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Benefits of Using GIS-based Analysis on Site Selection and Location Decision for Student's Final Project, Study Case: Solar Energy Farm in Java, Indonesia

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Abstract. *The use of GIS applications by architecture students is unusual, even though GIS has many tools to assist students' projects, in this case, selecting and determining project site location plans for their final project. This study used the GIS application to determine the right location for a solar power plant project or a solar energy farm on Java Island, Indonesia. By determining what the suitable criteria for this project location are, there are 1). Ground Elevation, 2). The Sun Direction, 3). Ground Slope, and 4). Maximum Radiation. Those multiple criteria are used as determining factors with the Weight Overlay function in the GIS application. Overlaying all data and criteria maps will produce a final map that can be used as a reference for final decision-making. We can make our own rules to determine which places are the most appropriate by adjusting the weighting value per criteria. By using the GIS application and adjusting it to the regulatory conditions of the student's project, it is clear that this application will significantly assist students in selecting and determining project locations in their Final Project.*

Keywords: *Final Project, GIS, Multi-Criteria, Site Selection, Solar Energy Farm, Weight Overlay*.

Abstrak. Penggunaan aplikasi GIS oleh mahasiswa arsitektur tidak umum, padahal GIS memiliki banyak alat untuk membantu proyek mahasiswa, dalam hal ini memilih dan menentukan rencana lokasi proyek untuk tugas akhir mereka. Studi ini menggunakan aplikasi GIS untuk menentukan lokasi yang tepat untuk proyek pembangkit listrik tenaga surya atau ladang energi surya di Pulau Jawa, Indonesia. Dengan menentukan apa kriteria yang cocok untuk lokasi proyek ini, yaitu 1). Ketinggian Tanah, 2). Arah Matahari, 3). Kemiringan Tanah, dan 4). Radiasi Maksimum. Beberapa kriteria tersebut digunakan sebagai faktor penentu dengan fungsi Weight Overlay pada aplikasi GIS. Overlay semua data dan peta kriteria akan menghasilkan peta akhir yang dapat digunakan sebagai referensi untuk pengambilan keputusan akhir. Kita bisa membuat aturan sendiri untuk menentukan tempat mana yang paling sesuai dengan menyesuaikan nilai pembobotan per kriteria. Dengan menggunakan aplikasi GIS dan menyesuaikan dengan kondisi regulasi proyek mahasiswa, jelas aplikasi ini akan sangat membantu mahasiswa dalam memilih dan menentukan lokasi proyek dalam Tugas Akhir mereka.

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Kata kunci: GIS, Ladang Energi Surya, Multi-Criteria, Pemilihan Lokasi Tapak, Tugas Akhir, Weight Overlay

INTRODUCTION

The world is in a critical condition that requires everyone to be concerned more seriously. The earth suffers from climate change due to the greenhouse effect because so much carbon dioxide (CO2) released into the atmosphere has caused many problems. Why is it matter? The reason is CO2 that has been accumulated in the atmosphere traps heat radiation, and only small numbers return to space. As a consequence, the earth becomes hotter and hotter, melting the polar caps and causing weather disaster phenomena (hurricanes, droughts, and alteration weather zone) (Mertens, 2018).

Much carbon dioxide (CO2) is produced from burning fossil fuels (oil, coal, and natural gas) used in cars and power plants; then, it makes up more than 80% of energy consumption worldwide. If this trend continues in around 41 years, we might run out of fossil fuel energy resources. And the growth of the world population will foster of using more and more energy for housing and car (Mertens, 2018).

In Indonesia, most of the energy supply comes from fossil fuels, especially for electricity. Year-to-year energy consumption of electricity always increases. In 2028, it predicted the consumption of electricity would be 433 TWh (PLN, 2021). So, we need alternative energy that keeps the environment and provides sufficient power in the long run.

