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Spatial Mapping and Potential Analysis of Solar Farm Prospective through GIS Utilization as Energy Sovereignty Technical Consideration for the New National Capital City (IKN) Area Development

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ABSTRACT

Solar energy makes up around 50% of Indonesia's renewable energy potential. Yet, only 0.08% has been utilized in 2021. In order to achieve the 2050 Sustainable Development Goals, a solution to help the acceleration towards renewable energy needs to be done, especially in New National Capital City (IKN) area development. Hence, the researchers came up with the idea of spatial mapping and potential analysis for renewable energy technologies, specifically solar farms in the IKN development area through Geographical Information System (GIS) utilization. The researchers map the suitable areas for solar energy tapping based on solar radiation data which provides a picture of the potential and assesses the feasibility for its development by integrating various datasets and spatial analysis. This paper is a mixed method research that applies the 4D (define, design, deliver, and discover) method to collect data and perform spatial mapping and potential analysis on data processing. The results of this study indicates that the IKN development area has significant potential for solar energy generation due to their favorable solar irradiance levels, land availability, and proximity to existing infrastructure. The findings of this study aim to contribute to the goal of achieving energy sovereignty in the IKN area development by providing valuable insights for decision-makers involved in energy planning and development through GIS analysis. However, this paper still has various shortcomings. Therefore, it is recommended for future research to undertake a comprehensive economic feasibility study to evaluate the viability of solar projects in the IKN development area.

INTRODUCTION

The global demand for energy continues to surge, driven by rapid population growth and urbanization. As a developing nation with a substantial population, Indonesia faces the challenge of meeting the rising energy demand while simultaneously transitioning towards more sustainable energy sources. In this context, renewable energy solutions hold the promise of reducing greenhouse gas emissions, enhancing energy security, and mitigating the adverse effects of climate change [1]. Indonesia, with its abundant solar radiation due to its geographical location near the equator, possesses tremendous solar energy potential.

Despite this, the utilization of solar energy remains disproportionately low compared to its potential. As of 2021, solar energy accounted for a mere 0.08% of Indonesia's total energy mix, primarily due to the historical reliance on fossil fuels [2]. Thus, there exists a pressing need to accelerate the adoption of renewable energy technologies, particularly solar energy, to achieve the country's sustainable development goals.

Solar energy has been recognized as one of the key drivers for achieving Indonesia's energy sustainability and decarbonization objectives. It is estimated that solar energy accounts for approximately 50% of the country's total renewable energy potential [3]. By harnessing solar energy, Indonesia can significantly reduce its dependence on fossil fuels, thereby reducing greenhouse gas

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emissions and mitigating the impacts of climate change. Moreover, the transition to solar energy can enhance the nation's energy security by diversifying its energy sources. Relying heavily on imported fossil fuels has exposed Indonesia to the volatility of international energy markets and geopolitical uncertainties. Embracing solar energy can not only provide a stable and sustainable energy supply but also foster energy sovereignty, enabling the nation to take charge of its energy future [6].

The IKN development project represents a transformative and visionary undertaking by the Indonesian government. The move to relocate the capital city from Jakarta to a new area in East Kalimantan aims to address the challenges posed by overpopulation, pollution, and inadequate infrastructure in Jakarta. The new capital is envisioned to be a sustainable and smart city, leveraging cutting-edge technologies and renewable energy solutions for its development [2]. With its vast expanse and a blank canvas for urban planning, the IKN development area presents an unprecedented opportunity to integrate renewable energy technologies into the city's infrastructure from its inception. By prioritizing solar energy integration, the new capital can set a precedent for sustainable urban development in Indonesia and inspire other cities to follow suit.

The adoption of solar farms as a significant renewable energy source in the IKN development aligns with Indonesia's commitments under the Paris Agreement and the Sustainable Development Goals (SDGs). Meeting these ambitious targets requires actual measures to transition from fossil fuels to renewable energy sources, and solar energy represents an immediate and viable solution [1]. The IKN area, located in East Kalimantan, benefits from abundant solar irradiance throughout the year, offering optimal conditions for solar energy tapping. By enlarging this solar energy potential, the new capital city can position itself as a leader in renewable energy adoption and create a model for sustainable and environmentally responsible urban development. The integration of solar farms in the IKN development area also has numerous economic benefits such as renewable energy infrastructure investment, resulting in the capability of the city to attract private investments, stimulate economic growth, and create employment opportunities in the renewable energy sector. Additionally, the reduced reliance on fossil fuels can mitigate the financial burden of energy imports, further bolstering the economic resilience of the new capital city.

