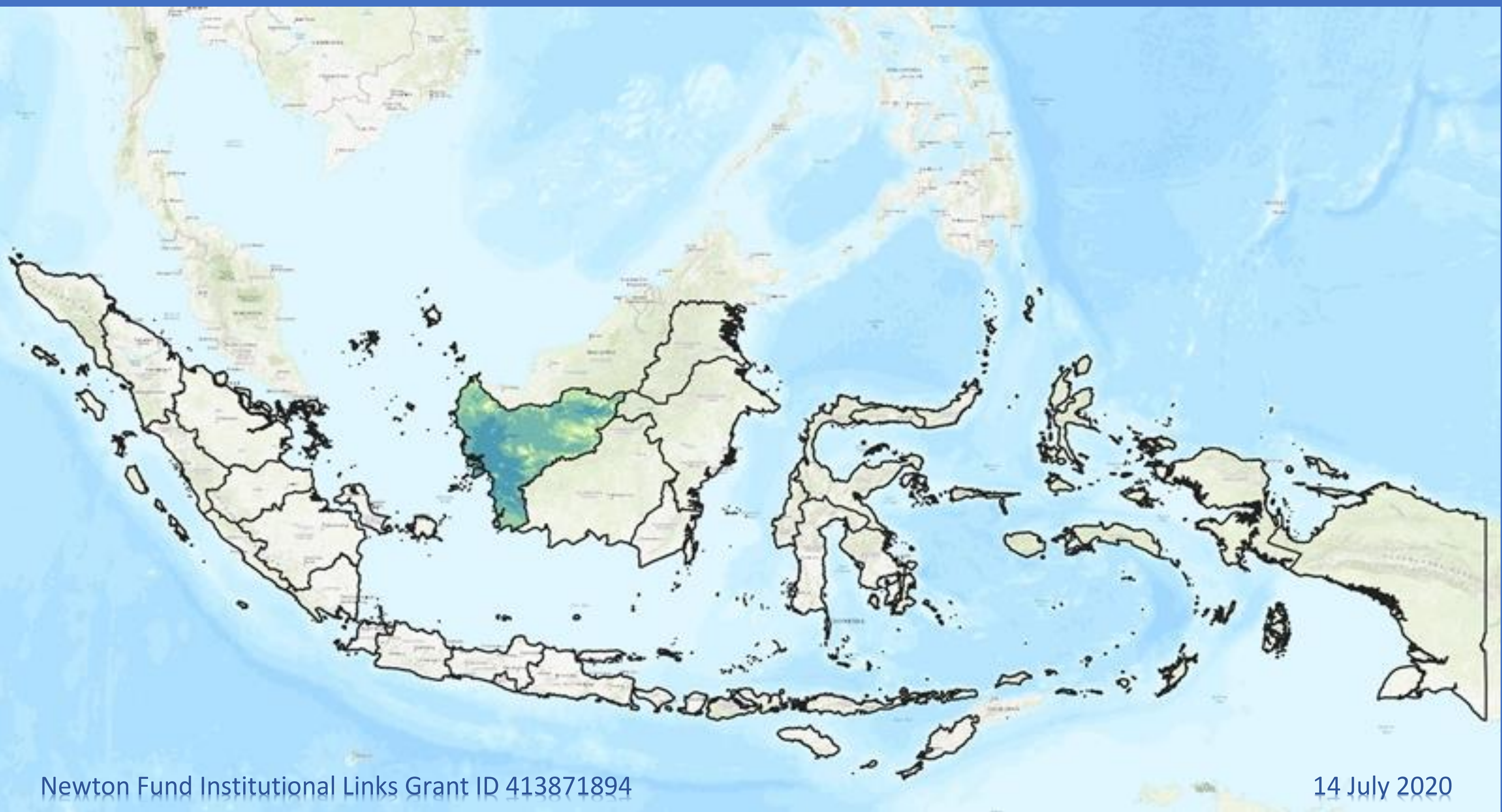
(Draft version) Boosting Solar Energy Capacity Of Indonesia Without Compromising Protected Areas

An Integrated GIS Platform Tailoring Solar Energy Resource And Local Information Channels (Solarboost)



Newton Fund Institutional Links Grant ID 413871894

14 July 2020

Boosting Solar Energy Capacity Of Indonesia Without Compromising Protected Areas

An Integrated GIS Platform Tailoring Solar Energy Resource And Local Information Channels (Solarboost)

Project Report

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KEMENTERIAN RISET, TEKNOLOGI DAN PENDIDIKAN TINGGI REPUBLIK INDONESIA

POLITEKNIK NEGERI PONTIANAK

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2020

Stakeholders

BAPPEDA PROVINSI KALBAR

PLN

KEMENTRIAN ESDM

PEMERINTAH PROVINSI KALIMANTAN BARAT
DINAS PERKEBUNAN

BADAN METEOROLOGI KLIMATOLOGI DAN GEOFISIKA
BMKG

KEMENTAN
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PEMERINTAH PROVINSI KALIMANTAN BARAT
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BALAI KONSERVASI SUMBERDAYA ALAM KALIMANTAN BARAT

KEMENTERIAN LINGKUNGAN HIDUP & KEHUTANAN REPUBLIK INDONESIA

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2020

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Abbreviations

AF:	Area factor
AHP:	Analytic Hierarchy Process
ASEAN:	Association of Southeast Asian Nations
BAPPEDA:	Badan Perencanaan Pembangunan Daerah (Regional Development Planning Agency)
BAU:	Business As Usual
BPMSG:	Business Performance Management Singapore
CI:	Consistency Index
CR:	Consistency Ratio
DEM:	Digital Elevation Model
DNI:	Direct normal irradiation
ESDM:	Energi dan Sumber Daya Mineral (Department of Energy and Mineral Resources)
GHI:	Global Horizontal Irradiation
GHS:	Green House System
GIS:	Geographic Information System
GP:	Generation Potentiality
GTI:	Global tilted irradiation
KEN:	Kebijakan Energi National (National Policy of Energy)
MCA:	Multi-Criteria Analysis
MSL:	means Sea level
PLN:	Perusahaan Listrik Negara (National Electricity Company)
POLNEP:	Politeknik Negeri Pontianak
PV:	Photovoltaics
RE:	Renewable Energy
RI:	Random consistency index
SDG:	Sustainable Development Goals
SEIS:	Solar Energy Information System
SR:	Solar radiation
SRTM:	Shuttle Radar Topography Mission
SSI:	Surface Solar irradiance
UK:	United Kingdom
UoL:	University of Leicester
WGS-UTM:	World Geodetic System Search-Universal Transverse Mercator
WKP:	West Kalimantan Province

Project Report 2020

1. Significance

Access to affordable and sustainable electricity resources is considered one of the primary global necessities where higher the electrification ratio is the greater the socioeconomic status as well as the technical advancement of a country.

Under the UN's Sustainable Development Goals (SDG 7) with a specific focus on "ensuring access to affordable, reliable and modern energy for all by 2030", it is necessary for all governments, industry, and academia to work together for enabling routes of access for improved electrification, in a current scenario where at least 1 billion of the world population remains without electrification (IEA, 2019; IRENA, 2019a). In the case of Indonesia, which amongst the members of the Association of Southeast Asian Nations (ASEAN), is the largest energy user accounting for 40% of its total energy use (IRENA, 2017), the implementation of sustainable routes for the deployment of renewables result vital.

As a result of a dedicated effort, Indonesia has achieved remarkable success in bringing national electrification ratio from 53.4% to 94.8% in 2000 and 2017 respectively with 100% urban electrification ratio and rural electrification ratio at 86% during the year 2017 (IEA, 2018). However, under this scenario, the West Kalimantan Province (WKP), and in general Borneo Island, has been left behind. According to the PLN statistics for the year 2018, WKP has only an 86.98% electrification ratio for PLN customers against its relative 97.05% for the entire country. The average per capita electricity sold during 2018 is only 473.1kWh in the WKP, whist in an average of 888.2 kWh are sold in other regions in the country. According to the 2018 PLN statistical report, 146,684 kiloliter diesel fuel was consumed for generating electricity, causing a total expenditure of about 96937 US dollars in the previous year. This represents an enormous burden for the national finances with a significant adverse impact on the environmental sustainability of the region.

Thus, in order to tackle the electricity demand and excessive burden on the national financial budget from fossil fuel-generated electricity at Indonesia, the UK-Indonesia Newton fund program has funded the creation of a GIS-based reliable tool with complete Solar Energy Information System (SEIS) for site suitability assessment of large-scale of solar power plants at the West Kalimantan Province of Indonesia called, **SolarBoost**.

Solar power is the most promising renewable energy in Indonesia with an average annual solar radiation of 4.8 kWh/m^2/day. With the rapid improvement in the innovation and technical development of global PV technology, the cost for modules and installation of solar PV has been dramatically reduced in recent years (Sabo *et al.*, 2016). However, the solar power sector in Indonesia is severely underdeveloped, representing less than 90 MW of installed capacity at the end of 2017 (Deon, Julius, and Pamela, 2018). In fact, in the case of the West Kalimantan Province, it has been found that less than 0.18 MW installed capacity comes from solar energy out of a total of 201 MW, in 2018, whereas 123 MW installed capacity accounted from Diesel generators (PLN, 2018). These figures indicate that the WKP has not yet been exploited solar renewable resources due to potential information and communication barriers, despite it is well known for the government that WKP represents one the most promising solar resources in the country, with potential of electrification corridors with Malaysia and Brunei.

After several discussions held in the framework of the 2019 Newton Fund SolarBoost Workshop, with the participation of Researcher from POLNEP-Indonesia and the University of Leicester – UK, with representatives from our large set of stakeholders, it has been concluded that the problem aforementioned is mainly due to communication barriers and knowledge gaps about technical, financial, economic, institutional, and social constraints, which demotes the interest on the installation of grid-connected solar power plants in regions subjected to a large diversity of conservation and protected areas. This highlighted the inexistence of adequate spatial analysis tools for site-specific planning and hand rich data for the technical exploration of solar energy across the region, and factor that is now covered as one our impact outcomes and online WebGIS platform available at www.solarboost.tech

1.1. Energy supply and demand

Indonesian's electricity demand is escalating rapidly driven by economic growth and increasing population. The economic growth was predicted steadily 6% over the total population of 260 million in 2017 including the estimation of the middle-class population growing from 88 million in 2014 to 141 million people in 2020. With these two important drivers, the electricity demand increased from 134.5 TWh in 2008 to 250 TWh in 2019 (PwC Indonesia, 2017). To supply this demand, PLN has created some strategic plans including increasing their plant capacity from nearly 60 GW in 2018 to be double capacity 120 GW in 2027 (PwC Indonesia, 2017). This strategic plan is not only for increasing the capacity but also providing the essential infrastructure that could support the 100% electrification program in 2020. In general, PLN has divided the strategic area for their plan including seven region operation which are Sumatera, West Java region, Central Java region, East Java region, Kalimantan, Sulawesi, Maluku and Papua.

The WKP has a total population of 5.4 million (2018) with an average population density of 30 per km square. With the assumed growth rate of the population at 1.58 % per year, the total population in 2050 will be projected at around 7.9 million. A total of 4,971 GWh energy demand required in 2020 with 1000 kWh per capita consumption. For future energy demand projection in 2050, the assumed energy consumption of 6,723 kWh/capita has been taken as reference from DEN (BAU scenario). With this assumption, the projected energy demand for West Kalimantan in 2050 is 53,688 GWh (Table.1). To supply this demand, PLN as the main operator for electricity distribution in the country has targeted producing 3,338 GWh energy in 2020 (Figure.1). With all consideration that the production has a consistent progression, the projected production for the energy in 2050 will be around 10,000 GWh. This projected production is still five times lesser than the projected demand based on the population and energy per-capita consumption which is according to the assumption from DEN (Table.1). This energy production - demand rate clearly shows that the WKP will be going to face the energy scarcity problem for the population, though it has a broad range of alternative sources of renewable energy (RE).

Table.1 The energy demand was calculated based on population data from Disdukcapil Kalimantan Barat and the demand per-capita project from DEN using the BAU scenario.

Regency	Demand 2020 (GWh)	Demand 2030 (GWh)	Demand 2050 (GWh)
Kab Sambas	647	2273	6987
Kab Mempawah	311	1094	3361
Kab Sanggau	495	1739	5347
Kab Ketapang	582	2046	6288
Kab Sintang	417	1466	4507
Kab Kapuas Hulu	251	881	2708
Kab Bengkayang	293	1030	3166
Kab Landak	408	1432	4401
Kab Sekadau	218	765	2351
Kab Melawi	237	834	2564
Kab Kayong Utara	129	454	1397
Kab Kubu Raya	62	217	667
Kota Pontianak	680	2388	7339
Kota Singkawang	241	847	2605
Total	**4971**	**17466**	**53688**

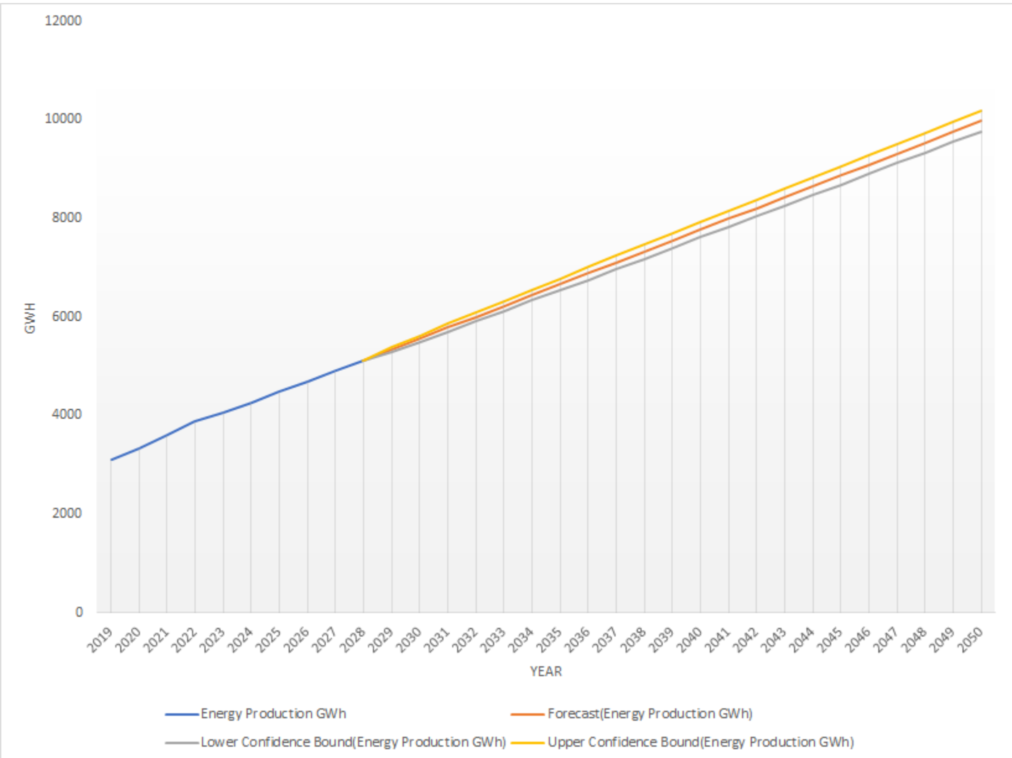


Figure.1 Forecasting energy production by PLN, Source: (ESDM, 2018)

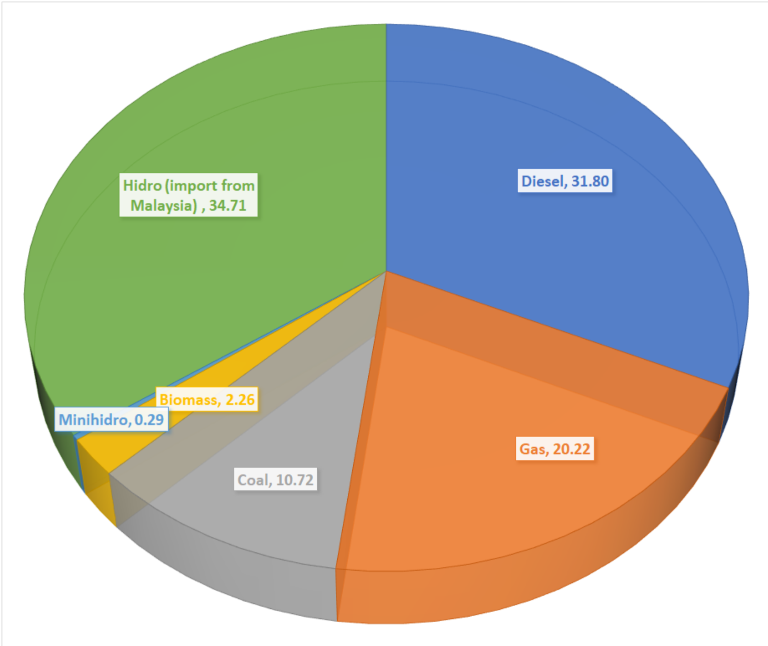


Figure.2 Percentage energy mix source for West Kalimantan electricity in 2018 (Source: ESDM, 2018)

Though the present sources of the energy mix in West Kalimantan are dominated by hydro, it was imported electricity from Malaysia, with a possible limitation in supply for the future energy demand. Diesel, as well as coal electricity sources, have been playing a majority of the energy mix in the WKP (Figure.1). since these energy sources are creating a burden for national finance with significant environmental impact. While there exists a huge gap between demand and supply, A sustainable alternative source of energy including the free energy source such as solar energy and wind is the most necessity for WKP to cope with the future energy mix.

