

SPATIAL MODELING OF MULTI-SCENARIO OPTIMAL SOLAR PV POWER PLANT DISTRIBUTION TO SUPPORT INDONESIA'S CLEAN ENERGY ACHIEVEMENT TARGETS

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KEYWORDS: Solar PV, Multi Scenario, Spatial Analysis, Remote Sensing, Socio-Economic, WebGIS.

ABSTRACT:

The increasing population brings the increasing energy demand. The increasing production of fossil energy makes many gas emissions. This causes some effect like global warming. The production of clean energy concerns the world government. Solar energy has great attention from many countries worldwide, seeing the potential of the energy produced, the ease of installation process, and the small risk of damage. The potential of solar energy in Indonesia itself reaches 4.8 KWh/m² or equivalent to 112,000 GWp. Currently, the Indonesian government has a target for constructing solar power plants in 2025 of 0.87 GW or around 50 MWp/year. The absence of research on determining the appropriate location based on multiple aspects is one of the obstacles in planning the construction of a solar PV power plant. Good planning is needed to determine the management and installation of an optimum and sustainable solar PV power plant. This research aims to develop an effective and efficient multi-scenario spatial model for the distribution of Solar PV (Photovoltaic) power plant development in Indonesia. The novelty in the study of the distribution of solar energy potential integrates meteorological and Geographic aspects and socio-economic aspects. The integration of dynamic multi-spatial data is used to determine the location of the development of solar power plants. Meteorological data is used to calculate potential energy, socio-economic data is used to determine the location for energy demand, and geographic aspect is used to know the suitable environment to install solar PV. The output of this research is the location of the priorities for the development of communal solar power plants in Indonesia. The distribution of effective Solar PV power plant development in Indonesia using a multi-scenario spatial model is divided into five suitability classes. The percentage of suitability class is 0.2% very low class, 3.5% low, 32.4% medium 56.9% high class, and very high 7%. The result is published in WebGIS that can access in link <http://bit.ly/ModelPLTSIndonesia>. It is hoped the results of this research can be used as material for consideration and one of the solutions for policymakers in making decisions regarding the development of communal solar power plants in Indonesia.

1. INTRODUCTION

In 2019, world energy consumption reached 158,839 TWh. Most of the energy consumed is produced from non-renewable energy sources such as oil which contributes 53,620 TWh, coal with 43,849 TWh, and gas with 39,292 TWh (Smil, 2016). At the same time, non-renewable energy sources such as fossil energy have weaknesses, such as their limited availability and taking a long time to be replenished (Shinn, 2018). Therefore, it is necessary to develop the use of renewable energy. Renewable energy is the energy obtained from the flow of energy that repeats naturally and continuously occurs in the local environment (Twidell and Weir, 2015). Renewable energy is energy that can reduce production costs and is environmentally friendly. Renewable energy sources include solar energy, biomass energy, wind energy, geothermal energy, hydro energy, and others (Shinn, 2018).

Indonesia has a vast potential for solar energy. According to the Ministry of Energy and Mineral Resources (ESDM), the potential is around 4.8 KWh/m² or 112,000 GWp. However, only about 10 MWp has been utilized. Seeing this potential, it is hoped that it

will support the spread of electrification in Indonesia. In Papua and NTT, the electrification ratio is still at 60%. The Ministry of Energy and Mineral Resources also mentioned that the government had issued a roadmap for the use of solar energy. The installed Solar PV Power Plant (PLTS) capacity will be targeted at 0.87 GW or 50 MWp/year in 2025 (Mineral, 2012). This number illustrates Indonesia's reasonably enormous market potential in developing renewable energy, especially solar energy, in the future.

To support the roadmap issued by the government, it is necessary to do good planning based on the potential of resources and energy needs spatially so that energy management and utilization can be maximized and sustainable. One of them is developing a multi-scenario spatial model in determining the distribution of Solar PV power plant development in Indonesia which is effective and efficient.