To successfully implement solar farms in the IKN development, careful planning and analysis are required. Geographical Information System (GIS) technology emerges as a powerful tool in this context, providing a platform for spatial mapping, potential analysis, and decision support. GIS can help identify suitable areas for solar farms, considering factors such as solar irradiance, land availability, and proximity to existing infrastructure [3].

The spatial mapping of solar energy potential in the IKN area can inform energy planners and policymakers about the optimal locations for solar farm installations, ensuring the efficient utilization of solar resources. Furthermore, GIS can facilitate the integration of solar energy into the city's grid, helping to balance energy supply and demand, enhance grid stability, and maximize the benefits of solar energy integration [11]. As the world grapples with the imperative of transitioning to a low-carbon and sustainable energy future, Indonesia's commitment to renewable energy, particularly solar energy, in the IKN development area exemplifies the nation's determination to become a leader in green urban development. By embracing solar energy, Indonesia can demonstrate its dedication to building a resilient and sustainable future for its people, while also contributing to the global efforts to combat climate change and achieve a greener and more prosperous world.

Based on this background, the researchers are interested in writing a paper entitled “Spatial Mapping and Potential Analysis of Solar Farm Prospective Through GIS Utilization as Energy Sovereignty Technical Consideration for the New National Capital City (IKN) Area Development” as an original paper researchers submit in the Youth Idea Competition (YIC) 2023 Paper Competition organized by the National Battery Research Institute. The formulation of the research problem revolves around addressing two key questions concerning solar farm deployment in the New National Capital City (IKN) development area:

1. **Spatial Identification of Suitable Areas for Solar Farms**

   The first research problem aims to identify specific areas in the vicinity of the IKN development that possess the potential to be utilized as solar farms. This involves conducting a comprehensive spatial analysis to identify locations with favorable conditions for solar energy tapping [3]. Factors such as solar irradiance, land availability, topography, and proximity to existing infrastructure will be considered to determine the suitability of each area for solar farm installations.

   The researchers seek to employ Geographical Information System (GIS) technology as a powerful tool in this endeavor, utilizing data layers and spatial analysis techniques to identify optimal sites for solar farms within the IKN area. The spatial identification of suitable areas for solar farms will play a crucial role in guiding future energy planning and investment decisions, ensuring the efficient utilization of solar resources and maximizing the potential for renewable energy generation in the new capital city.

2. **Assessment of Solar Energy Generation Potential**

The second research problem focuses on quantifying the solar energy generation potential of the identified areas that are suitable for solar farm development. This involves a detailed analysis of solar radiation data and its integration with spatial datasets [4]. By estimating the solar energy yield from each identified area, the researchers aim to provide valuable insights into the amount of energy that can be harnessed through solar farms in the IKN development.

The assessment of solar energy generation potential will take into account various parameters, including solar irradiance levels, climatic conditions, and potential shading factors. Additionally, the study will consider the land area available for solar panel installations and the efficiency of solar technologies to calculate the overall energy output that solar farms in the IKN area can contribute to the energy grid.

By quantifying the solar energy generation potential, the research aims to provide decision-makers and energy planners with critical information for formulating effective energy strategies and policies. Understanding the potential energy yield from solar farms will aid in determining the feasibility and economic viability of renewable energy projects in the IKN area, paving the way for the successful integration of solar energy into the city's energy mix.

The research objectives are aimed at addressing the two problem formulations concerning solar farm deployment in the New National Capital City (IKN) development area. The specific objectives encompass:

1. **Analyzing and Mapping Suitable Areas for Solar Farms around IKN using GIS**

To conduct comprehensive analysis and spatial mapping of areas in the vicinity of the IKN development that have the potential to be transformed into solar farms. This involves employing Geographical Information System (GIS) technology to integrate various data layers, including solar irradiance, land use, topography, and proximity to existing infrastructure [3]. By applying spatial analysis techniques, the research aims to identify specific locations that are conducive for solar farm installations.