1.2. KEN: Promotion of RE

The densely populated country like Indonesia, exert huge demand in the electricity energy sector to fulfill the demand from the overgrowing population in both urban and rural area. It was true that Indonesia is the largest energy user accounting for 40% of total energy use among the Association of Southeast Asian Nations (ASEAN) members (IRENA, 2017). To supply the overburden energy demand, the Indonesian energy sector is mainly dependent on fossil fuel and coal as the major energy source which causes a huge burden for the national finance with a significant adverse impact on the environmental sustainability of the region. It is crucial that Indonesia must share its energy demand with locally available renewable energy sources at its regional basis (IRENA, 2017). As per IRENA (IRENA, 2019b), the electrification from renewable energy sources can reduce more than 75% of energy-related CO_2 emissions. The privileged geographical location on the equatorial region, solar power is the most promising renewable energy in Indonesia with average annual insolation of 4.80 kWh/m^2/day and has a total potential of more than 500 GW (PwC Indonesia, 2017; Deon, Julius and Pamela, 2018). Indonesia has ample opportunity for solar PV systems to promote electrification, nevertheless, the country has not yet initiated to develop the solar PV system. Furthermore, Indonesia has comprised of 17,000+ islands spread across the archipelago, creating a challenge for the electronification because of the limitation in the distribution and transmission. Utilizing RE will provide a significant contribution for electrification especially for solar energy which can be found in every place. Recognizing this potential, the government has been stipulated Kebijakan Energi National (KEN) or the National Policy of Energy as the policy road map for energy management in Indonesia, stipulated as the governmental decree no. 79/2014. The national road map policy target for increasing the renewable energy share up to 23% by 2025 from the previous 15% (Figure.3). Geothermal, hydro, wind, solar, tidal, and biomass were the renewable energy sources that referred specifically to the KEN.

It was following up from the president to implement this KEN by the general plan of national energy (RUEN) in 2017 which provided a detailed share of RE in the energy mix until 2050. To accelerate the growth of RE in Indonesia, some policies were stipulated including (source: Deon, Julius, and Pamela, 2018):

- Presidential decree 4/2016 about the infrastructure acceleration for the electricity
- Presidential regulation 66/2018 about the funds for palm oil as biofuel
- Ministry of Energy and Mineral Resources 49/2018 about the solar rooftop.
- RUEN

At the regional level, each province including West Kalimantan Province should stipulate the legislation for formulating the legal umbrella at the regional level. This legal umbrella can be the regional regulation which consists of the detailed general plan for regional energy (RUED). However, the proposed regulation was discussed in the parliament office and targeted to finish as regional regulation (PERDA) in 2020 (Kementerian Energy dan Sumber Daya Mineral, 2018). This regulation has been expected to accelerate the investment in renewable energy including PV power plants in West Kalimantan Province (Table.2).

Table.2 Potential of renewable energy in Indonesia in 2015
Source: (Kementerian Energy dan Sumber Daya Mineral, 2018)

Energy source	Potential	Installed Capacity	Utilization (%)
Geothermal	29,544 MW	1,438.5 MW	4.9
Hydro	75,091 MW	4,826.7 MW	6.4
Mini-hydro	19,385 MW	197.4 MW	1.0
Bioenergy	32,654 MW	1,671.0 MW	5.1
Solar	207,898 MW	78.5 MW	0.04
Wind	60,647 MW	3.1 MW	0.01
Tidal	17,989 MW	0.3 MW	0.002
Total	443,208 MW	8,215 MW	1,9

These regulations and policies have been expected to accelerate investment in renewable energy. With a massive potential in solar energy, the investment in the PV power plants in Indonesia and especially in West Kalimantan Province will provide a significant contribution to increasing the energy share of RE. The domination of fossil fuel (diesel and gas) in the energy share in the country can be reduced by increasing of utilizing solar energy especially the most abundant solar energy in Indonesia.

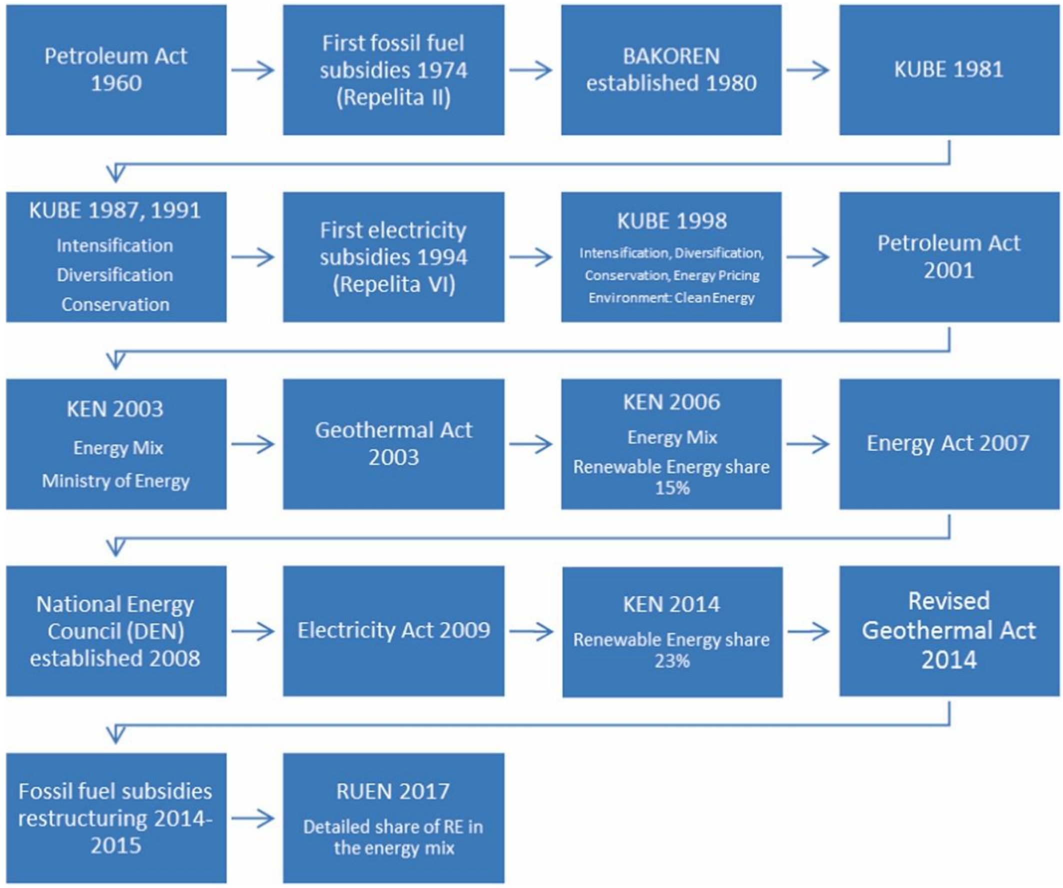


Figure.3 Potential for renewable energy in Indonesia in 2015
Source: (Maulidia et al., 2019)

1.3. Large-scale solar power plant development process

A solar panel can generate electricity from incoming solar radiation (Light) using a solar cell that converts light energy into electricity. This conversion device is known as Photovoltaics (PV). Solar energy is considered to be one of the cheapest and sustainable modes of renewable energy with no harmful emissions and no noise pollution. The large-scale solar energy power plant is generally connected with the multiple numbers of PV modules interconnected with each other series to produce a higher voltage. Accordingly, the large-scale solar PV power plants have components including PV modules, mounting structures, inverters, transformers, switchgear, and DC and AC cables which are connected for transmitting the electricity to the power grid (Figure.4). A common solar module manufactured from silicon contains two semiconductors cells having different properties such as n-type silicon and p-type silicon. These semiconductors responses to light and generate positively charged particles and negatively charged particles to produce electricity. The PV modules are fixed to the ground with the required tilt angle for appropriate orientation towards the sun using the Mounting structures. The mounting structures are of both fixed and tracking axis systems. The fixed structures are infirm fixed with predetermined tilt angle and orientation based on the location and altitude of the ground. However, the later systems capable of modifying the orientation and the tilt angle concerning the sun position allowing the maximum capturing of the sun radiations. Usually, PV modules generate DC electricity which is converted and synchronized to AC electricity using an Inverters to accomplish with grid requirements. The voltage produced from the PV modules is step-up by using the transformers to meet the grid requirements. However, the development of a large-scale solar power plant project is a long complex process with a multidisciplinary team of experts from different fields such as site and technical planning, construction and engineering side, electrical installation, and project management (Figure.5).

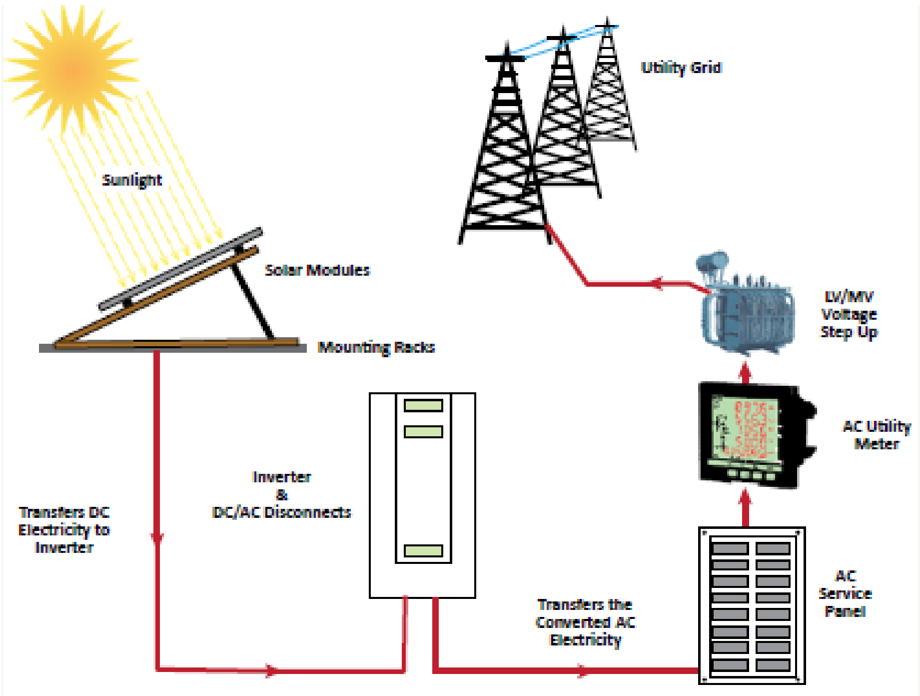


Figure.4 Diagram of largescale solar power plant source: (IFC, 2015)

1.3.1 Project plan and design development

The preliminary concept of the developmental process for the large-scale Solar power plant includes a detailed structure of the proposed project plan and design. The identification of the investment opportunity and the formulation of a strategy for project development is an important consideration in the preliminary process. The development plan may be carried in succeeding phases such as conceptual, pre-feasibility study, feasibility study, development, and design.

1.3.2 Geographical Site selection

Selecting a feasible site for maximum solar electricity production with a minimum cost of investment is a challenging task for developing a largescale solar PV project. The geographical site with the characteristics representing the feasible technical, economical as well as environmental prerequisites for solar energy development is the most crucial stages in the developmental planning processes of Solar PV project. The extensive study on a different aspect of site-specific criteria parameter which influencing the solar energy production capacity can carry both in the desktop application (GIS spatial application) and field survey-based. The key important characteristic of an ideal site selection for large scale solar PV plant development must include the following parameters:

1. Solar resources (Global Horizontal Irradiation); analyzing the Technical potential

2. Grid connection (Power grid data) accessibility to the power and cost economy
3. Local climate (temperature and relative humidity); determine the energy efficiency
4. Topography (Elevation, Slope and land aspect)**:** physical limitation for development
5. Accessibility (Main road): significant accessibility for sites selection
6. Population and settlement data; analyzing the electricity supply and demand
7. Protected/conservative/infrastructures areas**,** acts as a constraint for development

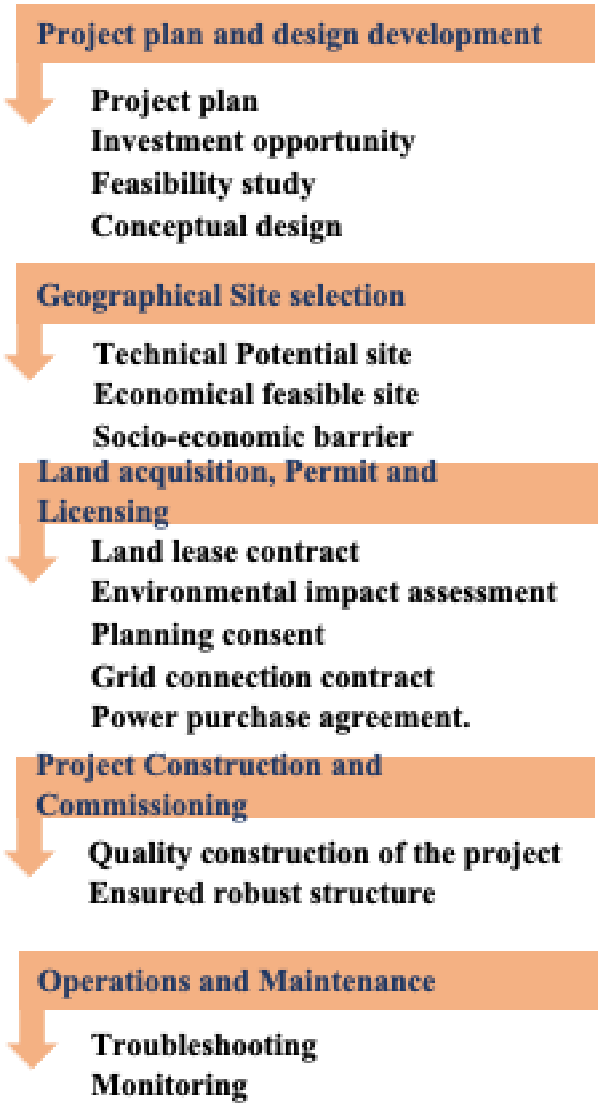


Figure.5 The development process for large scale solar power plant project (source: modified from IFC, 2015)

1.3.3 Land acquisition, Permit, and Licensing

Upon identifying the feasible site for the development, then continues by land acquisition, permit, and licensing. The land permitting and licensing process is complicated and challenging aspects of the large-scale solar development process by achieving all required approvals from the local, region or national governing authority including the Land lease contract, Environmental impact assessment, Building permit/planning consent, Grid connection contract, and Power purchase agreement.

