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Renewable Investment in Indonesia: A decarbonized electrical supply vision to 2030 (the solar energy case)

Executive Summary

To meet the 38% of Indonesia's energy demand by 2030 with alternative energy sources, a significant amount of power capacity needs to be installed, which creates a spatial problem.

This study performs a spatial and economical assessment, projecting demand to 2030 and proposing a strategy to meet the *148.43TWh* of estimated demand requirement solely with solar energy.
Using geographic information system (GIS) tools spatial suitability is analysed together with solar potential and proximity to the grid, suggesting solar plants of two varying sizes in 74 different locations with a total capacity of 163TW. The distribution of the proposed solar capacity is based on regional energy demand distribution and local solar potential.

Financial analysis of the proposed strategy found that over a 32.5-year lifetime of the proposed solar plants, net present value (NPV) will be $7.2bn and levelized cost of energy (LCOE) $0.98-0.10/kWh, which is marginally better than the assumed electricity price of $0.103/kWh. Despite the strategy being financially viable, the suggestions made are to build only a portion of the suggested capacity and instead diversify the renewable energy portfolio of the country, as well as consider this as a feasibility study.

Furthermore, a business case of building a green ammonia plant adjacent to three of the suggested solar farms is considered. For 15 years of operation, LCOE is around *$160/tonne of ammonia*, which is significantly less than the assumed selling price of *$1,070/tonne*. This makes ammonia production financially attractive and strongly suggested for implementation.

Comparing LCOE against the GDI, as well as performing spatial analysis to find locations with easy access to water resources and ports, three preferred sites have been identified: West Java – 3, South Sumatra – 71, South Sulawesi – 50. In total the three sites amount to *6459.09MW* installed capacity and would produce *540097.78* tonnes of green ammonia.

All deliverables are available at:
https://www.dropbox.com/s/nsb8p8d9vdiakje/TYGR3_deliverables.zip?dl=0

1. Introduction & Literature Review

Being the largest exporter of coal by weight[1] and one of the largest exporters of liquefied natural gas[2], it is no surprise that over 80% of the total energy consumption in Indonesia is supplied by fossil fuels (***Fig. 1***).

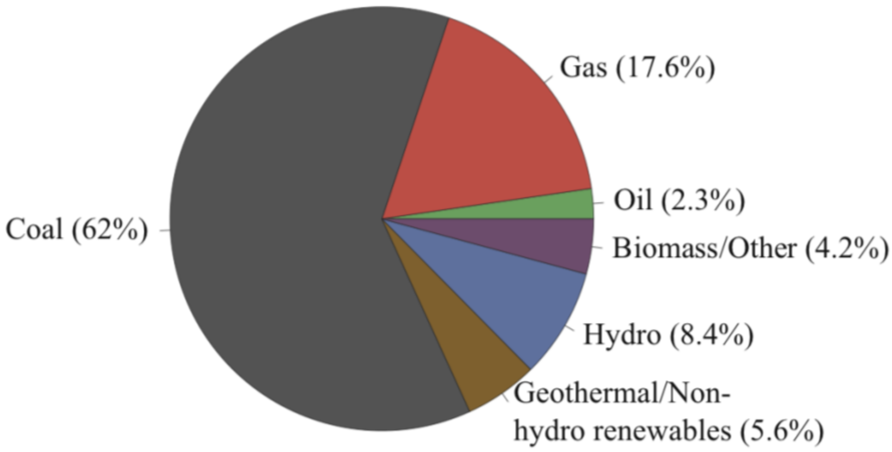


Figure 1. *Indonesia energy consumption mix in 2020*[3].

Figure 2 shows currently installed power plants with their capacities and status in Indonesia, as well as coal and gas plants that are planned or under construction in the country. Additionally, Indonesia is reported to have *0.15GW* of wind power[4], *0.16GW* of solar power and *9GW* of hydropower capacity[5], which are not displayed in ***Figure 2***.
The current energy capacity then adds up to *70GW*, which differs from the *63.3GW* of installed capacity reported by PLN in 2020[6], mainly due to the recently built *9GW* hydropower plant. Together with the plants that are planned or under construction, the capacity rises to *113.7GW*.

Despite the high proportion of fossil fuels, the Indonesian government set out an ambitious goal to reach net-zero by 2060[7]. The recent National Energy Policy aims to decarbonize the Indonesian energy mix, increasing the share of renewable capacity to 23% by 2025[8]. Following this, the Indonesian state electricity company PLN also announced its plan to gradually phase out coal plants[9].

This study will focus on assessing the economic feasibility of increasing the share of renewables to 38% by 2030, building additional solar plant capacity. Locations of the new solar farms will be suggested using the GIS tools, subsequently evaluating the economic feasibility of the farms.
Moreover, this study will explore the business case of installing green ammonia plants adjacent to the three of the most promising solar farms, intending to sell the ammonia as fertilizer for the agricultural sector or zero-carbon fuel for shipping over 15 years.

GIS tools provide an efficient method in finding the best location for the deployment of renewable energy systems (RES)[10]. Determination of renewable energy sources or solar radiation potential using GIS-based evaluation is often implemented in countries all over the world, including China[11], Taiwan[12], Greece[13] or England[14].
Whilst in South Asia most studies primarily focus on technical potential[15–17], there are some studies assessing the economic potential of RES deployment, such as in Bangladesh[18].

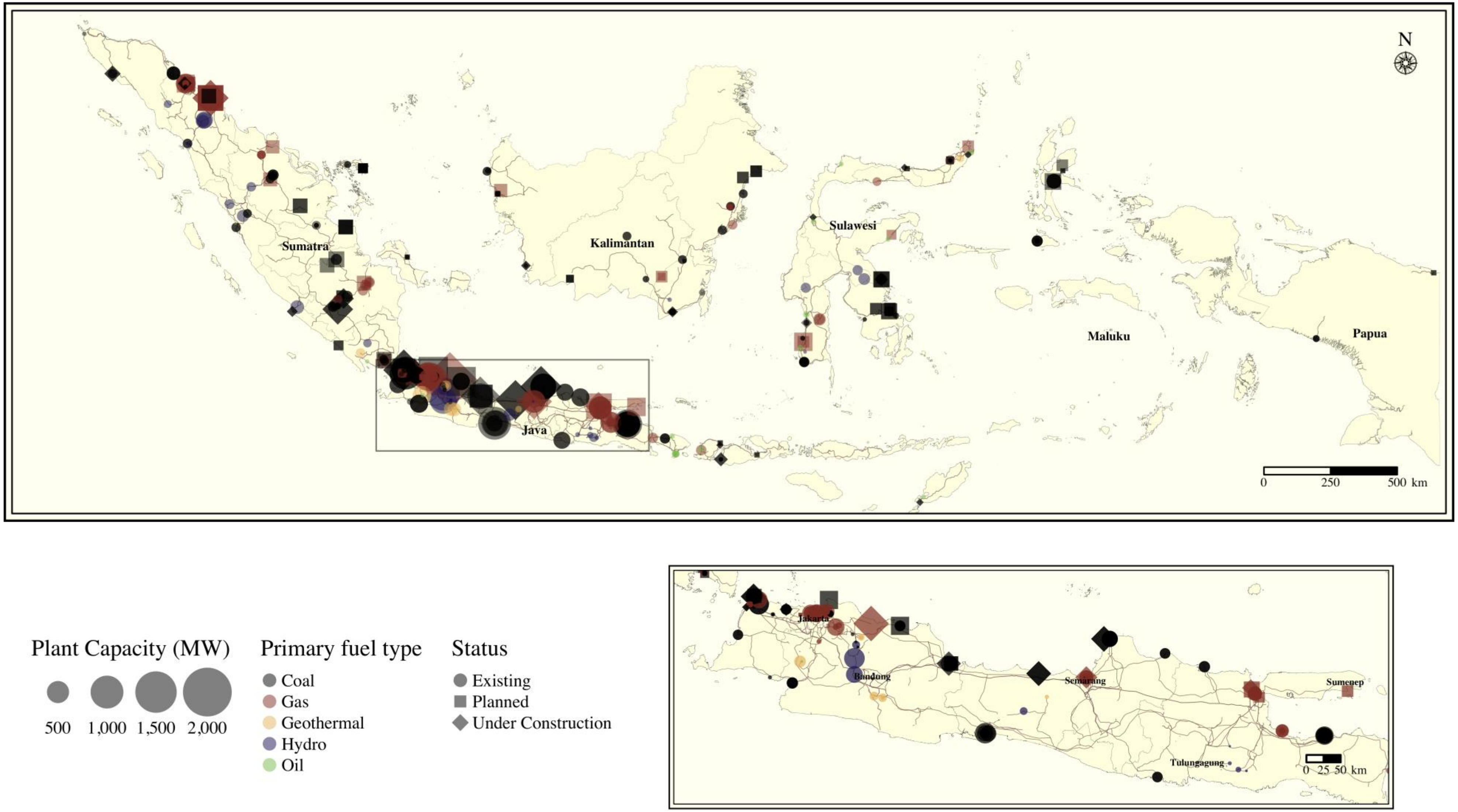


***Figure 2**. Snapshot of power plants in Indonesia. Includes installed capacity of Hydro, Geothermal and Oil plants in 2018 [19], as well as capacity installed and in construction in 2020 or planned until 2030 of country's main power supply – Coal [20] and Gas [21]. Point sizes (capacities) in the label are indicative of the main map.*

2. Methodology

The analysis for this study consists of 7 sequential steps.

2.1 Energy demand projection

To find the energy demand of Indonesia, first, the electricity consumption per capita for the country is projected based on historical data[22] using polynomial regression:

$$y = b_0 + b_1 x + b_2 x^2 + b_3 x^3$$

Then, historical data on population[23] is projected linearly and multiplied by consumption per capita.

Two assumptions are made in projecting energy demand. Firstly, that energy demand is the product of population and electricity consumption per capita, which is usually considered as electricity consumption. Secondly, projections assume continuous growth based on historical trends. This assumption might prove to be false, especially in the case of electricity consumption per capita (***Fig. 3a***), which would most likely level out as the country develops.

2.2 Spatial constraints

Using GIS tools multiple raster and vector layers are combined according to Boolean logic[10]. Each layer is assessed by specific criteria to determine locations unsuitable for solar farms. The layers are then removed from the Indonesia vector[24], leaving a single layer of suitable land.

2.3 Interpolation

The inverse distance weighting approach (IDW) has been adapted for interpolation of solar irradiance layers, where estimation of value z (irradiance) at location x is a weighted mean of nearby observations[25].

$$\hat{z}\,(\boldsymbol{x}) = \frac{\sum_{ni} w_i z_i}{\sum_{ni} w_i}$$

$w_i = |x - x_i|^{-\beta}$ and β determines the degree of preference towards the nearer points. Local weighting with 3 surrounding points has been selected.