Solar energy can be a sustainable, renewable and environment-friendly alternative to providing electricity. It is a cheap, clean and zero-emission source of energy. As renewable energy resources, solar energy supply is unlimited and free because it comes from the sun's light. Moreover, it will be an essential energy system in the future.

Nowadays, technology is based on one hundred years ago research on photovoltaic technology. In 1873, Willoughby Smith, a British scientist, noted that selenium is an element sensitive to light. Then, in 1880, Charles Fritts created the first solar electric cell based on selenium, and the cell successfully produced electricity. In 1954, Bell elaborated silicon into cells, making it six per cent more efficient than selenium. Moreover, the

National Aeronautics and Space Administration (NASA) apply solar photovoltaics too in the first satellite Vanguard I; later, most satellites NASA start using it (Solar Energy International, 2007).

Solar photovoltaics have become well-known and commonly used in developed countries, big industries, or houses for small-scale energy suppliers. It is very flexible and reliable because less maintenance is needed, and it can last at least 25 years. It is a very promising investment. Many large-scale projects were commenced to welcome the new era of electricity. Many countries have allowed electric vehicles, including Indonesia (Dephub, 2022). There are five largest solar energy projects in the world, two in China, two in India, and one in Egypt, with a capacity of at least 1.500 Mega Watt (Sharma, 2022).

No wonder architecture students are interested in the Solar Energy Farm Project for their final assignment. This paper will focus on finding a suitable place to construct a solar photovoltaic farm in Indonesia, precisely in Java, using GIS software. Moreover, to determine the place, we will consider the characteristic of finding the best location with these criteria: 1). High from the ground, so there is nothing that will block the solar photovoltaic panels. 2). The sun is the primary source of energy most of the time. 3). Have a suitable slope, less than 35°. 4). High solar radiation area (Chaves & Bahill, 2010).

METHODS

Study Area

Indonesia is situated in the middle of the Equator, so it only has two seasons, sunny and rainy. More detail on the astronomic location of Indonesia is 6° NL - 11° SL and 95° EL - 141° EL. Indonesia is an archipelago country with 17.504 Islands (Both named and no-named). Because Indonesia is on the Equator, it has tropical conditions, like 1. High Rainfall, 2. Have many forests, 3. Get sun almost a year, 4. Very humid. For the geographic location, Indonesia is situated between two continents, Asia and Australia, and it is also flanked by two oceans, the Hindi and Pacific (see Picture 1).

Picture 1 Geographic Location of Indonesia (source: Google Maps)

The total area of Indonesia is 1.904.569 km2, becoming the 15th largest country according to nationsonline.org. Indonesia has five big islands Sumatra, Java, Kalimantan, Sulawesi, and Papua, and the capital city is Jakarta, situated on Java Island. Along Sumatra and Java, there are a series of active mountains that can erupt in certain periodical times.

Indonesia had a considerable population of around 252.812.245 inhabitants in 2014, according to worldometers.info, and became number 4th most populous country. With such a significant population, sure, the energy demand will increase. In 2009, electricity use per capita was 597 KWh (International Renewable Energy Agency, 2013).

But, uneven population distribution in Indonesia makes Java Island more burdensome because around 57% of the total population lives in Java. So, automatically electricity demand always increases while electricity capacity from solar energy grid connected in Indonesia only 123 MW and off-grid or local only 61 MW in 2020 (International Renewable Energy Agency, 2022). That is why in this paper, we will focus on Java Island, and another reason is that gathering data collecting is so tricky from other islands (see Picture 2).