Solar energy is a renewable energy that is obtained through the process of converting solar heat through certain technologies. At present, solar energy is one of the energy generators besides water, wind, steam, gas, and petroleum. As a tropical country,

Indonesia has enormous potential for solar energy. Seeing this potential, the government is trying to develop solar energy. Indonesia has an average solar energy potential of about 4.8 kWh/m²/day with a monthly variation of around 9% (Mineral, 2012). The potential for solar energy can be determined by determining the amount of solar radiation to the earth. Solar radiation to the earth's surface will be influenced by geometric factors, the direction of the sun's rays, and meteorological factors. The geometry of the sun's arrival that affects solar radiation is the altitude and azimuth of the sun (Desthieux et al., 2018). Meanwhile, atmospheric factors that affect solar radiation include clouds, temperature, dust, snow, and humidity (Principe and Takeuci, 2019). Solar radiation hitting the object is influenced by other things around the object (Desthieux et al., 2018).

Solar energy has great potential, and many solar technologies are developing to harness it. Solar energy does not cause pollution, and it is also unlimited and free. However, the solar energy sector still loses in terms of costs compared to fossil fuels. Indonesia is the largest energy user in Southeast Asia, with consumption in 2015 reaching 1033.24 million BOE (Barrel Oil Equivalent) (IRENA, 2017). The demand for electricity in Indonesia is growing higher than the demand for other energy sources in Indonesia. Electricity consumption in 2019 in Indonesia reached 1.08 kWh/capita (World Bank, 2019). Prediction, the share of electricity demand will increase from 60% in 2018 to 90% in 2050 (ESDM, 2019). To anticipate national energy needs and the limitations of fossil energy, the government makes a National Energy Policy (KEN) which contains a national energy management policy or renewable energy roadmap, one of which is PLTS (Boedoyo, 2013). The use of PLTS in Indonesia has been carried out since the 1980s. However, its application is still limited to small-power systems or solar home systems (SHS), usually used by rural communities without electricity. It is hoped that by 2025, renewable energy will reach 5% of the national power generation capacity, and it is expected that PLTS can contribute 800 MW (Kumara, 2010). PLTS, like renewable energy, of course, has many advantages. Including the benefits of PLTS based on (Boedoyo, 2013) are as follows: environmentally friendly, renewable, and environmentally friendly, and abundant resources.

The electrification ratio is between the number of households with an electric lighting source and the total number of homes. In 2017, the electrification ratio in Indonesia reached 95.25%. However, some areas have low electrification ratios, such as NTT and Papua, which have 59.85% and 61.42%, respectively (ESDM, 2017). The uneven distribution of electrification in Indonesia is caused by several factors, including the problem of funds to expand the construction of the electricity network, limited energy sources, and Indonesia's geographical conditions, which are difficult to reach for development (Akhmad, 2005). To achieve this electrification, alternative energy such as PLTS is needed. Therefore, in choosing a location, it is necessary to pay attention to spatial factors and to pay attention to socio and economic factors so that electrification with PLTS can be right on target.

The world's human population has passed 7 billion in 2015. If the population growth rate is constant, it is estimated that there will be 12 billion people in the world in 2050. In line with population growth, the world's Gross Domestic Product (GDP) has reached 75.590 trillion US dollars in 2015 (World Bank, 2019). Population growth and rapid increases in spending are causing increased pressure on natural resources. One example is the oil crisis that occurred in 1973, and there were several other natural

resource crises. This situation has led to a new development approach that considers economic, socio, and environmental factors to create a better growth-development paradigm (Han and Kaya, 2008). There are three principles in this development approach. The first principle is related to the community's quality of life, where it is necessary to produce goods and services. Second, an agreed and acceptable standard of living must be provided for all people living in the world. Third, it must provide opportunities not only for today's society to benefit but also for future generations (Chambers et al., 2014).

Economic sustainability can be defined as providing strength and consistency in the economy and other fields, and it is also defined as how humans should behave towards nature. Focusing on the relationship between humans and nature can ascertain what responsibilities people have when considering future generations and the world they will leave behind (Baumgärtner and Quass, 2010).

