The Bartlett School of Environment, Energy and Resources

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Coursework Title: Solar Power Plant Investment in Indonesia: A decarbonised electrical supply vision to 2030

Module Leader:	Dr. Yuerong Zhang
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1. INTRODUCTION

Indonesia has been grappling with an economic downturn and a consequent decline in energy demand due to the COVID-19 pandemic. Recent updates on the forthcoming RUPTL (2021–2030) indicate the government's intention to reduce 15.5 GW of power capacity, predominantly from fossil-fuel power plants. In the updated RUPTL (2021–2030)[1], PLN aims to incorporate an additional 3.7 GW from a combination of various renewable sources, including solar PV, wind power, and waste-to-energy plants.

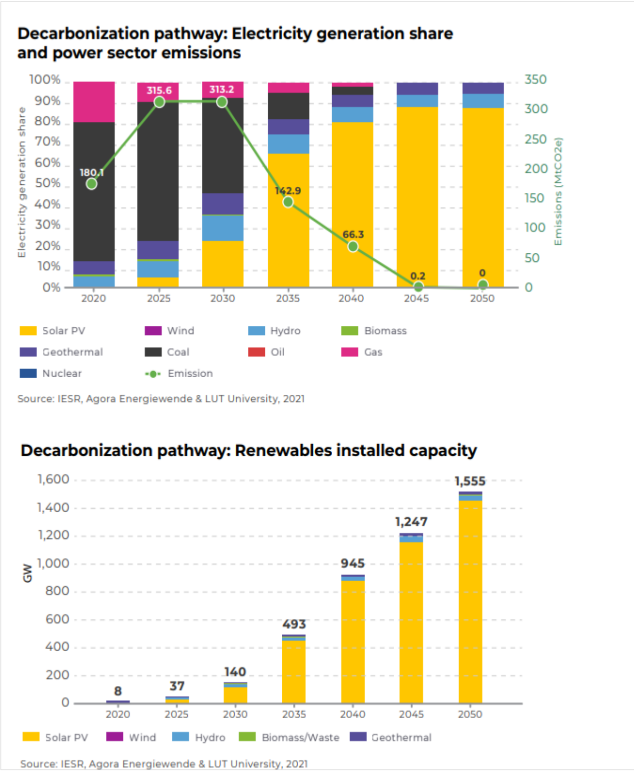


Figure 1: Decarbonization Pathway

Indonesia in its roadmap has said it will target deeper reductions in carbon emissions by 2030, cutting those to a peak of 250 million metric tons by 2030.That includes the early retirement of some coal-fired units (Figure 1). The planning document released in November said Indonesia wants to increase the share of renewables in its generation mix to 44% by 2030.Indonesia currently receives about half of its electricity from coal-fired generation, according to government data. It receives about 12% of its energy from renewables, mostly hydropower and geothermal.

Renewable energy development remains sluggish this year with installed capacity only increasing by 386 MW by Q3 2021.Hydropower, geothermal, bioenergy, and solar PV contributed to an increase of 291 MW, 55 MW, 19 MW, and 21 MW respectively.

In terms of generation, however, coal generation still dominated the power generation by accounting for around 66% of total power generation. Meanwhile, renewables only contributed to around 13%. To align with the zero-emission scenario, at least 47% of the generation share should come from renewables by 2030. As shown on figure 2, the Solar power will become the backbone of the decarbonized power system, followed by hydropower and geothermal.

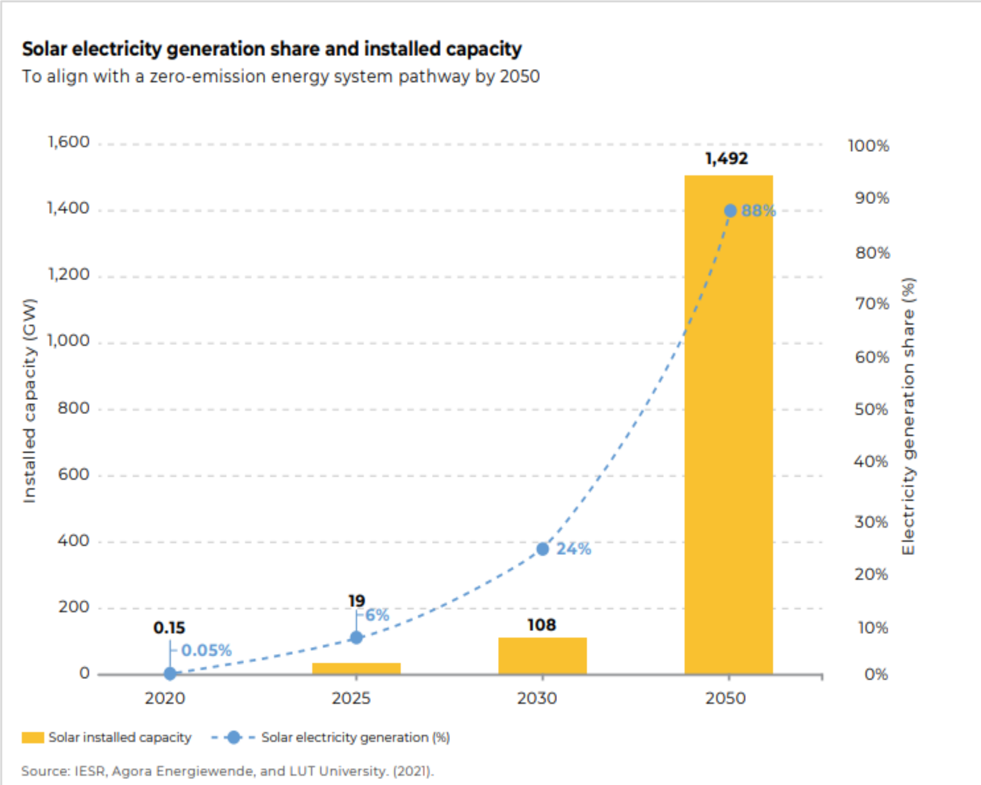


Figure-2: Solar Power Generation Projections

Figure 3 further shows the location of existing, planned, and under construction renewable power plants scattered in the country.

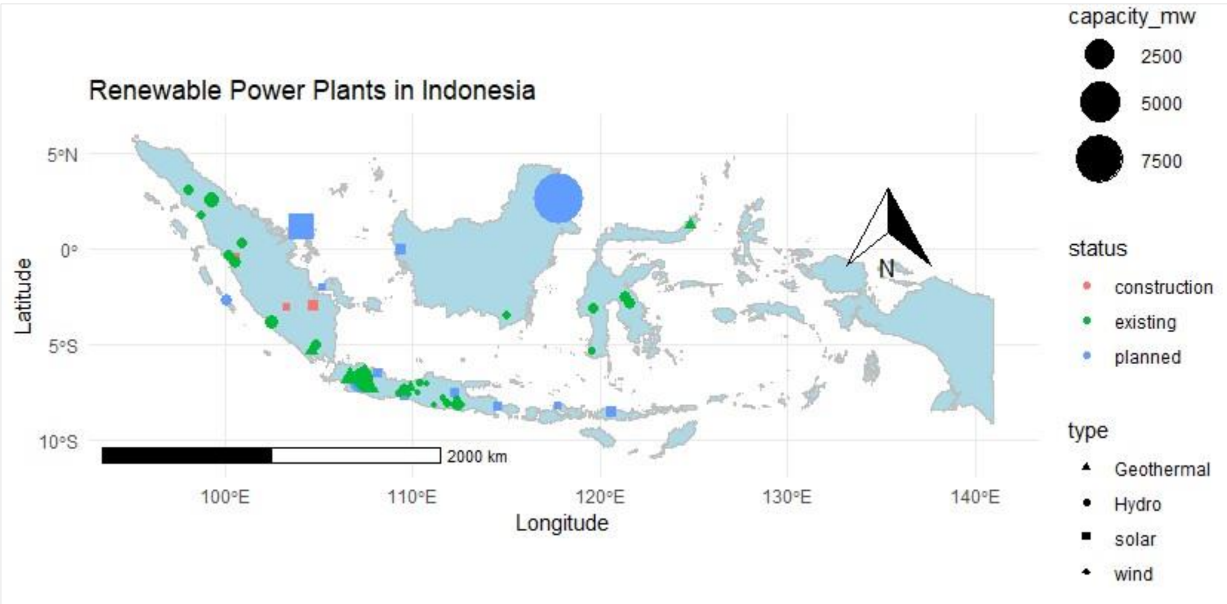


Figure-3. Location of existing, planned, and under construction Solar power plants in Indonesia (Global Power Plant Database, 2021)

National Energy Council's Indonesia Energy Outlook 2017 listed Indonesia's solar theoretical and technical potential by converting land area with solar potential (in kWh/m2/day) and assuming 15% module efficiency to that resource potential; resulting in approximately 3,700

GW of theoretical solar potential and 559 GW of technical potential, although this estimate appears to be revised to 207 GW in 2017, as listed in RUEN. Given a more restrictive land cover/use constraints and policy and regulatory limits, the potential estimate (so-called economic or market potential) might be lower. Nevertheless, this estimate can provide better (geospatial) information regarding policymaking or power system planning related to solar power development in the country Those constraints may produce a more pessimistic yet more realistic and implementable potential of renewable energy.