2.4 Solar potential and suggested locations

The solar irradiation layer (***Fig. 10a***) is cropped by the extent of the final suitability map (***Fig. 10b***). The irradiation values are then filtered to only show values higher than *4.5kWh/*m^2 to highlight optimal locations. Annual electricity generations of the suggested solar farms are then estimated using standard conversion equation[26]:

$$E = A \cdot r \cdot G \cdot \rho$$

Where *A* is the total solar panel area (m^2), *r* is the panel yield parameter, *G* is the average annual solar radiation on tilted panels, ρ is the performance ratio.

2.5 Financial analysis

To find the financial viability of the suggested plants, the study estimates the NPV and LCOE for the plants over a 32.5-year lifetime with an OpEx of *USD17/kW-yr*[27].

First, the capacity of the suggested plants is estimated as the electricity generation for one hour at the maximum output. Therefore,

$$Capacity = \frac{Generation}{yield \cdot Pr \cdot h}$$

where h is the amount of time it took to generate the electricity.

Subsequently, CapEx is found, which is a sum of initial costs for the plant (*1,119 USD/MW*[28]) and the cost of connecting the plant to the electricity grid (*590 USD/MWkm*).

The annual revenue is found, which is equal to the product of generated energy (*kWh*) with an assumed selling price (*0.103 USD/kWh*). Moreover, three years with no production and revenue are added before the lifetime, assuming this period for construction of the plant[29].

Hence, the annual cash flow for the three years of construction is -$\frac{Total\ CAPEX}{3}$, and for the subsequent 32.5 years it is $annual\ revenue - annual\ OpEx$.

NPV is calculated from the sum of the discounted cash flow, assuming a *5%* discount rate over the total 35,5 years.
LCOE is calculated as:

$$\frac{discounted\ sum\ of\ OpEx\ and\ CapEx\ over\ the\ lifetime}{discounted\ sum\ of\ electrical\ energy\ produced\ over\ the\ lifetime}[30].$$

2.6 GDI

GDI is developed to support the business case rationale of ammonia plant development.
The purpose of the GDI is to offer locations with maximum development impact for the lowest cost possible.
The following criteria and weights were considered in the development of the index:

- High GINI index, high unemployment rate, low GDP are considered to allow for development in the region.
- High road density, high installed capacity and low share of illiterate individuals are considered to lead to cost savings.
- High particulate matter is considered unfavourable due to air pollution associated with ammonia plants, while low water access is considered unfavourable due to the high water demand of ammonia plants.
- Low critical land and high populations values were considered as spatial constraints.

All of the criteria were normalized and weighted according to ***Table 1***.

Table 1. *GDI Criteria weights and relation to data (inverse or normal).*

<table>
<tr><td rowspan="4">40%</td><td rowspan="4">Economic</td><td>25%</td><td>Inverse</td><td>Nominal GDP $Billion (2020)[31]</td></tr>
<tr><td>25%</td><td>Normal</td><td>Installed Capacity by Province (MW)[32]</td></tr>
<tr><td>25%</td><td>Normal</td><td>Urban & rural GINI (2021)[33]</td></tr>
<tr><td>25%</td><td>Normal</td><td>Road density (2016)[34]</td></tr>
<tr><td rowspan="3">20%</td><td rowspan="3">Demographic</td><td>20%</td><td>Inverse</td><td>Percentage of illiterate individuals aged 15 years or over (2021)[35]</td></tr>
<tr><td>40%</td><td>Inverse</td><td>Population density per km^2 (2019)[36]</td></tr>
<tr><td>40%</td><td>Normal</td><td>Unemployment rate[37]</td></tr>
<tr><td rowspan="4">40%</td><td rowspan="4">Environment</td><td>20%</td><td>Inverse</td><td>Pollution (particulate matter, 2019)[38]</td></tr>
<tr><td>30%</td><td>Inverse</td><td>Share of the population lacking access to improved water sources (2019)[39]</td></tr>
<tr><td>30%</td><td>Normal</td><td>Critical Land (hectare, 2020)[40]</td></tr>
<tr><td>20%</td><td>Inverse</td><td>Natural disasters (people directly affected)[41]</td></tr>
</table>

2.7 Green ammonia business case

To assess the business case for green ammonia adjacent to solar plants, the costs of installing green ammonia capacity are estimated for each of the solar farms. Installation costs are estimated from the plant capacity assuming *$1,500/tonne*, while the costs required for connection to the grid are the same as for the solar plant. The CapEx is then calculated as the sum of costs.
The annual output is estimated assuming a requirement of *11MWh* generated from the associated solar plant for every tonne of ammonia. Revenue is calculated according to the price of *$1070/tonne*.

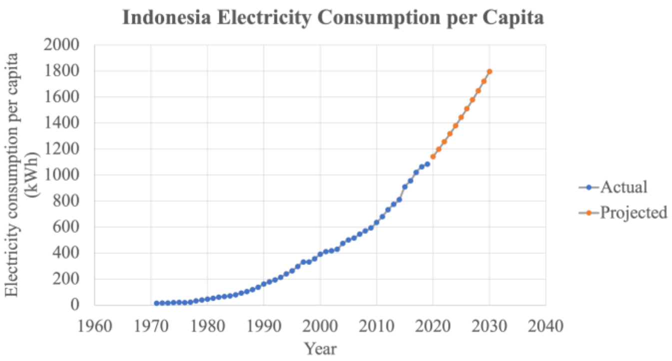
3 years are assumed for construction of the plant, while OpEx is assumed to be zero, due to energy being provided by the solar plant. NPV for 5, 10 and 15 years is then calculated as a sum of discounted cash flow with a discount rate of *5%*. LCOE for 15 years of production is compared against the ammonia price to assess profitability.

Finally, three optimal locations are suggested based on the GDI, financial analysis, as well as GIS analysis considering the proximity to water resources (freshwater required in ammonia production) and seaports (ammonia is planned to be sold for shipping).

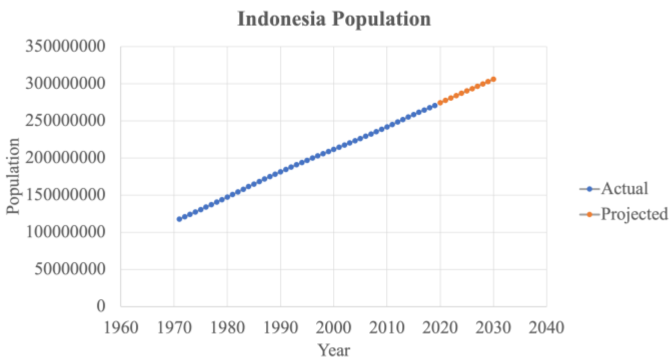
3. Results & Analysis

3.1 Energy demand projection

Indonesia’s total electricity/energy consumption (***Fig. 3c***) is found from a product of projected electricity consumption per capita[22] (***Fig. 3a***) and projected population[23] (***Fig. 3b***). The resulting consumption in 2030 is around *550TWh*, which is larger than *478TWh* estimated by Global Data[42] in 2021. This discrepancy could be accredited to over-projecting consumption per capita due to the assumptions made.



(a)



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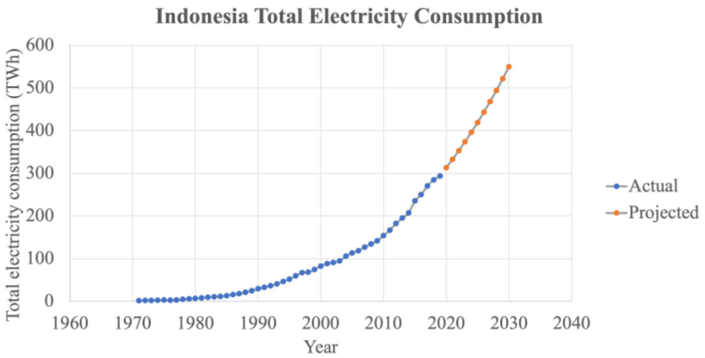

(c)

Figure 3*. Projections of (a) electricity consumption per capita, (b) population, (c) total electricity/energy consumption.*

The energy demand rises from *332.66TWh* in 2020 to *550TWh* in 2030. Considering that the current share of renewables is 18.2% (***Fig. 1***), which is equal *60.5TWh*, existing renewables make up 11% of the 2030 energy demand. This leaves *27%* more renewable energy generation needed to reach the *38%* goal[1]. The remaining *27%* of 2030 energy demand would then be equal to ***148.43TWh***.

3.2 Spatial constraints

Multiple raster and vector layers are analysed using GIS tools (***Fig. 4-7***) to produce binary suitability map based on constraints and criteria given in ***Table 2***. ***Figure 8*** displays the combined map of the previous suitability layers showing locations suitable for solar farm construction.

Table 2*. Constraints and criteria for location suitability.*

Constraint	Criteria	Criteria reference	Data source
Slope	Suitable below 10 degrees inclination	43	44
Protected areas & in-land water	Not suitable	45	46, 47
Land use	Burnt/dry/sparse vegetation and non-forest vegetation as suitable	45	48
Distance from population	Not suitable within 1km buffer	43	49

[1]Due to the small capacity factor, solar generation is much less compared to other types of plants of similar capacity. As such, assuming for the average capacity factor, when converting the required demand to required capacity, could lead to underestimating and subsequent blackouts. For this reason, this study will consider the economic feasibility of 38% of 2030 total demand/generation, which will further lead to significant overbuild that is expected with solar energy generation.