1.3.4 Project Construction and Commissioning

The present stage aims to construct the project to the required level of quality within the scheduled time and allotted cost expenditure. This task is carried by the professional and skilled crew for efficient and expedited plant construction with consideration of the satisfying the Commissioning such as the power plant is structurally and electrically safe and sufficiently robust to operate for the specified project lifetime.

1.3.5 Ongoing operations and Maintenance

The solar PV project continue efficiently producing clean, and renewable energy with very little operations and maintenance cost as compared to other energy generation sources. The solar PV power project is one of the most efficient energy generation resources available with maintenance limited to including monitoring the installed equipment, troubleshooting and perform ongoing maintenance, and maintain the grounds and site condition.

1.4. Importance of SEIS in the development process

Since the development of a large scale, solar PV plants require a vast study on multi-thematic data and information on a spatial basis. The large scale solar PV plant would require two important planning processes such as demarcating the barrier zone and identifying the feasible zone. Though the solar power PV plant is considered to be an environmental green source of energy, the social and environmental barriers such as infrastructural and protected areas have to be demarcated before the development of large scale projects to prevent the impact on these constraints layer. This would be the first planning process in the development process. The power potential capacity of a solar PV plant is core depended on the important factor such as surface solar radiation, and highly variant on a spatial scale with subsequent deviations in respect of local climate and topography. however, identification of the feasible site with consideration to these influencing factors is the second most important planning process in the development of the large scale solar PV Plant. The integrated information system which capable of analyzing both the spatial and nonspatial data to deliver a policy decision to minimize the total investment cost of the project while maximizing power output from solar PV plants. The essential advantages of the SEIS are highlighted as follows.

- Proposes a suitable area with ensuring a high level of solar power potential, and energy efficiency by considering the solar data as well as climate data.

- Enhancing the orientation of the solar site according to the topography and ground condition for improved performance and to reduce the initial investment for the cost-benefit.
- Access easy transportation and transmission utility by identifying the feasible site at proximity locations such as power grid and road.
- Fulfilling the energy demand by identifying the site located near to major settlement and densely populated area.
- Minimize the environmental, societal, and infrastructural impacts by mapping the constraints area for large scale solar power projects.
- Reliable energy security and power sustainability from the feasible site by future energy projection scenario.
- Identifying the cost-effective source of energy at a geographical spatial basis by analyzing the energy production cost on various energy sources.

2. SolarBoost Project

SolarBoost is a collaborative research project between Politeknik Negeri Pontianak (POLNEP) and the University of Leicester (UoL) the UK. This work was supported by the Institutional Links grant, ID 413871894, under the Newton Fund Indonesia partnership. The grant is funded by the UK Department for Business, Energy and Industrial Strategy and the Indonesian Ministry of Research, Technology, Higher Education and delivered by the British Council. For further information, please visit www.newtonfund.ac.uk. The institutional link project is aimed to promote the massive development of solar power plants in Indonesia by comprehensive consideration of solar renewable energy share in the Indonesia energy mix. Since the country has relied on fuel generated electricity which has been a burden in the financial sector as well as the severe impact on the environment. To improve green energy security, and a sustainable energy transition to solar renewable energy in the country, the SolarBoost will arrive with an interactive web-oriented GIS platform to exploit and explore the solar energy potential and scope in the country. The detailed information on the SolarBoost project can be found in the main project website @ http://solarboost.tech/ and the comprehensive research outcomes in the form of web-oriented GIS spatial maps in SolarBoost web mapping tool @ http://webmap.solarboost.tech/.

2.1 Project Aims

The chief aim of the SolarBoost is to exploit the solar energy potentials to boost the solar renewable energy share in the Indonesia energy mix. As a pilot study, a case study at West Kalimantan has been considered. To derive the successive imprint of the project, the following objectives are framed and achieved:

- Developing a GIS package enabling the integration of satellite retrieved SSI data with Indonesian local information of demography, infrastructure, electric network, and land usage.

- Collection and processing of the spatial data and multi-criteria algorithms for analysis, visualization, and integration of local resources of information in Indonesia.
- showcasing the potential site for exploiting the solar energy resources with GIS packages for solving energy-related problems Indonesia
- Preparation of the first web-oriented GIS mapping tools for solar farms deployment and energy policymaking, with consideration protected areas and vulnerability barriers in Indonesia.

2.2 Expected outcomes

SolarBoost will be brought the high-resolution solar power potential spatial maps with statistical tabular data on the feasible site location, potential energy capacity as a case study in WKP. To boost the solar renewables power share in the country's energy mix, the portrayed output data products of SolarBoost will be able to explore the information on the grid connectivity, the spatial distance between the potential solar power sites to the power grid and major road. Since the SolarBoost has collected the rich local data on land cover and protected area in the WKP, the local barrier and constraints from the protected area and infrastructural land are can duly be demarcated from the solar potential sites. The important factor that determines the solar potential capacity such as global solar insolation data, climate, and topography, etc. are available to further study on a regional basis as interest. Finally, SolarBoost delivered the first version of a web-enabled GIS package focused on the easy visualization of satellite-retrieved data for SSI maps, tailored to the actual needs, conditions, and infrastructure of the WKP. The key derivatives including the web-enabled spatial maps, GIS layers, statistical tabular data, and figures created the first-ever SSI benchmark report aimed to enable an adequate inclusion of solar energy farms and energy policymaking in Indonesia on special focus to the WKP, where routes of grid development are respectful with the protection of natural resources and native communities. So far SolarBoost demonstrated the usefulness of GIS by performing multiple assessments of the power cost/benefits that could be derived from the installation of a solar farm at West Kalimantan (or any other Indonesian province), reporting the legal and infrastructure constraints that could affect its timely deployment.

2.3 Project activities and contribution of the stakeholders

The SolarBoost has developed GIS packages for solar resource data retrieval and, the development of custom algorithms for image processing and analyzing the SSI data provided by WBG with local information. This integration specifies the potential locations of PV plants without compromising the use of land protected areas and targeting maximum solar energy resources, appropriate access of road, and greater accessibility to grid connection. Updated the cartographic maps with the topography, demography, infrastructure, electric network, and land usage with data access from the stakeholders such as BAPPEDA, ESDM, and PLN and but in some cases, data also obtained from the website of national agencies. SolarBoost has integrated these satellite-derived data and local information by managing the data into layers of a GIS package. The local land cover layers including conserved forest, national park, rice cultivation area, legal forestry area, peatland, cultural or community forest, water bodies, wildlife habitat, and public infrastructure area are considered as constraints layer and excluded from feasible site for the solar PV power project. The suitability map was developed by applying the Analytic Hierarchy Process (AHP) for the selected input criteria in West Kalimantan. SolarBoost web-enabled GIS packages are easy to explore, extract, and visualize the spatial solar data for even non-GIS users. The analyses will determine solar energy resources, the performance of PV plants under local weather conditions such as air temperature and humidity, number of prospective consumers, distance from communities, access to the major road and land status, and anticipated constraints such as land cover and protected land. The GIS package with data management tools would provide a reliable tool for policymaking, sites planning, and development of solar power plants, for government, communities, and industrial investors, that would accelerate massive development in solar power plants, which in turn would strengthen the energy security and development of Indonesia.

The stakeholders have supported the SolarBoost project by attending the SolarBoost workshop and providing advice and information for the development of a GIS package. Following up the workshop, the partners provide the following supports:

- National Electricity Company (PLN) has provided access data and information related to installing and planned power plants/networks in the West Kalimantan Province, that required in the criteria analysis for the feasible site selection.
- Department of Energy and Mineral Resources has provided information about the existing power generator in the West Kalimantan Province. This information has outlined the status of the existing power sector in the West Kalimantan Provinces.
- Regional Development Planning Agency (BAPPEDA) had shared all the available Spatial and non-spatial data on different layers including the admirative boundary with cadastral level data LULC, Soil, Geological and Physiographical data, Public infrastructure, transportation, data on the protected and conserved area. These data are required for excluding areas in the site suitability analysis.
- Department of Forestry has provided access to cartographic data of land protected areas, latest peat moratorium (legal map and guidance), and general legal regularities in the field of forestry. These data are vital for solar boost project to elucidate the clear information to the investor about the area (peat and protect forest) that cannot be developed or converted to any land use.
- Department of Agriculture and Horticulture has provided the latest and updated information about the farming areas with rice fields and other important cropland in the West Kalimantan Provinces.
- Department of Population and Civil Registry has provided census data on population at the village level. This data has given more importance to identify the most feasible solar site in the remote areas to provide the electric energy service where the grid connection and other sources of energy have failed to provide the services.

2.4 Design of SEIS (SolarBoost)

To Boost the solar PV power energy development in West Kalimantan Province of Indonesia, the satellite-derived solar information layers, climatic data, and local land protected area, land cover area, and proximity to locations data are analyzed concerning their spatial interrelationship with the surface solar irradiation and solar energy potential. The AHP method is employed to assign the rank and priority for these layers and spatial weighted overlay integration analysis is performed in the GIS software (ArcMap 10.6.1). The AHP pairwise calculations have been done using the Business Performance Management Singapore (BPMSG) AHP priority calculator (utilized under the Creative Commons Attribution-Noncommercial 3.0 Singapore License). The entire procedure includes a step by step process, such as identifying criteria layers, reclassifying to assigning priority grade for factors, and defining the AHP weight. The solar PV plant should install in an area where it can receive more solar daily irradiation to produce high electricity. Since the WKP has been characterized by the promising amount of GHI throughout the year, we have considered the GHI factor only next to proximity to the locations such as distance to the Power grid, road, and major settlements. For this purpose, the SolarBoost has carried with two distinct approaches by giving the highest priority to proximity to the power grid as Business as usual analysis in approach-1, and proximity to the major roads as Progressive expansion analysis in approach-2. In approach-1, the proximity to the grid factor has assigned the highest priority, the GHI given priority next to the grid, and the road, settlements, temperature, slope, aspect, elevation, and relative humidity are given priority as the ascending order. This approach is mainly focused on finding the best suitable site for the large-scale PV plants near to the existing power grid such that the produced solar electricity energy can be injected into the power grid. Whereas approach-2, suitability criteria are more focused on proximity to the road and the GHI, such that the ideal site should be near to the major road for easy access during the installation of the PV plant. The latter approach is mainly concentrated to determine the exploitable solar sites near the roads and major settlements. Since the WKP has a limited grid connection with presently connected between Pontianak and Singkawang, while further extending the grid connection, considerations to these exportable solar sites will boost the electricity share mix in the WKP. In both approaches, only selected criteria such as proximity to grid, and proximity to the road have modified the priority according to the objective, and remaining technical and topographical criteria such as temperature, relative humidity, elevation, slope, and aspect are kept constant consideration.

The detailed flow chart of work methodology and the data analysis employed in the SolarBoost research are depicted in Figure.6. The spatial integration and GIS weighted overlay analysis are performed to aggregate the overall AHP weight to show the suitability map for solar PV development. The constraints layer such as protected areas, land cover, and infrastructure layer where the Solar PV deployment is restricted, are masked off from the suitability map. The annual electric power generation potential has projected from the suitable map figure out the exploitable solar energy production capacity in WKP. All the layers and data are uploaded to HTML for visualizing and exploring the web-enabled GIS information on solar PV power energy development in the WKP.

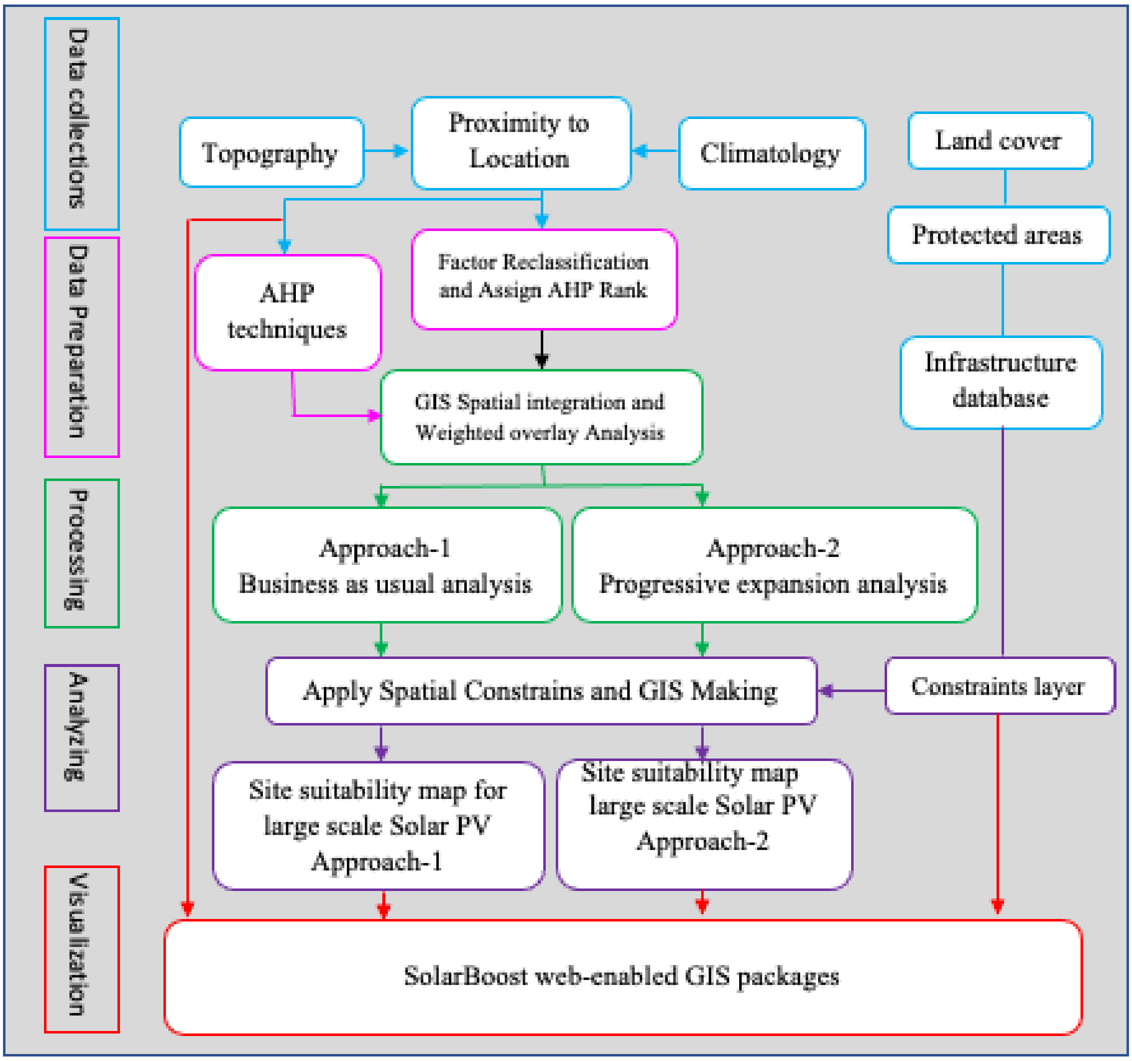


Figure.6 Flow chart representing the detailed working design employed in SolarBoost

2.4.1 Features

A SolarBoost web-enabled GIS packages designed to visualize, retrieve, manage, and analyze geographic and spatial data for solar PV power development in the WKP. GIS software (ArcGIS) capable of producing spatial maps and table-graphic representation of the geographic information for analysis and exploring the data and information on the potential site for the solar PV plant development and to build a firm decision support system to Boost the solar PV energy in WKP. Weighted overlay tool in Spatial analysis has been implemented to solve the complex location-oriented perspective of solar energy to better understanding where and what kind of solar capacity can be producible at WKP. Multi-thematic layers varying from solar irradiation to data to the local land protected layers are integrated to study the interrelationship between each data and layer information against the solar PV power production. The SolarBoost has been employed on both raster and vector data layers wherever it was a convenience to analyze and process the data and layer variables. Since the system enabled GIS is envisioned for only GIS professionals and trainers with experience in GIS. Though the SolarBoost WebGIS is intended to be designed with simpler, and convenience so that it can be visualized as easy as using a regular website even for a wider public user, including non-GIS professionals' who may not be familiar with GIS or complex spatial data. The important feature oriented with the SolarBoost web-enabled GIS packages is underlined below.