2. **Analyzing Energy Projections from Potential Solar Farm Areas using PVsyst Software**

The second research objective is to analyze the energy projections from the identified areas that show potential for solar farm development using the PVsyst software. PVsyst is a powerful simulation tool that enables the calculation of solar energy generation potential based on solar irradiance data, technology efficiencies, and system configurations. By utilizing PVsyst, the research aims to accurately estimate the amount of energy that can be generated from solar farms in the IKN development area.

Through this objective, the researchers seek to quantify the solar energy output from the potential solar farm areas, considering various parameters such as solar panel efficiency, tilt angles, and shading effects. PVsyst simulations will provide valuable insights into the energy yield under different scenarios, helping to optimize solar farm design and configuration for maximum energy production.

By achieving this research objective, decision-makers and stakeholders can better assess the economic viability and performance of solar farm projects in the IKN development. The analysis of energy projections will aid in formulating energy policies and strategies, ensuring that solar energy resources are effectively harnessed to meet the energy demands of the new capital city.

The combination of GIS-based spatial mapping and PVsyst software analysis will enable a comprehensive assessment of solar energy potential in the IKN area. The research outcomes will serve as a valuable resource for energy planning and investment decisions, guiding the successful integration of solar energy into the city's energy mix and contributing to the realization of energy sovereignty in the new capital city.

The research on spatial mapping and potential analysis of solar farm prospective through GIS utilization in the New National Capital City (IKN) area development holds significant benefits for various stakeholders.

METHODOLOGY

The research conducted in this paper adopts a quantitative research approach with an experimental design. This approach allows the researchers to systematically gather and analyze numerical data pertaining to solar energy potential in the New National Capital City (IKN) area development.

Quantitative research is well-suited for this study as it involves the collection of measurable data, such as solar radiation levels, land availability, and infrastructure proximity, which can be analyzed using statistical techniques. Additionally, the experimental approach employed in this research enables the researchers to establish cause-and-effect relationships between the identified potential areas for solar farm development and their projected energy generation capacity. This design allows for the controlled manipulation of variables, contributing to a more reliable and objective investigation.

The researchers apply the 4D method (Define, Design, Deliver, and Discover) as the underlying research methodology. Each stage of the 4D method plays a crucial role in shaping the research process and generating meaningful outcomes. In the Define stage, the researchers clearly define the research objectives, which primarily focus on identifying potential areas for solar farm development in the IKN area. By establishing well-defined objectives, the researchers set a clear direction for their study and ensure that the research outcomes are relevant to the intended goals. During the Design phase, meticulous planning takes place to determine the appropriate data collection methodologies and data sources. It is in this stage that the researchers identify and gather various spatial datasets relevant to the IKN area, including GIS data, topographic information, land use patterns, and infrastructure distribution. Additionally, methods for measuring solar radiation levels, such as the deployment of pyranometers or the utilization of remote sensing technologies, are decided upon. The researchers carefully select these instruments to ensure accurate and reliable solar radiation data, which is essential for accurately assessing solar energy potential.

To facilitate a comprehensive and systematic analysis, the researchers also develop a framework for integrating the acquired data and applying GIS tools and techniques. Geographic Information System (GIS) software is a critical component of this stage as it allows for the integration and visualization of spatial data. By leveraging GIS, the researchers can effectively combine various datasets, enabling them to conduct spatial mapping and potential analysis for solar farm sites within the IKN development area. The research incorporates several key variables that are central to the analysis. The Independent Variable comprises the potential areas for solar farm development around the New National Capital City (IKN) area. This variable encompasses various spatial factors, such as land availability, solar radiation levels, proximity to existing infrastructure, and geographical suitability for solar energy tapping. Identifying these potential areas is crucial to understanding where renewable energy projects can be most effectively implemented.