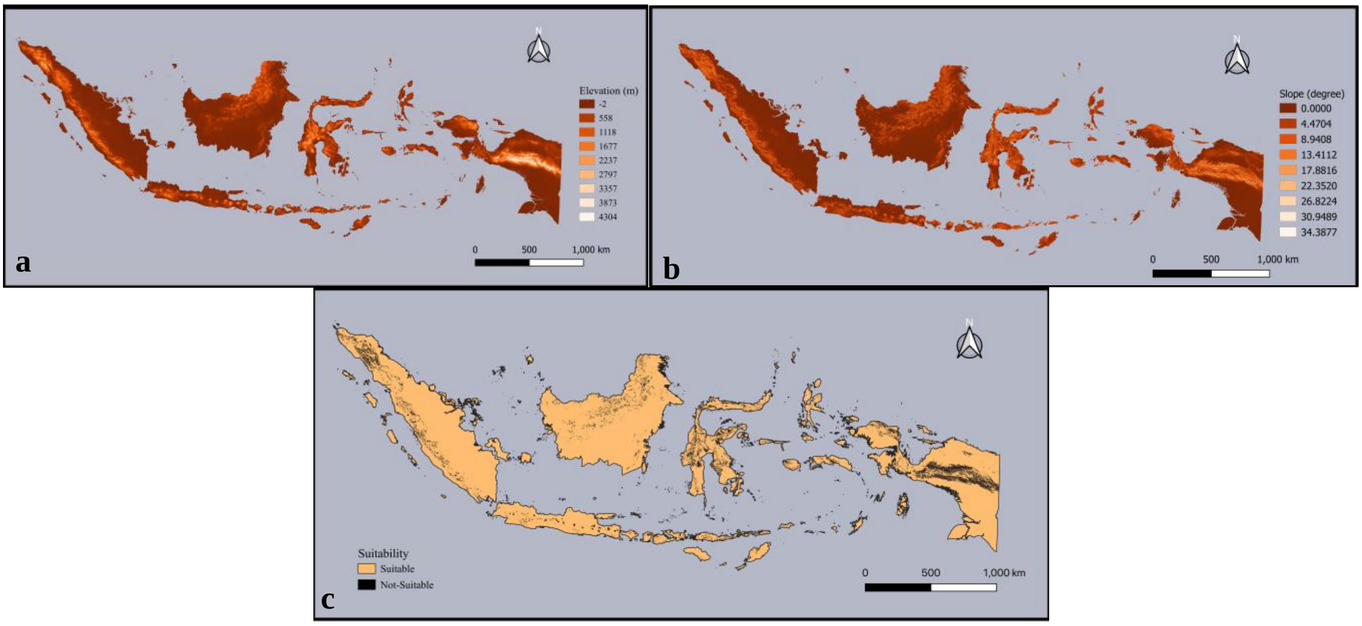

Figure 4. *(a) elevation[44], (b) slope analysis, (c) slope suitability.*

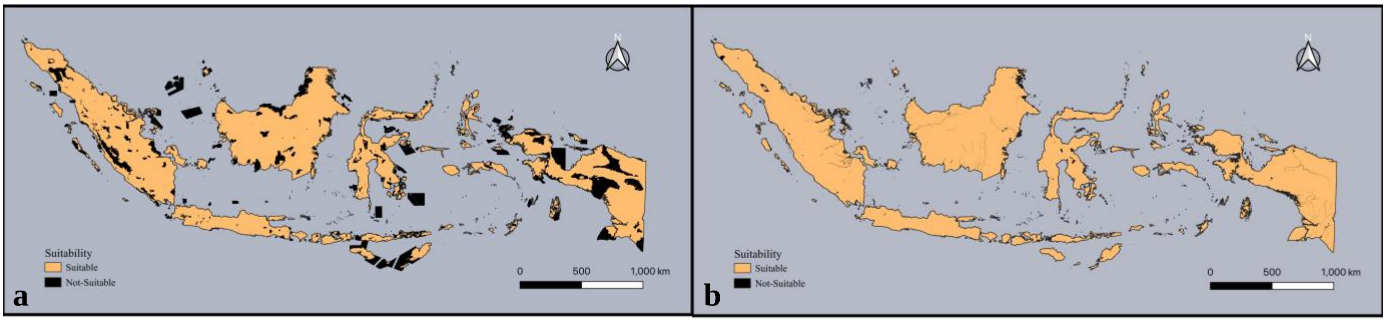

Figure 5. *(a) protected areas[47], (b) inland water[46].*

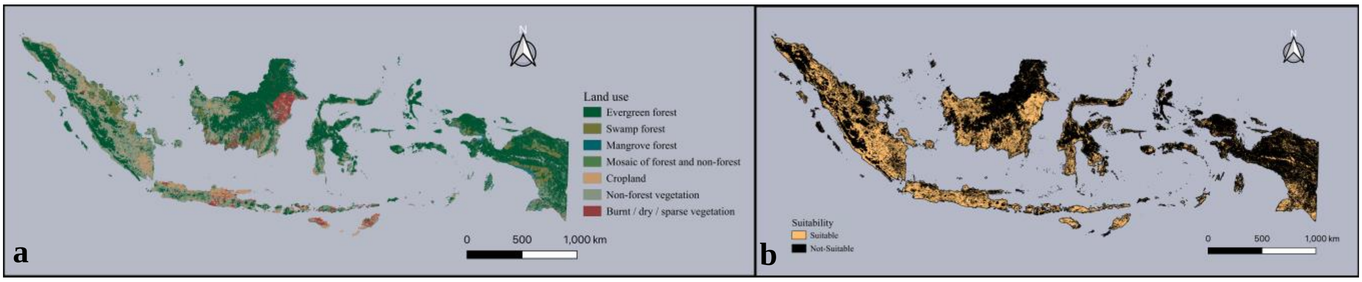

Figure 6. *(a) land use[48], (b) land suitability.*

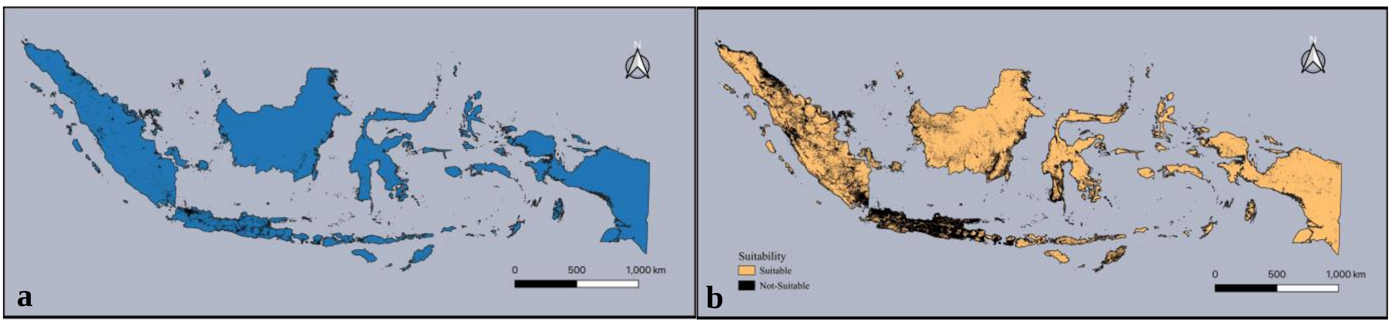

Figure 7. *(a) population[49] (b) population with 1km buffer as unsuitable.*

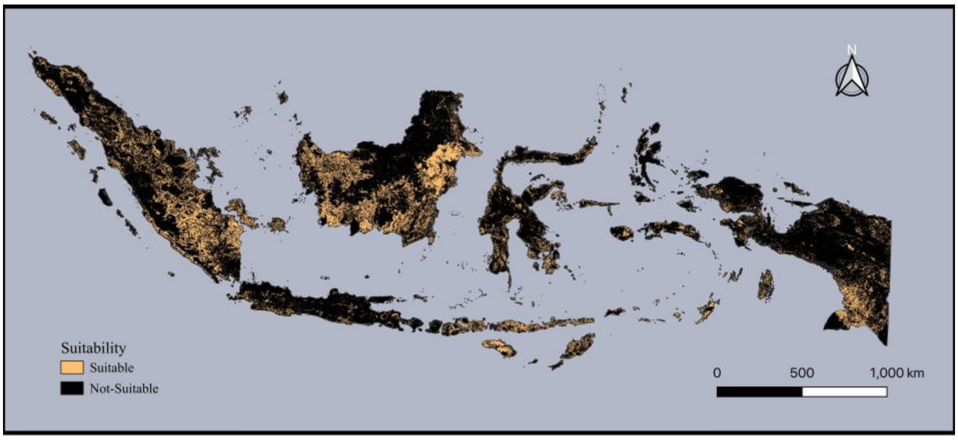

Figure 8. *Final suitability map.*

3.3 Interpolation

Figure 9 shows an example of the data provided by the government before and after IDW interpolation. The remaining layers are displayed in ***Appendix 1***.

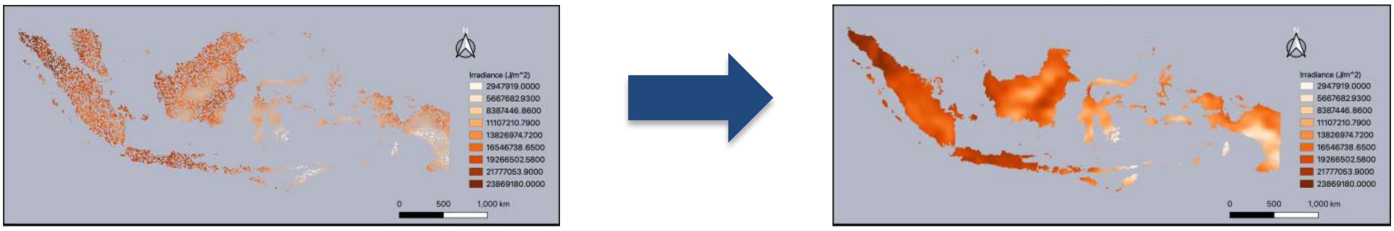

Figure 9. *Solar irradiance at 12pm in the summer interpolated using IDW*

Interpolating data assumes gradual variation of values in local areas, which could lead to incorrect estimations. Moreover, although the provided data for 4 hours in summer and winter is representative of the overall day, a long-term yearly average of total daily irradiation is used for this study, as it would provide more accurate estimates.

3.4 Solar potential and suggested locations

Locations of solar farms with areas of $6.3km^2$ and $11.9km^2$ are picked based on the long-term yearly average of total daily global irradiation at an optimum tilt (GTI)[50] (***Fig. 10a***). The irradiation is displayed for suitable locations only (***Fig. 10b***), with the highest values considered as optimal locations (***Fig. 10c***). Additionally, proximity to the electricity grid is considered to prevent the costs related to infrastructure.

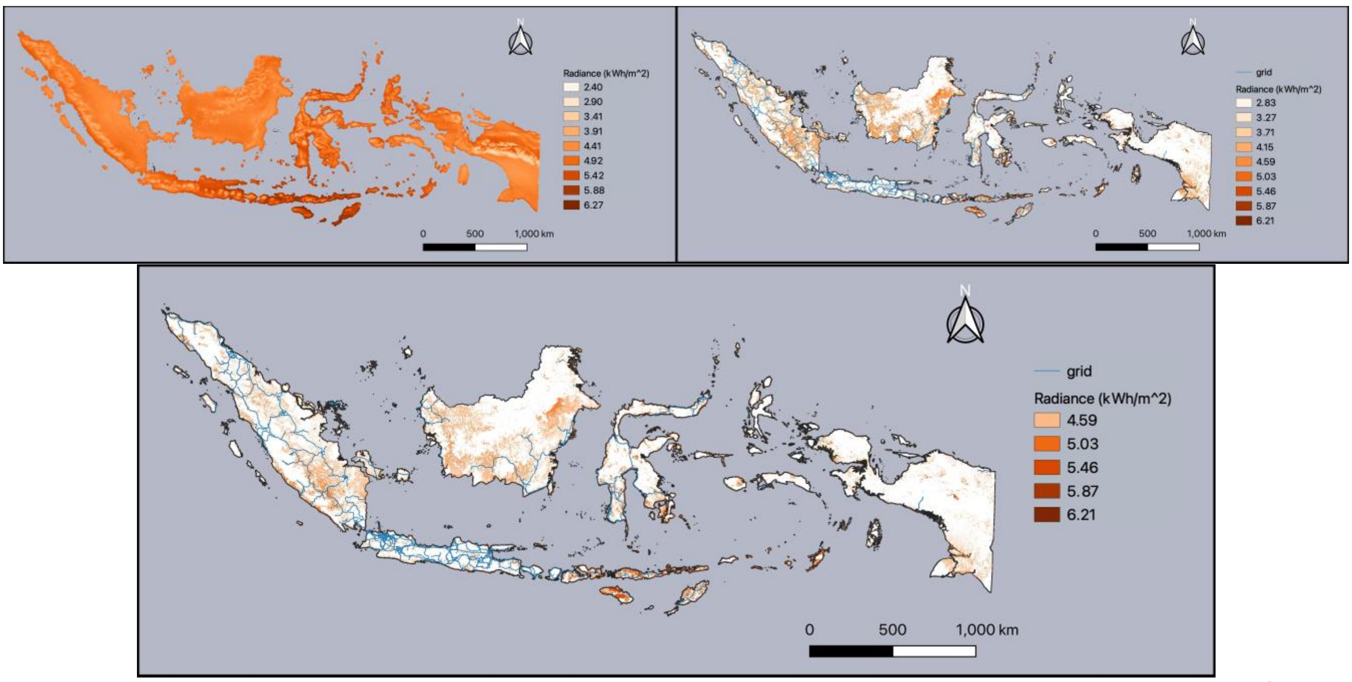

Figure 10. *(a) GTI, (b) GTI on suitable land with the electricity grid, (c) GTI filtered for values over 4.5kWh/m*^{2}.