One framework to evaluate multi-criteria constraints is the multi-criteria decision making (MCDM) techniques (Al Garni, Hassan Z., Anjali Awasthi, 2018).
AHP is an accepted MCDM tool (Sánchez-Lozano *et al.*, 2016) that index the overall significance of each criterion based on goal hierarchy and the pair-wise comparison with other criteria (Saaty, 2008). Hence, this study will use the AHP tool for MCDM techniques.

Thus, this study will provide analysis to answer the following question:

What is the least-cost development strategy to decarbonise Indonesia's electricity supply in 2030 considering the net potential of solar energy?

This study implements financial analysis using the least-cost optimisation energy modelling and NPV to assess the feasibility based on the resulting net potential from spatial analysis considering the resource and cost constraints (Wolfram Wiesemann, Daniel Kuhn,2010).

2. METHODOLOGY

Unveiling a Sustainable Energy Future: A Four-Step Journey

To navigate the energy landscape of 2030, our study embarks on a four-step journey, to craft a sustainable energy strategy for the future.

Step 1: Charting the Course - Projecting Future Demand

Our voyage begins with charting the course, accurately forecasting electricity demand for 2030. We meticulously assess the key drivers influencing this demand, ensuring our map reflects the full landscape of economic, social, and technological shifts.

Step 2: Unveiling the Gems - Mapping Renewable Resource Potential

Next, we set sail towards renewable energy treasures. Our spatial analysis tools, guided by both general suitability criteria and resource-specific needs, unlock the hidden potential of solar energy across the land. Imagine this analysis as a double filter: first, we identify areas meeting all essential criteria, then, within these promising zones, we leverage the AHP tool to rank locations based on their suitability for specific resources.

Step 3: Building the Bridge - Optimization and Strategy

With the map of renewable bounty in hand, we build the bridge to 2030. Least-cost optimization modelling, fuelled by net potential data and guided by NPV (Net Present Value) analysis, guides our strategy. In conclusion, we bridge any potential gaps by planning for additional capacity in the most cost-effective manner to meet projected demand in 2030.

Step 4: Setting Sail - Embracing the Sustainable Future. With a robust strategy charted and the optimal energy mix identified, we're ready to set sail towards a sustainable future for harnessing renewable resources efficiently, paving the way for a brighter, cleaner tomorrow.

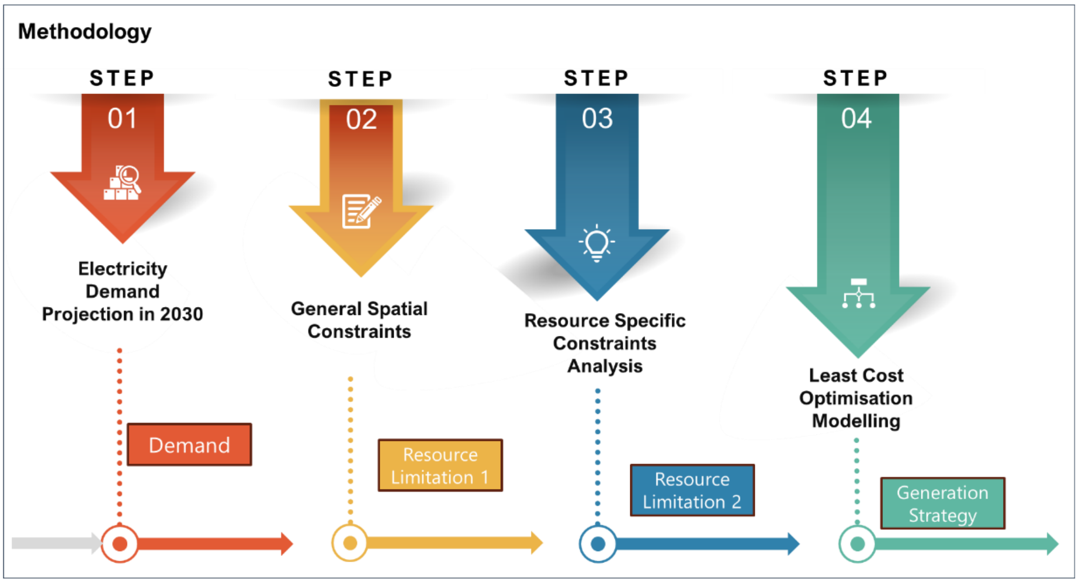


Figure 4. Methodology Summary

3. ANALYSIS AND RESULTS

3.1. Electricity Demand Projection

This study centres its attention on the comprehension of Indonesia's forthcoming electricity demand. This demand is underpinned by two primary factors: the escalating per capita electricity consumption and the burgeoning population. Notably, economic growth, as measured by GDP per capita, assumes a pivotal role in driving electricity consumption.

In Figure 5a, one observes the depiction of historical data and the projection spanning from 1967 to 2030, showcasing GDP per capita trends. Concurrently, Figure 5b illustrates historical data pertaining to electricity consumption Vs GDP. A significant correlation (evident from R-squared value 0.95) emerges from this data, providing the basis for projecting electricity consumption per capita up to the year 2030 as demonstrated in Figure 5c, based on the anticipated GDP per capita trajectory.

The ultimate projection for electricity demand, as delineated in Figure 6b, involves the multiplication of this per capita consumption figure with Indonesia's foreseen population growth, as presented in Figure 6a (The World bank-2023). This computation leads to an envisaged total electricity demand of 486 Terawatt-hours by the year 2030.It is noteworthy that this projection closely aligns with another forecast posited by IEA in 2019, which estimated a 440 terawatt-hour demand for 2030.