Picture 2 Map of Indonesia and Java Island (source: Google Maps)

Multi-Criteria Decision Making

To determine the suitable location for Photovoltaic Solar Panel Farm has a specific characteristic that has to be fulfilled (Chaves & Bahill, 2010). Here are the characteristics of a suitable location:

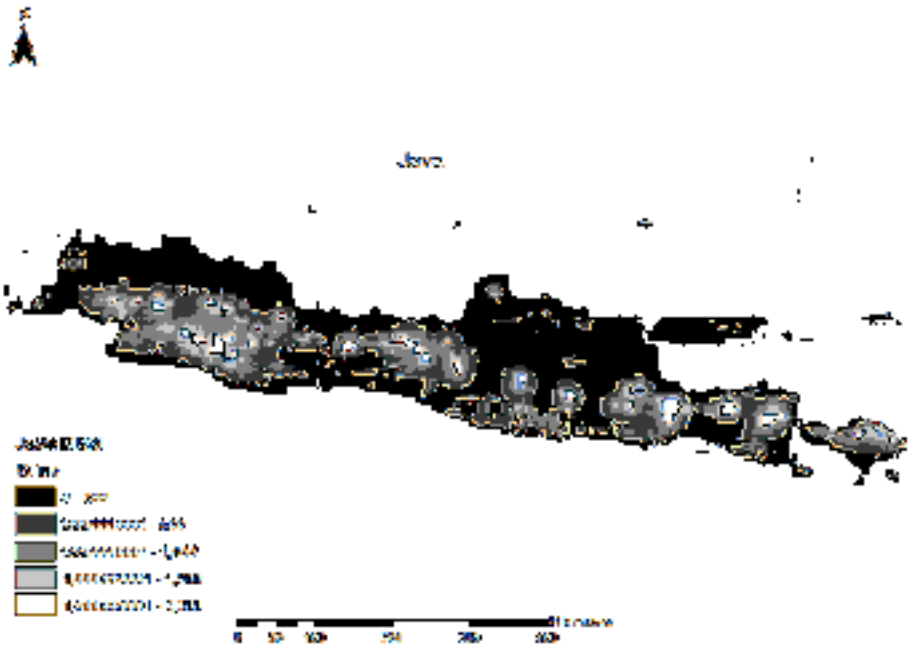
A. Suitable Elevation, which means that solar panels should not be installed on the ground since big buildings or hills will block direct sunlight from reaching the panel.
B. Suitable Facing Aspect, means solar panels must be set towards the sun for best effects; consequently, the course of the sun at that site must also be considered.
C. Suitable Slope, means the ideal slope is less than 35 degrees, so that the Solar Panel may receive sun rays from a wider angle and have a longer solar period.
D. Suitable Radiation, means the area need to get at least a certain quantity of sun radiation annually on average.

Then a solar map containing a map of Java Island and yearly interval sun radiation maps was created from the georeferenced data using the Area Solar Radiation Tool in the GIS Software. The sun's elevation and position variations are taken into account in this solar map, as well as any shading effects brought on by slopes and radiation intensity into raster maps. The last, Weight Overlay will play the big role of determining the final result that different from others (Giamalaki & Tsoutsos, 2019; Watson & Hudson, 2015).

RESULTS AND DICUSSION

Elevation Map

Solar panels should not be placed on ground level because if there are tall buildings or hills around it, it will prevent direct sun rays from the panel. But, if there is vast flat land and nothing can obstruct the direct sun, that is a good place for constructing a Photovoltaic Solar Panel farm. In Picture 3, a Java map was generated with GIS to create a thematic map which tells about elevation. Flat land is described with black colour, and mountains or highlands are associated with white colour.



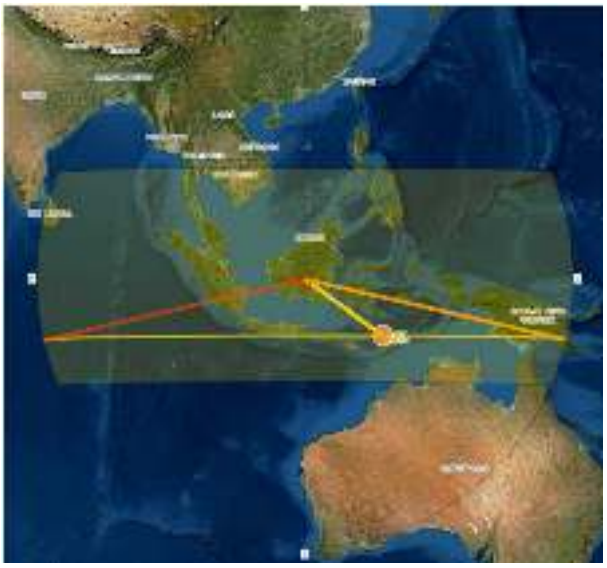
Picture 3 DEM (Digital Elevation Model) for Java Island (Author)