Geographic location information (latitude/Longitude and Elevation)

SolarBoost web-enabled GIS packages utilize the geographically rectified raster as well as vector data. It is possible to measure location information as well as elevation or height data of any places on the map. The positional value will be denoted in the World Geodetic System Search-Universal Transverse Mercator (WGS-UTM 1984) geographical projection system as Latitude and Longitude in Degree, minute, and second format. The elevation from the means Sea level (MSL) will be used in a meter.

Extracting qualitative Geometric measurements (point, distance/path, and area)

Our WebGIS enabled us to measure the qualitative measurements such as distance between two objects or path distance as well as the area for an area of a polygon. Here users are free to draw an area of interest as a polygon or can draw a line or path distance along the road or between multiple locations to measure the respective geometry, e.g. a user can measure the distance between the proposed solar PV sites and the power grid, or major road.

Geospatial visualization and analysis.

SolarBoost has been employed with many layers of data including climatology, land cover, topography as well as infrastructure layer. Map users can explore the spatial pattern of each data layer and analyze the spatial heterogeneity in the data. Users can be visualizing all the data together or analyzing any region or place with individual data layers; e.g., studying variables such as GHI, temperature, and relative humidity for any selected places.

Export data and print option

SolarBoost has enabled the users to export the data for future use and can be printed the selected dataset in the content.

Better capability on cross-platform

SolarBoost WebGIS is programmed on HTML and compatible with any web browsers such as Internet Explorer, Google Chrome, Mozilla Firefox, Apple Safari, etc.

World-Wide reach with multiple users at a time

Since the SolarBoost GIS data layers are connected with the GeoServer, the end-user can access the geographic data and maps from anywhere in the world with HTTP requests and responses to go through the local server. SolarBoost can be used by multiple users simultaneously with higher performance and scalability than the desktop GIS.

2.4.2 Source of info

The data and information used in the SolarBoost are collected from different governmental, stakeholders, and open sources. The published secondary maps are digitized to work on the GIS software and the non-spatial data collected from the different sources are converted into the spatial data and assigned UTM projection system. The WKP lies partially in both the side of the equator with two different UTM projection zone. To avoid the misleading during the area calculation, both north and south UTM zone is considered for the area calculation. The spatial maps including land protected areas, land-use/land cover, road network, electricity grid line, settlement area, and administrative boundaries are collected from the representative Stakeholder. The average monthly Global Horizontal Irradiation and air temperature dataset for 11 years are collected from the World Bank Group (WorldBank, 2017). Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM), was downloaded from CGIAR (http://srtm.csi.cgiar.org/srtmdata/) utilized to prepare the topographical factor layers such as the Elevation, Slope, and aspect map. The briefs about the data used in the SolarBoost are categorized into constraints and criteria according to their significance to the Solar PV power developments and are represented in

Table.3.

2.4.3 Layers

SolarBoost categorized the input layers as constraints and criteria according to their significance to the solar PV power energy. The land cover, protected land, and infrastructure layer have law enforcement in the national as well as region regulation, hence these features are considered as the constraints layer and are duly mapped to exclude from the site suitability for the large scale solar PV plant deployment in the WKP. These constraints layer covers together with a total of 66% of the land area in the whole WKP. As per these constraints forbid land conversion activities, the remaining 34% only feasible for the solar PV plant deployment in the WKP. The SolarBoost has considered nine criteria layers to perform the AHP weighing and GIS spatial overlay analysis. Both two layers are described in the following section.

2.4.3.1 Constraints Layers

The protected land which has national and regional laws and the regulation as vulnerability zones in the WKP, such areas are treated as constraints to exclude from the solar suitability study. These constraint layers include a Land cover (forestry area and rice field), Protected lands (Peatland, Cultural or Community forest, Water bodies and Wildlife or endangered habitat), and Infrastructure layer (Settlement area, road, and power grid network).

Table.3 shows more details about the constrained layer, data sources, and law enforcement on protected land. These constraints layer covers more than 66% of WKP total land (Figure.7) and any kind of developmental activities or inversion of these lands may be threatening to the steady environmental and ecological system in the province. The detailed spatial maps for excluded constrains layers are shown in Figure.8. The land-use layers such as oil palm and mining area could be considered, but these are the country major energy and economic sources, hence the SolarBoost has not been included as the constraints factor furthermore. These lands areas do not belong to the protected or conserved region as per the laws. If only one of the constraints layers such as Land cover, protected land, or infrastructure layer is considered without taking into consideration the other, the impact of the constraints area for the deployment of PV plants could be considerably reduced from 66% (Figure.7 and Figure.8). It is worth necessary to mention that the areas defined by each one of these constrain usually overlap with the others. Therefore, 66% is the total area mentioned before is the result of considered all these layers simultaneously.

Table.3 Representing SolarBoost datasets and sources of data.

Variable	Data Source	Remarks
GHI	World bank 2017	Criteria factor
Temperature	World bank 2017	Criteria factor
Relative Humidity	NASA	Criteria factor
Elevation (DEM)	NASA SRTEM DEM	Criteria factor, Elevation < 90 meter
		Excluded, Elevation > 90 meter
Slope	Derivate from DEM	Criteria factor, Slope < 9%
		Excluded, Slope > 9%
Land Aspect	Derivate from DEM	Criteria factor
Major Road	Ministry of Public Work, Indonesia 2016	Criteria factor, Proximity to road <10km
		Excluded, buffer 100 m
Power Grid	National Energy Council, Indonesia	Criteria factor, Proximity to Grid <10Km
		Excluded, buffer 100 m
Major Settlements	Indonesian Geospatial Agency 2014	Criteria factor, Proximity to Settlement <10Km
		Excluded, buffer 500 m
Forestry area	Ministry of Environment and Forestry, Indonesia.2014	Excluded as constraints layer Protected area by law enforcement No. 733/2014 and no. 45/2004
Peatland		Excluded as constraints layer Protected area by law enforcement No. 8599/MENLHK/2018
Cultural/Community Forest		Excluded as constraints layer Protected area by law enforcement No.21/MENLHK/2019
Water bodies		Excluded as constraints layer Protected area by law enforcement No. 38/2011
Wildlife or Endangered habitat		Excluded as constraints layer Protected area by law enforcement No. 308/MENLHK/2019
Rice field	Indonesian Geospatial Agency 2012	Excluded as constraints layer Protected for conversion by law enforcement No. No.1/Perda Kalbar/2018
Electricity per capita	Indonesia energy outlook, National Energy Council, 2019	Used for Energy projection in respect of population

2.4.3.2 Criteria

The constraints layer forbids the development Solar PV site, whereas the criteria layer will indicate feasibility towards the deployment and installations of the Solar PV system. The SolarBoost has considered three important criteria with their nine corresponding factors such as Climatology (GHI, Temperature and Relative Humidity), Topography (Elevation, Slope, and Aspect), and Proximity to Location (Proximity to Grid, Road, and the major Settlements) to prioritize the feasibility for the large-scale solar PV deployment. The detailed information on the criteria, source of data, and their corresponding AHP grade classification are shown in Table.4. And the significance of the criteria to the solar power energy is mentioned in Table.5. The spatial map of all selected nine factors with the reclassified into nine classes is shown in Figure.9.

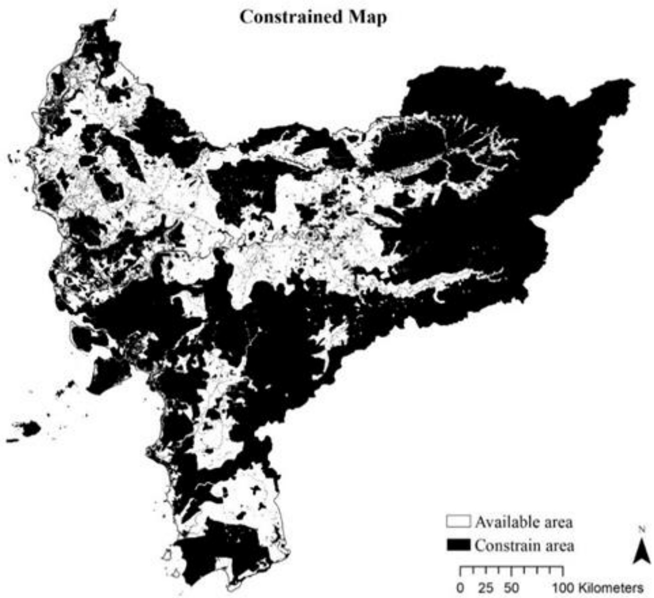


Figure.7 Map showing the prohibited area for PV deployment as these areas are covered with constraining layer

2.4.4 Data processing

SolarBoost has used ArcMap GIS software for analyzing the spatial dataset of both constraints layer and criteria layers. The AHP pairwise calculations have been done using the Business Performance Management Singapore (BPMSG) AHP priority calculator (utilized under the Creative Commons Attribution-Noncommercial 3.0 Singapore License) (Goepel, 2018).

A. Georectification and Spatial Projection processing

SolarBoost has collected GIS spatial and non-spatial data from different sources. Some of the data are in the form of a printed map and paper map, are digitalized to work on the GIS software, and the non-spatial data are converted into the spatial data and assigned UTM projection system. The WKP lies partially in both the side of the equator with two different UTM projection zone. To avoid the misleading during the area calculation, both north and south UTM zone is considered for the area calculation. The proper geographical rectification and assigning the correct projection coordinate system is important since the collected data contains different projection system and also some of the data need topology to build.

Table.4 GIS criteria layers, sources of data, unit ranges, class ranges, and AHP grading classification applied in the SolarBoost for large scale PV implementation (also see Table.A2).

<table>
<tr><th>AHP criteria Layer</th><th>Class Range (Δ)</th><th>AHP Grading Classification</th></tr>
<tr><td>GHI
2.6 kWh/m^2 – 5.04 kWh/m^2</td><td>0.28 kWh/m^2</td><td>Grade 1 @ class 2.60 kWh/m^2 + Δ up to grade 9</td></tr>
<tr><td>Temperature
17.1ºC – 27.8ºC</td><td>1ºC</td><td>Grade 1 @ class >27.8ºC,
Grade 2 @ class 27 ºC - Δ up to grade 8 and Grade 9 @ class < 20ºC</td></tr>
<tr><td>Relative Humidity
81.99% - 91.58%</td><td>1%</td><td>Grade 1 @ class >91%,
Grade 2 @ 91% - Δ up to grade 8 and
Grade 9 @ <84%</td></tr>
<tr><td>Elevation in meter</td><td>10 meters</td><td>Grade 1 @ class 90 meters - Δ up to grade 9</td></tr>
<tr><td>Slope
In %</td><td>1%</td><td>Grade 9 @ class 0% + Δ up to grade 1</td></tr>
<tr><td>Aspect (Azimuth)</td><td>N, NE, E, SE, S, SW, W, NW</td><td>Grade 9 @ N (00 – 22.50) and S (157.50 – 202.50), Grade 5 @ NE (22.50 – 67.50) SE (112.50 – 157.50) SW (202.50 – 247.50) NW (292.50 – 337.50), Grade 1 @ E (67.50 – 112.50) and W (247.50 – 292.50).</td></tr>
<tr><td>Road Proximity</td><td>1.1 km</td><td rowspan="3">Grade 1 @ class 10 km - Δ up to grade 9</td></tr>
<tr><td>Power Grid Proximity</td><td>1.1 km</td></tr>
<tr><td>Major Settlements Proximity</td><td>1.055 km</td></tr>
</table>

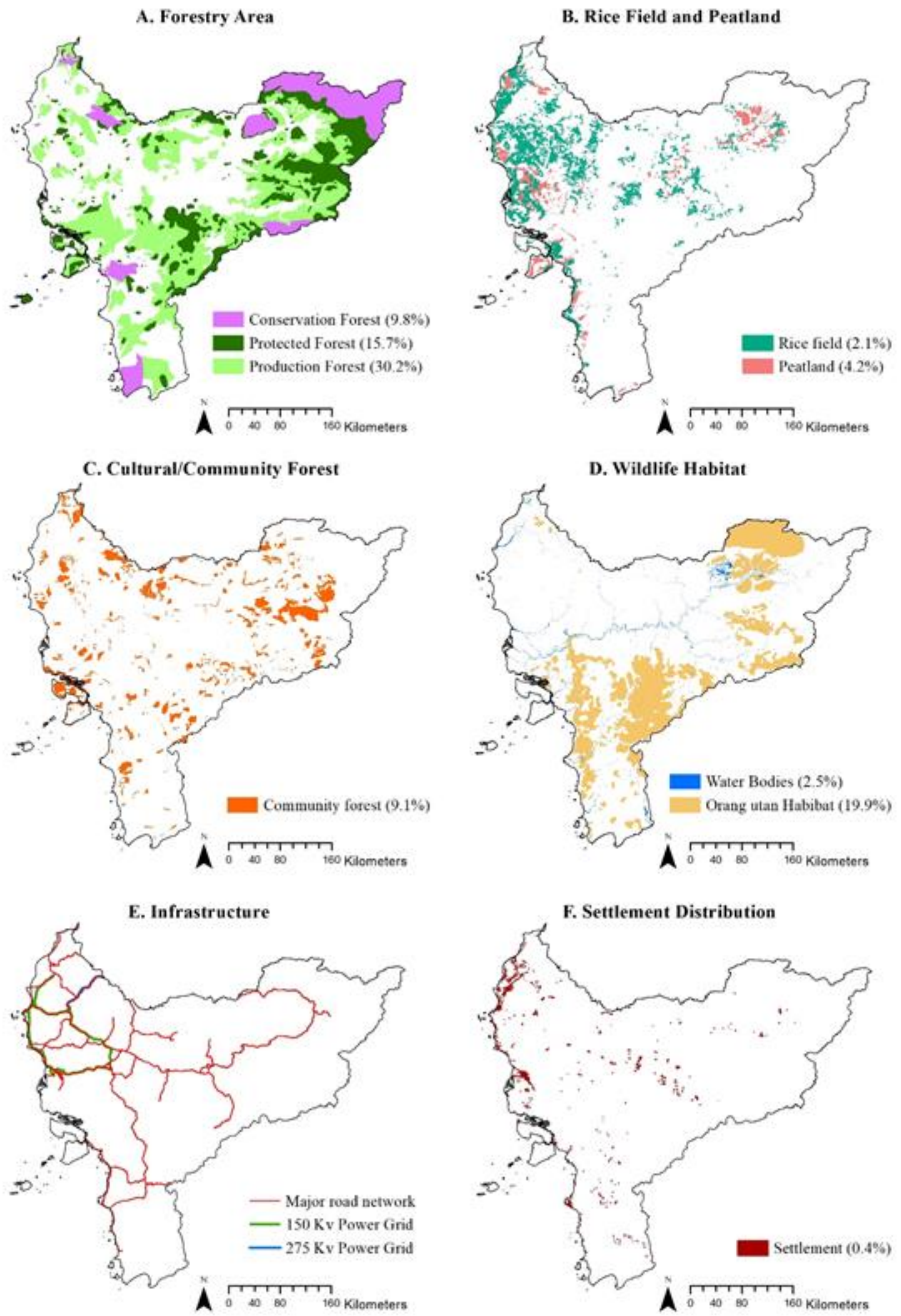


Figure.8 Thematic maps used as the constrains layer to exclude from site suitability analysis for the deployment of solar PV plants in WKP

Table.5 Criteria and their significance to the Solar PV site suitability.