The dependent variable is the energy projection derived from the identified potential areas for solar farm development. This variable quantifies the expected energy generation capacity of the selected sites based on solar irradiance levels and other relevant factors. By calculating the projected energy generation capacity, the researchers can assess the viability and sustainability of each site, providing valuable information for energy planning and decision-making. The Control Variable consists of the GIS data from the IKN area and its surroundings. This variable includes a wide range of spatial information, such as land cover, elevation, slope, aspect, and infrastructure distribution. The control variable is essential for conducting a comprehensive spatial analysis, as it allows the researchers to consider various geographic and environmental factors that may influence the suitability of solar farm locations. The Delivery stage involves the execution of the data collection and analysis plan. During this stage, the researchers collect solar radiation data and integrate the various spatial datasets. The data integration process is a crucial step as it enables the researchers to create a holistic understanding of the study area, combining information from multiple sources to form a comprehensive view of the potential areas for solar farm development.

Through spatial mapping, the researchers can visualize the spatial distribution of solar energy potential, highlighting areas that show promise for solar farm development. By conducting potential analysis, the researchers evaluate the feasibility of solar energy projects in the identified areas, considering various factors such as solar radiation levels, land availability, and proximity to existing infrastructure. The Discover phase is where the research findings are interpreted, and meaningful insights are extracted. The researchers draw conclusions based on the results of the spatial mapping and potential analysis. They identify trends, patterns, and correlations between solar energy potential and spatial factors in the IKN development zone. These insights provide valuable information for decision-makers involved in energy planning and development, offering guidance on where and how to implement solar energy projects effectively.

RESULTS AND DISCUSSION

Geographical Information System (GIS)

GIS is a software system that contains functions to perform input, storage, editing, manipulation, analysis, and display of geographically located data [13]. The GIS system mainly deals with data on earth's surface in a 2-dimensional format, able to store geographically referenced (cartographic or spatial) data in raster data structure or in an x and y coordinate reference-based (vector) data structure as points (nodes), lines (arcs), and polygons. GIS makes use of a variety of coordinate referencing systems to locate features on the earth relative to others, and the coordinate systems make use of a variety of map projections to transform earth references onto a map of 2-dimensional surface [14].

The IKN development area is studied with the consideration that the amount of radiation differs from one place to another, therefore in order to get accuracy, the researchers considered certain factors such as latitude, time of the year, Global Horizontal Irradiation (GHI), elevation, and land cover.

The first step was to get a Digital Elevation Map (DEM) and Landsat-8 data through the United States Geological Survey (USGS) database of the IKN development area, precisely East Kalimantan. The researchers then used ArcGIS along with various literature studies to do spatial analysis to calculate watt-hours/meter2 at the surface of East Kalimantan.

GIS Analysis

Through various data processing and literature studies, the researchers found that IKN development area in East Kalimantan has relatively high values of GHI over its entire area of 127,347 km2. Taking into consideration that not all areas are not able to be developed since it has pre-existing land usage as shown in **Fig. 1**, only 42,997.85 km2 or approximately 33.7% of the total area is available for solar power plants. With further analysis for the solar farm using PVsysts, this corresponds to an area of 244,094 m2 with an estimated generation capacity of 50 Megawatt (Mw). Indicating that the abundant resources of East Kalimantan is able to provide for the IKN development area energy requirements and help achieving Indonesia's renewable energy target.

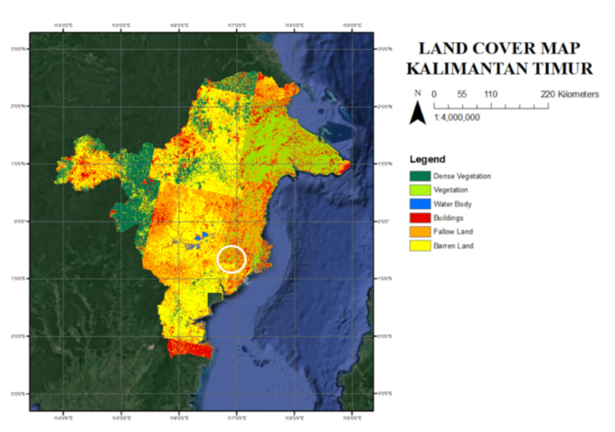


Fig. 1. Land cover map of East Kalimantan.

To further prove the previous analysis from land cover map, the researchers also utilize topography maps as it plays a crucial role in solar energy potential analysis by providing information about the terrain of the targeted field. Through topography map analysis, the researchers could determine the orientation and slope of the land, which will be useful to analyze sunlight exposure, suitability, and shading potential of the area.