So we can choose whether highland or flat land for applying Solar Photovoltaic, but if we want to build a Photovoltaic Solar Panels farm, we have to prioritize flat land as the first choice.

Aspect Facing Map

Solar panel has to be placed facing the sun for maximum results. Because Indonesia is located on the equator, the sun will shine right above the solar panel in the middle of

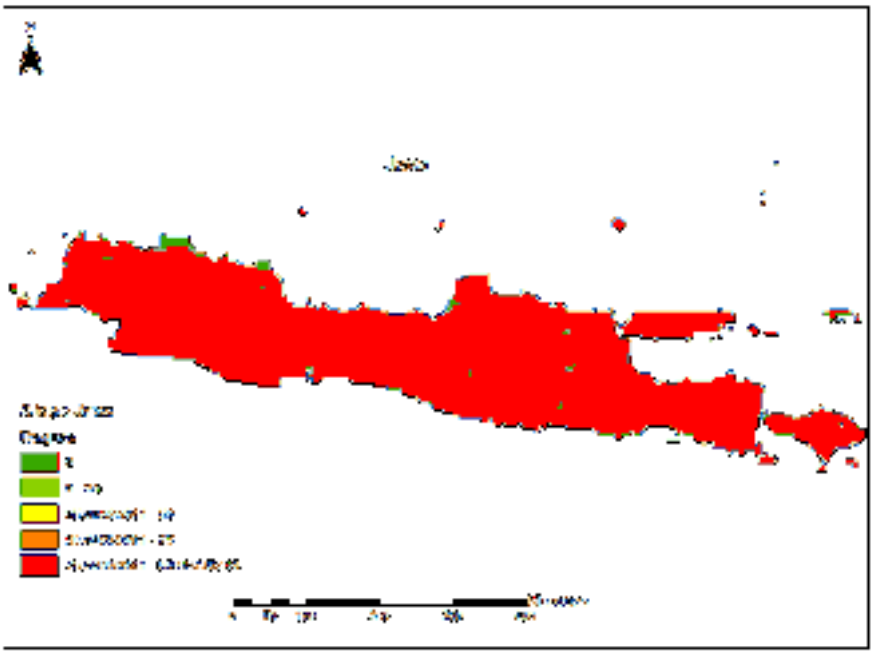
the day (check Picture 4). Red and Blue lines are tracks of sun rotation that always pass above Indonesia and give maximum solar radiation most of the time.



Picture 4 Track Sun rotation crossing Indonesia (source: suncalc.org)

Slope Map

Solar Panels can receive sun rays from a wider angle and get more prolonged solar radiation, if it gets best slope less than 35 degrees. In Picture 5, we can see only a little piece of land with a green colour of fewer than 35 degrees.