Moreover, energy demand distribution (***Fig. 11***) was considered together with the irradiance and proximity to the electricity grid. Bali and Nusa Tenggara show the highest solar potential and therefore, 6 solar farms with a total annual generation of *15.4TWh* were suggested for the region. This would cover almost all the *16.5TWh* total demand projected for the region. ***Appendix 2*** shows the suggested generation distributed across the regions.

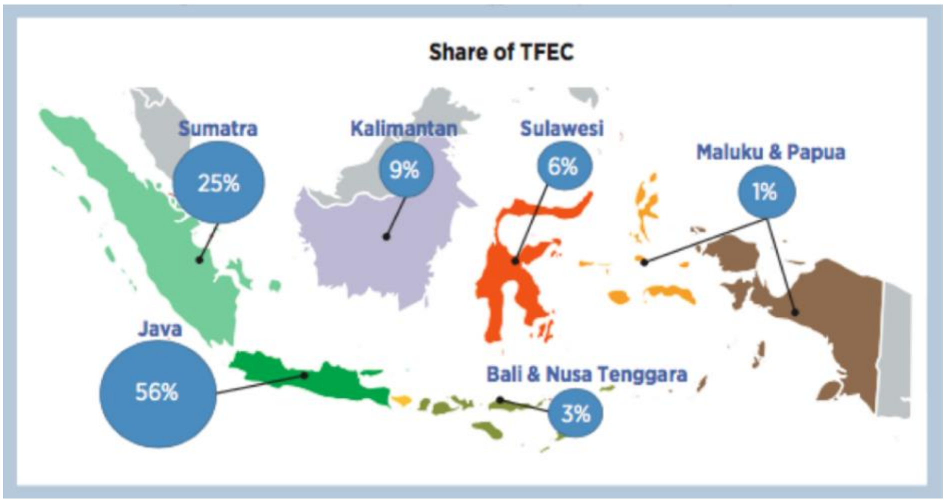

Figure 11. *Total final energy consumption (TFEC) distribution across the regions*[51].

As a result, to meet the demand of *148.43TWh*, 74 solar plans are suggested with their locations displayed in ***Figure 12***. ***Appendix 3*** shows the parameters of all the suggested solar farms.

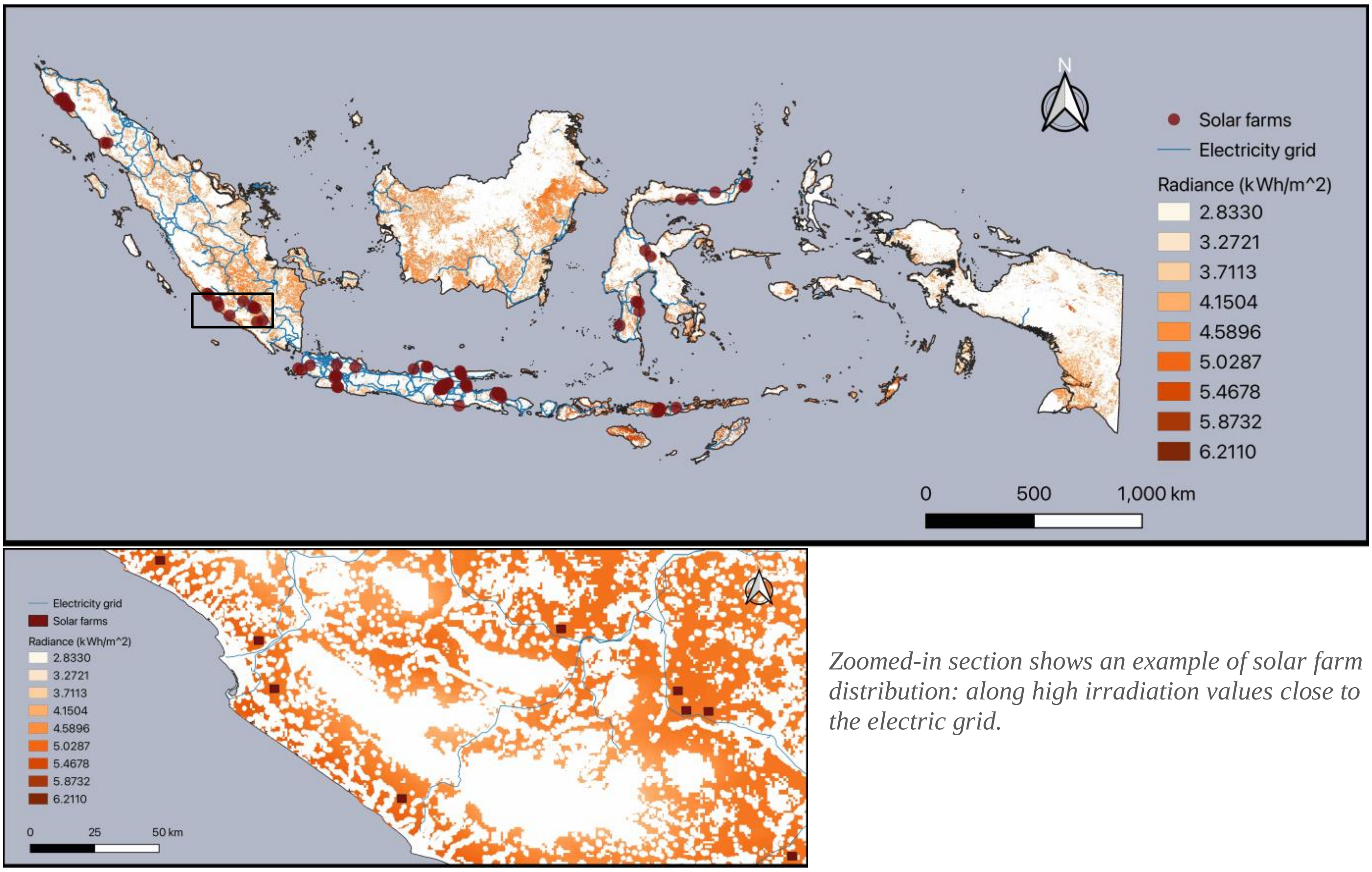

Figure 12. *Locations of the suggested solar farms.*

3.5 Financial analysis

The suggested solar farms were analysed, giving estimates on capacity, revenue, CapEx and OpEx, NPV and LCOE (***Appendix 4***).

The capacities ranged *1-3TW* for each plant, with most close to *2.2TW*, the capacity of the largest solar plant in the world[52]. The total new installed capacity was estimated to be around *163TW*, which is significantly larger than the current total capacity of around *70TW*. Although the high estimate is most probably an artefact of demand over-projection, it is also expected that meeting *38%* of demand with solar energy would require an overbuild due to low yield.

The NPV for all plants is positive, with the total coming up to *$7.2bn*. The overall discounted cost (CapEx & OpEx) of 74 solar farms over the 35,5 years comes up to *$209,523.68M*, which amounts to *20%* of the Indonesian GDP in 2020[53].

The estimated LCOE is in the range of *$0.98-0.10/kWh*, which is almost twice as much as the typical LCOE for solar panels[54] but is marginally smaller than the assumed electricity price in 2030 *($0.98-0.10/kWh*).

3.6 GDI

GDI was developed according to the chosen criteria and associated weights. The highest index values were assigned to North Sumatra, West Java, Banten, and North and South Sulawesi (***Fig. 13***). The Special Region of Yogyakarta received a high index value but is not being considered due to the small area of the region.

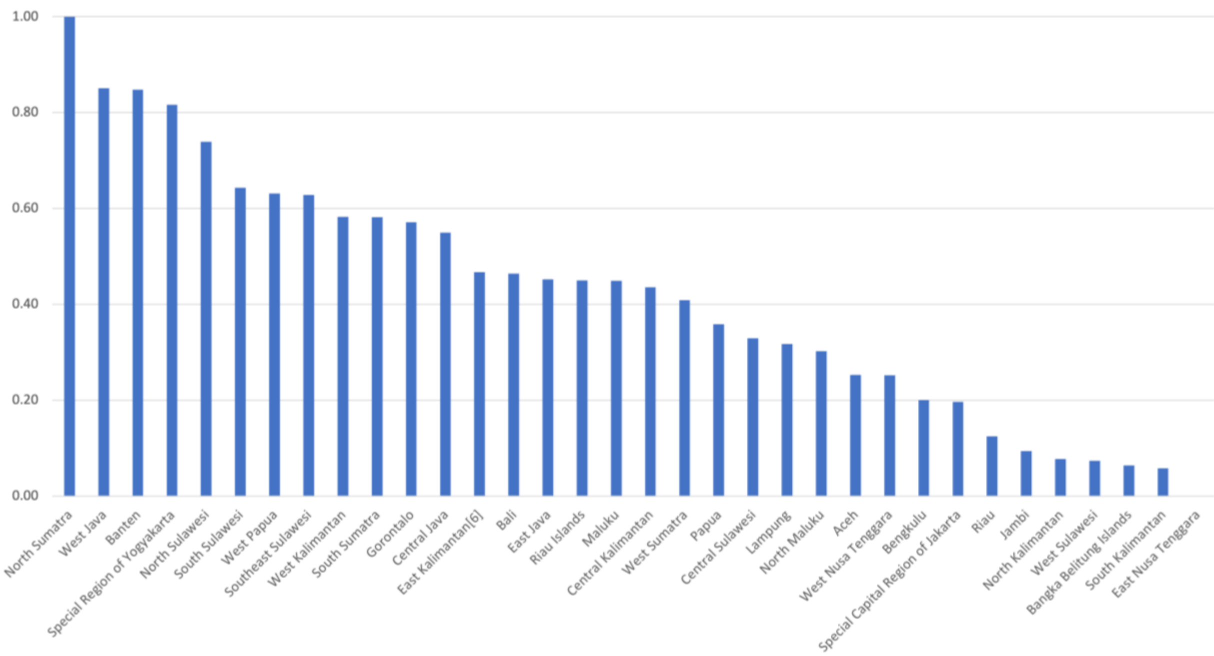

Figure 13*. Indonesia provinces and associated GDI.*

3.7 Green ammonia business case

The financial feasibility of green ammonia has been assessed at suggested solar plants, giving estimates of annual output and revenue, total CapEx and LCOE for 15-years lifetime, as well as NPV for 5, 10 and 15 years of operation (***Appendix 5***).