One method that can be used to obtain data on the suitability of the PLTS location is by using remote sensing technology. Many studies have been carried out to model the potential of the Solar PV Power Plant, including the research of Principe and Takeuchi (2019), explaining that the efficiency of solar panels is influenced by meteorological factors such as precipitation, rainfall, dust, and snow. This research results in an evaluation of the potential of solar panels in a Spatio-temporal manner in the Asia Pacific region based on meteorological factors. Solar panels will experience a decrease in efficiency due to dust, snow, and temperature drops. The research by Adeh et al. (2019) classified potential areas for solar panels based on their land cover. This research explains that the location with the greatest solar panel efficiency is on agricultural land because the efficiency of solar panels is influenced by insolation, air temperature, wind speed, and relative humidity, which is suitable for agricultural land. In addition, there was also a Gašparović study in 2019, which determined suitable areas for solar panels by using climate, spatial, environmental, and geomorphological data and using socio, economic, population, unemployment, and electricity consumption parameters. From the study results, the parameters that most determine the optimal location of PLTS are GHI (global horizontal irradiation), land cover, and distance to the electricity network. Based on the research that has been done, there are limitations. Namely, there is no research on the potential of solar panels in Indonesia, which relates not only to spatial data but also to socio-economic data. Furthermore, these limitations become the novelty of this study.

2. METHODOLOGY

2.1 Data

In modeling the spatial distribution of Solar-PV Power Plant, several things need to be considered in addition to the spatial or geographic aspects; other aspects that need to be considered are socio-economic aspects and also the effectiveness of solar panels (meteorologically) (Ihsan, et al., 2021(a)) (Gašparović and Gašparović, 2019). Therefore, the data used in this study will be divided into three classes based on the aspects of their influence. The data source and the resolution of the data used can be seen in Table 1.

Table 1. Data

No	Data	Product	Year	Resolution	Reference

1	Land Cover	GLC2000	2018	30 s	(Bartholome & Belward, 2005)
2	Built Area	Geospatial Information Agency	-	1:250000	(BIG, 2015)
3	Digital Elevation Model or DEM (m)	CGIAR SRTM	2011	30 s	(Farr et al., 2007)
4	Inland Water	Digital Chart of the World	2011	1:1000000	(United States, 1992)
5	Protected Area	Protected Planet	2019	-	(UNEP-WCMC & IUCN, 2019)
6	Road	Geospatial Information Agency	2011	1:250000	(BIG, 2015)
7	Electrification (W)	(Arderne, et al., 2020)	2015 - 2019	1 km	(Arderne et al., 2020)
8	Human Development Index or HDI	Statistics Indonesia	2019	Province Level	(BPS, 2019)
9	Population Density (people/km ²)	Statistics Indonesia	2018	Province Level	(BPS, 2019)
10	Frontier, Remote and Disadvantaged Areas (3T Areas)	Presidential Regulation No. 131 of 2015	2015	City Level	PP No.131 2015
11	Aerosol Optical Depth or AOD	Terra & Aqua MAIAC	2019	1 km	(Lyapustin & Wang, 2018)

12	Precipitation (mm/day)	Terra Climate	2019	~4 km	(Funk et al., 2015)
13	Land Surface Temperature or LST (K)	Modis	2019	1 km	(Wan et al., 2015)
14	Short Wave Radiation (W/m ²)	Terra Climate	2019	~4 km	(Abatzoglou et al., 2018)
15	Global Photovoltaic Power Potential (kWh/kWp)	Global Solar Atlas	2019	1 km	(ESMAP, 2019)

2.2 Methods

The data processing process to determine the distribution of Solar PV power plant development in Indonesia effectively uses the spatial model shown in Figure 1. Data processing is divided into three stages: modeling based on Geographic aspects, modeling based on socio-economic factors, and modeling based on practical aspects (meteorology).

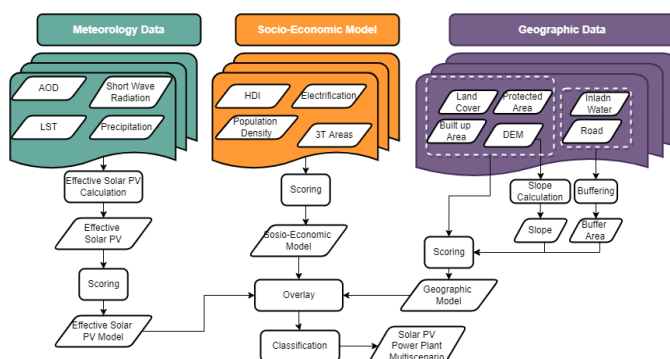


Figure 1. Methods

2.2.1 Modeling Based on Geographic aspect

Modeling based on Geographic aspect use scoring parameter that modified from Gašparović and Gašparović (2019) and Kencana et al. (2018), which can be seen in Table 2.