Criteria layer	Significance
Global Horizontal Irradiation (GHI) 2.6 – 5.04 [kWh/m^2].	Determine the total amount of incoming shortwave radiation received by a horizontal surface, including both the direct and diffuse components of solar radiation (Al Garni and Awasthi, 2018). The highest grade scale is given to the location where it receives the highest amount of GHI value, and vice versa.
Air Temperature 17ºC - 28ºC	The efficiency of the PV system increases when the temperatures below 25ºC (Alami Merrouni *et al.*, 2018). Hence for the areas with lower average temperatures are more favorable in the context of enhancing PV system performance.
Relative Humidity (RH) 82% - 91%	The higher the amount of the RH in the atmosphere, absorb more shortwave solar radiation and causing certain dips in the total incident solar irradiation in the Solar PV surface (Doorga, Rughooputh, and Boojhawon, 2019). The lower humidity area is given with the highest rank value in the AHP algorithm.
Elevation (in Meter), Slope (in %) and land Aspects (in Direction)	High slope areas are not preferable due to the high risk for accessibility and needed additional cost for land leveling. Elevation below 90 m, the slope must less than 9% with north/south-facing are given more priority.
Proximity to the Grid in km	The farther the Proximity from the Grid, the greater the investment value must be provided by the solar power plant and the greater the risk of evaporation of electricity during the power injection to the grid. The highest-grade scale assigned to the area nearest to the power grid.
Proximity to the Road in km	Proximity to the road is an essential factor for transporting large and fragile equipment such as solar modules. The highest-grade scale assigned to the area nearest to the road.
Proximity to the Major Settlement	The maximum radius of 10 km from the city/settlements is considered as proximity layer for the preferable development of the PV site.

B. Spatial analyst tool

Spatial analyst toolkit in ArcMap GIS software has been used for processing the raster and vector data. DEM raster data has been preprocessed using the FIL function tool in the Hydrology tool to generalize the uneven distortion in the elevation as well as depression in the input DEM data. Slope and Aspect map has prepared from processed DEM data using the surface spatial analyst tool. The processed map is shown in Figure.9.

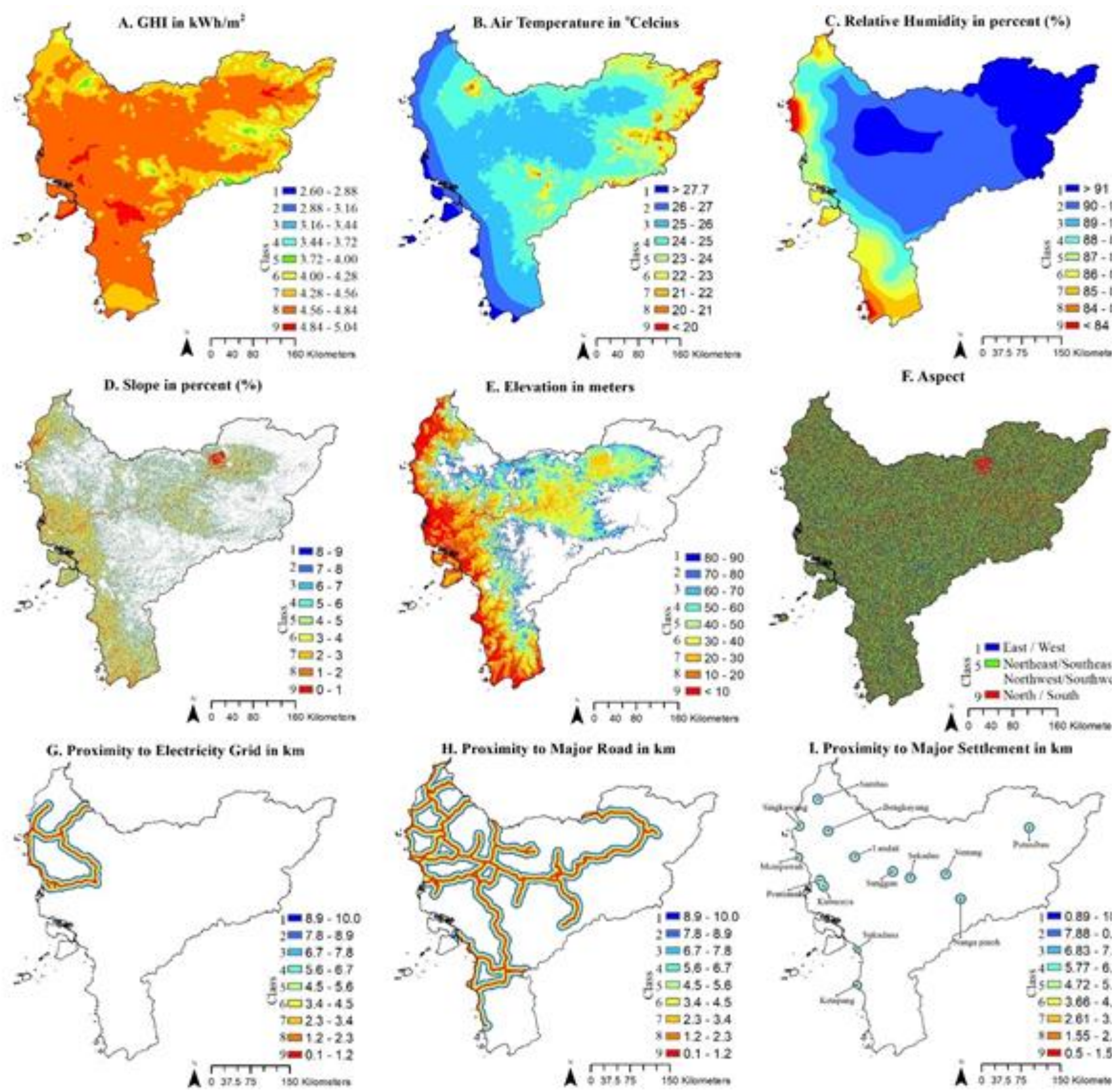


Figure.9 Reclassified layers of input criteria and factor including global horizontal irradiation, air temperature, relative humidity, slope, elevation, aspect, proximity to grid, road networks, and settlement (reclassified class ranges from class 1 (blue color)

C. Raster reclassification

Since the AHP rank priority is assigned using a numerical grade scale from 1 to 9, where 1 indicates the least suitable and 9 indicate best suitable for solar PV plant development. So far included nine criteria layers are further reclassified into nine grade classes with an equal class interval. The respective range used to reclass each input criterion shown in the appendix Table.A2. Reclass tool in ArcGIS software was utilized to perform the reclassification function and the same tool is embedded in the flow modeler tool in the SolarBoost (Figure.10).

D. Euclidean Distance

Euclidean Distance was calculated for each cell the Euclidean distance to the location such as power grid, major road, and major settlements performed in the spatial analyst tool. A maximum Euclidean distance of 10 km for each location is used for site suitability study. Reclassification was applied with nine equal class for input layers such as grid, road, and settlements (Table.4 and Figure.9). Euclidean Distance tool was embedded in the SolarBoost GIS modeler function.

E. Weighted Sum Spatial overlay

Weighted sum spatial overlay analysis of selected nine criteria raster layer by multiplying each concerning given AHP weight and sum together to form an overall weighted map. The reclassified input criteria layer is sum together with the AHP weight rank to prepare a final weighted map for the solar PV site suitability map. The weight for each criterion was derived from AHP pairwise comparison. Weighted sum overlay map has weight value ranges from 1 to 9 as per the AHP weight and reclassified grade of each pixel in the nine criteria layers. The final weighted sum map was categorized into four class groups with final sum weight for analyzing the suitability map such as the least suitable (1-3), moderately suitable (3-5), suitable (5-7), and best suitable (7-9) respectively.

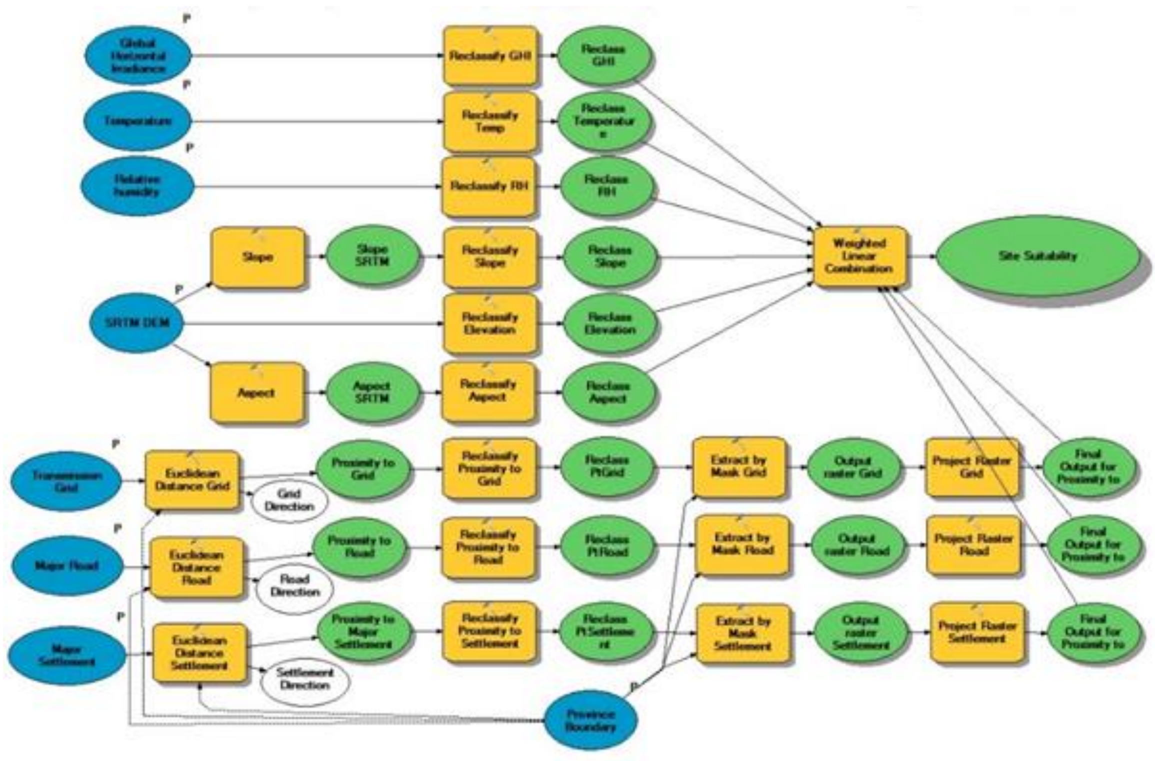


Figure.10 Schematic Model builder application executed for the large-scale Solar PV site suitability analysis

2.4.5 Analytic Hierarchy Process (AHP) process

The Analytic Hierarchy Process (AHP) is a powerful tool for MCA using ratio scales for pairwise comparison to make a judgment or decision from several criteria (Saaty, 2002). The SolarBoost has applied the standard Criteria grade scale to perform the pairwise comparison. The pairwise comparison matrix is generated for nine factors and the ranks are assigned to the relative importance of two factors using a numerical scale from 1 to 9 (see Table.A1 in the Appendix).

Then, to check the consistency of the decision maker's pairwise scores, we have calculated the Consistency Index (CI) by:

$$CI = \frac{\lambda_{max} - n}{(n-1)} \qquad (1)$$

Where,

λ_{max}- the eigenvalue of the pairwise comparison matrix

n- the number of the criteria.

With which the Consistency Ratio (CR) is calculated by dividing CI by the random consistency index (RI). The RI values for the appropriate ***n*** values have been considered (Saaty, 2002).

$$CR = \frac{CI}{RI} \qquad (2)$$

It is worth mentioning that, to obtain significant results with the AHP technique, the CR must be equal to or less than 10%, otherwise, the pairwise comparisons values must be recalculated again to improve the consistency.

2.4.5.1 Estimation of Electric power generation

Depending on the chosen PV technologies and the GHI value, the required area for the production of 1 MW energy can vary. In general, two hectares of land required to produce the one MW electric power for the location close to the Equator (Konsultan Basel, 2010; MEMR, 2015). The yearly electric power generation potential in WKP is estimated based on the calculated yearly solar radiation per unit surface, and the efficiency of the solar panel to convert solar radiation into electricity. To estimate the annual electric power generation potential from the available land in WKP, the Gastli and Charabi, (2010) equation is used.

$$GP = SR \times CA \times AF \times \eta \times 365 \qquad (3)$$

Where,

GP - annual electric power generation potentiality (kWh/year),

SR - average annual daily global solar horizontal irradiation (kWh/m^2/day),

CA - available best suitable land area for large scale PV development (m^2), AF - area factor, indicates what fraction of the calculated areas is exploitable for PV panel. An area factor (AF) of 0.70 was chosen based on the maximum fraction of land that can be covered with solar panels with minimum shading effect.

Ƞ - The efficiency with which solar panel converts sunlight into electricity. According to Doorga, Rughooputh, and Boojhawon, (2019) a PV panel efficiency (Ƞ) of 16% can be selected since this value is representative of the average efficiency of commercial silicon modules.

2.5 Implementation of SEIS

The innovative and spatial site suitable mapping methodology carried in the SolarBoost research will be a model to portrait solar power capability in Indonesia. Since, the present research has explored the potential sites for deployment of large scale grid connected solar PV plants, as a case study in WKP to boost the country's solar energy capacity without the deforestation or invasion of land protected areas. However, delineation of feasible sites for large scale solar PV deployment is highly determined by the criteria layer that has been prioritized and the corresponding weight assigned for the selected factor, these are arbitrary to the research objective. In the present study, the criteria and factor given priority based on the objective of identifying the best suitable sites for the large scale solar PV plant such as proximity to the grid as well as proximity to the major road in the WKP respectively in the two different approaches. Hence the site demarcated, and the area quantified as the potential energy in one approach simultaneously changes to other approaches concerning the priority implemented for specific criteria in the corresponding approaches. The SolarBoost research methodology can be utilized in any other provinces in Indonesia as well as any other region considering the locally favoring factor. As per the WKP considered, the province has high GHI to produce the potential solar electricity. However, most of the suitable site is far from the power grid and major road which will depressingly indicate the huge financial budgeting for the initial installation and the project startup. Hence the best suitable area classified under approach-1 is economically feasible for the large scale deployment of solar PV plants such that they are very close to the power grid as well as the area has a high amount of GHI through the year. While the other approaches implemented in the present study are indicating potential sites for the deployment of large scale solar PV plants near to the major roads in WKP. Since these regions are not connected with a power grid network, hence the grid connectivity needs to be assured to develop the large scale solar PV project. These potential sites have to be considered for energy sustainability planning as well as the future extension of the power grid.