The NPVs for the plants are positive, amounting to a total of *$36bn* in 5 years, *$79.9bn* in 10 years and up to *$114.2bn* in 15 years. Furthermore, the LCOEs for a 15-year project are around *$160/tonne of ammonia*, which is much less than the selling price of *$1070/tonne*. This makes ammonia production a very attractive business venture.

Comparing the LCOEs against the GDI (***Appendix 6***), solar plants 67-71 in South Sumatra, 3 in West Java, 34, 29, 35 in Central Java, 54 in Gorontalo, 50 and 51 in South Sulawesi show the highest values in both. From further GIS analysis, solar farms in Central Java appear to lack significant inland water resources in proximity, while Gorontalo does not have a seaport nearby (***Fig. 14***).

Figure 14. *Prospect ID-54 in Gorontalo, no ports in proximity.*

As such, three selected provinces are South Sumatra, South Sulawesi and West Java (***Fig. 15***). Out of prioritized solar farms, *farm 71* is picked in South Sumatra and *farm 50* in South Sulawesi, due to them being closer to water resources compared to other plants. Only *farm 3* was prioritized in West Java.

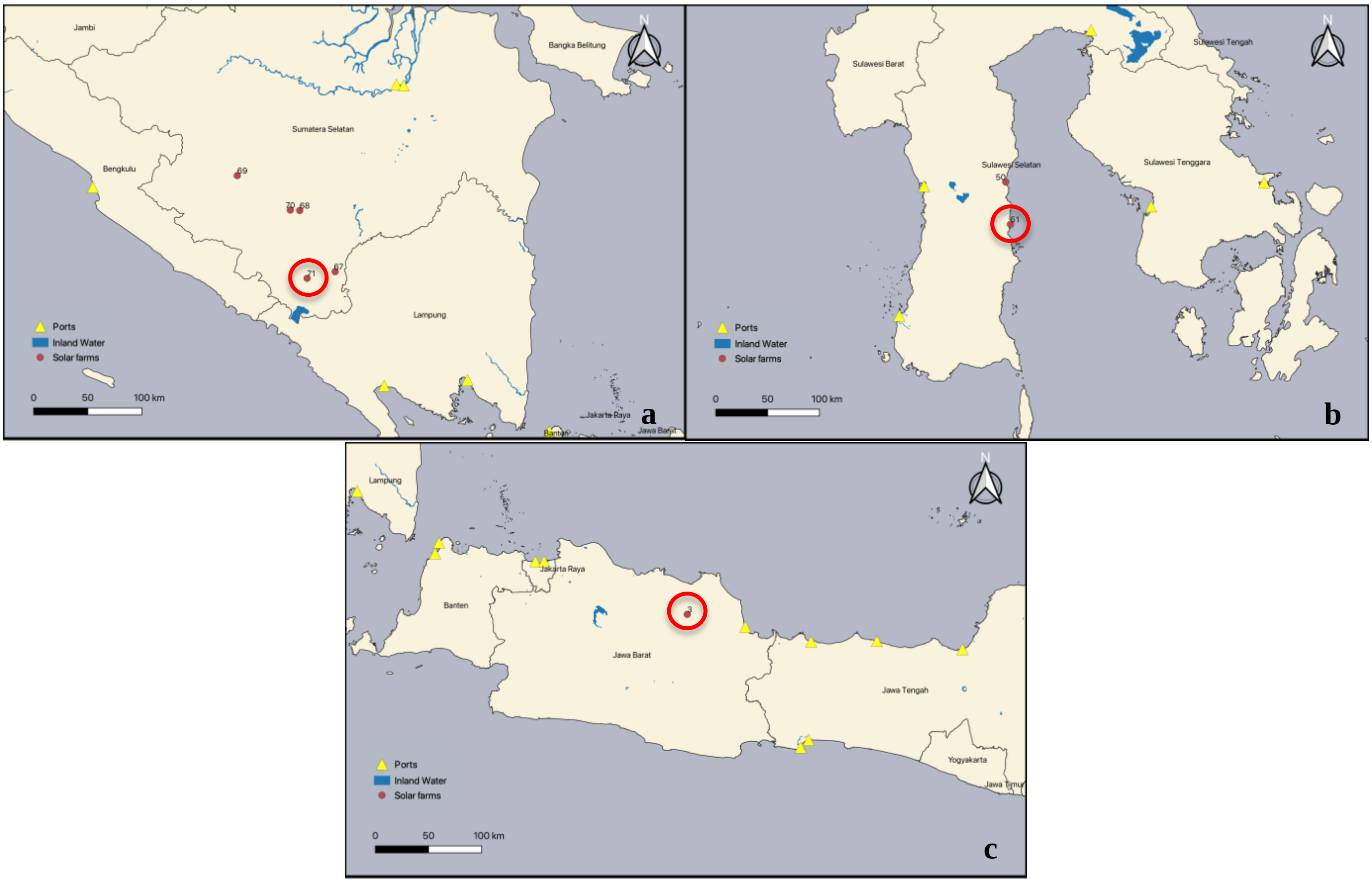

Figure 15. *Solar farms prioritized for ammonia production. (a) 71-South Sumatra, (b) 50-South Sulawesi, (c) 3-West Java.*

In total the three sites amount to *6459.09MW* installed capacity and would produce *540097.78* tonnes of green ammonia (***Table 3***).

Table 3. *Main characteristics of the selected plants.*

ID	Latitude	Longitude	GDI	Area km^2	Distance to grid km	Technology	Capacity MW	Annual ammonia production tonne
3	-1772072.04	968445.4	0.85	11.92	11.18	solar	2529.93	211548.08
50	70207.2345	1061153.8	0.64	6.32	4.85	solar	1439.07	120332.19
71	-1297564.32	751024.3	0.58	11.92	4.37	solar	2490.1	208217.51

ID	LCOE solar USD/MWh	LCOE ammonia USD/tonne	NPV solar (32,5yr) $M	NPV ammonia (5yr) $M	NPV ammonia (10yr) $M	NPV ammonia (15yr) $M
3	0.09934625	159.84738	109.0826218	556.78	1,236.47	1,769.02
50	0.09907775	155.3224	67.0508136	321.71	708.33	1,011.25
71	0.0990575	154.98101	116.6748615	557.33	1,226.31	1,750.48

4. Discussion & Conclusion

While the proposed solar energy plan is financially viable and would result in some profits, under the current assumptions the low margin on LCOE would probably result in solar farms not being financially attractive and require some subsidies to incentivize the producers. Estimating the return rate would allow a better understanding of this matter. Despite this, the rising carbon prices and costs of environmental damages due to CO2 pollution, as well as decreasing costs of solar energy, are not considered in this study and would make this a more attractive solution (Fig. 16).

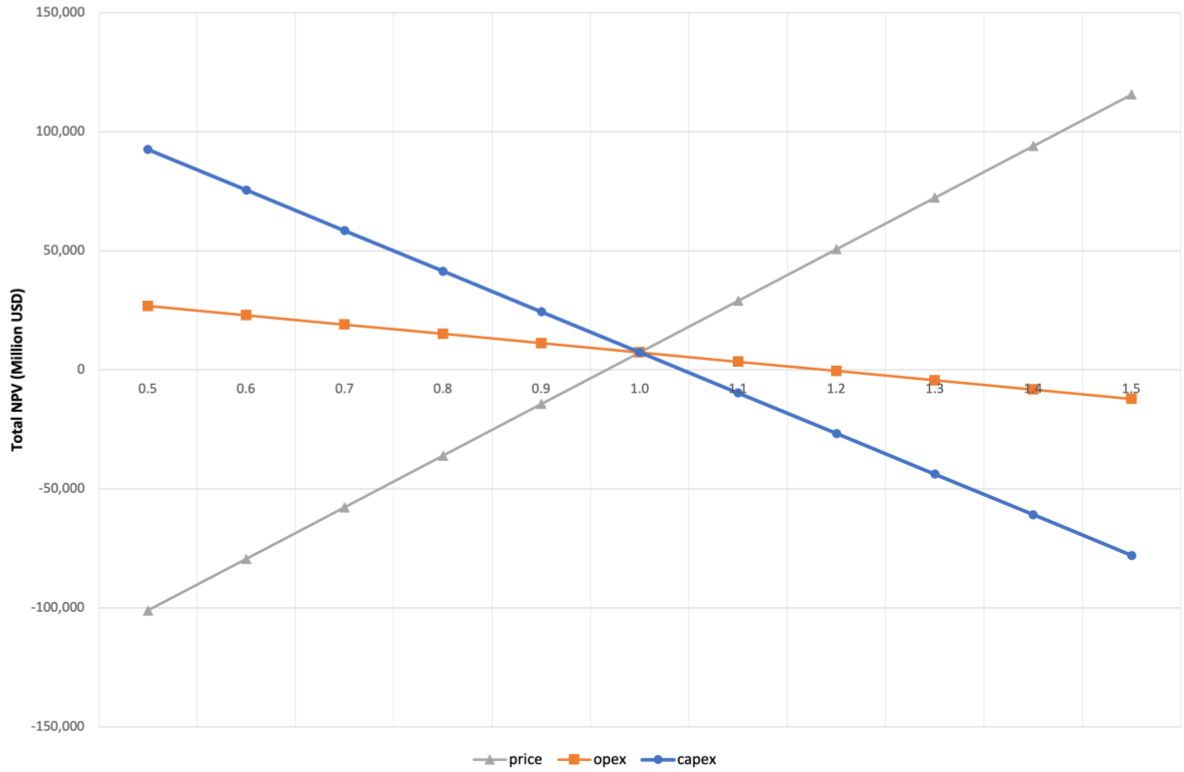

Figure 16. *Sensitivity plot of total NPV for all 74 solar plants. Even a small decrease in CapEx or increase in price would result in a large variation.*

In conclusion, the strong need for decarbonization, as well as the large solar potential of Indonesia makes the suggested approach a financially viable solution. However, such strong dependency on solar power could pose unforeseen risks in the future and a more diverse approach would be optimal.

Hence, the recommendations for the Indonesian government would be:

1. **Treat this as a feasibility study and use it in comparison with alternate renewable solutions.**
2. **Install a fraction of the suggested solar farms that are most financially attractive, while considering alternative renewable solutions for the remainder of the capacity.**

With the regard to ammonia plants, financial analysis shows the high profitability of the venture. As such, the instalment of ammonia plants at the three identified solar farms is strongly recommended.