Table 2. Parameter Scoring in Geographic aspect

Parameter	Sub-Criteria	Score
Land Cover	Forest, Paddy Field, Field, Garden, Wetland, Bush	3
	Built-up Area and Inland Water	0
Built-up Area	≥100 m	3
	<100 m	1
DEM	<150 m	3
	150-500 m	2

	>500 m	1
Slope (from DEM)	<25%	3
	≥25 %	1
Inland Water	≥100 m	3
	<100 m	1
Protected Area	≥100 m	3
	<100 m	1
Road	<3000 m	2
	≥3000 m	1

2.2.2 Modeling Based on Socio-economic Aspect

Modeling based on Geographic aspect use scoring parameter that modified from Gašparović and Gašparović (2019), Kencana et al. (2018), and Statistic Indonesia (2019), which can be seen in Table 3.

Table 3. Parameter Scoring in Socio-economic Aspect

Parameter	Sub-Criteria	Score
Electrification	Electrified	1
	Not Yet Electrified	3
Human Development Index	≥ 80	1
	70-80	2
Population Density	60-70	3
	≥1250	3
3T Areas	500-1249	2
	<500	1
3T Areas	3T Areas	3
	Non-areas of 3T	1

2.2.3 Modeling Based on Meteorology Aspect

Modeling based on meteorology aspect used some equation. The first is solar radiation modeling that can be calculated using Equation 1 (Principe and Takeuci, 2019), where P_{pv} is solar PV output theory (W), A_{CELL} is pixel area (m^2), and R is solar radiation data (W/m^2).

$$p_{pv} = A_{CELL} \times \eta \times R \quad (1)$$

After that, PV output theory is corrected by temperature, aerosol, and precipitation effect to get Effective Solar PV (p'_{pv}) using Equation 2 (Principe and Takeuci, 2019), which η is solar cell efficiency, R' solar radiation, and temperature and $\Delta\eta_t$ is aerosol and precipitation correction.

$$p'_{pv} = A_{CELL} \times \eta \times R' (1 - \overline{\Delta\eta_t} - \overline{\Delta\eta_d}) \quad (2)$$

3. RESULT AND DISCUSSION

3.1 Suitable Model Based on Geographic, Socio-Economic, and Meteorology aspect

Several analytical processes such as buffer and overlay analysis were carried out in Indonesia's multi-scenario modeling process of Solar PV Power Plant distribution. Buffer analysis is carried out on data that has criteria, such as being at a certain distance. This analysis is carried out on data such as access roads, protected areas, water bodies, and built-up areas. Then an overlay analysis is carried out to combine the data based on its aspects, where there are three aspects for modeling, and each aspect has its parameters. An overlay analysis was performed to combine the parameters used in this study.

However, in modeling the distribution of Solar PV Power Plant in Indonesia, there are still some parameters that have not been included, such as geological data containing rock types in an area, because this data is also a consideration of the geographical conditions of an area where Solar PV Power Plant is built. For example, Karst rock which has a complex and irregular texture, is a location that needs to be avoided for the construction of PLTS in the area. In addition, it also considers the location of the fault in an area, whether the area is close to the fault or not. The closer to the fault, the greater the level of danger posed if at any time a fault occurs. In addition, this research has not carried out weighting for each parameter and modeling aspect. So that all parameters and aspects of modeling are given the same weight.

Based on the geographic and socio-economic aspects of data processing, the results are as shown in Figure 2. The results are divided into 5 appropriate classes: very low, low, medium, high, and very high.