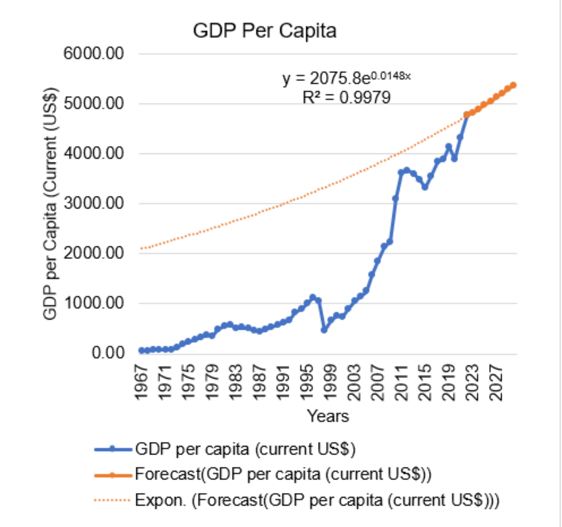


Figure 5(a). Projection of GDP per Capita

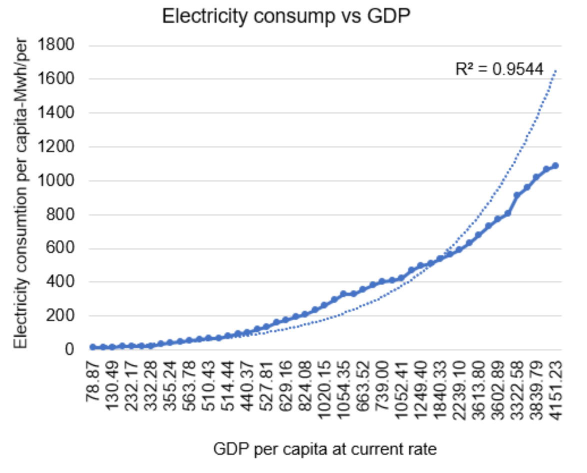


Figure 5(b). Correlation between electricity per capita and GDP per Capita

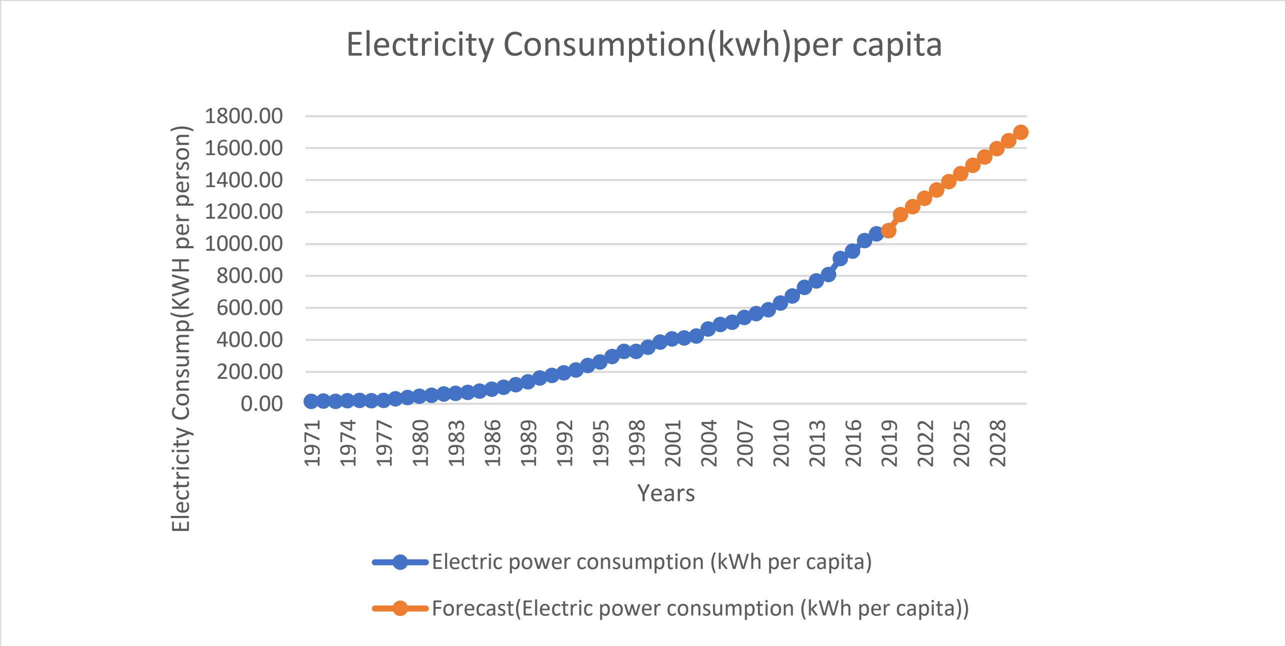
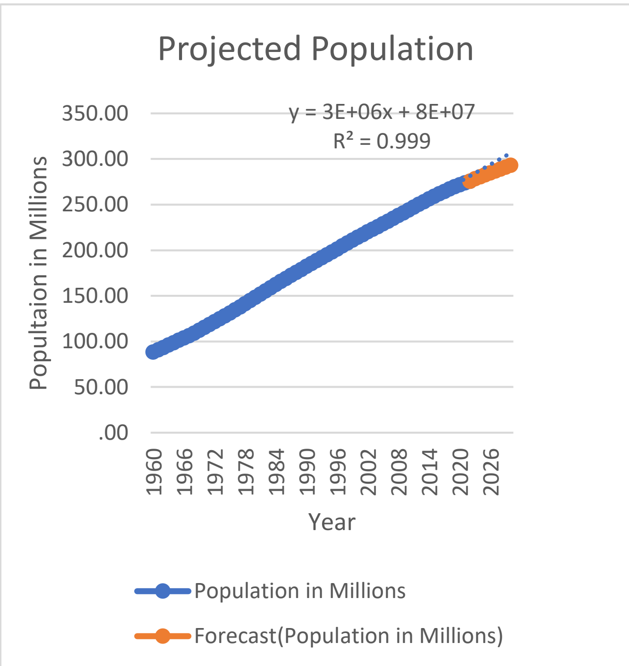


Figure 5(c). Result of electricity per capita projection



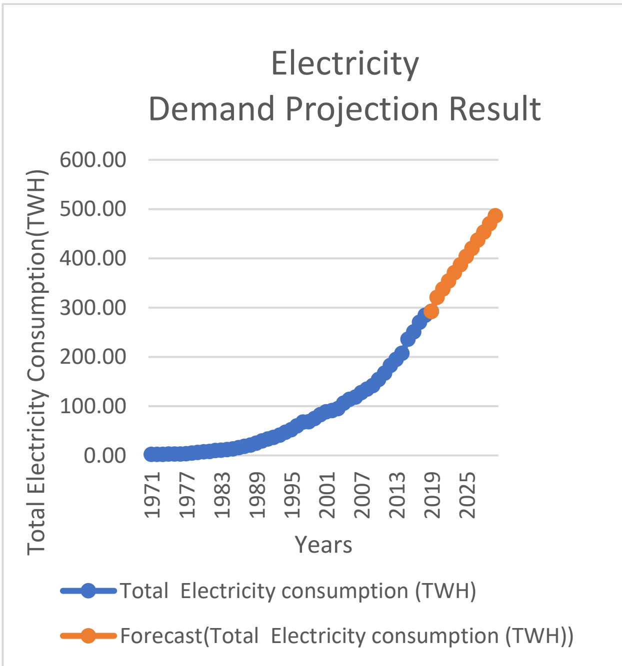


Figure 6. (a) Population projection Figure 6 (b). Result of total electricity demand projection

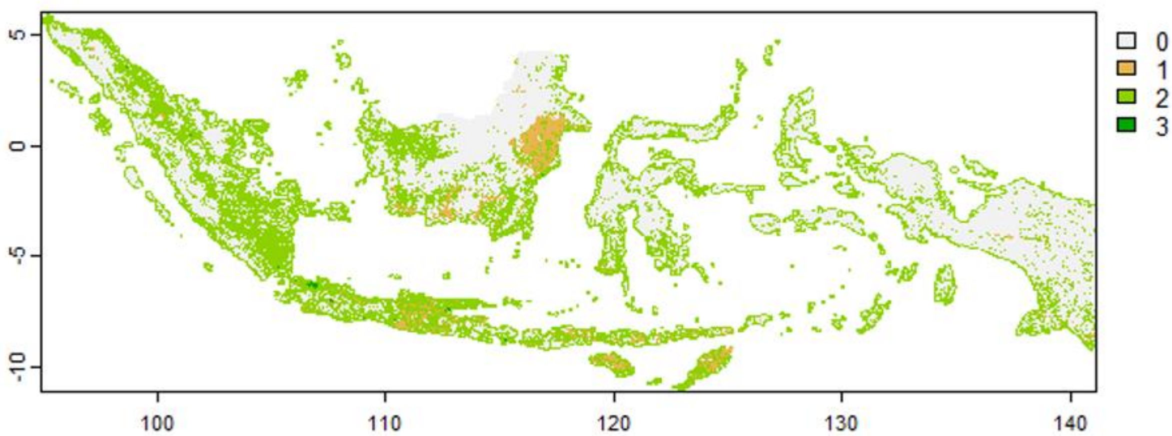
3.2 General Spatial Constraints

General spatial constraints are crucial in selecting sites for solar energy projects, encompassing land use, environmental protection, Peatland protection and proximity to populated areas. Land use analysis ensures no conflict with existing agricultural, residential, or commercial areas. Environmental considerations protect sensitive habitats, and proximity to populations influences transmission costs and community relations.

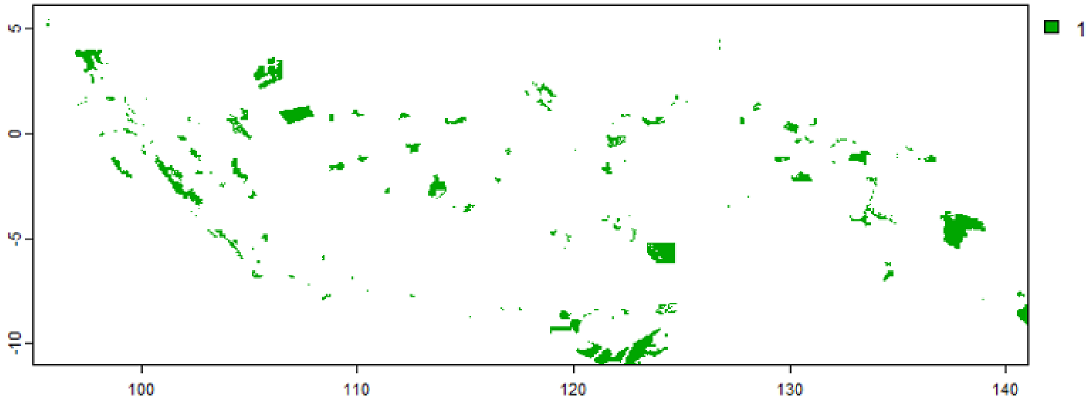
S.no.	Constraint	Suitability Requirements	Source Data
GENERAL SPATIAL CONSTRAINTS			
1.	Landcover	Not on forest (Tree cover), Residential (Buil-tup areas), agricultural (Cropland) and Water Bodies.	ESA
2.	**Protected /sensitive natural areas**	>1000 meter	Protected planet
3.	Human Settlement	>1000 meter	World pop hub
4.	Peatland	Not on peat swampy forests.	Global forest watch

Table-1: General spatial constraints applied in this study.

General spatial constraints that need to be applied for solar power plant development are summarised in Table 1. This study uses ‘AND logic’ which means one location needs to fulfil all four constraints as shown by the four plots consisting of: A) Landcover classification, B) Protected land, C) Population settlement, and D) Peatland to be determined as a suitable location which is presented as Resultant Constrained Plot (Figure 7).