The comprehensive research outcomes of the SolarBoost project have been portrayed in the web-oriented GIS mapping application tool, which is publicly accessible to anyone. The GIS-based web mapping tool can be available at http://webmap.solarboost.tech/. The web-oriented mapping tool is developed with a GIS package enabling the integration of satellite retrieved data with Indonesian local information of administrative, infrastructure, electric network, and land usage to inform the beneficiaries and stakeholders over the existence and potential uses of SolarBoost GIS-based web mapping tool for the sustainable solution for the energy problem of Indonesia. The SolarBoost web mapping tool is a responsive widget-based application that runs on all devices (PC, laptop, tablet, smartphone) as well as all platforms (Apple, Android, and Windows). The complete introductory guide to explore and extract the data and information about solar energy availability as well as the site suitability analysis for the deployment of large scale solar PV farms in the West Kalimantan Province from the SolarBoost Web Mapping Application provides at the download tab button in the web mapping website and also at the main project website of Solarboost. The SolarBoost highly recommends to follow this user manual for getting familiarity in accessing and visualizing the Solarboost data and information from the web map tool. Some of the key functionality in the SolarBoost web mapping tool are represented below.

2.5.1 Basic functionality

SolarBoost has been employed with multiple layers of data such as satellite retrieved data (including surface radiation, climatology, and topographic data), and Indonesian local information (including the land cover, protected layer data, administrative, infrastructure, and electric network). Detailed information on these datasets is mentioned in Table.3, Table.4 and Table.5. The spatial maps of all these datasets are displayed in the SolarBoost web map in the **Layer** Button with the corresponding subtitle. Map users can explore the spatial pattern of each data layer and analyze the spatial heterogeneity in the data. Users can visualize and analyzing any region or place with individual data layers. E.g. Studying the variable such as GHI, temperature, and relative humidity for any selected places. The screenshot shown below represents all available spatial data that are embedded in the subtitle according to the nature of the data.

SUITABILITY MAP; The represents the result outcomes of GIS-AHP Multi-Decision-Criteria-Analysis (MDCA) for the deployment of solar energy plants.

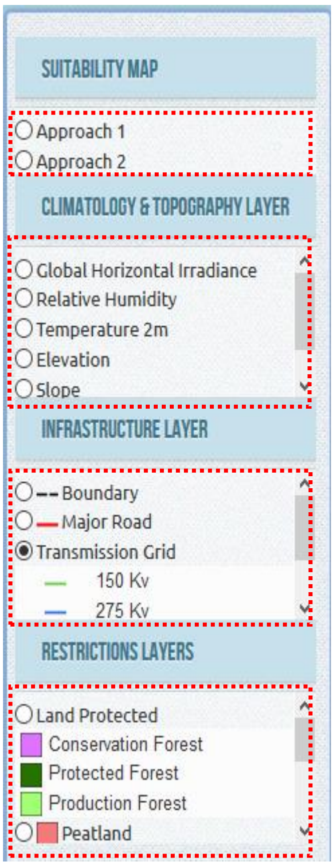
Approach 1: Weighting criteria approach focuses on the distance between the prospective solar plant and the existing power grid.

Approach 2: Weighting criteria approach focuses on the distance between the prospective solar plant and the existing road infrastructure.

CLIMATOLOGY & TOPOGRAPHY LAYER: Contain major input data used for the GIS-MDCA integration in the AHP algorithm.

INFRASTRUCTURE LAYER: this layer includes major roads and power networks.

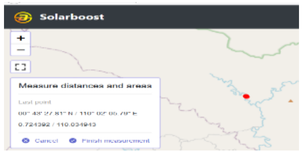
RESTRICTION LAYERS: The Restriction layers include information about the major protected and conservation land areas which are subject to National and Regional law enforcement and regulations as vulnerability zones in the WKP.



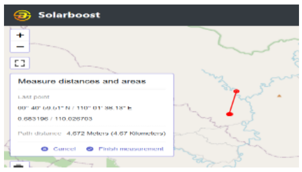
BASIC TOOLS:

The web mapping tool has all the basic functionality such as ***Zoom in/out****, **view full-screen mode**, **Measurements,** and an option for* ***print*** the web map viewer. These embedded tools are located at the top left corner of the web map viewer. The measurement tool can be used to calculate the quantitative measurements such as point location, path distance as well as area using the tool **Create a new measurement.** The user can apply this tool to extract the pointwise data for selected sites to collect the geographical coordinated value. The linear measurements such as path distance can also utilize by adding two or more point locations in the map viewer. The distance between two locations, distance along with the road or power grid, the distance between solar sites and road, etc. can be measure by this leaner tool. The surface area for any particulate features of user interest can also measure by adding three or more than three points in the measurement tool. The quantitative measurements such as area and perimeter can be estimated from this tool. Upon adding the required number of points in the measurement tool user has to click the **Finish measurement** tab in the tool to display the measure quantities in SI units. The below screenshot figure shows the geometry functionality calculated on the web map.

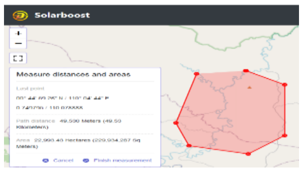
Last Point:



Path Distance:

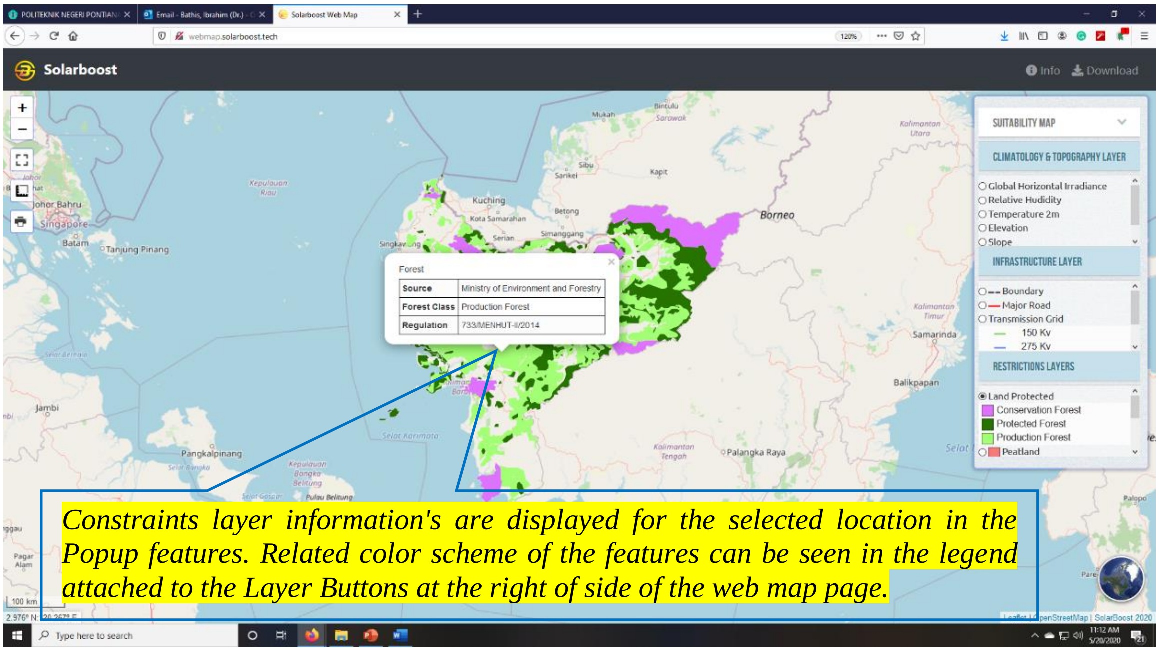


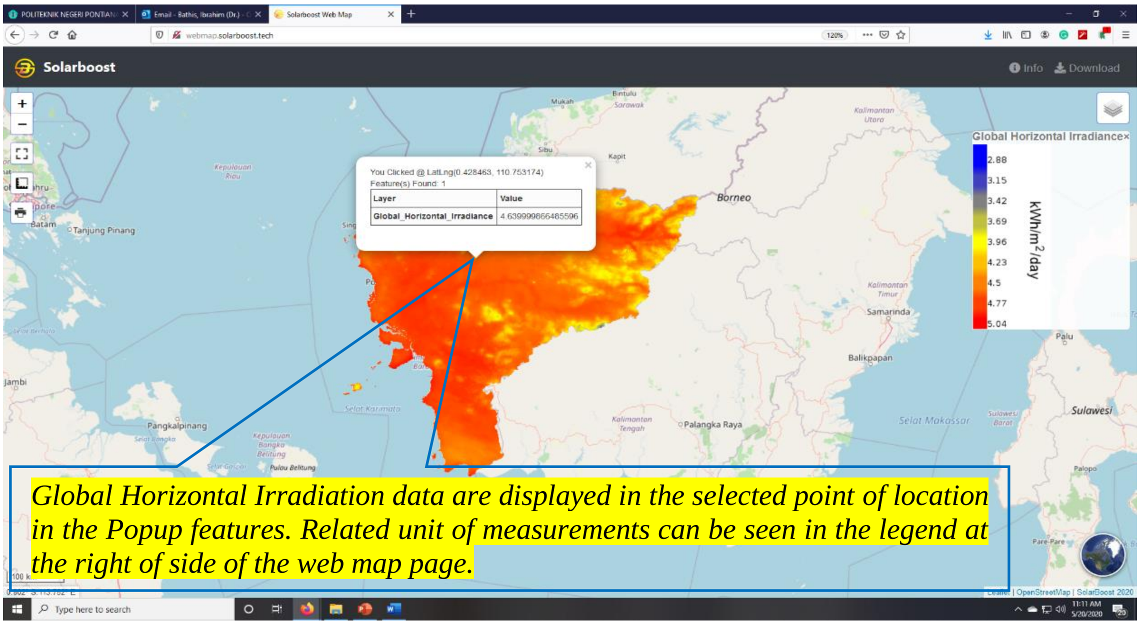
Area:



2.5.3 Attribute data extraction and Pop-up Layers

Each spatial data embedded in the **Layer** Button have the additional attribute information which is available at the popup level in the main map viewer. Popup features may be enabled by clicking anywhere in the spatial data displayed on the main map viewer. These popup features enable extracting further finer information on each spatial layer at a selected point of interest in the main map viewer. Some of the examples are displayed in the following screenshot.


Solarboost
Info
Download
SUITABILITY MAP
CLIMATOLOGY & TOPOGRAPHY LAYER
Global Horizontal Irradiance
Relative Hudidity
Temperature 2m
Elevation
Slope
INFRASTRUCTURE LAYER
Boundary
Major Road
Transmission Grid
150 Kv
275 Kv
RESTRICTIONS LAYERS
Land Protected
Conservation Forest
Protected Forest
Production Forest
Peatland
Forest
Source
Ministry of Environment and Forestry
Forest Class
Production Forest
Regulation
733/MENHUT-II/2014
Constraints layer information's are displayed for the selected location in the Popup features. Related color scheme of the features can be seen in the legend attached to the Layer Buttons at the right of side of the web map page.


Solarboost
Info
Download
Global Horizontal Irradiance
kWh/m²/day
2.88
3.15
3.42
3.69
3.96
4.23
4.5
4.77
5.04
Layer
Value
Global_Horizontal_Irradiance
Global Horizontal Irradiation data are displayed in the selected point of location in the Popup features. Related unit of measurements can be seen in the legend at the right of side of the web map page.

3. Analysis of Solar energy potential

3.1 Theoretical potential (GHI)

Solar radiation is the fuel for the solar energy systems and the extraterrestrial condition such as the atmospheric condition, solar geometry, slope, and shadows are the key factor that depends on the viability of solar sources at place and time. The solar PV power energy system capable of producing energy using the following types of solar resource data.

1. **Direct normal irradiation (DNI).** The DNI is most essentially solar parameter for energy yield calculation and performance assessment involved in thermal (concentrating solar power, CSP) and photovoltaic concentration technology (concentrated photovoltaic, CPV).

2. **Global horizontal irradiation (GHI).** The GHI the most important parameter for energy yield calculation and performance assessment of flat-plate photovoltaic (PV) technologies and it is the total amount of incoming shortwave radiation received by a horizontal surface, including both the direct and diffuse components of solar radiation. The amount of annual and daily solar surface irradiation in a region is the chief governing factor to locate and identify the best site to install the solar farms because the intensity of radiation determines the magnitude of the electrical output from a PV system. The PV modules can utilize both the diffused and Direct irradiation (sum GHI) and are economically optimal where such solar resources are 4 kWh/m^2/day or greater. GHI data for the WKP was obtained from solar energy resource data provided by the World Bank Group (WBG). Since WKP receives GHI values from 2.6 to 5.04 (kWh/m^2/day) with an average of 4.58 kWh/m^2/day with almost stable in entire the year possess highly suitable for the solar energy exploitation (Figure.11).

3. **Global tilted irradiation (GTI).** GTI as a total of scattered radiation, direct reflected and received in the solar power system that utilized defined tilt and azimuth, fixed or the sun tracking system. The SolarBoost has been utilized the high resolution publicly disclosed satellite retrieved data by WBG, with SSI, air temperature, and PV output calculations from 1999 to 2016, with an acceptable resolution of 275x275m. To estimate the theoretical potential or the geographical solar power potential in the WKP, GHI data has been processed by ArcGIS software. The detailed information regarding the GHI data has been discussed in the earlier section (2.4.3.2 Criteria). Since the GHI is had a higher value in WKP, the whole WKP can utilize for solar power developments. Figure.12 shows the total theoretical solar potential in the major city of WKP.

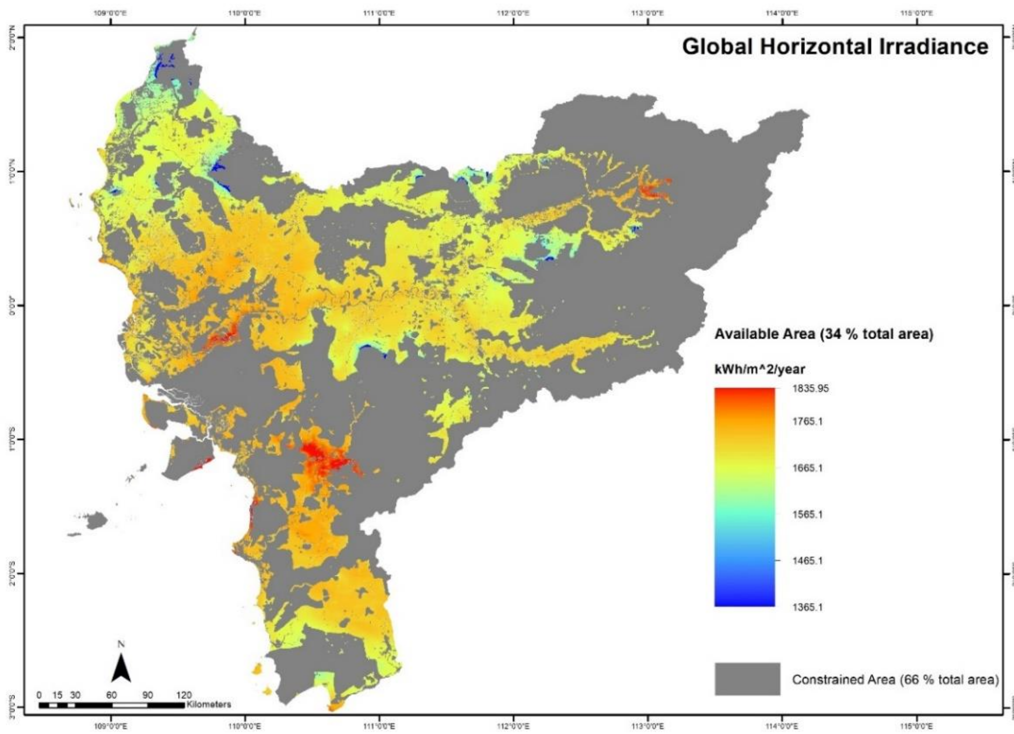


Figure.11 Average Annual Daily GHI potential in West Kalimantan Province with the exclusion from the protected area

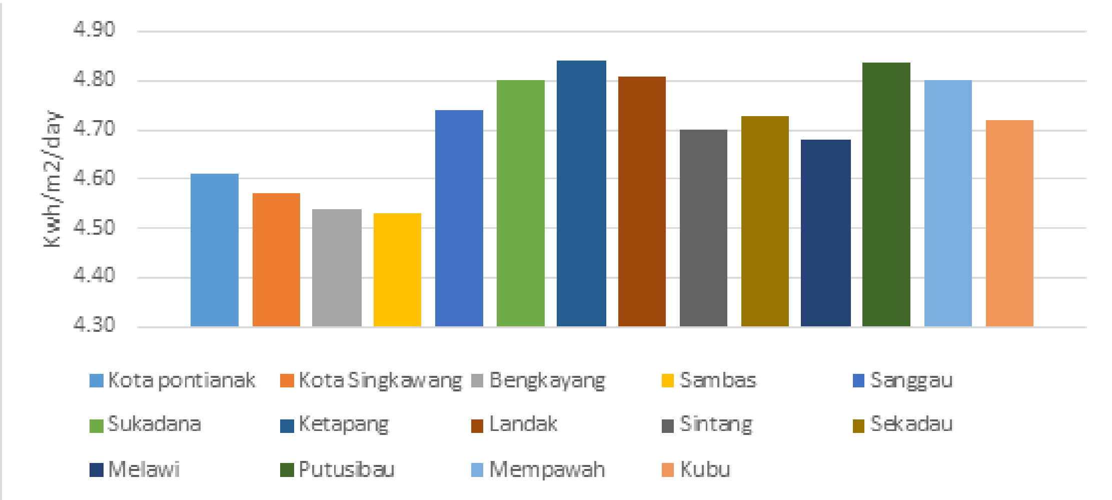


Figure.12 GHI potential for each city in West Kalimantan Province. Ketapang and Putussibau were considered as the region with the highest potential of solar irradiation.