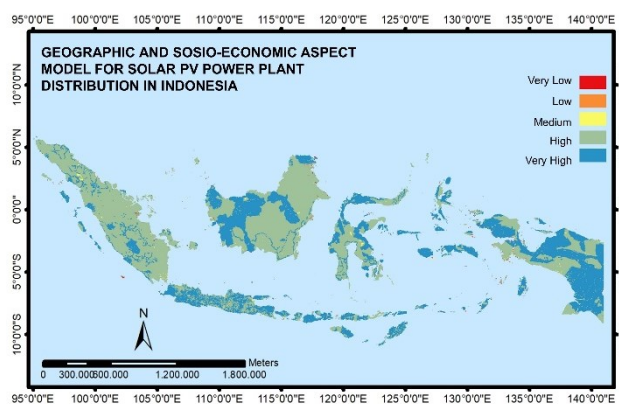


Figure 2. Geographic and Socio-Economic aspect Model

After modeling the distribution of Solar PV Power Plant based on geographical and socio-economic aspects, the next step is modeling the distribution of Solar PV Power Plant based on meteorological aspects, as shown in Figure 3. The results are also classified into five suitability classes, namely very low, low, medium, high, and very high.

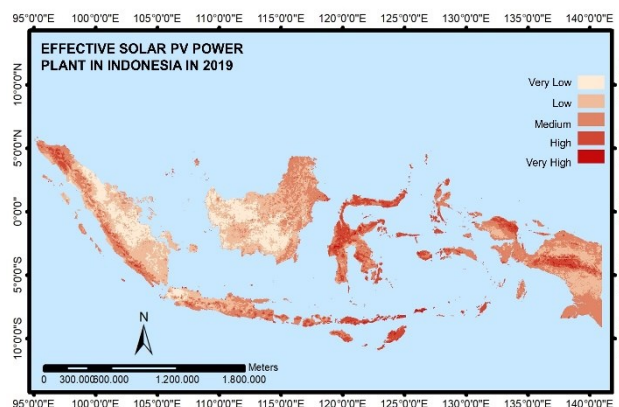


Figure 3. Meteorology Aspect Model

3.2 Multi-Scenario Model

Furthermore, an analysis of the three spatial models was carried out, and a multi-scenario Solar PV Power Plant distribution model was produced in Indonesia, as shown in Figure 4.

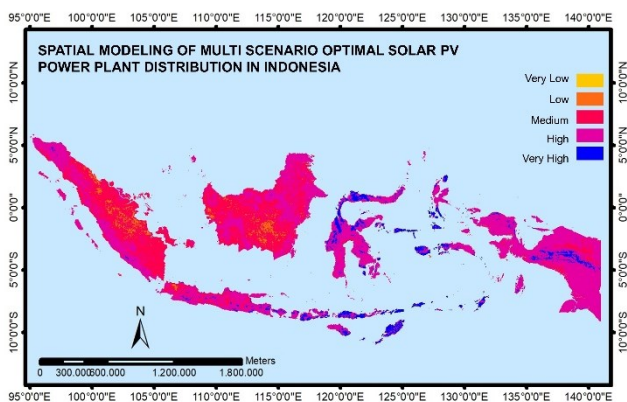


Figure 4. Multi-Scenario Model

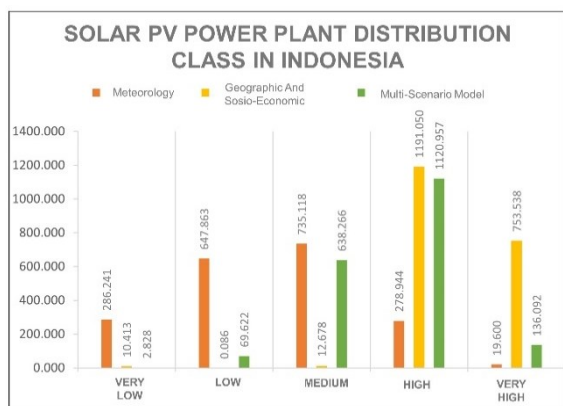


Figure 5. Solar PV Power Plant Distribution Class in Indonesia

The area of each suitability class for each modeling aspect is shown in Figure 5. Based on the annual effective power data, a solar-PV power plant distribution model based on meteorological aspects, it is found that the highest effective power is at 125° longitude and -12° latitude.