However, the analysis does not consider transfer costs and assumes zero OpEx, which does not stand in real market conditions. Taxation for both ammonia and solar plants is also not considered by this study. Aside from this, further improvements could include selecting additional layers for GIS suitability analysis and adapting a multi-criterion weighted approach for more rigorous estimation of optimal locations.

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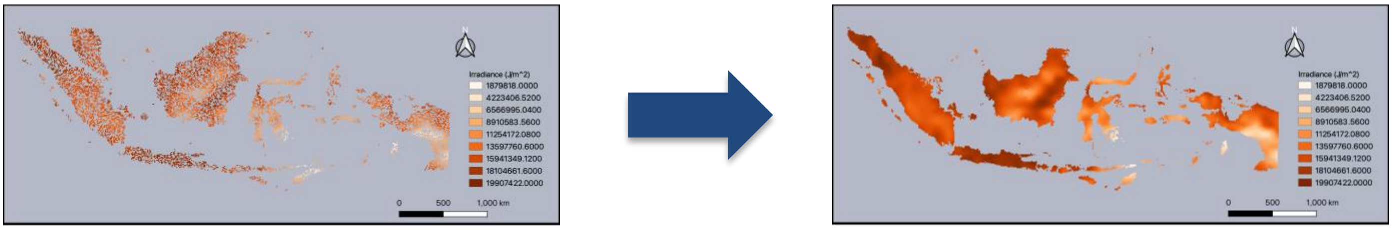
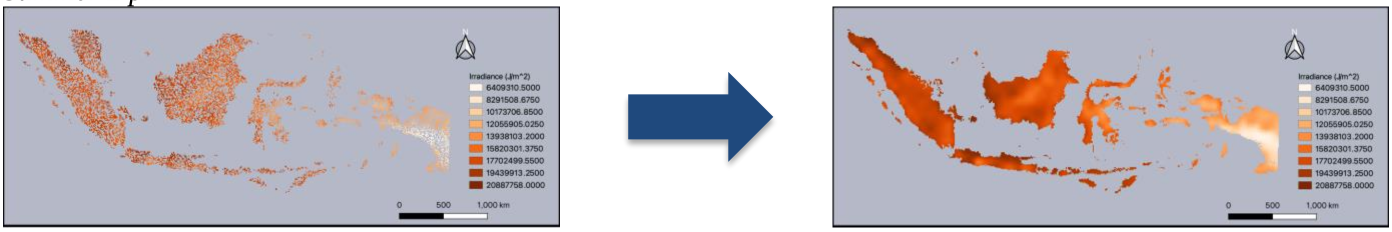
Appendices

Appendix 1. IDW interpolation of solar layers.

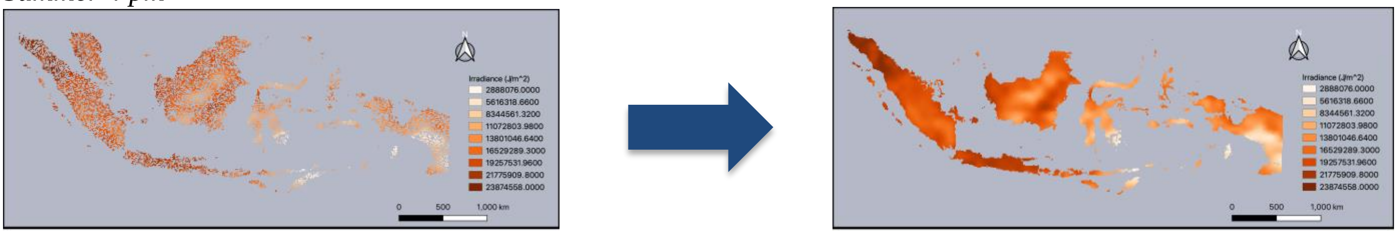
Summer 8 am



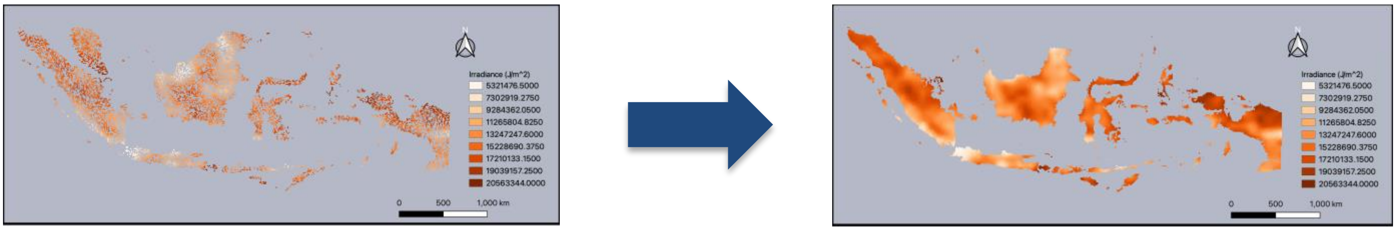
Summer 2 pm



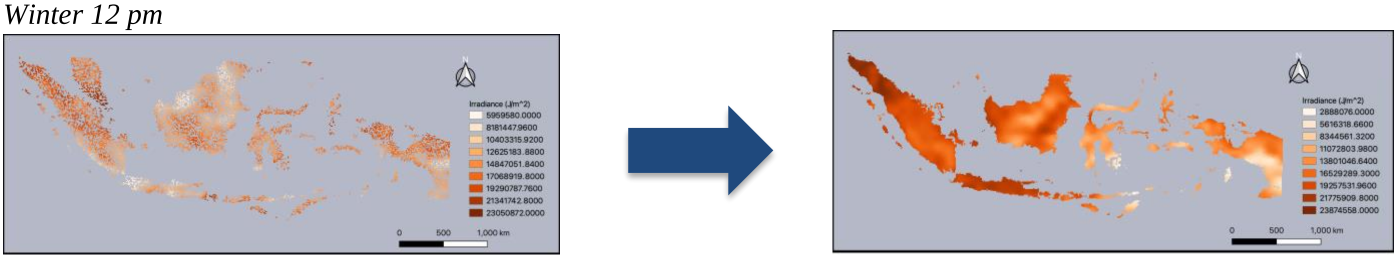
Summer 4 pm



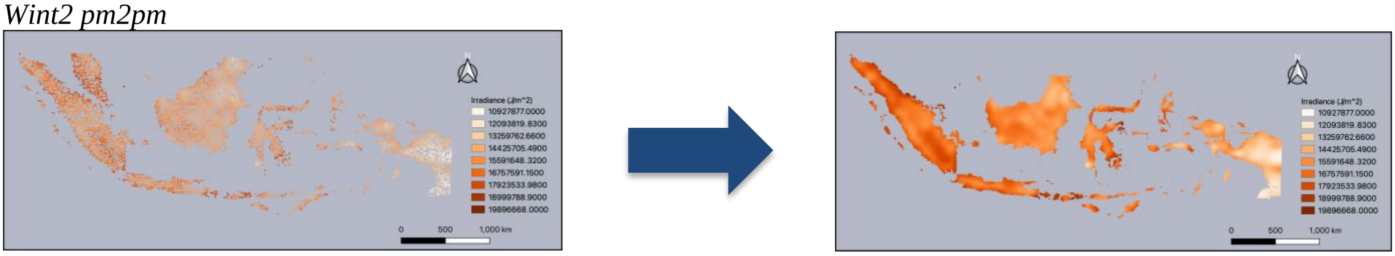
Winter 8 am



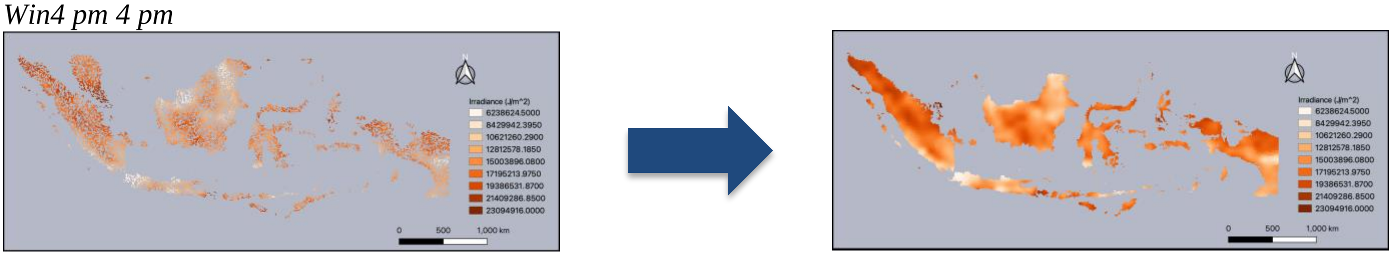
Winter 12 pm



Wint2 pm2pm



Win4 pm 4 pm



Appendix 2. Regional distribution of demand and suggested generation.

Region	Demand distribution	Total electricity/energy demand TWh	38% of the total electricity/energy demand TWh	Generation from suggested plants TWh
Java	56%	307.77	83.12	73.89
Sumatra	25%	137.40	37.11	45.46
Kalimantan	9%	49.46	13.36	0.00
Sulawesi	6%	32.98	8.91	15.24
Bali & Nusa Tenggara	3%	16.49	4.45	15.39
Maluku & Papua	1%	5.50	1.48	0.00

Appendix 3. Suggested solar farms and their parameters.