3.2 Exploitable energy (excluded constrained area)

Since the WKP has been fortunate to the geographical position at the equatorial region having a higher GHI value through the year encouraging promising scope for the solar PV power development. However, WKP has been rich in natural biodiversity and ecosystem that gain the protected land with national and regional laws enforcements and the regulation for conservation. However, the initial process of the SolarBoost is to demarcate the constraints layer that forbids land conversion activities of solar PV plants. These constraints layers which have national and regional laws enforcements and the regulation as vulnerability zones include Land cover (forestry area and rice field), Protected lands (Peatland, Cultural or Community forest, Water bodies and Wildlife or endangered habitat), and Infrastructure layer (Settlement area, road, and power grid network). The detailed information on the constraints layer is depicted in the earlier section (2.4.3.1 Constraints Layers). When the restricted land cover and protected layers are considered as constraints layer, the concurrent area covers more than 66% of the total land area in the WKP leaving only remaining less than 34% feasible for the solar PV plant deployment. With accompaniments to the GHI, the potential exploitable solar power capacity was estimated using the general energy equation (Eq. 3). The annual energy generation potential in the WKP is shown in Figure.13.

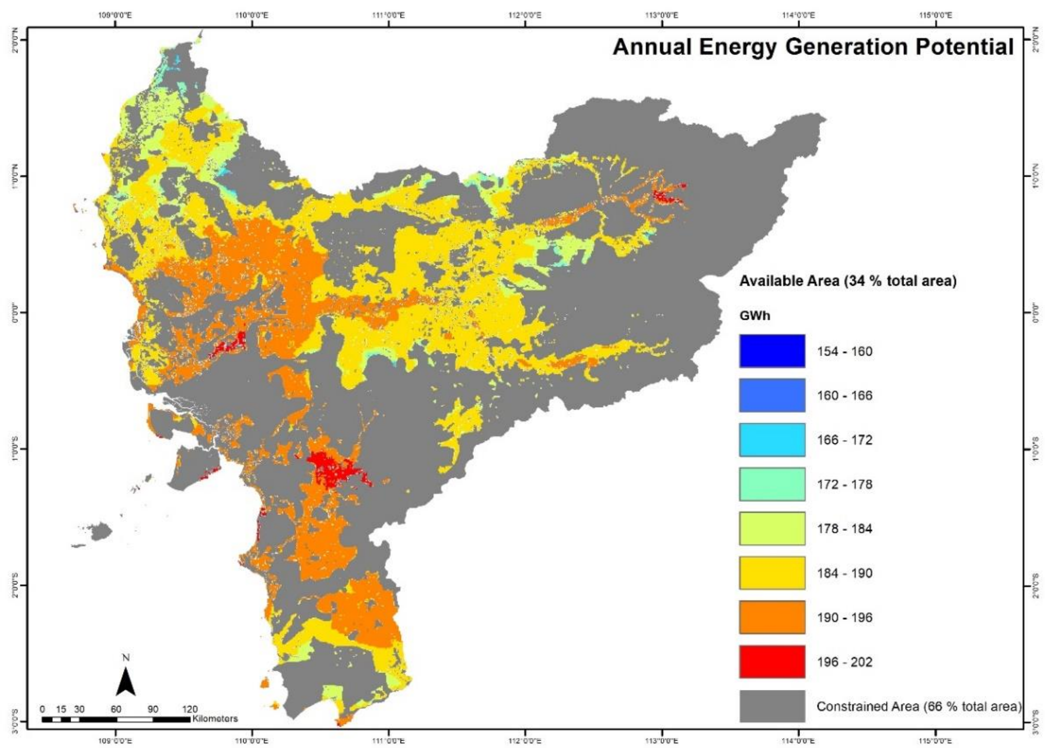


Figure.13 Annual energy generation potential in West Kalimantan Province.

3.3 Site suitability

SolarBoost assessed the feasible site for large scale solar PV power developments in the WKP with two possible approaches such approach-1 for business as usual and approach-2 for Progressive Expansion analysis.

Global Horizontal Irradiation (GHI) is the key factor in PV plant development which gained an important consideration in the major suitability study research. However, the WKP has fortunate to locate in the equatorial region, the GHI value is high and constant throughout the year, GHI factor is assigned priority rank after the proximity to the location factor such as power grid in the first approach and road in the second approach while assuring a feasible amount of the GHI value for potential energy production in the WKP. SolarBoost has performed the integrated AHP criteria analysis and GIS weighted spatial overlay sum analysis for delineating the suitable site for the solar PV plant deployment in both the two approaches. The detailed work methodology was explained in section 2.4 Design of SEIS (SolarBoost). AHP algorithm was implemented to the pairwise comparison of the selected nine criteria. The more details on AHP implementation is mentioned in Section 2.4.5 Analytic Hierarchy Process (AHP) process. Detailed data on criteria layers are mentioned in

Table.3, Table.4, and Table.5, and reclassified information on each criterion is mentioned in the appendix (Table.A6). The SolarBoost has arrived with CR index below 10%, such as CR for approach-1 is 4.2%, and CR for approach-2 is 4.1%. The pairwise comparison matrix and eigenvalue matrix for both two approaches are shown in the appendix (Table.A3 to Table.A8).

The detailed criteria and factor value derived from the AHP algorithm for both the approaches are explained in Table.6 Criteria and their corresponding factor weight derived from the AHP model for the two different approaches in the SolarBoost.Table.6. Upon generating the AHP weight for each factor, the weighted overlay spatial analysis was applied in the ArcGIS software to prepare the integrated final overlay map for the solar power site suitability map. The detailed stepwise analysis employed for mapping the site suitability for the large-scale solar PV plants in the WKP has been run using the ArcGIS modeler function as shown in Figure.10.

The final land suitability map that has the aggregate weight value ranges from 1 to 9 scale indicating the level of suitability such as the lowest value of 1 represents the least suitable whereas the highest value of 9 indicates the best suitable site for the large scale solar PV plants deployments. To analyze the final maps, the weighted overlay analysis suitability maps were grouped into four suitability categories such as the least suitable (1-3), moderately suitable (3-5), suitable (5-7), and best suitable (7-9) respectively.

3.3.1 Business As Usual (BAU) analysis

The PLN statistic data shows that average electricity selling for the last 5 years (2013-2017) was 7.04 per year whereas electricity selling in 2028 was projected as 4,309 GWh according to the economic growth assumption of 6.5 per year. The huge demands are expected to be concentrated on the existing Khatulistiwa power grid as the potential production capacity at the power grid. While considering the future energy projection scenario and economic profit against the construction investments of the new power grid, the SolarBoost has analyzed the solar PV site suitability and energy generation capacity at proximity to the existing power grid, where the producible energy can be directly injected to the existing power grid without additional cost, this will fast track the project commencement and installation process. As the National energy policy has been considered to improve the energy mix for 2025 with 23% of the renewable resources in Indonesia. Though the solar renewables are abundant in the WKP, however the spatial demarcation of the feasible site location for the solar PV plant deployment is limited. Especially, this approach solves the inexistence of such spatial data for the policy planning and solar PV power plant development in the WKP.

Table.6 Criteria and their corresponding factor weight derived from the AHP model for the two different approaches in the SolarBoost.

Criteria	Aggregate criteria weight for Approach		Factors	Factor Weight for Approach	
	1	2		1	2
Climatology	0.355	0.344	Global Horizontal Irradiation	0.25	0.222
			Temperature	0.086	0.093
			Relative humidity	0.019	0.029
Topography	0.114	0.15	Elevation	0.026	0.03
			Slope	0.052	0.71
			Aspect	0.036	0.049
Proximity to Location	0.531	0.506	Distance to Grid	0.272	0.0
			Distance to Major Road	0.148	0.351
			Distance to Major Settlements	0.111	0.155

When the approach-1 is considered there is about 46.60 km^2 area identified as the best suitable for the solar PV plant deployment. If these areas are deployed with solar PV plants, there can produce 8.91 TWh solar electric energy annually only from the best suitable site (Figure.14). Though the best suitable sites are special consideration for the solar PV deployments, the suitable site class which has an area of 2615 km^2, also feasible for the large scale solar PV deployment (Table.7). However, the WKP has a limited grid network with only connected to the major cities such as Pontianak and Singkawang, hence the best suitable and suitable sites in this approach are only concentrated to these cities even though the WKP has high GHI factor. The massive area is classified as the least suitable and moderate suitable because of the far distance from the existing grid. These potential areas can satisfactorily fulfill the gross energy demand in the whole WKP several times greater than the present production rate. Since the net electricity production in WKP from all sources by the PLN in the year, 2018 is only 2.725 TWh. The best suitability class near the city of Mempawah in approach-1 has an exceptional exploitable area of 3019 hectares with an annual solar energy production capacity of 4.23 TWh. The average annual electricity demand of the entire city of Mempawah in the year 2023 is less than 2.4 TWh which is merely less than 50% of the actual annual producible solar energy from the available best suitable sites. Since this site is close to the existing power grid, the excess electricity produced can be injected into the power grid to enable electricity access to nearby cities including Pontianak and Singkawang where the energy demand is still high.

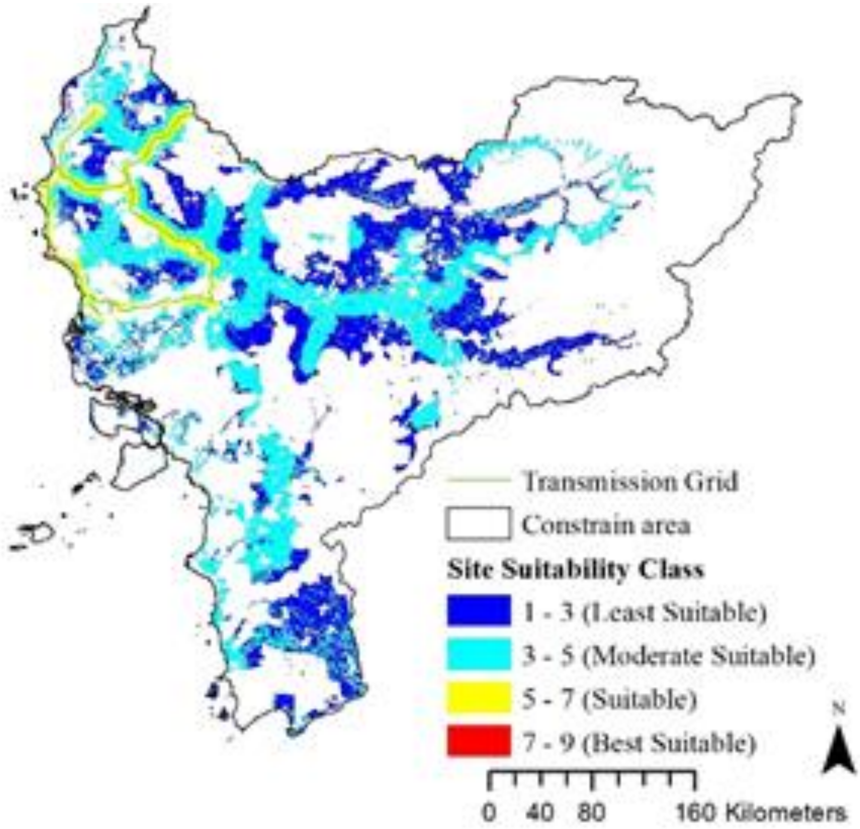


Figure.14 Spatial site suitability map for the large-scale PV deployment when the approach-1, Proximity to the power grid was considered.

Table.7 Statistical summaries of feasible area for the large-scale PV development in the WKP derived from Approach-1, proximity to grid, and corresponding projected annual Solar energy generation potential in TWh/year.

Suitable Class	**Exploitable Area**		**Energy potential in TWh/year**
	km^2	%	
Least Suitable	21537.00	14.67	4090.97
Moderate Suitable	24323.86	16.57	4663.51
Suitable	2615.42	1.78	498.28
Best Suitable	46.60	0.03	8.91
Total	48522.88	33.05	9261.67
% to total WKP land area (146807)			

3.3.2 Progressive Expansion analysis

Progressive expansion analysis is implemented while considering the proximity to the road and major settlement in West Kalimantan Province as more priority for the site suitability for the large scale Solar PV deployment. Since the WKP limited grid connection and has huge electricity demand from the major settlements, the existing power connection fails to supply the electricity to the remaining region which has not been connected with the major power grid. This approach is focused to is map the exploitable for the sits for the large scale solar PV development which are far from the grid connection and are close to the exiting major road. However, the whole WKP has been characterized by a productive amount of GHI, the priority rank for GHI has been given next to the location factor such as proximity road and major settlements. The approach also considered the assumption of the PLN business plan (RUPTL 2019) about the transmission expansion in respect of the demand BAU scenario. the potential site which is demarcated by the SolarBoost can bring consideration for future transmission expansion such that there can be a possible way of connecting the potential sites with the power grid. To tackle consumer growth and electricity demand, the suitable site or the solar PV power plant should be proximity to the major settlements and road. Progressive expansion scenario can also fulfill the renewable energy mix target in 2023 with 23% of renewable energy and supply connection to the whole WKP.

However, in the Progressive expansion analysis, the area which is close to the major road and settlements with reasonable GHI value will be classified as the best suitable site (Figure.15). The available area for the large scale solar PV development is estimated as 108 km^2 and 11506 km^2 of the area as the best suitable and suitable respectively (Table.8). The city of Putussibau has notified with excellent exploitable best suitable sites covering an area of 1689 Ha. The average annual energy demand in Putussibau is about 1.7 TWh against the total annual solar energy producible capacity of 3 TWh. Similarly, major settlements such as Sintang, Sanggau, Nanga Pinoh, Sukadana, and Ketapang have a massive best suitable area for solar PV development. Considering the potential exploitable solar energy resources in these populated regions would possess worthy for further grid extension to promote sustainable solar electricity this will have a great concern for the environment as well as reduce the financial burden against the high-cost diesel-powered electricity.