The following is attached a WebGIS link for the results of the Spatial Modeling of Multi Scenario Distribution of Optimal Solar Power Plants to Support Indonesia's Clean Energy Achievement Target: <http://bit.ly/ModelPLTSIndonesia>.

Based on Figure 5, it can be seen that the majority of Suitability classes in Indonesia are in the medium and high categories. This proves that Indonesia has a huge potential for solar energy and is spread evenly throughout Indonesia. Then it can be seen in Figure 2 and Figure 3 if in modeling the distribution of Solar PV Power Plant in Indonesia only by considering the meteorological aspect, without considering the spatial and socio-economic aspects, the results of the suitability will be different. On the other hand, if only the spatial and socio-economic aspects are considered, the results will be inconsistent without considering the meteorological aspects. They will reduce the level of confidence in these results. As shown in Figure and Figure 3, if only the spatial and socio-economic aspects are considered, the majority of the level of Suitability in Indonesia is in the high and very high class. However, after combining the meteorological aspects, most of the suitability levels changed to medium and high classes. This multi-scenario model can determine the location

that is the main priority for the construction of PLTS in that location.

3.3 Solar PV Power Plant Suitability Area

Based on Figure 6, some areas are most suitable for constructing solar PV power plants. The most suitable areas are seen from the area with the highest suitability level. The provinces with the most suitable areas are the provinces of East Nusa Tenggara, Papua, Central Sulawesi, Maluku, North Maluku, West Nusa Tenggara, Gorontalo, West Sulawesi, East Java and Southeast Sulawesi. The ten provinces can later be used as priority areas for PLTS to be built.

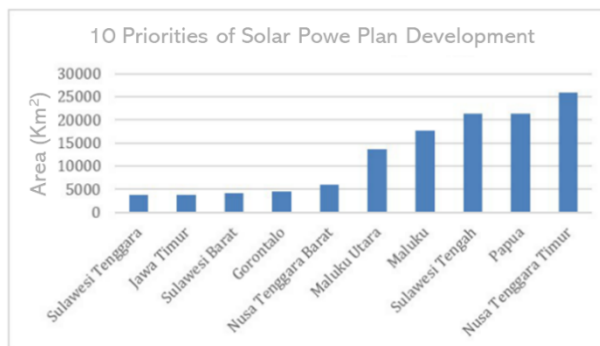


Figure 6. 10 Potential Areas for PLTS Construction

The priority of PLTS development can also be chosen based on the region's needs in regional development. The 3T area can be linked to the results of the suitability of the PLTS development area, where PLTS can be used to develop the 3T area. Eight provinces have the most districts/cities in the 3T classification, and these eight provinces can be prioritized for PLTS development. The very suitable area for 8 provinces can be seen in Figure 7 and 8. Suppose the regions with the highest area of conformity and the 3T regions are combined. In that case, there are provinces with high priority for PV mini-grid development, namely the provinces of East Nusa Tenggara, Papua, Central Sulawesi, Maluku, and North Maluku.

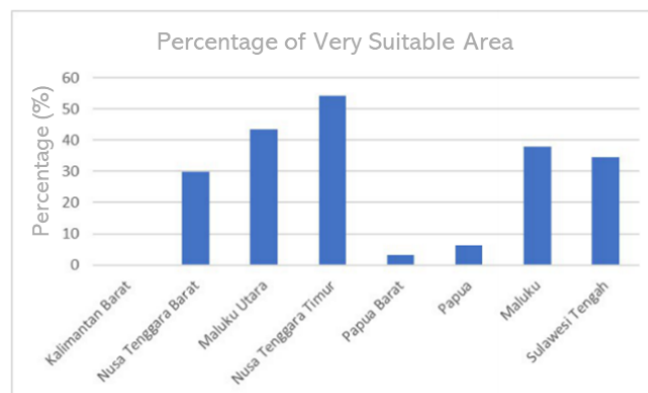


Figure 7. Area Percentage of PLTS Development in Very High Suitability Class in 3T Region