As seen in **Fig. 2**, the area that the researchers chose for the field development (0°54'40.14"S 116°44'58.72"E) is suitable topography-wise, ultimately contributing to the successful and efficient implementation of solar energy projects.

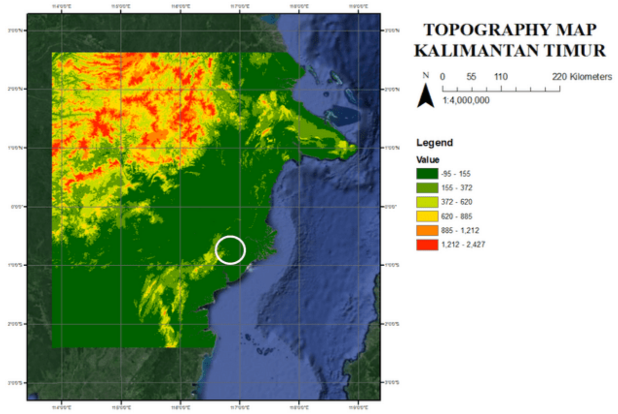


Fig. 2. Topography map of East Kalimantan.

Solar Energy Potential in East Kalimantan

Satellite-based and meteorological models are used for computing solar resource and meteorological data that are suitable for production of high-resolution maps and for use in Geographical Information Systems (GIS). Through analyzing the data recorded by Solargis and The World Bank Group [12], there are several relevant factors for evaluation of energy yield and performance of the use of photovoltaic technology, one of which is Global Horizontal Irradiation (GHI) and Direct Normal Irradiance (DNI).

GHI is a sum of direct and diffuse radiation received on a horizontal plane and is a reference for comparison and an essential parameter for calculation of radiation on an area. However, GHI are prone to error of thermal imbalance which results in uncertainty of daily sums at about ±2%. As seen in **Fig. 3**, the East Kalimantan area has a GHI of 4.2-5.0 kWh/m^2. This data is also supported by the DNI rate as shown in **Fig. 4**, which shows that the IKN area has an average rate of 2.6-3.0 kWh/m^2 daily.

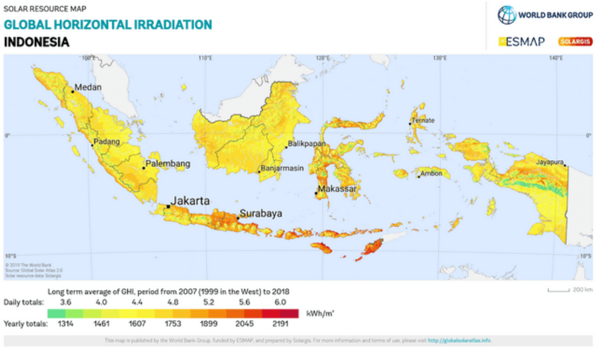


Fig. 3. Global Horizontal Irradiation Map of Indonesia [12].

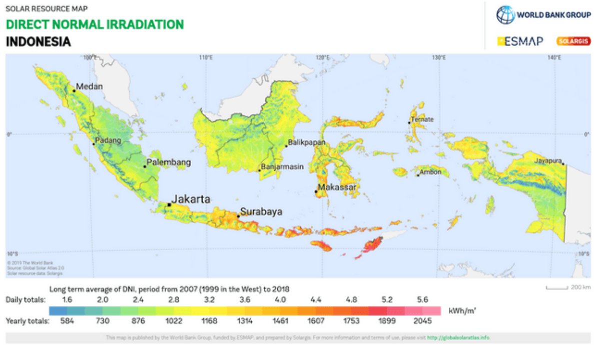


Fig. 4. Direct Normal Irradiation Map of Indonesia [12].

Energy Projection Analysis

To perform solar resource assessments by determining solar irradiation at specific locations, it's crucial to estimate a PV system's potential energy that will be generated. By using PVsyst it allows users to design PV systems by inputting parameters such as module characteristics, inverter specifications, and mounting configuration, with a wide selection of accurate PV module and inverter models. In this analysis we used a PV module from Longi solar as this is one of the most efficient. To generate the solar energy capacity of 50 MW as planned by State Electricity Enterprise (PLN), we need a total area of 244,094 m^2 of Solar Farm as shown in **Fig. 5** to be built around The IKN development area.

