           |                         |                             |
| Site B        | Flat area  | Mining area   | 103.104,45| 1.78                    | 183,525                     |
|               | Easy access| Sandy soil    |           |                         |                             |
|               |            | Water bodies  |           |                         |                             |
| Site C        | Flat Area  | Mining area   | 3.652.927,04| 1.78               | 6.502,210                   |
|               | Easy access| Sandy soil    |           |                         |                             |
|               |            | Water bodies  |           |                         |                             |
| Site D        | Very Wide  | Plantation area| 1.215.296,84| 1.78               | 2.163,228                   |
|               | Flat area  | Forested area |           |                         |                             |
|               | Easy access|               |           |                         |                             |
| Site E        | Wide area  | Far access    | 81.454,63 | 1.78                    | 144,989                     |
|               | Flat area  |               |           |                         |                             |
|               | Flat area  |               |           |                         |                             |
| Site F        | Flat area  | Mining area   | 2.414.685,3| 1.78                    | 4.298,139                   |
|               | Very Wide  | Hard to access|           |                         |                             |
|               | Shrublands |              |           |                         |                             |
|               | Flat area  |               |           |                         |                             |
The final analysis shows that regions A, D, and E are more potentially suited as PV system installations site, whereas regions B, C, and F is less potentially suited. The main factor causing this is the absence of land restrictions. Mining land is not taken into account when conducting a multi-criteria analysis, this makes the resulted area not takes into account the existence of mining land, but after a field survey, it turns out that a lot of mining land is in these potential areas.

For the electricity potential produced by each area of suitability, it ranges from the smallest 144, 9 kW to the largest, namely the potential D area which is 602,2 kW, equivalent to 6.5 Megawatts. PLN always uses the term Megawatt to measure the ability of its generator. An average of 1 megawatt is enough to cover about a thousand homes (PLN, 2015), meaning that if the installed PV system is 6.5 Mw then there are 6,500 additional houses that can be electrified by this plant.

4. Conclusion
The suitability area obtained using Spatial Multi Criteria Analysis still has shortcomings, therefore a field survey was conducted to find out the characteristics of the region directly. After surveying it turns out that the area that has the potential to have an area that is smaller than the suitability of the results of data processing. On average this potential area has flat land, but has land cover that varies between shrubs, forests, plantations, and mining land. The final analysis shows that regions A, D, and E are more potential areas for PV system installations, while regions B, C, and F have less potential. The main factor that led to this was the absence of land restrictions during a review of the field survey. Mining land is not taken into account when conducting a multi-criteria analysis, this makes the resulting area do not consider the existence of mining land, but after a field survey, it turns out that a lot of mining land is in these potential areas. The biggest potential electricity capacity is in Manggar Regency with a potential of 6.5 Megawatts which is estimated to be able to electrify 6,500 additional houses in East Belitung Regency. In conducting suitability analysis, SMCA still has subjectivity in its utilization, because the criteria for same regional problem solving could be different from one to other, therefore it is recommended for future research to conduct more literature review to increase the objectivity of the analysis.

As a conclusion, GIS-based suitability analysis to select a location of solar photovoltaic system site could assist the planner in the decision-making process by incorporating multi-criteria. The GIS based multi-criteria analysis allows incorporation of many variables into the considerations. This method will also applicable in various regional or urban planning fields which incorporates various criteria consideration which were spatially related.

5. References
[1] ESDM (2015) ‘Statistik Ketenagalistrikan 2017’, Directorate General of Electricity and Energy Utilization. Available at: http://www.djk.esdm.go.id/pdf/Buku Statistik Ketenagalistrikan/Statistik Ketenagalistrikan T.A. 2015.pdf.
[2] Badan Pusat Statistik (BPS) Kabupaten Belitung Timur. (2016). Regional Statistic of East Belitung Regency. Available at https://belitungtimurkab.bps.go.id/backend/pdf_publikasi/Statistik-Daerah-Kabupaten-Belitung-Timur-2016.pdf
[3] Li, D. (2013) ‘Using GIS and Remote Sensing Techniques for Solar Panel Installation Site Selection by’, Thesis presented to the University of Waterloo in fulfillment of the requirement for the degree of Master of Science in Geography.
[4] Wang, J.-J., Jing, Y.-Y., Zhang, C.-F. and Zhao, J.-H. (2009). Review on multi-criteria decision analysis aid in sustainable energy decision-making. Renewable and Sustainable Energy Reviews, 13(9), 2263–2278.
[5] Hofierka, J. and Kaňuk, J. (2009) ‘Assessment of photovoltaic potential in urban areas using open-source solar radiation tools’, Renewable Energy, 34(10), pp. 2206–2214. doi: 10.1016/j.renene.2009.02.021.
[6] Gastli, A. and Charabi, Y. (2010b). Siting of large PV farms in Al-Batinah region of Oman. IEEE,
548-552.

[7] ESRI. (2011). Area Solar Radiation (Spatial Analyst). Available at http://desktop.arcgis.com/en/arcmap/10.3/tools/spatial-analyst-toolbox/area-solar-radiation.htm

[8] Bravo, J.D., Casals, X.G. and Pascua, I.P. (2007). GIS approach to the definition of capacity and generation ceilings of renewable energy technologies. Energy Policy, 35, 4879-4892.

[9] Chaves, A. and Bahill, A.T. (2010). Locating Sites for Photovoltaic Solar. ArcUser, 24- 27. Retrieved from http://www.esri.com/news/arcuser/1010/files/solarsiting.pdf

Acknowledgements
The author would like to thank Ms. Nurul Rahatiningtyas S.Si, lecturer of Department Geography, Universitas Indonesia for the guidance to complete this research. This article is presented at the International Conference on Smart City Innovation 2018 that supported by the United States Agency for International Development (USAID) through the Sustainable Higher Education Research Alliance (SHERA) Program for Universitas Indonesia’s Scientific Modeling, Application, Research and Training for City-centered Innovation and Technology (SMART CITY) Project, Grant #AID-497-A-1600004, Sub Grant #IIE-0000078-UI-1.