ID	Area km^2	Distance to the grid m	Region	Total daily GTI kWh/m^2	Annual generation TWh
1	11.92	5078.54	Java	4.86	2.22
2	11.92	9704.26	Java	4.88	2.23
3	11.92	11182.21	Java	5.10	2.33
4	11.92	27935.28	Java	4.69	2.14
5	11.92	27991.55	Java	4.80	2.19
6	11.92	2144.78	Java	4.57	2.09
7	11.92	10967.34	Java	4.73	2.16
8	11.92	19399.83	Java	4.68	2.14
9	11.92	26485.29	Java	4.63	2.12
10	11.92	2548.64	Java	5.63	2.57
11	11.92	3024.51	Java	5.61	2.56
12	11.92	7478.83	Java	5.52	2.52
13	11.92	10672.29	Java	5.32	2.43
14	11.92	7313.80	Java	5.41	2.47
15	11.92	11821.76	Java	4.89	2.23
16	11.92	7262.66	Java	5.34	2.44
17	11.92	8735.21	Java	5.70	2.60
18	11.92	3644.17	Java	5.75	2.63
19	11.92	18219.76	Java	5.41	2.47
20	11.92	1098.02	Java	5.24	2.39
21	11.92	4069.02	Java	5.34	2.44
22	11.92	1619.29	Java	5.72	2.61
23	11.92	26890.73	Java	5.58	2.55
24	6.32	10474.34	Java	5.36	1.30
25	6.32	15543.93	Java	5.45	1.32
26	6.32	20070.79	Java	5.51	1.33
27	6.32	13979.95	Java	5.37	1.30
28	6.32	2522.16	Java	5.58	1.35
29	6.32	8979.72	Java	5.23	1.27
30	6.32	8328.28	Java	5.33	1.29
31	6.32	5616.97	Java	5.49	1.33
32	6.32	7194.16	Java	5.43	1.32
33	11.92	2075.35	Java	4.93	2.25
34	6.32	6347.89	Java	5.34	1.29
35	6.32	10481.80	Java	5.37	1.30
36	6.32	6634.74	Java	5.39	1.30
37	6.32	5292.59	Java	5.81	1.41
38	11.92	203.19	Nusa Tenggara	5.45	2.49
39	11.92	1006.98	Nusa Tenggara	5.72	2.61
40	11.92	2915.05	Nusa Tenggara	5.79	2.65
41	11.92	1181.73	Nusa Tenggara	5.52	2.52
42	11.92	2716.82	Nusa Tenggara	5.65	2.58
43	11.92	924.08	Nusa Tenggara	5.58	2.55

44	6.32	4214.29	Sulawesi	5.10	1.24
45	6.32	4318.37	Sulawesi	5.31	1.29
46	6.32	3468.90	Sulawesi	5.29	1.28
47	6.32	15373.60	Sulawesi	5.39	1.30
48	6.32	16345.50	Sulawesi	5.31	1.29
49	6.32	1483.88	Sulawesi	5.39	1.31
50	6.32	4847.68	Sulawesi	5.46	1.32
51	6.32	20789.89	Sulawesi	5.52	1.34
52	6.32	2254.06	Sulawesi	5.06	1.23
53	11.92	15169.26	Sulawesi	5.24	2.39
54	6.32	1934.09	Sulawesi	5.19	1.26
55	11.92	16890.04	Sumatra	5.10	2.33
56	11.92	2440.76	Sumatra	4.99	2.28
57	11.92	1690.04	Sumatra	4.97	2.27
58	11.92	7786.89	Sumatra	5.04	2.30
59	11.92	8110.82	Sumatra	4.97	2.27
60	11.92	2799.50	Sumatra	4.98	2.27
61	11.92	3107.15	Sumatra	4.94	2.26
62	11.92	13992.83	Sumatra	4.93	2.25
63	11.92	26195.47	Sumatra	5.03	2.30
64	11.92	1974.39	Sumatra	5.02	2.29
65	11.92	4104.43	Sumatra	4.95	2.26
66	11.92	6983.07	Sumatra	4.94	2.26
67	11.92	2048.81	Sumatra	4.97	2.27
68	11.92	652.27	Sumatra	4.90	2.24
69	11.92	1231.29	Sumatra	4.95	2.26
70	11.92	559.17	Sumatra	4.90	2.24
71	11.92	4369.77	Sumatra	5.02	2.29
72	11.92	2651.27	Sumatra	4.91	2.24
73	11.92	34846.60	Sumatra	5.01	2.29
74	11.92	37754.83	Sumatra	5.04	2.30

Appendix 4. Financial assessment of the suggested solar farms.

ID	Area km^2	Region	Generation TWh	Annual revenue $M/yr	Capacity TW	Total CapEx $M	Annual OpEx USD/yr	LCOE USD/ MWh	NPV $M
1	11.92	Java	2.22	228.39	2.41	2,704.79	40.98	99.09	112.02
2	11.92	Java	2.23	229.75	2.43	2,727.59	41.23	99.28	106.53
3	11.92	Java	2.33	239.68	2.53	2,847.68	43.01	99.35	109.08
4	11.92	Java	2.14	220.62	2.33	2,644.23	39.59	100.06	79.00
5	11.92	Java	2.19	225.94	2.38	2,707.99	40.54	100.06	80.83
6	11.92	Java	2.09	215.04	2.27	2,542.83	38.59	98.96	109.13
7	11.92	Java	2.16	222.54	2.35	2,643.74	39.93	99.34	101.56
8	11.92	Java	2.14	220.26	2.32	2,628.13	39.52	99.69	89.76
9	11.92	Java	2.12	217.86	2.30	2,609.15	39.09	99.99	79.84
10	11.92	Java	2.57	264.77	2.79	3,131.54	47.51	98.98	133.74
11	11.92	Java	2.56	263.67	2.78	3,119.24	47.31	99.00	132.46
12	11.92	Java	2.52	259.47	2.74	3,076.77	46.56	99.19	123.65
13	11.92	Java	2.43	250.34	2.64	2,973.50	44.92	99.32	114.67
14	11.92	Java	2.47	254.40	2.69	3,016.41	45.65	99.18	121.48
15	11.92	Java	2.23	230.08	2.43	2,734.52	41.29	99.37	103.86
16	11.92	Java	2.44	250.99	2.65	2,975.91	45.04	99.18	119.93
17	11.92	Java	2.60	268.03	2.83	3,180.40	48.10	99.24	125.78
18	11.92	Java	2.63	270.61	2.86	3,202.40	48.56	99.03	134.97
19	11.92	Java	2.47	254.45	2.69	3,034.29	45.66	99.64	105.43
20	11.92	Java	2.39	246.25	2.60	2,910.21	44.19	98.92	126.45
21	11.92	Java	2.44	251.22	2.65	2,973.59	45.08	99.04	124.68
22	11.92	Java	2.61	268.96	2.84	3,179.44	48.26	98.94	137.30
23	11.92	Java	2.55	262.40	2.77	3,143.27	47.09	100.01	95.54
24	6.32	Java	1.30	133.75	1.41	1,588.50	24.00	99.32	61.42
25	6.32	Java	1.32	136.02	1.44	1,619.75	24.41	99.53	58.47
26	6.32	Java	1.33	137.47	1.45	1,640.92	24.67	99.72	55.49
27	6.32	Java	1.30	134.03	1.41	1,594.69	24.05	99.46	58.82
28	6.32	Java	1.35	139.21	1.47	1,646.47	24.98	98.98	70.34
29	6.32	Java	1.27	130.42	1.38	1,547.75	23.40	99.25	61.02
30	6.32	Java	1.29	133.01	1.40	1,577.95	23.87	99.23	62.73
31	6.32	Java	1.33	137.06	1.45	1,623.69	24.59	99.11	66.80
32	6.32	Java	1.32	135.54	1.43	1,607.00	24.32	99.18	64.82
33	11.92	Java	2.25	231.75	2.45	2,740.24	41.58	98.96	117.70
34	6.32	Java	1.29	133.21	1.41	1,578.64	23.90	99.14	64.35
35	6.32	Java	1.30	134.05	1.41	1,592.06	24.05	99.32	61.55
36	6.32	Java	1.30	134.38	1.42	1,592.79	24.11	99.15	64.70
37	6.32	Java	1.41	144.93	1.53	1,716.63	26.01	99.10	70.90
38	11.92	Nusa Teng.	2.49	256.19	2.70	3,026.22	45.97	98.88	132.89
39	11.92	Nusa Teng.	2.61	269.18	2.84	3,181.11	48.30	98.91	138.37
40	11.92	Nusa Teng.	2.65	272.44	2.88	3,222.80	48.89	99.00	137.04
41	11.92	Nusa Teng.	2.52	259.44	2.74	3,066.22	46.55	98.92	133.10
42	11.92	Nusa Teng.	2.58	265.67	2.80	3,142.39	47.67	98.99	133.94

43	11.92	Nusa Teng.	2.55	262.52	2.77	3,102.18	47.11	98.91	135.07
44	6.32	Sulawesi	1.24	127.34	1.34	1,507.41	22.85	99.05	63.09
45	6.32	Sulawesi	1.29	132.56	1.40	1,569.30	23.79	99.06	65.60
46	6.32	Sulawesi	1.28	132.10	1.39	1,563.12	23.70	99.02	66.02
47	6.32	Sulawesi	1.30	134.38	1.42	1,600.10	24.11	99.52	57.90
48	6.32	Sulawesi	1.29	132.43	1.40	1,577.68	23.76	99.57	56.31
49	6.32	Sulawesi	1.31	134.59	1.42	1,590.98	24.15	98.94	68.82
50	6.32	Sulawesi	1.32	136.34	1.44	1,614.43	24.46	99.08	67.05
51	6.32	Sulawesi	1.34	137.65	1.45	1,643.61	24.70	99.75	54.98
52	6.32	Sulawesi	1.23	126.37	1.33	1,494.37	22.68	98.97	64.05
53	11.92	Sulawesi	2.39	246.23	2.60	2,931.60	44.18	99.52	106.38
54	6.32	Sulawesi	1.26	129.55	1.37	1,531.76	23.25	98.95	65.90
55	11.92	Sumatra	2.33	239.67	2.53	2,856.04	43.01	99.59	101.15
56	11.92	Sumatra	2.28	234.82	2.48	2,777.16	42.14	98.98	118.76
57	11.92	Sumatra	2.27	233.64	2.47	2,762.12	41.93	98.94	119.18
58	11.92	Sumatra	2.30	236.95	2.50	2,810.24	42.52	99.20	112.50
59	11.92	Sumatra	2.27	233.71	2.47	2,772.28	41.94	99.22	110.52
60	11.92	Sumatra	2.27	234.32	2.47	2,771.74	42.05	98.99	118.02
61	11.92	Sumatra	2.26	232.46	2.45	2,750.14	41.71	99.00	116.67
62	11.92	Sumatra	2.25	231.76	2.45	2,757.59	41.59	99.47	101.70
63	11.92	Sumatra	2.30	236.44	2.50	2,831.29	42.43	99.98	87.04
64	11.92	Sumatra	2.29	235.95	2.49	2,789.73	42.34	98.96	119.97
65	11.92	Sumatra	2.26	233.03	2.46	2,758.30	41.81	99.05	115.61
66	11.92	Sumatra	2.26	232.28	2.45	2,753.69	41.68	99.17	111.37
67	11.92	Sumatra	2.27	233.88	2.47	2,765.38	41.97	98.96	118.81
68	11.92	Sumatra	2.24	230.50	2.43	2,723.45	41.36	98.90	118.96
69	11.92	Sumatra	2.26	232.61	2.46	2,749.17	41.74	98.92	119.27
70	11.92	Sumatra	2.24	230.30	2.43	2,720.91	41.32	98.90	118.98
71	11.92	Sumatra	2.29	235.91	2.49	2,792.84	42.33	99.06	116.67
72	11.92	Sumatra	2.24	230.84	2.44	2,730.31	41.42	98.98	116.46
73	11.92	Sumatra	2.29	235.83	2.49	2,836.70	42.32	100.35	75.00
74	11.92	Sumatra	2.30	237.14	2.50	2,856.68	42.55	100.47	71.42

Appendix 5. Financial assessment of potential ammonia plants.