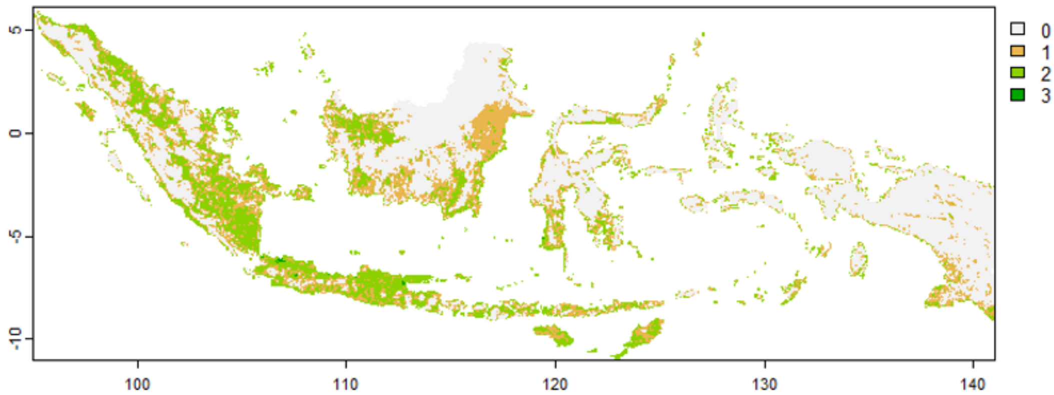


A. LANDCOVER CLASSIFICATION PLOT



B. PROTECTIVE LAND/SENSITIVE NATURAL AREAS PLOT

C. POPULATION SETTLEMENT PLOT



D. PEAT LAND PLOT

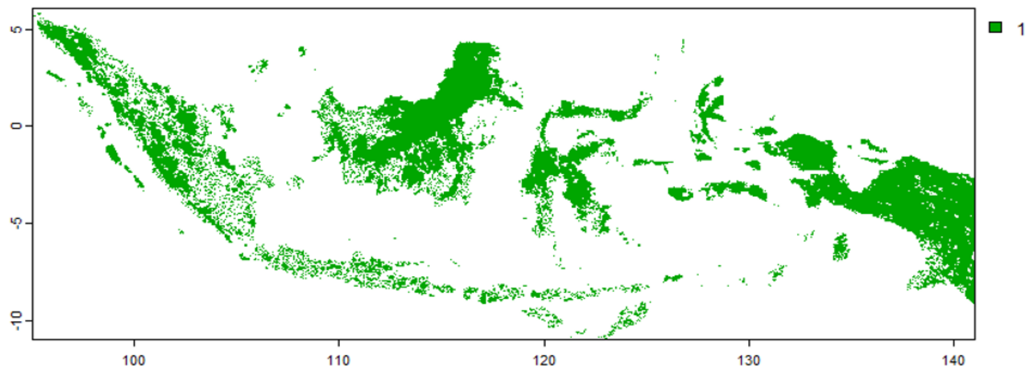


Figure 7: CONSTRAINED PLOT

Figure 7: Results of suitable location based on the general spatial constraints

3.3. Resource-specific Spatial Constraints

Following comprehensive general spatial constraint analysis, the focus shifts to a detail examination of resource-specific spatial constraints tailored for solar energy development, the essentials of which are concisely outlined in Table 2.

In this context, particular attention is paid to, SSRD, the proximity of potential solar farm sites to existing transmission lines and roads and geographical Topography that affects solar panel installation and efficiency These aspects of the analysis is crucial, as they directly impact the feasibility and efficiency of solar farm construction and operation.

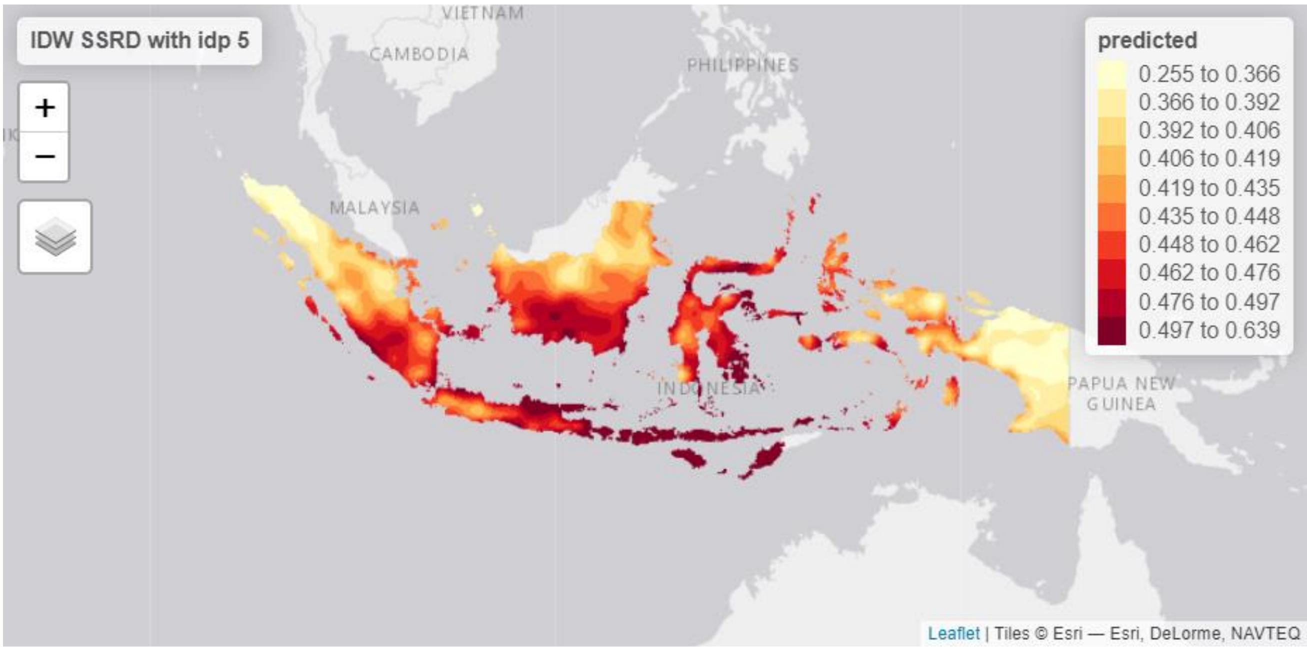
For a more nuanced and comprehensive assessment of the resource-specific constraints, a multi-index approach is employed. This approach goes beyond simple binary (yes/no) decisions. Instead, it utilizes multiple indexes to evaluate each factor, providing a more layered and detailed analysis. Such an approach is integral to the Analytical Hierarchy Process (AHP), which takes into account all types of constraints and assigns them varying degrees of importance or weightage.

The culmination of this resource-specific constraint analysis is visually represented in Figure 8, where plots numbered A) to E) display the results.

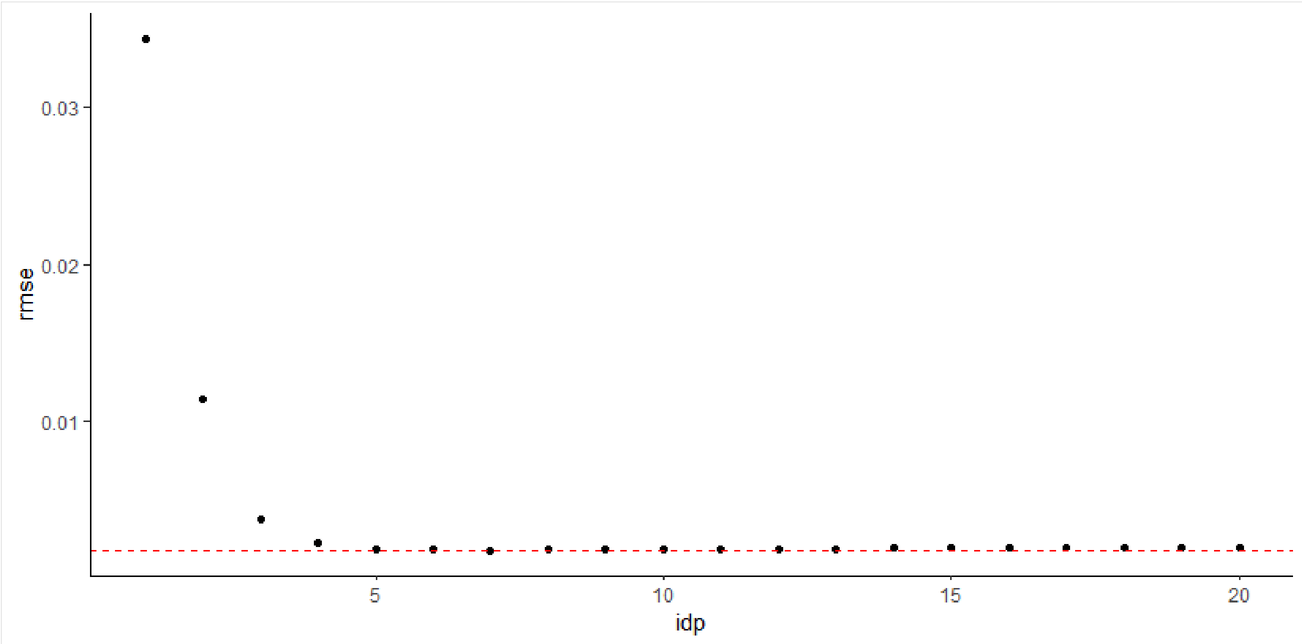
S.no.	Criteria (Code)	Data Source	Index Requirements	Data Reference
SOLAR SPATIAL CONSTRAINTS				
1.	Surface Solar Radiation Downward (SSRD)	ECMWF	1.<1500 kWh/m2=1 2.1500-1700 kWh/m2=2 3. >1700 kWh/m2=3	(SolarGIS, 2019)
2.	Slope	DIVA-GIS	1. >10 =1 2. 1-10=2	(SolarGIS, 2019)
3.	Temperature	WORLD BANK	1. < 20 deg. C =1 2. 20-25 deg. C =2 3. 25-30 deg. C =3	(Diva-GIS.org, 2020)
4.	Distance to Transmission Line	OSM	1. 5 -10 km = 1 2. 1 – 5 km = 2 3. <1 km = 2	(Arderne, 2017)
5.	Distance to Road	DIVA-GIS	1. 25000 m-50000 m = 1 2. 100 m – 25000 m=2	(WorldPop *et al.*, 2018)