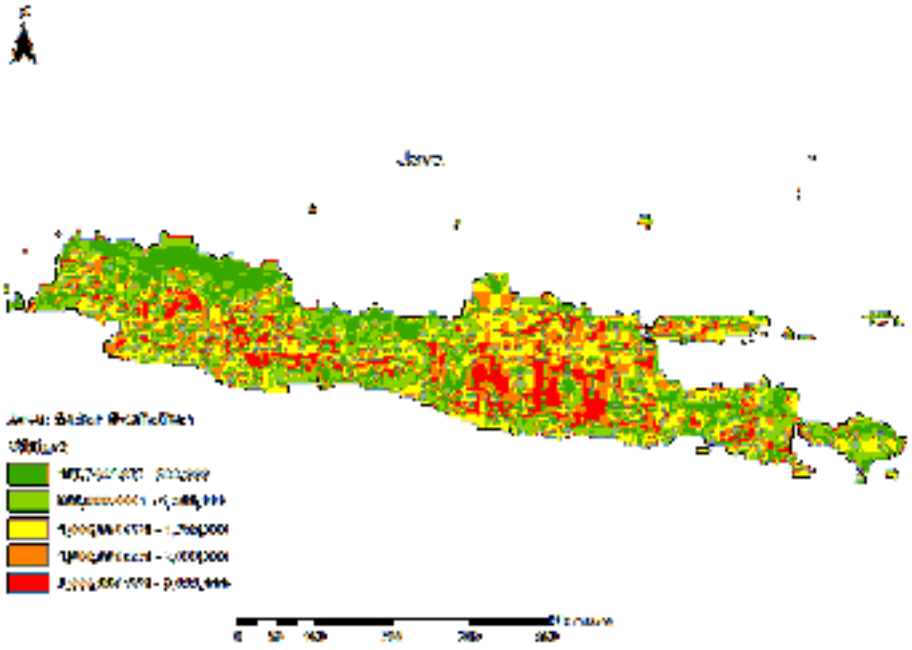


Picture 5 Map of Slope Area in Java Island (Author)

Indeed, that is because Java Island has so many Mountains in the south, and most of them are still active. Most of them are flat lands in the island's northern part.

High Radiation Map

High Radiation is the key to all solar things work. Without this, we will not be able to produce single electricity. This map in Picture 6 is created using Area Solar Radiation Tool in ArcGIS. That is because we cannot find the correct data on solar radiation intensity in Indonesia or even on Java Island.

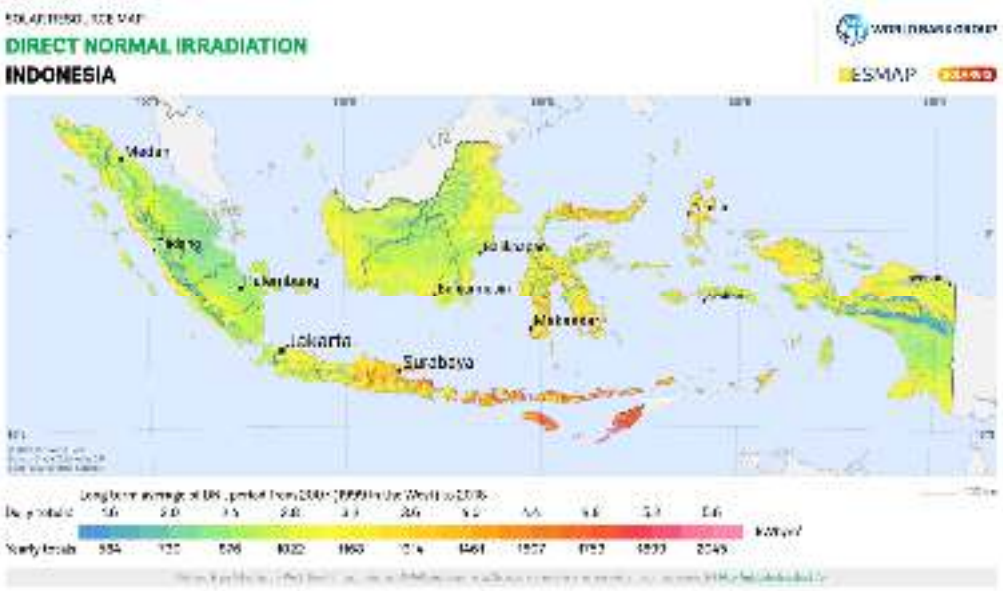


Picture 6 Intensity of Solar Radiation in Java Island (Author)

In the option of Area Solar Radiation, we fill the Latitude with -7 because Java Island is at 7° South Latitude. And for time configuration, we use the Whole year with monthly intervals. The rest is allowed by default.