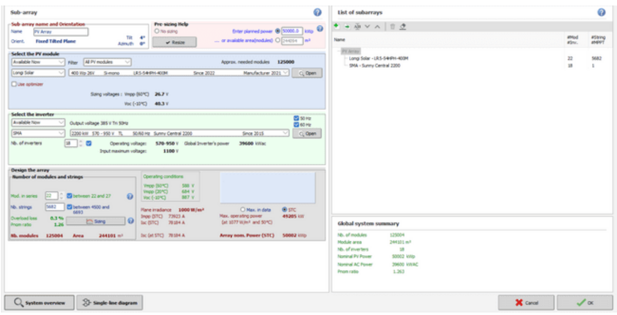
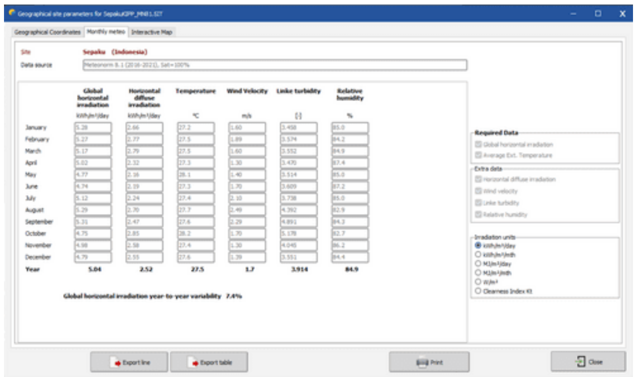
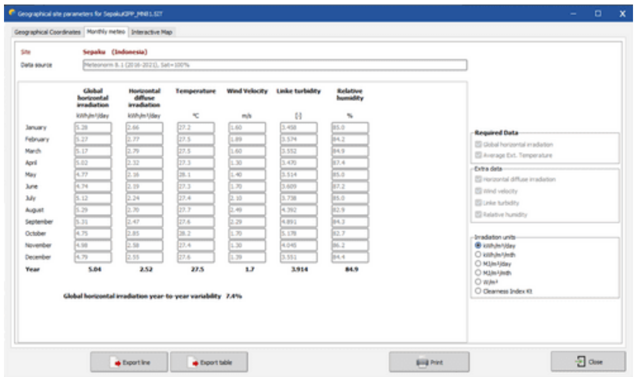


Fig. 5. Input data specification of sizing, module, and inverter.

As shown in **Fig. 6**, PVsyst also supports importing weather data from various sources and presents long-term weather patterns at specific locations. After inputting coordinates of the area that will be assessed, we will obtain several data parameters that affect the output on the solar farm system in PVsyst software. Detailed simulation outputs, including energy production, performance ratios, and capacity factors, aid users in evaluating system performance. The GHI of 5.04 kWh/m^2 generated from this software is corresponding with GHI of 4.2-5.0 kWh/m^2 recorded by Solargis and The World Bank Group.



(a)

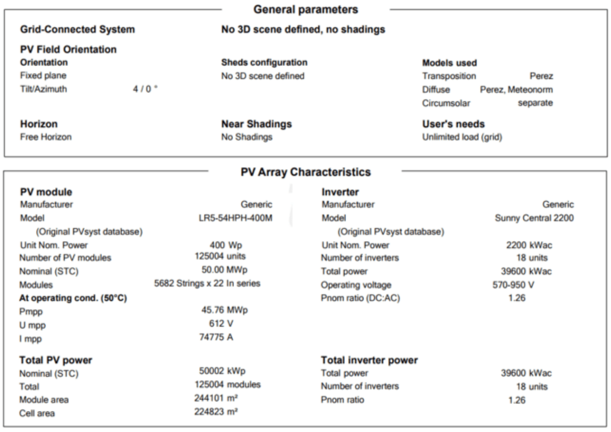


(b)