Table 2. Solar constraints and requirement for index benchmark

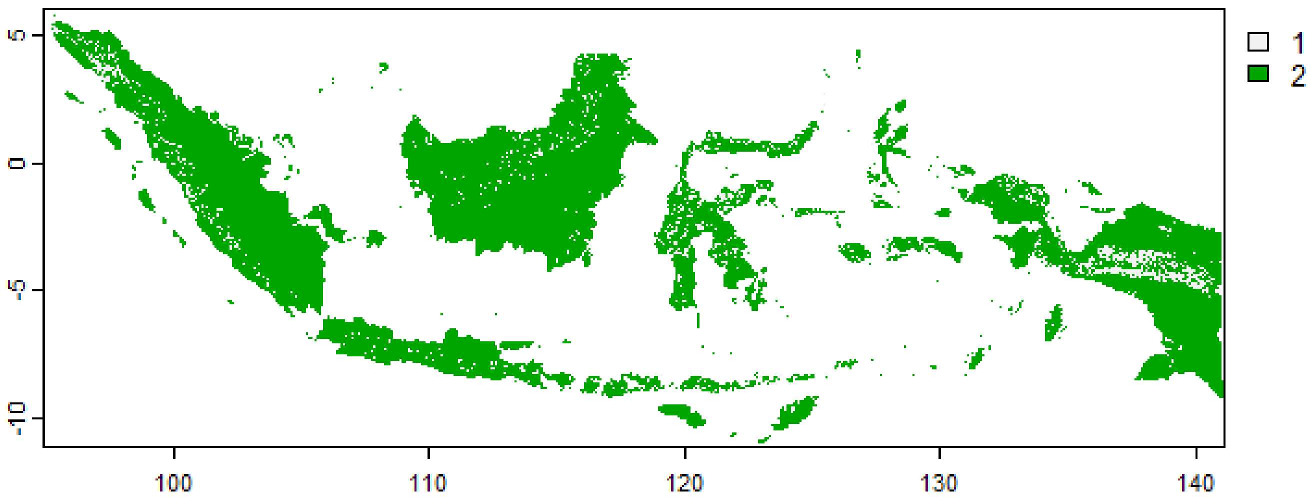
A1) Average SSRD FOR 2021-2022



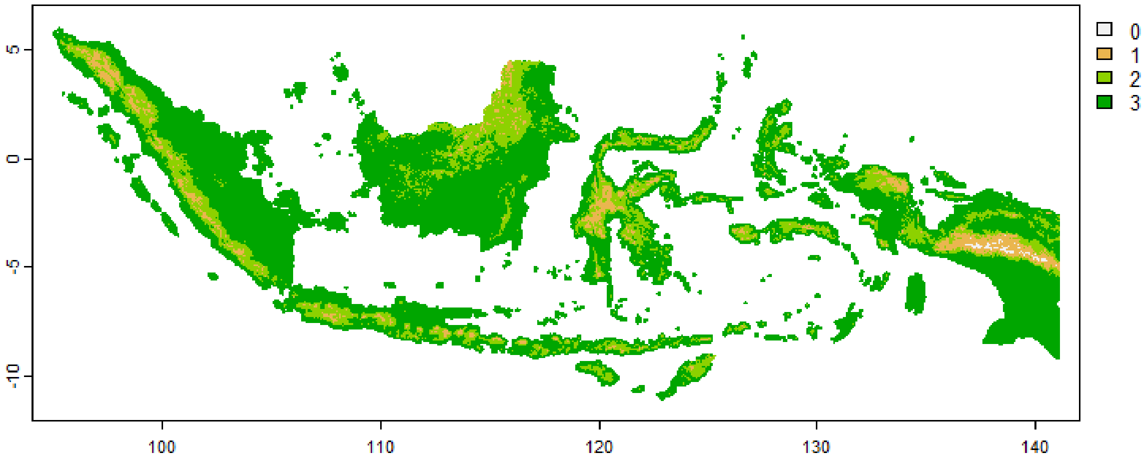
A2) SSRD With IDW interpolation with idp5



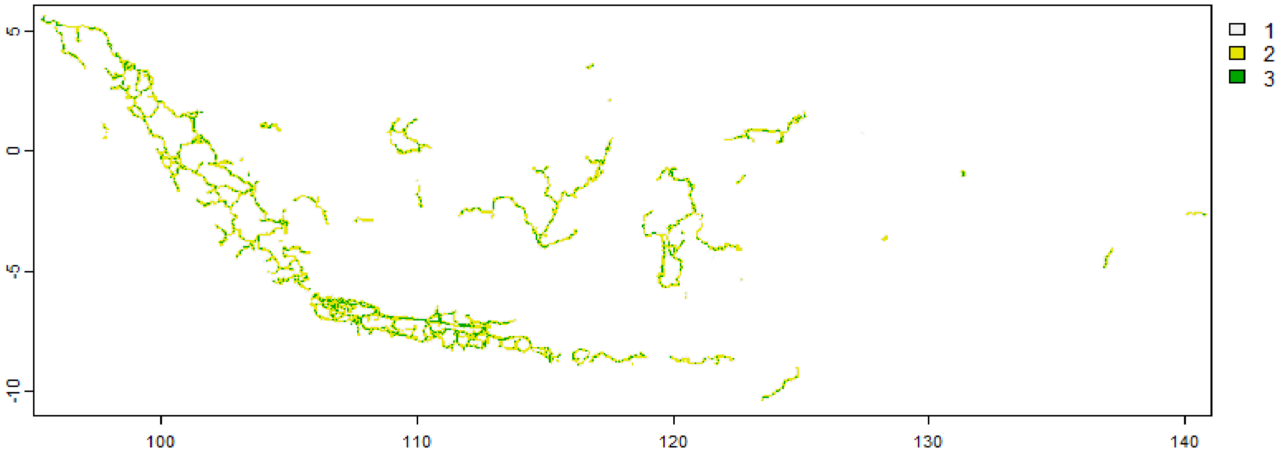
A3) RMSE PLOT FOR IDP



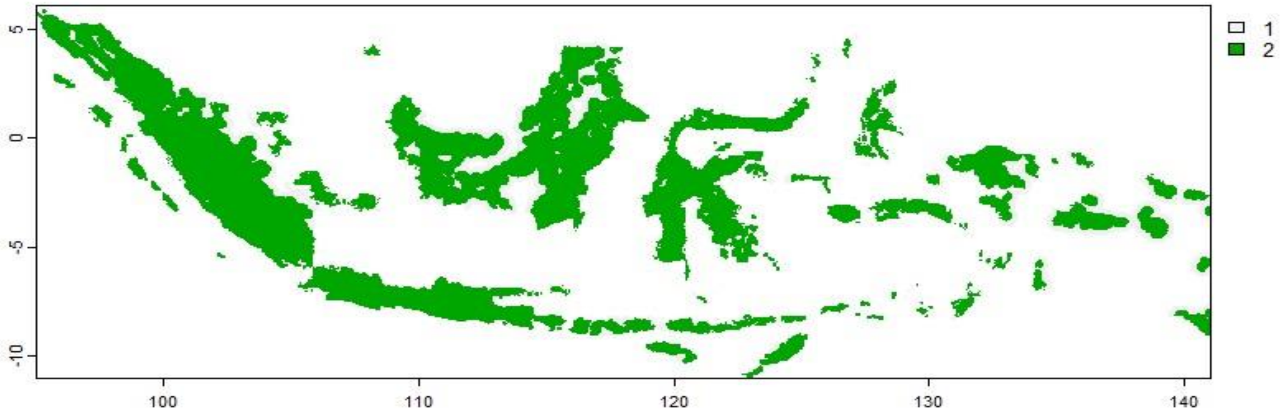
B) SLOPE PLOT



C) TEMPERATURE DISTRIBUTION PLOT



D) POWERGRID PLOT



E). ROAD NETWORK PLOT FOR 25KM AND 50KM

3.4. Geographical Potential

To ascertain the geographical potential for solar farm development, the process begins with a Multi-Criteria Decision Making (MCDM) approach, utilizing the Analytical Hierarchy Process (AHP). The initial and critical step in AHP is to conduct a pair-wise comparison of each criterion, evaluating their relative significance using a 5-level scale, as delineated by Saaty in 2008. This comparison is essential to understand how each criterion weighs against others. If one criterion is less significant compared to another, its value is assigned as the reciprocal in the scale, as detailed in Appendix A1.