As we can see, the red zones are the areas with high solar radiation intensity, with the most diverse evenly in Whole Island. Even in the green zones, the minimum radiation is still big enough to produce electricity. The minimum point we get is 105,704 WH/m2, and the maximum is 5000 kWh/m2.

For comparison data, we get generated-Solar Maps from solargis.info and then we can compare them together. So with cross-examination, we can get more confident about those two data and justify them. Here are the maps from Solar GIS.

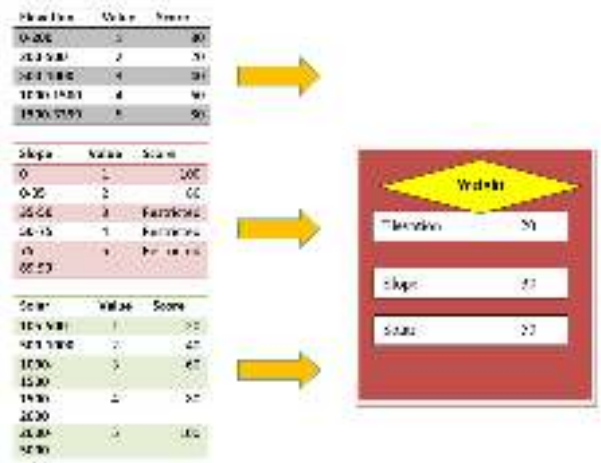


Picture 7 Direct Normal Irradiation (DNI) of Indonesia (source: SolarGIS)

It seems that both Pictures 6 and 7 have similar patterns even though they are not so identical. Both have more red-zone areas on the island's eastern side in the picture. The definition of Direct Normal Irradiation (DNI), according to 3tier.com, is "The amount of solar radiation received per unit area by a surface that is always held perpendicular (or normal) to the rays that come in a straight line from the direction of the sun at its current position in the sky" (Vaisala Energy, 2022).

Final Raster Map

Earlier, we found each characteristic of a suitable place for a Photovoltaic Solar Panels farm. The next question is where and how to determine the best site for Solar Photovoltaic Farm. In the ArcGIS tool, there is a pretty unique tool that can help us to decide it, and it is Weighted Overlay Tool. We set what and how important those factors or characteristics are and then calculate based on the priority portion of the elements. For further information, we can see the table (Picture 8).



Picture 8 Scheme Weight Overlay

We set the solar factor in the weightiest portion because it is the primary key. And between Elevation and Slope, Slope is more matter than Elevation because it has a strict specific number of no more than 35-degree slope.

The next step is using the Weighted Overlay tool, and as a result, we add a base map and increase the transparency so we can figure out where the place is. So, let's see in Picture 9.

Picture 9 Final Raster Map from Weight Overlay to determine suitable place (Author)

From Picture 9, we can find a suitable place after using the weight overlay method. Green area is the most relevant, but only a few are located on the map, for example, one near Surakarta city right in the middle. The second is pale green which we can find near Cilacap city on the southern coastline. The third is light green in Jepara city, the northern part of the middle of the Island, and the area is big enough that it has the potential for constructing Solar Photovoltaic Farm there. And the fourth option is the pink colour that you can find in the northwest of the Island near Bekasi City, even though the area is less suitable. However, it has ample flat land and still can produce electricity well from solar radiation, around 1000 kWh/m2 (check Pictures 6 and 7 again).

CONCLUSION

In conclusion, with the help of the GIS application, we can find some places that can be used as a suitable place for Solar Energy Farm on Java Island. Jepara City is recommended as the first option for Solar Energy Farms on a colossal scale, then Cilacap City and Surabaya. For small-scale Solar Photovoltaic, we can take near Surakarta City. Not only limited to finding a suitable site for Solar Energy Farm. GIS application is also possible in other project site selection by providing the proper criteria as the formula in GIS to determine the best site location for the project. As for architecture students, it will help them find the best site location more accountable and systematic.

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