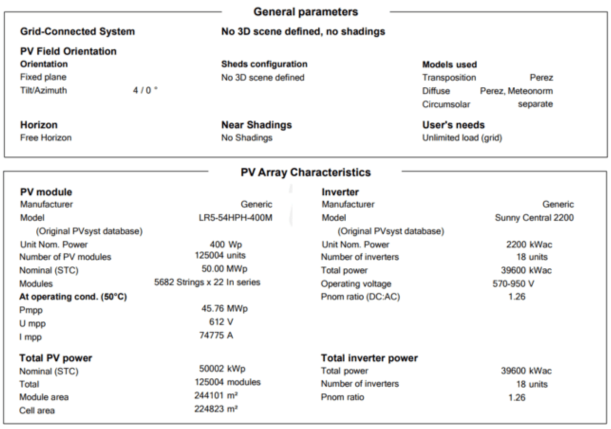
Fig. 6. (a) Coordinate input to determine location details, (b) Meteo data result (kWh/m^2).

In this research, the optimal tilt/slope angle of 0% loss is determined by aligning the solar panels towards the west direction with a bearing of 100 degrees. The selection of the slope angle is based on the latitude of the research location, which is 5.840, and the positioning of the module buffer installation at 100 degrees. The slope of the solar panel installation has a significant impact on the amount of solar radiation received and the panel's temperature. The ambient temperature, which is influenced by the distance between the panels, plays a crucial role in determining the amount of energy generated by the solar panel at the research location. To achieve standard working conditions for the solar panels, a reference temperature (TRef) of 25°C is considered. It is essential to maintain optimal working conditions to ensure that the panels can generate energy efficiently.

The sunlight received on Earth under the right conditions is standardized to be 1000 W/m^2. The research involves the manual input of product specifications, including the selected panel module and inverter specifications as shown in **Fig. 7**.



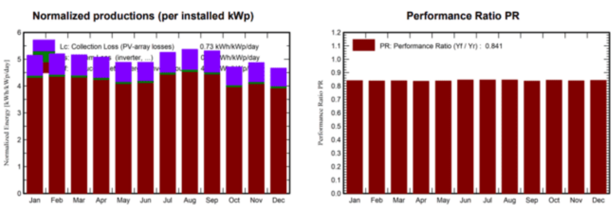
(a)



(b)

Fig. 7. PVsyst assessment (a) General parameter and (b) PV array characteristic details.

Since the focused area is located near the equator, the energy generated each month is similar to one another. As represented in **Fig. 8** which depicts the performance of the plant which is around 0.841 for every month. As shown in **Fig. 9**, with a Global Horizontal Irradiation (GHI) of 1839 kWh/m^2/year and a total Solar Farm area of 244,094 m2 minus the energy loss from various variable, the assessed area could generate around 77.4 GWh energy. From that number, the daily input and output of the system are represented by **Fig. 10.**



(a) (b)

Fig. 8. (a) Normalized productions graph, (b) Performance ratio of the system in 1 year.

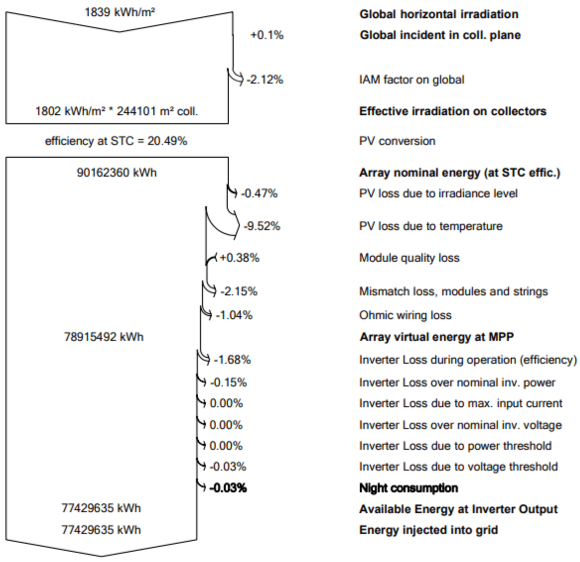


Fig. 9 Energy loss diagram projection.