Following this, the results of the pair-wise comparisons are used to construct a matrix. This matrix is then normalized to ascertain the significance of each criterion, as presented in Table 3. The next step involves integrating these normalized values with the indices for each criterion from Table 2. This integration calculates the overall suitability of each site for solar farm development. The outcome of this calculation is presented in Figure 10, which visually represents the most suitable sites. Based on the criteria's, 74 project sites are identified.

The process culminates in the selection of the most promising sites for solar development, specifically, those that exhibit over 80% suitability. These selected sites are then advanced for further technical potential analysis.

	AHP ANALYSIS USING MDCM							
S.no.	Criteria	SSRD	Elevation	Power Grid	Temperature	Road		
1	SSRD	1.00	4.00	2.00	5.00	7.00		
2	Elevation	0.25	1.00	0.33	4.00	2.50		
3	Power Grid	0.50	3.03	1.00	5.00	4.00		
4	Temperature	0.20	0.25	0.20	1.00	0.40		
5	Road	0.14	0.40	0.25	2.50	1.00		
		2.09	8.68	3.78	18.50	14.90		
	NORMALIZED							
S.no.	Criteria	SSRD	Elevation	Power Grid	Temperature	Road		
1	SSRD	0.49	0.46	0.53	0.32	0.47	2.27	45%
2	Elevation	0.12	0.12	0.09	0.22	0.17	0.71	15%
3	Power Grid	0.24	0.35	0.26	0.27	0.27	1.39	28%
4	Temperature	0.08	0.03	0.05	0.05	0.03	0.24	5%
5	Road	0.07	0.05	0.07	0.14	0.07	0.38	8%
							2.78	100%

Table 3. Significance results from AHP analysis for all criteria

3.5. Technical and Net Potential

The technical potential is calculated based on the yield of solar energy (DTU, 2019; Solar-GIS, 2019) on the resulted geographical potential areas presented in Table 4.

Next, the net potential is calculated from the resulted technical potential multiplied by the foot-print consideration (De Castro et al., 2013) due to the limitation caused by the configuration of the solar cell (PV), or reflectors.

Finally, this study assumes only 10% of potential areas will be realistic for the development to calculate the final net potential to be used as the resource constraint for least-cost optimization (Table 5).

Hence 14 Project sites out of 74 sites across 3 different regions broadly classified on the basis of Geographic location and the solar Irradiation potential have been identified for the development of Solar Farms. The development areas for these sites have been considered based on the same factors.

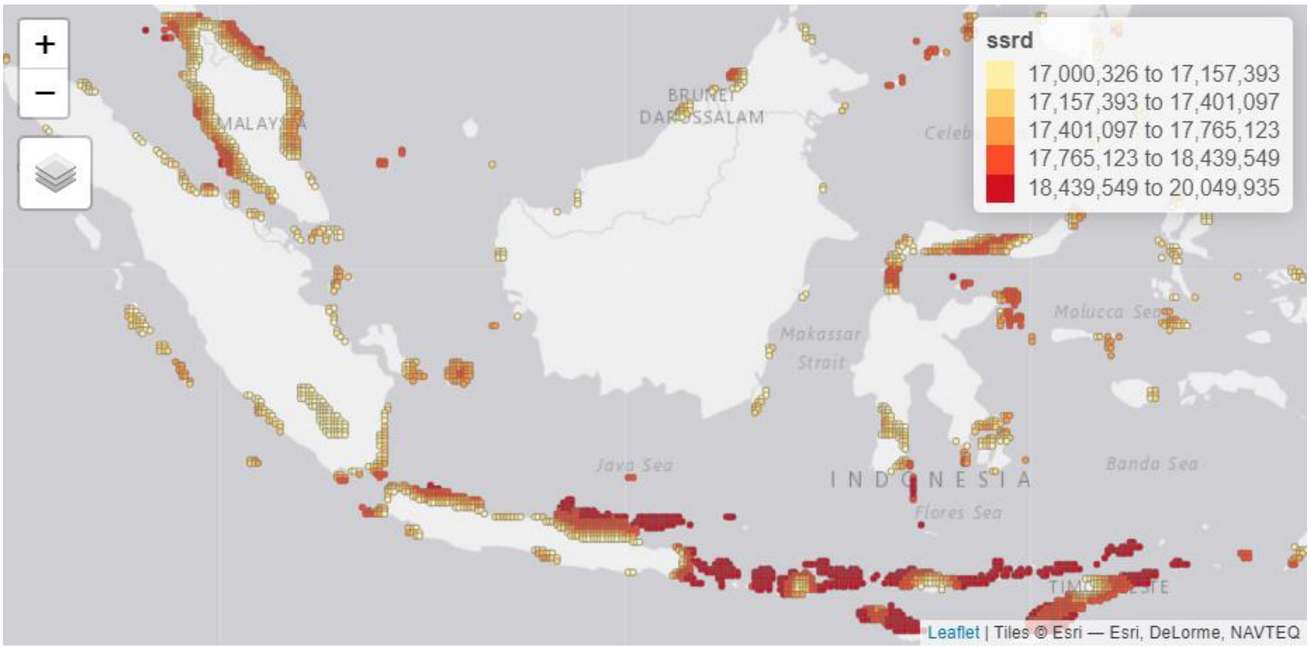


Figure-9: Regions with SSRD > 17,000,000

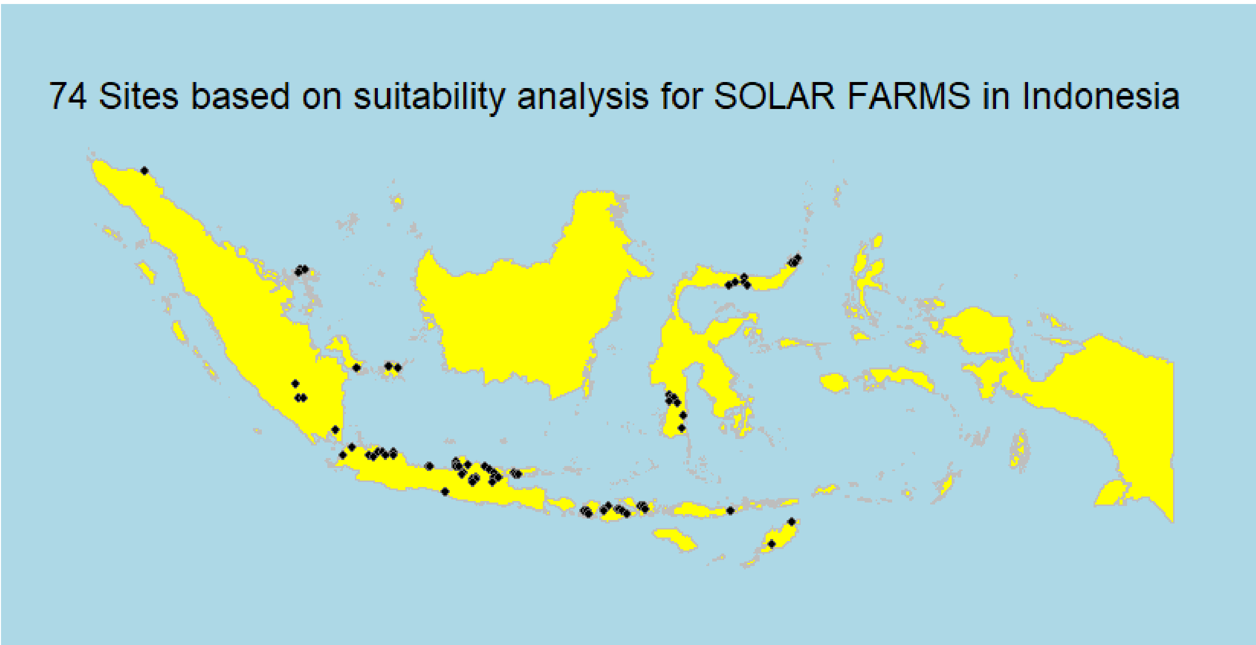


Figure- 10: Overall Suitability and 74 Sites satisfying criteria

Power type	Average Yield(kw/m2)	Geographic Potential(km2)	Technical Potential	
			MW/km2	GW
Solar	0.52	1588	520	826

Table 4. Technical potential calculation

Power type	Footprint Ratio	Effective Area (km2)	Final Net Potential (GW)
Solar	45%	72	38.16

Table 5. Final net potential calculation

3.6. Financial Analysis using Net Present Value (NPV) & Least-Cost Optimization (LCOE)

For the required installed capacity of 38 GW in Indonesia by 2030 based on the projected demand, the three regions are identified with SSRD ranging from 17000000 – 19000000 J/m2. Fourteen project sites are selected with capacities ranging from 1 GW to 6 GW.