ID	Region	Solar Capacity TW	Annual output tonne	Total CapEx USD	Annual revenue $M	5 yr NPV $M	10 yr NPV $M	15 yr NPV $M	LCOE USD/ tonne
1	Java	2.41	201,577.88	309.59	215.69	538.62	1,186.27	1,693.72	155.49
2	Java	2.43	202,784.00	318.06	216.98	535.68	1,187.21	1,697.70	158.79
3	Java	2.53	211,548.08	334.01	226.36	556.78	1,236.47	1,769.02	159.85
4	Java	2.33	194,723.86	330.47	208.35	491.09	1,116.72	1,606.92	171.81
5	Java	2.38	199,413.60	338.51	213.37	502.85	1,143.55	1,645.55	171.85
6	Java	2.27	189,800.64	287.57	203.09	510.80	1,120.62	1,598.42	153.39
7	Java	2.35	196,419.70	309.83	210.17	517.24	1,148.32	1,642.79	159.69
8	Java	2.32	194,401.05	318.21	208.01	501.17	1,125.76	1,615.15	165.72
9	Java	2.30	192,285.92	324.36	205.75	486.77	1,104.57	1,588.63	170.78
10	Java	2.79	233,693.08	354.74	250.05	628.31	1,379.15	1,967.45	153.68
11	Java	2.78	232,716.62	354.04	249.01	624.96	1,372.66	1,958.50	154.02
12	Java	2.74	229,011.23	355.60	245.04	608.31	1,344.11	1,920.62	157.20
13	Java	2.64	220,953.84	348.07	236.42	582.28	1,292.18	1,848.41	159.48
14	Java	2.69	224,537.90	348.39	240.26	596.67	1,318.09	1,883.35	157.08
15	Java	2.43	203,073.34	321.55	217.29	533.63	1,186.08	1,697.30	160.30
16	Java	2.65	221,528.90	343.65	237.04	588.75	1,300.50	1,858.18	157.05
17	Java	2.83	236,568.43	369.43	253.13	626.43	1,386.51	1,982.05	158.10
18	Java	2.86	238,842.67	364.41	255.56	640.44	1,407.82	2,009.08	154.46
19	Java	2.69	224,582.36	365.75	240.30	580.72	1,302.28	1,867.64	164.87
20	Java	2.60	217,341.67	327.70	232.56	586.42	1,284.72	1,831.85	152.64
21	Java	2.65	221,728.25	338.96	237.25	593.93	1,306.32	1,864.50	154.77
22	Java	2.84	237,383.54	358.79	254.00	639.68	1,402.37	1,999.96	153.02
23	Java	2.77	231,599.59	391.34	247.81	585.68	1,329.79	1,912.82	171.07
24	Java	1.41	118,050.29	185.80	126.31	311.25	690.54	987.72	159.34
25	Java	1.44	120,053.37	193.25	128.46	312.54	698.26	1,000.48	162.96
26	Java	1.45	121,334.83	199.19	129.83	312.27	702.11	1,007.56	166.20
27	Java	1.41	118,292.54	189.11	126.57	309.17	689.23	987.02	161.85
28	Java	1.47	122,870.60	186.49	131.47	330.37	725.15	1,034.46	153.66
29	Java	1.38	115,111.51	179.96	123.17	304.63	674.47	964.26	158.27
30	Java	1.40	117,398.07	183.00	125.62	311.18	688.37	983.91	157.81
31	Java	1.45	120,973.15	186.25	129.44	322.81	711.49	1,016.03	155.87
32	Java	1.43	119,630.86	185.52	128.01	317.99	702.36	1,003.52	157.00
33	Java	2.45	204,542.97	309.81	218.86	550.57	1,207.75	1,722.67	153.34
34	Java	1.41	117,571.43	181.62	125.80	313.17	690.92	986.89	156.39
35	Java	1.41	118,314.39	186.22	126.60	311.94	692.08	989.92	159.35
36	Java	1.42	118,607.29	183.46	126.91	315.71	696.78	995.37	156.60
37	Java	1.53	127,919.37	196.66	136.87	341.62	752.62	1,074.64	155.64
38	Nusa Teng.	2.70	226,112.48	339.49	241.94	611.41	1,337.89	1,907.11	152.00
39	Nusa Teng.	2.84	237,585.15	358.07	254.22	641.18	1,404.52	2,002.62	152.58
40	Nusa Teng.	2.88	240,456.89	365.63	257.29	645.92	1,418.48	2,023.81	153.94
41	Nusa Teng.	2.74	228,983.44	345.38	245.01	617.70	1,353.41	1,929.85	152.70

42	Nusa Teng.	2.80	234,482.11	356.22	250.90	630.17	1,383.54	1,973.83	153.80
43	Nusa Teng.	2.77	231,700.14	349.06	247.92	625.42	1,369.85	1,953.14	152.52
44	Sulawesi	1.34	112,392.97	171.93	120.26	300.95	662.06	945.00	154.87
45	Sulawesi	1.40	117,000.97	179.07	125.19	313.21	689.13	983.66	154.94
46	Sulawesi	1.39	116,592.33	177.74	124.75	312.77	687.37	980.88	154.34
47	Sulawesi	1.42	118,607.62	190.78	126.91	308.91	689.98	988.57	162.84
48	Sulawesi	1.40	116,885.70	188.81	125.07	303.68	679.22	973.47	163.54
49	Sulawesi	1.42	118,794.62	179.44	127.11	320.22	701.90	1,000.95	152.92
50	Sulawesi	1.44	120,332.19	184.61	128.76	321.71	708.33	1,011.25	155.32
51	Sulawesi	1.45	121,488.61	200.05	129.99	312.09	702.42	1,008.26	166.71
52	Sulawesi	1.33	111,535.70	169.08	119.34	300.09	658.45	939.23	153.47
53	Sulawesi	2.60	217,327.83	349.25	232.54	566.31	1,264.56	1,811.67	162.70
54	Sulawesi	1.37	114,345.38	173.08	122.35	307.89	675.27	963.13	153.24
55	Sumatra	2.53	211,535.95	342.51	226.34	548.83	1,228.47	1,761.00	163.92
56	Sumatra	2.48	207,259.08	314.46	221.77	557.39	1,223.29	1,745.05	153.60
57	Sumatra	2.47	206,217.95	311.79	220.65	555.60	1,218.16	1,737.30	153.07
58	Sumatra	2.50	209,138.55	325.20	223.78	555.10	1,227.05	1,753.53	157.42
59	Sumatra	2.47	206,278.90	321.22	220.72	547.07	1,209.83	1,729.12	157.65
60	Sumatra	2.47	206,814.92	314.31	221.29	555.70	1,220.18	1,740.82	153.86
61	Sumatra	2.45	205,170.54	312.25	219.53	550.87	1,210.07	1,726.56	154.08
62	Sumatra	2.45	204,554.23	327.03	218.87	534.60	1,191.82	1,706.76	161.86
63	Sumatra	2.50	208,687.89	351.60	223.30	528.69	1,199.19	1,724.54	170.57
64	Sumatra	2.49	208,248.37	315.27	222.83	560.68	1,229.77	1,754.01	153.27
65	Sumatra	2.46	205,670.96	314.46	220.07	550.87	1,211.67	1,729.43	154.79
66	Sumatra	2.45	205,017.08	317.63	219.37	545.24	1,203.95	1,720.06	156.85
67	Sumatra	2.47	206,421.95	312.62	220.87	555.67	1,218.88	1,738.53	153.32
68	Sumatra	2.43	203,441.93	306.10	217.68	549.51	1,203.15	1,715.30	152.33
69	Sumatra	2.46	205,300.40	309.73	219.67	553.75	1,213.36	1,730.18	152.74
70	Sumatra	2.43	203,262.04	305.70	217.49	549.15	1,202.21	1,713.90	152.26
71	Sumatra	2.49	208,217.51	318.75	222.79	557.33	1,226.31	1,750.48	154.98
72	Sumatra	2.44	203,739.80	309.42	218.00	547.64	1,202.24	1,715.13	153.75
73	Sumatra	2.49	208,150.24	363.40	222.72	515.51	1,184.28	1,708.28	176.75
74	Sumatra	2.50	209,301.17	369.71	223.95	514.37	1,186.83	1,713.73	178.83

Appendix 6. Solar plants sorted by ammonia LCOE values compared against the GDI.

ID	Province (eng)	GDI	Ammonia LCOE (USD/ tonne)
74	Bengkulu	0.20	178.83
73	Bengkulu	0.20	176.75
72	South Sumatra	0.58	171.85
71	South Sumatra	0.58	171.81
70	South Sumatra	0.58	171.07
69	South Sumatra	0.58	170.78
68	East Java	0.45	170.57
67	Central Java	0.55	166.71
66	Central Java	0.55	166.20
65	Central Java	0.55	165.72
64	West Java	0.85	164.87
63	South Sumatra	0.58	163.92
62	South Sumatra	0.58	163.54
61	Bengkulu	0.20	162.96
60	Bengkulu	0.20	162.84
59	Bengkulu	0.20	162.70
58	Aceh	0.25	161.86
57	Aceh	0.25	161.85
56	Aceh	0.25	160.30
55	Gorontalo	0.57	159.85
54	Central Sulawesi	0.33	159.69
53	Central Sulawesi	0.33	159.48
52	South Sumatra	0.58	159.35
51	South Sulawesi	0.64	159.34
50	Aceh	0.25	158.79
49	Aceh	0.25	158.27
48	Aceh	0.25	158.10
47	Aceh	0.25	157.81
46	Aceh	0.25	157.65
45	Aceh	0.25	157.42
44	North Sulawesi	0.74	157.20
43	North Sulawesi	0.74	157.08
42	North Sulawesi	0.74	157.05
41	South Sulawesi	0.64	157.00
40	South Sulawesi	0.64	156.85
39	Gorontalo	0.57	156.60
38	East Nusa Tenggara	0.00	156.39
37	East Nusa Tenggara	0.00	155.87
36	East Nusa Tenggara	0.00	155.64
35	East Nusa Tenggara	0.00	155.49
34	East Nusa Tenggara	0.00	155.32
33	East Java	0.45	154.98

32	East Java	0.45	154.94
31	East Java	0.45	154.87
30	East Java	0.45	154.79
29	East Java	0.45	154.77
28	East Java	0.45	154.46
27	East Java	0.45	154.34
26	East Java	0.45	154.08
25	East Java	0.45	154.02
24	East Java	0.45	153.94
23	East Java	0.45	153.86
22	East Nusa Tenggara	0.00	153.80
21	East Java	0.45	153.75
20	East Java	0.45	153.68
19	East Java	0.45	153.66
18	East Java	0.45	153.60
17	East Java	0.45	153.47
16	East Java	0.45	153.39
15	East Java	0.45	153.34
14	East Java	0.45	153.32
13	East Java	0.45	153.27
12	East Java	0.45	153.24
11	East Java	0.45	153.07
10	East Java	0.45	153.02
9	Banten	0.85	152.92
8	Banten	0.85	152.74
7	Banten	0.85	152.70
6	West Java	0.85	152.64
5	West Java	0.85	152.58
4	West Java	0.85	152.52
3	West Java	0.85	152.33
2	West Java	0.85	152.26
1	West Java	0.85	152.00