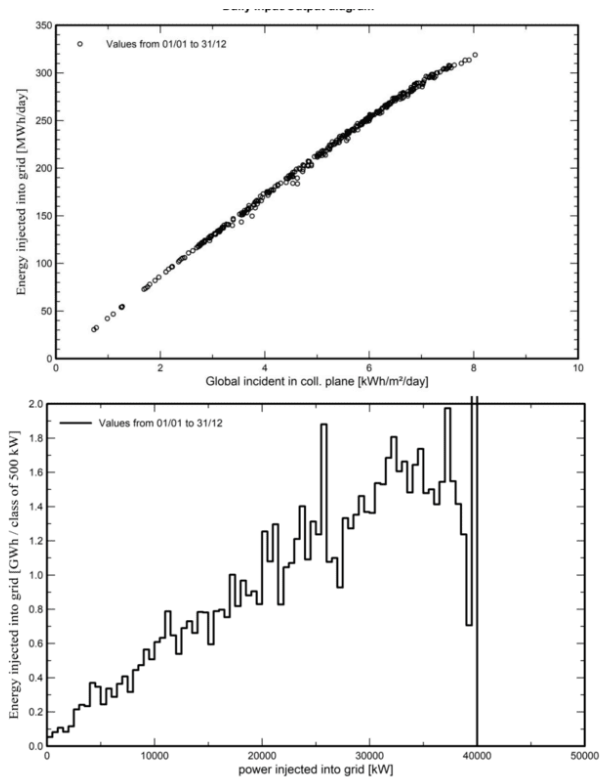


Fig. 10. (a) Daily Input/Output Diagram, (b) System Output Power Distribution.

CONCLUSION

In conclusion, this research employed a quantitative approach and utilized the Geographical Information System (GIS) to map potential solar farm sites in the New National Capital City (IKN) development area. Through spatial analysis, it was found that approximately 33.7% of East Kalimantan's area is suitable for solar power plants, with an estimated generation capacity of 50 MW. Topography analysis further confirmed the chosen area's suitability for solar energy projects. The study revealed significant solar energy potential in East Kalimantan, offering a viable solution to meet IKN's energy requirements and contribute to Indonesia's renewable energy goals. The use of PVsyst software allowed for accurate simulations of energy generation throughout the year. These findings can serve as a valuable resource for decision-makers and urban planners, guiding sustainable energy development and supporting the realization of energy sovereignty in the IKN area.

Based on these conclusions, the researcher provides the following recommendations:

For Other Researchers

Fellow researchers should focus on conducting similar spatial mapping and potential analysis studies using GIS to assess solar farm prospects in other regions with high energy demand and development plans, similar to the New National Capital City (IKN) area. Exploring different areas will provide valuable insights into the applicability of solar energy for meeting energy sovereignty goals in various urban development projects. Researchers can also investigate the integration of other renewable energy sources, such as wind or biomass, into the GIS-based analysis to offer comprehensive renewable energy solutions for sustainable city development.

For Governments

Governments should prioritize the incorporation of GIS technology and solar energy potential analysis in their urban development planning, especially for new city development projects like the New National Capital City (IKN). By utilizing GIS tools, governments can accurately identify suitable areas for solar farm installations, making informed decisions for efficient energy infrastructure development. Policymakers should establish clear renewable energy targets and incentivize solar energy investments to ensure energy security and environmental sustainability in the new city. Moreover, governments can collaborate with research institutions and the renewable energy community to develop comprehensive energy strategies that integrate solar energy as a significant component of their renewable energy mix.

For the Renewable Energy Community

The renewable energy community should actively engage with policymakers and city planners involved in the development of the New National Capital City (IKN) and other similar urban projects. By offering expertise in GIS-based solar energy potential analysis, the community can contribute valuable insights to optimize energy infrastructure planning. Advocacy efforts should focus on promoting the integration of renewable energy, particularly solar energy, in new city developments to achieve energy sovereignty and reduce carbon emissions. Collaborations between the renewable energy community and urban planners can lead to innovative solutions for sustainable energy development and demonstrate the viability of solar energy as a reliable and environmentally friendly energy source.

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AUTHOR CONTRIBUTION

S. E. Andoko as the First author and A. H. Wibowo also A. Hanabila as the Second author equally contributed as the main contributors of this paper. All authors read and approved the final version of the paper.

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