The length of transmission lines is assumed on an average of about 5km as outlined in AHP criteria. Based on the result in Table 6, the detailed location of the plant1 suggested with the development area, installed capacity, length of the connection to transmission and cost is presented in Figure 11.

The various technical assumptions required for the calculations are indicated in Appendix-I.

Plant Name	Developed Area(km2)	Installed Capacity (GWe)	Avg. Length of transmission line(km)	Total Cost (Million USD)
REGION-I				
Aceh	2	1	5	1162.95
Riau-Sumatra	2	1	5	1162.95
Sumatera Barat	6	3	5	3488.85
Jambi	2	1	5	1162.95
Lampung	2	1	5	1162.95
Total	14	7	25	8140.65
REGION-II				
Kalimantan Utara	3	1.5	5	1744.425
North Kalimantan	8	4.2	5	4884.39
Kalimantan Selatan	2	1	5	1162.95
Papua	3	1.5	5	1744.425
Total	16	8.2	20	9536.19
REGION-III				
West Java	8	4.1	5	4768.095
Sulawesi Selatan	10	5.6	5	6512.52
Nusa T Barat	10	5.8	5	6745.11
West Sulawesi	6	3.1	5	3605.145
Nusa Taimur	8	4.3	5	5000.685
Total	42	22.9	25	26631.555

Table- 6: Power plant cost input

Using the investment Cost for each plant in Different Regions (**Table 6**) and their Annual Generation & Revenue, **Table 7** summarizes the resulting cost analysis performance (Net Present Value (NPV) and LCOE (Least Cost Optimization in 25 years operation) for different Project Sites in Region-I, II & III.

Plant Name	Total Cost (Million USD)	Annual Generation (Million Kwh)	Rate of electricity(USD/kwh)	Annual Revenue (Million USD)	NPV(USD)	LCOE	Support(S)/Reject(R)
REGION-I							
Aceh	1162.95	8760	0.103	902.28	126,003,893,031	0.33	S
Riau-sumatra	1162.95	8760	0.103	902.28	126,003,893,031	0.33	S
Sumatera Barat	3488.85	26280	0.103	2706.84	34,661,202,909	0.11	S
Jambi	1162.95	8760	0.103	902.28	126,003,893,031	0.33	S
Lampung	1162.95	8760	0.103	902.28	126,003,893,031	0.33	S
Total	8140.65	61320	0.103	6315.96			
REGION-II							
Kalimantan Utara	1744.425	13140	0.103	1353.42	17,330,606,455	0.22	S
North Kalimantan	4884.39	36792	0.103	3789.576	48,525,684,073	0.08	S
Kalimantan Selatan	1162.95	8760	0.103	902.28	126,003,893,031	0.33	S
Papua	1744.425	13140	0.103	1353.42	17,330,606,455	0.22	S
Total	9536.19	71832	0.103	7398.696			
REGION-III							
West Java	4768.095	35916	0.103	3699.348	47,370,310,643	0.08	S
Sulawesi Selatan	6512.52	49056	0.103	5052.768	64,700,912,097	0.06	S
Nusa T Barat	6745.11	50808	0.103	5233.224	67,011,658.958	0.01	S
West Sulawesi	3605.145	27156	0.103	2797.068	35,816,576,339	0.02	S
Sulawesi Selatan	5,000.685	37668	0.103	3879.804	49,681,057,503	0.02	S
Total	26,631.555	200,604	0.103	20662.212			

Table-7: Financial Analysis using NPV & LCOE

Plant Name	Developed Area(km2)	Installed Capacity(GWe)	Avg. Length of transmission line(km)	Total Cost(Million USD)
Kalimantan Utara	3	1.5	5	1,744
North Kalimantan	8	4.2	5	4,884
Kalimantan Selatan	2	1	5	1,163
Papua	3	1.5	5	1,744
Total	**16**	**8.2**	**20**	**9,536**

Plant Name	Developed Area(km2)	Installed Capacity (GWe)	Avg. Length of transmission line(km)	Total Cost (m' USD)
Aceh	2	1	5	1,163
Riau-Sumatra	2	1	5	1,163
Sumatera Barat	6	3	5	3,489
Jambi	2	1	5	1,163
Lampung	2	1	5	1,163
Total	**14**	**7**	**25**	**8,141**

Plant Name	Developed Area(km2)	Installed Capacity(GWe)	Avg. Length of transmission line(km)	Total Cost(Million USD)
West Java	8	4.1	5	4,768
Sulawesi Selatan	10	5.6	5	6,512
Nusa T Barat	10	5.8	5	6,745
West Sulawesi	6	3.1	5	3,605
Nusa Taimur	8	4.3	5	5,000

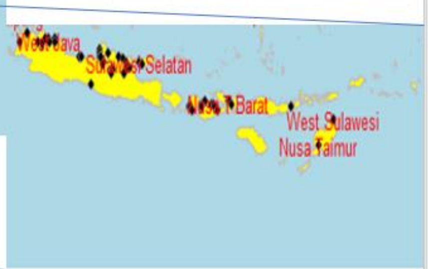


Figure-11: Suggested development area with total installed capacity and cost

4. DISCUSSION AND RECOMMENDATIONS

This section elaborates on how the extensive technical potential identified in this study could significantly contribute to Indonesia's future energy planning. By 2035, the goal of Indonesian Government is to reach an installed solar capacity of 17.6 gigawatts (GW), with utility-scale solar PV expected to contribute about 76% of this target, equating to approximately 13.5 GW (IESR, 2021). The study has shown that the target of projected installed solar capacity of 38GW by 2030 can be achieved based on the solar potential and other factors at the identified geographical location of the sites.

Additionally, the geospatial assessment highlighted in this research could be instrumental in achieving the solar energy objectives outlined in the Rencana Umum Energi Nasional (RUEN), specifically the target of 6.5 GW of solar installed capacity by 2025.

The geospatial assessment of Indonesia's nationwide solar PV technical potential in this report finds that Indonesia's solar PV technical potential capacity is 826 GWp (depending on restricted land-use exclusions). In terms of generation potential, Indonesia can achieve 486 TWh/ year, by taking up less than 1% of the total land mass). The results also show that Indonesia's utility-scale solar PV potential is well above (4 times larger) the current national official estimate, that is 207 GW. The findings presented in this work could be used to support solar power development in the country, while at the same time, meet future electricity demand and achieve renewable energy targets.

General Recommendations

Recommendations to follow up this assessment:

It is recommended that:

1. The government updates the nation-wide solar technical potential figure, as to reflect more detailed potential for solar energy development in Indonesia. Current assessment shows Indonesia's solar potential is higher than current official estimate and it has the potential to supply Indonesia's future energy demand.

2. Identification of prospective locations at provincial levels is performed together with the provincial government and respective PLN's regional offices. Assessment should include current and projection of electricity supply and demand in the area, grid study, financing needs, as well as related policies and incentives.

3. Further technical assessments can be conducted, particularly to zoom in specific locations at cities/regional level and even smaller, not only for utility/large-scale solar, but also for floating solar and rooftop solar.

5.CONCLUSION

Overall assessment as presented in Table 4, the analysis finds that Indonesia's nationwide technical potential for solar PV capacity reach even, in the more conservative estimates Indonesia's PV technical potentials are found to be around 826 GWp, with generation potential of 486 TWh/year, taking up less than 1% Indonesia's total land mass of 1.9 million km2.

In comparison with the current national estimates, the results in this assessment are 4 times higher than MEMR's official technical potential estimate, that is 207 GWp.

Technical potential on each island/archipelago Generally speaking, the magnitude of the technical potential for capacity (and generation) is proportional to the corresponding suitable area. That is not to say that islands or provinces with larger administrative areas will have higher potential, as some might be excluded due to having large forest areas, for instance.

That said, in most of the scenarios, Kalimantan (Borneo), Sumatra, and Papua islands are in the top three for the largest technical potential for solar PV given its large land mass. When looking at province-level, North Kalimantan (4.2GW), Sulawesi Selwatan(5.6 GW), and Nusa T Barat (East Nusa Tengaraa) (5.8 GW), respectively, are the top three provinces with the largest suitable areas, potential capacity, and potential generation . Other provinces like Riau, West Sumatera (Sumatera Barat), South Sumatera (Sumatera Selatan), Papua (province), West Java (Jawa Barat), and Nusa Taimur are also amongst the largest potential for solar PV generation.

The financial analysis done for the 14 selected sites through the NPV value calculation for 25 years lifetime of the project (Table7) suggests that it is feasible to install the indicated capacities of the solar farms and supports the plan.

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APPENDIX A1

I. The values of the pairwise comparisons in the AHP are determined according to the scale introduced by (Saaty, 2000) composed of a set of discrete values for the pairwise comparisons defined in Table 2.

For example, when comparing criterion A with respect to a B criterion: if A is judged strongly more important than B - 5 is assigned, inversely if B is judged strongly more important than A - 1/5 would be assigned. The comparison is summarized in a NxN matrix where N is the number of the identified criterions, each cell would represent the importance a *i,j* of the criterion in row *i* with the corresponding one in the column j resulting in a square matrix (with the value 1 in the diagonal elements).