Table.8 Statistical summaries of feasible area for the large-scale PV development in the WKP derived from Approach-2, proximity to road, and corresponding projected annual Solar energy generation potential in TWh/year.

Suitable Class	Exploitable Area		Energy potential in TWh/year
	km^2	%	
Least Suitable	14568.91	9.9	2758.76
Moderate Suitable	22339.82	15.22	4271.06
Suitable	11506.28	7.84	2196.54
Best Suitable	108.58	0.07	20.96
Total	48523.59	33.03	9247.32
% to total WKP land area (146807)			

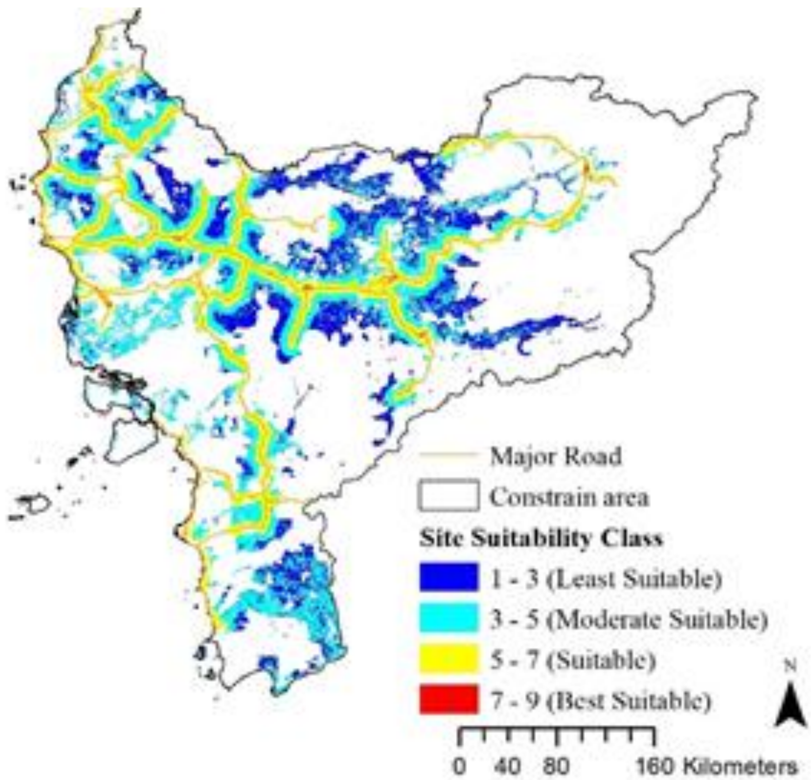


Figure.15 Spatial site suitability map for the large-scale PV deployment when the approach-2, Proximity to the power grid was considered.

3.4 Impact of the results

Though the WKP has been representing potentially exploitable sites for solar energy production, yet the solar renewable energy production is underdeveloped. 80% share of the energy sector of Indonesia has been conquered through fossil fuel and coal, causing a severe environmental and climatic change problem in the country. Since the solar energy sources are environmentally clean such as no GHG and CO_2 emissions, the country considered a vital strategy in the gross energy sector and given more priority in the national energy policy. The integrated web-oriented GIS spatial mapping solution provide by the SolarBoost will be new research complements to WKP solar PV power sector for strengthening the sustainable focus on clear and green energy promotions as well as to reduce the country's dependence on imported oil which has been one of the country's burdens in the financial budget. The exceptional spatial information of site acute suitability analysis for deployment of large scale solar PV power plant and also enabling to perusing spatial location data on local land use, infrastructure, and grid connection data, will be a great asset for the investors as well as PLN and the local government to initiate a strategic plan for the sustainable energy security in the province.

Nevertheless, the constraints layer has a massive area, but even the WKP has still enough power generation capacity which is several times greater than the current and future electricity demand. The average annual power generation estimated in the present study was based on the annual average GHI value and this may be fluctuating to the local climatic topographic conditions or also may vary with the daily or Monthly calculation. The ideal site from the best suitability class for the large scale solar PV development has been noticed near the city of Mempawah in both approaches with an average exploitable area of 3019 hectares and an annual solar energy production capacity of 6.63 TWh. Since this location is close to the existing power grid, it can easily connect to the existing power grid to enable the electricity access to the nearby cities including Pontianak and Singkawang. The exploitable best suitable site is also situated in the Pontianak city, Singkawang, Bengkayang city, and Sambas city where the exiting grid network is worthy to connect for electricity networking. These are also have characterized by massive area for the suitable class for solar PV development, can be considered for grid networking since these sites are favorable with criteria factor. The city of Putussibau has been notified with excellent exploitable sites in the second approach with covering an average area of 1689 Ha. Similarly, Sintang, Sanggau, Sekadau City, Nanga Pinoh, Sukadana, and Ketapang are also had massive sites for solar PV development in the second approach, since these regions have potential solar energy generation capacity with the highest GHI factor among WKP. Yet there is no connected power grid at these regions, further grid extension or providing with concentric interconnection would be worthy for the encouraging the large solar electricity production for the sustainable environmental emission-free energy and to overcome electricity energy demands in these regions. The SolarBoost highly recommends considering these areas which have potential in solar energy production capacity for developing the Solar PV power plants with ensuring that these inversions will not affect the natural greenery in the region.

4. Future works

4.1 SolarBoost future development

Currently, there is no large-scale renewable energy including PV power plants in West Kalimantan Province. In the future, with extensive and careful data collection, the economic and technological objective can be calculated to find the site that has the highest potential energy and lowest cost of energy production. The site-specific grassroots level study for the solar PV and quantitative measurement of the reduction in Green House System (GHS) and CO_2 emission as compared to the fossil fuel and the coal energy source should be conducted to achieve the government target. Even though only solar PV systems are considered in SolarBoost, the suitability approach can easily be adapted for the other renewable energy resources including wind and hydro.

4.2 What is demanded by the stakeholders?

SolarBoost conducted a web-based GIS mapping tool for the stakeholder that can support the boosting of solar energy projects in Indonesia. The main stakeholders who have assigned the responsible functional improvement of renewable energy in Indonesia are underlined in Table.9 (Yudha and Tjahjono (2019). The detailed on the corresponding stakeholders and their working demands role in the country are highlighted in Table.9.

- **National level**
    a. Ministry of Energy and Mineral Resources
    b. National energy board
    c. National development and planning agency
    d. Ministry of finance
    e. Ministry of Agriculture
    f. Ministry of Environment and Forestry
    g. Ministry of Home affairs
    h. Parliament
    i. Ministry of state-owned enterprise
    j. PLN
- **Regional level**
    a. Governor/Bupati administration office
    b. Regional parliament
    c. Regional development and planning agency
    d. Energy and Mineral resources agency
    e. Environment and forestry agency
    f. Public work agency
    g. NGO
    h. University
    i. Others

Table.9 Chief stakeholders and their corresponding demanded roles in Indonesia

Stakeholders	**Demanded role**					
	Political	**Economic**	**Social**	**Technology**	**Environment**	**Legal**
Ministry of Energy and Mineral Resources	Proposal for regional energy planning	Stabilizing price regime		Local component regulation		The legal framework for boosting the solar system
National energy board	Monitoring the development of the solar system					
National Development Planning Agency	Planning energy strategies					Permit issuance
Ministry of Finance		• Fiscal incentives • Budget composition • Loans • Govt. equity		Fiscal incentives	Incentives for greenhouse gas reduction	
Ministry of agriculture					Supporting the other stakeholder for the agriculture protection	
Regional/Province office	Finishing RUED		Mitigating the social impact		Supporting the environmental impact assessment	Permit issuance for solar development
Ministry of Environment and Forestry			Monitoring the assessment of the social impact		Monitoring the assessment of the environmental impact. Greenhouse gas reduction. Air pollution reduction action.	
Ministry of home affairs	Coordination with the local government Registration for RUED					
National/local Parliament	Approval for local general planning and regulation, and regional general plan					
Ministry of state-owned Enterprise				Cooperation with the national-state industry		
PLN		Investment for solar energy				
University	Calls for the regulation that is driven by market			Cooperation with Industry to conduct the research for solar cell and system improvement		
Others		Bank or financing institute can provide the soft loan			NGO can provide the training for the RE awareness	

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6. Appendix

Table.A1 AHP Criteria grade scale used in the SolarBoost

Criteria Grade	Grade Definition	Description
1	Equal importance	Two criteria contribute equally to the objective
3	Moderate importance	The contribution slightly favors with one criterion over another
5	Strong importance	The contribution strongly favors with one criterion over another
7	Very strong importance	The contribution of one criterion is favored very strongly over another
9	Extreme importance	The contribution of one criterion over another is at the highest in the grade
2,4,6 and 8	criteria grades can be assigned to define the intermediate contributions	

Table.A2 Criteria and factor weights with their corresponding grades used in the AHP Algorithm

Criteria	Factor	Classes	Grade
Climatology	**Global Horizontal Irradiation** ($KWh/m^2/day$)	2.60-2.88	1
		2.88-3.16	2
		3.16-3.44	3
		3.44-3.72	4
		3.72-4.00	5
		4.00-4.28	6
		4.28-4.56	7
		4.56-4.84	8
		4.84-5.04	9
	Temperature (°C)	<20	9
		20-21	8
		21-22	7
		22-23	6
		23-24	5

		24-25	4
		25-26	3
		26-27	2
		>27.7	1
	Relative humidity (%)	<84	9
		84-85	8
		85-86	7
		86-87	6
		87-88	5
		88-89	4
		89-90	3
		90-91	2
		>91	1
Topography	**Elevation** <=90 (m), beyond 90 m is not suitable	>10	9
		10-20	8
		20-30	7
		30-40	6
		40-50	5
		50-60	4
		70-70	3
		70-80	2
		80-90	1
	Slope <= 9 (%), beyond 9 is not suitable	0-1	9
		1-2	8
		2-3	7
		3-4	6
		4-5	5
		5-6	4
		6-7	3
		7-8	2
		8-9	1
	Aspect (°Azimuth)	North	9
		Northeast	5
		East	1

		Southeast	5
		South	9
		Southwest	5
		West	1
		Northwest	5
Location	**Distance to Grid** 100-10000 (m), beyond 10000 m is not suitable	100-1200	9
		1200-2300	8
		2300-3400	7
		3400-4500	6
		4500-5600	5
		5600-6700	4
		6700-7800	3
		7800-8900	2
		8900-10000	1
	Distance to Road 100-10000 (m), beyond 10000 m is not suitable	100-1200	9
		1200-2300	8
		2300-3400	7
		3400-4500	6
		4500-5600	5
		5600-6700	4
		6700-7800	3
		7800-8900	2
		8900-10000	1
	Distance to Major Settlements 500-10000 (m), beyond 10000 m is not suitable	500-1555	9
		1555-2610	8
		2610-3665	7
		3665-4720	6
		4720-5775	5
		5775-6830	4
		6830-7885	3
		7385-8940	2
		8940-10000	1

Table.A3 AHP Pairwise comparison table for Approach-1

Criteria		more important	Scale
A	**B**	**A or B**	**(1-9)**
Proximity Grid	GHI	A	2
	Proximity Road	A	3
	Proximity City	A	3
	Temperature	A	3
	Slope	A	4
	Aspect	A	6
	Elevation	A	7
GHI	Proximity Road	A	2
	Proximity City	A	3
	Temperature	A	5
	Slope	A	6
	Aspect	A	7
	Elevation	A	8
Proximity Road	Proximity City	A	2
	Temperature	A	2
	Slope	A	3
	Aspect	A	5
	Elevation	A	7
Proximity City	Temperature	A	2
	Slope	A	4
	Aspect	A	4
	Elevation	A	3
Temperature	Slope	A	3
	Aspect	A	3
	Elevation	A	4
Slope	Aspect	A	2
	Elevation	A	3
Aspect	Elevation	A	2
Proximity Grid	Relative Humidity	A	9
GHI	Relative Humidity	A	8
Proximity Road	Relative Humidity	A	7
Proximity City	Relative Humidity	A	5
Temperature	Relative Humidity	A	5
Slope	Relative Humidity	A	4
Aspect	Relative Humidity	A	3
Elevation	Relative Humidity	A	2

Table.A4 AHP pairwise Comparison matrix for Approach-1.

Matrix		Proximity Grid	GHI	Proximity Road	Proximity City	Temperature	Slope	Aspect	Elevation	Relative Humidity
		1	2	3	4	5	6	7	8	9
Proximity Grid	1	1	2	3	3	3	4	6	7	9
GHI	2	1/2	1	2	3	5	6	7	8	8
Proximity Road	3	1/3	1/2	1	2	2	3	5	7	7
Proximity City	4	1/3	1/3	1/2	1	2	4	4	3	5
Temperature	5	1/3	1/5	1/2	1/2	1	3	3	4	5
Slope	6	1/4	1/6	1/3	1/4	1/3	1	2	3	4
Aspect	7	1/6	1/7	1/5	1/4	1/3	1/2	1	2	3
Elevation	8	1/7	1/8	1/7	1/3	1/4	1/3	1/2	1	2
Relative Humidity	9	1/9	1/8	1/7	1/5	1/5	1/4	1/3	1/2	1

Table.A5 AHP Eigenvalue of criteria for Approach-1. (Number of comparisons 36, and Consistency Ratio CR = 4.0%)

Approach -1	
Criteria	AHP weight
Proximity Grid	27.2%
GHI	25.1%
Proximity Road	14.8%
Proximity City	11.1%
Temperature	8.6%
Slope	5.2%
Aspect	3.5%
Elevation	2.6%
Relative Humidity	1.9%

Table.A6 AHP Pairwise comparison table for Approach-2

Criteria		more important?	Scale
A	**B**	**- A or B**	**(1-9)**
GH	Proximity Road	B	3
	Proximity City	A	3
	Temperature	A	2
	Slope	A	6
	Aspect	A	7
	Elevation	A	8
	Relative Humidity	A	8
Proximity Road	Proximity City	A	3
	Temperature	A	4
	Slope	A	5
	Aspect	A	7
	Elevation	A	8
	Relative Humidity	A	9
Proximity City	Temperature	A	2
	Slope	A	4
	Aspect	A	4
	Elevation	A	3
	Relative Humidity	A	5
Temperature	Slope	A	3
	Aspect	A	3
	Elevation	A	4
	Relative Humidity	A	5
Slope	Aspect	A	2
	Elevation	A	3
	Relative Humidity	A	4
Aspect	Elevation	A	2
	Relative Humidity	A	3
Elevation	Relative Humidity	A	2

Table.A7 AHP pairwise Comparison matrix for Approach-2.

Matrix		GHI	Proximity Road	Proximity City	Temperature	Slope	Aspect	Elevation	Relative Humidity
		1	2	3	4	5	6	7	8
GHI	1	1	1/3	3	2	6	7	8	8
Proximity Road	2	3	1	3	4	5	7	8	9
Proximity City	3	1/3	1/3	1	2	4	4	3	5
Temperature	4	1/2	1/4	1/2	1	3	3	4	5
Slope	5	1/6	1/5	1/4	1/3	1	2	3	4
Aspect	6	1/7	1/7	1/4	1/3	1/2	1	2	3
Elevation	7	1/8	1/8	1/3	1/4	1/3	1/2	1	2
Relative Humidity	8	1/8	1/9	1/5	1/5	1/4	1/3	1/2	1

Table.A8 AHP Eigenvalue of criteria for Approach-2. (Number of comparisons 28, and Consistency Ratio CR = 4.8%)

Approach -2	
Criteria	AHP weight
GHI	24.7%
Proximity Road	35.1%
Proximity City	13.8%
Temperature	11.0%
Slope	6.0%
Aspect	4.2%
Elevation	3.1%
Relative Humidity	2.2%

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