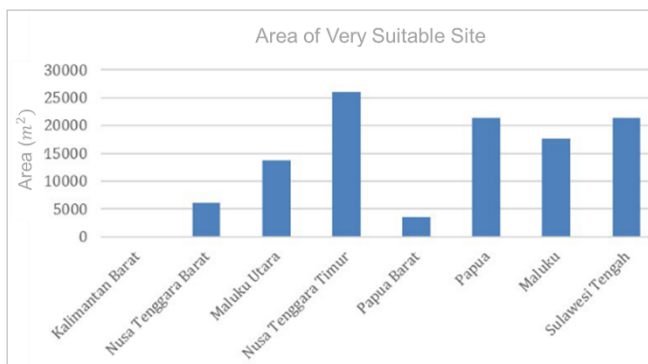


Figure 8. PLTS Development Area with Very High Suitability Class in Region 3T

3.4 Data Comparison

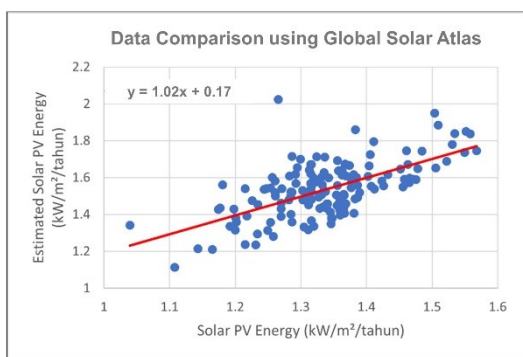


Figure 9. Global Solar Atlas Comparison

Global Solar Atlas' Global Photovoltaic Power Potential data validate the resulting effective power data. The two data were regressed to see the relationship between the two data. The calculation results show that the coefficient of determination (R^2) is 0.412, which means that the two data have a deterministic coefficient of 41.2%. The two data have a good correlation but still have differences caused by differences in processing methods and differences in the input data produced. Several factors may cause differences in results. The first factor is the different data used to determine the solar PV potential. Global Solar Atlas data uses DEM data to determine potential energy, but we do not use it; meanwhile, Global Solar Atlas does not use AOD and Precipitation data, but we use both data. In addition, the algorithm used in determining the solar PV used is also different.

4. CONCLUSIONS

The following conclusions are obtained through all the research carried out: The distribution of effective Solar PV power plant development in Indonesia using a multi-scenario spatial model is divided into 5 suitability classes, namely very low, low, medium, high, and very high classes. The percentage of Suitability class is 0.2% very low class, 3.5% low, 32.4% medium and 56.9% high class, and very high 7%. Several factors will influence the determination of an effective and efficient PLTS development area, namely spatial factors, socio-economic factors, and meteorological factors. Comparison between processed solar PV yields and Solar PV from Global Solar Atlas to see how well the

processed yields are. The coefficient of determination (R^2) is 0.412, which means that the two data correlate 41.2%.

This research can improve by Integrate the results that have been obtained with other parameters that have not been included, such as geological data in the form of rock types, fault data, and other data that refers to the guide to the feasibility study of centralized solar power plant (Karimi et al., 2018). The need improves to determine the appropriate weight value for each parameter so that the results have a higher level of trust, like Analytical Hierarchy Process (AHP) (Tercan et al., 2021). The Approach of this research also can be used to plant detail in urban (Ihsan et al., 2021(b)) and rural (Islam et al., 2018) specific locations to determine the suitable area to build solar PV. For easier access and more informative information, WebGIS can be developed to interactive WebGIS (Ihsan et al., 2021(c)). Furthermore, to find out the specific impact of the role of solar PV on the provision of clean energy, analysis can be done using calculations of carbon stock and carbon emission models (Sakti et al., 2022). In this study, there has also been no analysis by considering multi-disaster aspects (landslides, floods, earthquakes, fires, etc.) that can be done using spatial hazard analyses (Sakti et al., 2021).

ACKNOWLEDGEMENTS

The authors are grateful to acknowledge the support from Institut Teknologi Bandung. We also thank the anonymous reviewers whose valuable comments helped us prepare an improved and more precise version of this paper. All people and institutes who kindly made their data available for this analysis are acknowledged.

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