Importance	Definition	Interpretation
1	Equal importance	Two sub-objectives contribute equally to the objective
3	Weak importance of one over other	Experience and judgment slightly favour one over another
5	Essential or strong importance	Experience and judgment strongly favour one over another
7	Demonstrated importance	A sub-objective is strongly favoured, and its dominance demonstrated in practice
9	Absolute importance	The evidence favouring one Sub-objective over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values	A compromise is needed

Table 2. Scale of relative importance (Saaty, 2000).

II. Technical Assumptions:

A) For the estimation of the capacity of electricity generation from renewable, it is assumed that '38% of total projected electricity generation capacity in 2030 shall be contributed from renewable sources.
Hence the shortfall to be made up by new solar power plants = (Projection * 38%) – (existing + planned + under-construction).

B) To calculate the capacity of renewables, it is assumed that average capacity factor is 0.45 for non-renewables and 0.24 for renewables.

C) Assumption for Financial Analysis:

Technical Assumptions			
Source	**Concept**	**Base Assumption**	**Used Assumption**
Solar	Cap Ex capacity installation	1.16M USD/MW installed power	1.16M USD/MW installed power
	Cap Ex Network connection inland	590 USD/MW.km	590 USD/MW.km
	Discount Rate (NPV)	5%	5%
	Discount Rate (LCOE)	8%	8%
	Life Span	25 Years	25 Years
	Opex	0	0
	Yield	0.175	0.175
	Pr	0.6	0.6
	Revenue	0.103 USD/kwh	0.103 USD/kwh

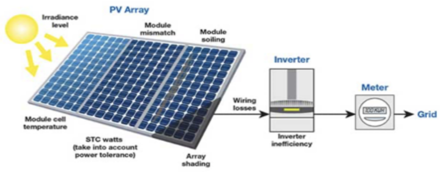
D) **Formulas Used:**

From SSRD to power (Global formula)

$$E = H * A * r * * pr$$

E: energy (kWh)

H: Surface solar radiation downwards on tilted panels ($J\ m^{-2}$)
A is total area of the panel (m^2)
r: Panel efficiency (yield) parameter (%). 0.175
pr: Performance ratio of the overall system (%). 0.6



E) **Capital Expenditure**

CapEx: Capital Expenditure are funds to acquire, upgrade and maintain physical assets.

CapEx_solar = installed capacity *capacity installation cost +
distance between plant and the nearest grid * network connection cost

Yearly revenue = yearly solar energy generation * electricity selling price

F)

Net Present value (NPV)

Net present value (NPV) is a metric that seeks to capture the total value of an investment opportunity. NPV will help us decide to **accept or object** the project.

$$NPV = \sum_{t=0}^{n} \frac{R_t}{(1+i)^t}$$

R_t = net cashflow at time t.
i = discount rate
t = time of the cash flow

G)

Levelised cost of energy (LCOE)

Levelized cost of energy (LCOE) measures **lifetime costs** divided by energy production.

$$\text{LCOE}= \frac{NPV}{\sum_{t=0}^{n}\frac{E_t}{(1+r)^t}}$$

E_t = yearly electricity generation
r = the discount rate of the project
t = life span of the project

NPV= net present value

Projected Capacity Calculations FOR 2030:

Projected Consumption (Generation) for Indonesia in 2030 = 486 TWH/Year
=486 X1000/365X24 GW=55479.45 MW

Projected Capacity in 2030
0.38 CX0.24 +0.62Cx0.45 = 55479.45 MW
C=149863.45 MW

Projected Renewable Power plant capacity in 2030----------=0.38 x 149863.45 MW=56948.11MW
Renewable Power plant Capacity in 2023 (Existing, under Construction & planned) =18958.09 MW

Net Demand of Solar Capacity by 2030 =56948.11-18958.09 MW
=37990.02 MW=37.99 GW

Total Sites based on Suitability analysis :

x	y	solar	Temperature	slope	Road	Grid	Constraint	Region Name
97.48579	5.11738	**17126872**	3	2	2	2	1	**Aceh**
125.0858	1.61738	**17473490**	3	2	2	2	1	**Kalimantan Utara**
124.8858	1.41738	17181530	3	1.971448	2	2	1	
124.9858	1.41738	17310518	3	1.83003	2	2	1	
104.0858	1.11738	17127552	3	2	2	2	1	
104.2858	1.11738	17032770	3		2	2	1	
103.9858	1.01738	**17389224**	3	2	2	2	1	**Riau-sumatra**
122.8858	0.81738	17930006	3	2	2	2	1	
122.4858	0.61738	**18007816**	3	2	2	2	1	**North Kalimantan**
122.8858	0.61738	17677734	3	2	2	2	1	
122.1858	0.51738	17903448	3	1.99879	2	2	1	
122.9858	0.51738	17435192	3	1.808961	2	2	1	
107.7858	-2.78262	**17708808**	3	2	2	2	1	**Sumatera Barat**
106.4858	-2.88262	17301868	3	2	2	2	1	
108.1858	-2.88262	17657786	3	2	2	2	1	
103.8858	-3.48262	**17009126**	3	2	2	2	1	**Jambi**
119.6858	-3.98262	**17233688**	3	2	2	2	1	**Kalimantan Selatan**
103.9858	-4.08262	17039164	3	2	2	2	1	
104.1858	-4.08262	17100706	3	2	2	2	1	
119.7858	-4.08262	17194232	3	1.996888	2	2	1	
119.8858	-4.08262	17035068	3	2	2	2	1	
119.6858	-4.18262	17421286	3	1.950001	2	2	1	
119.9858	-4.28262	17118766	3	2	2	2	1	
120.2858	-4.78262	17284340	3	2	2	2	1	

120.1858	-5.28262	**17117216**	3	2	2	2	1	**Papua**
105.5858	-5.38262	**17001134**	3	2	2	2	1	**Lampung**
106.2858	-6.08262	17165220	3	2	2	2	1	
107.3858	-6.28262	17994062	3	2	2	2	1	
107.5858	-6.28262	**17969530**	3	2	2	2	1	**West Java**
107.9858	-6.28262	17903224	3		2	2	1	
105.8858	-6.38262	17082712	3	2	2	2	1	
106.9858	-6.38262	17412944	3	2	2	2	1	
107.6858	-6.38262	17631622	3	2	2	2	1	
107.9858	-6.38262	17661770	3	2	2	2	1	
107.1858	-6.48262	17125762	3	2	2	2	1	
110.6858	-6.68262	18401206	3	2	2	2	1	
110.6858	-6.78262	18182742	3	2	2	2	1	
111.1858	-6.78262	**18419846**	3	2	2	2	1	
109.4858	-6.88262	17139372	3	2	2	2	1	
109.5858	-6.88262	17094766	3	2	2	2	1	
110.6858	-6.88262	17961130	3	2	2	2	1	
110.7858	-6.88262	18107768	3	2	2	2	1	
111.8858	-6.88262	18576672	3	2	2	2	1	
112.0858	-6.98262	18297462	3	2	2	2	1	
110.9858	-7.08262	17806558	3	2	2	2	1	
112.2858	-7.08262	18161458	3	2	2	2	1	
113.0858	-7.08262	**19020396**	3	2	2	2	1	**Sulawesi Selatan**
110.8858	-7.18262	17401482	3	2	2	2	1	
113.1858	-7.18262	19133588	3	2	2	2	1	
113.2858	-7.18262	19233548	3	2	2	2	1	
111.4858	-7.28262	17632490	3	2	2	2	1	
112.2858	-7.28262	17642008	3	2	2	2	1	
112.4858	-7.28262	17704192	3	2	2	2	1	
111.3858	-7.38262	17351810	3	2	2	2	1	
111.4858	-7.38262	17362122	3	2	2	2	1	
111.3858	-7.48262	17054804	3	2	2	2	1	
112.1858	-7.48262	17031018	3	2	2	2	1	
110.1858	-7.88262	17352582	3	2	2	2	1	
117.0858	-8.48262	18445378	3	1.91018	2	2	1	
118.4858	-8.48262	**19741422**	3	2	2	2	1	**Nusa T Barat**
118.5858	-8.48262	19669298	3	1.967571	2	2	1	
116.8858	-8.58262	18797326	3	1.973498	2	2	1	
117.4858	-8.58262	17599910	3	2	2	2	1	
117.5858	-8.58262	17707190	3	2	2	2	1	
118.6858	-8.58262	19564734	3	1.997884	2	2	1	
116.0858	-8.68262	18725092	3	2	2	2	1	
116.1858	-8.68262	18861388	3	2	2	2	1	
116.8858	-8.68262	18639070	3	1.992849	2	2	1	
117.6858	-8.68262	17818188	3	2	2	2	1	
122.2858	-8.68262	19707874	3	1.995625	2	2	1	

116.2858	-8.78262	18844672	3	2	2	2	1	
117.8858	-8.78262	18737096	3	2	2	2	1	
124.8858	-9.08262	**17801642**	3	2	2	2	1	**West Sulawesi**
123.9858	-9.98262	**18228928**	3	2	2	2	1	**Nusa Taimur**