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Potential Solar Power Sources at the Indonesian Border Post Papua New Guinea

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ABSTRACT
The border post serves as a means of supervision, security, and community services in the border area between Indonesia and Papua New Guinea. Electricity needs have not been met due to limitations both in terms of economic and geographical conditions. To overcome this problem, the method is measure the potential of solar power sources in the area using GIS data from NASA Prediction of Worldwide Energy Resources (POWER) which provides data on solar radiation and temperature in a 5-year period (2018-2022). So that the potential for solar electricity is obtained, which is 4.974 kWh/m^2 /day, which means that it has the potential for the construction of solar power plants.

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INTRODUCTION

The 750 km long border between Indonesia and Papua New Guinea (PNG) plays an important role in connecting Asia and the Pacific (Heathcote, 2021). Border posts are one of the important infrastructures that must be available in land border areas commonly referred to as Pos Lintas Batas Negara (PLBN). The border post serves as a means of monitoring, security, and community services in the border area between Indonesia and Papua New Guinea (Metherall et al., 2022). Based on the Indonesian National Border Management Agency (2021), the Waris Cross Border Post (PLBN) is located in Waris District, Keerom Regency, Papua. PLBN Waris is one of Indonesia's land border posts with Papua New Guinea. To support the function of the border post, it must be equipped with adequate facilities and infrastructure, one of which is a source of electricity. The quality of human life is highly dependent on the availability of energy (Grätzel, 2005).

At present, electricity sources at the Indonesia-Papua New Guinea border post still rely on electricity sources from PLN. However, this cannot optimally meet the electricity needs at the border post. This is due to several factors, including: The distance of the border post is far from the PLN electricity center, the geographical condition of the border post is difficult to reach, Limited budget availability. Therefore, the focus has been shifted to Renewable Energy such as wind, solar, biomass, hydrogen power, etc. Among all, solar and wind energy are common renewable energy sources that are easy to use for power generation. Renewable Energy provides clean energy The analysis of power generation systems is of scientific interest and is also important for efficient use of energy resources (Sathish et al., 2022). The most widely used types of renewable energy include wind and hydrogen energy, solar energy, biomass energy and convertible household waste energy, and geothermal energy (Mytrofanov & Proskurin, 2020).The challenges of energy supply and utilization are related to environmental issues such as air pollution, acid rain, ozone layer depletion, deforestation, and radioactive emissions in addition to global warming (Sathish et al., 2023).

The most commonly used method to analyze energy conversion processes is the first law of thermodynamics (Aljundi, 2009). Without these assumptions, thermodynamic analysis of real applications forces thousands of nonlinear equations, solving which is almost impossible or requires too much computational time and effort (Tüfekci, 2014).Recent work on the economics of civil war clearly shows that to understand civil warfare today we need to understand the role that natural resources play in financing weapons purchases (Buhaug & Gates, 2002). To overcome these problems, an alternative source of electricity is needed that can optimally meet the electricity needs of border posts. Site selection for solar power plants is a critical issue for utility-size projects due to the importance of weather factors, proximity to facilities, and the presence of environmental protection areas.

LITERATURE REVIEW

The main objective of this research is to evaluate and select the best locations for utility-scale solar PV projects using a geographic information

system (GIS)(Al Garni & Awasthi, 2017). One alternative source of electricity that can be used is solar power. Solar energy greatly reduces environmental pollution (e.g., greenhouse gases and air pollution) (Liu et al., 2018). Solar power is a renewable energy source that has great potential in Indonesia. The potential of solar power in Indonesia can reach 207.8 GWp (Simamora & Tumiwa, 2019). Increased demand and shortage of conventional sources have triggered scientists to pave the way for research development in the field of renewable energy sources, especially solar energy (Shiva Kumar & Sudhakar, 2015). The potential for solar power in the Indonesia-Papua New Guinea border area is also quite large. This is supported by the geographical condition of the border area which has a lot of sunlight. Based on this, it is necessary to conduct research to determine the potential for solar power sources at the Indonesia-Papua New Guinea border post. Estimation of sunlight on any curved surface is important in building design and is made with the help of a potential calculation model (Harrison, 1991). For certain remote detection applications, image data may be available from several different sources. More and more satellite-based sensors are collecting data for geography, oceans, geophysics, meteorology and surveillance studies. In addition to digital satellite images, spatial data from Geographic Information Systems (GIS) can also provide information about specific phenomena (Schistad Solberg et al., 1996). GIS data can be used to determine solar intensity by utilizing data sourced from NASA Prediction of Worldwide Energy Resources (POWER).

SSE satellite data, surface spectral emissivity (SSE) and surface temperature from current and future operating satellites can and will reveal important information about Earth's ecosystems and land surface type properties, which can be used as a means of long-term monitoring of Earth's environment and global climate change (Zhou et al., 2011). Can be used to display several parameters related to solar intensity, such as: Global solar radiation is the total solar radiation received by the earth, whether absorbed, reflected, or transmitted. Direct solar radiation is solar radiation that comes directly from the sun without refraction or scattering. Diffuse solar radiation is solar radiation that comes from the sky after refraction or scattering (Choi et al., 2019). Solar energy is one of the most potential renewable energy sources to be developed in Indonesia. Several previous studies have examined the potential of solar energy in various parts of Indonesia, including in border areas. Research conducted by Suryadi et al. (2019) showed that the potential of solar energy in Indonesia can reach 207.8 GWp. Another study by Wibowo et al. (2021) identified that the Indonesia-Papua New Guinea border region has considerable solar energy potential. This is supported by geographical and climatic conditions that support the utilization of solar energy. Solar Power Plant Siting Theory, Selection of the right location for the construction of a solar power plant is a key factor in the success of the project. Some theories that can be used include: Siting Theory This theory considers factors such as solar radiation intensity, distance from the grid, transportation access, land conditions, and environmental impacts (Sánchez-Lozano et al., 2016).

Study Area

This study is a potential solar power plant using GIS data, Secure, clean and sustainable energy supply is the most important scientific and technical challenge facing humanity in the 21st century(Lewis & Nocera, 2007).Renewable technologies are considered as clean energy sources and the optimal use of these sources minimizes environmental impact, produces minimum secondary waste and is sustainable based on the current and future economic and social needs of society (Panwar et al., 2011).Concentrated solar thermal power generation is becoming a very attractive renewable energy production system among all the different options, as it has a better potential for dispatch ability (Gil et al., 2010). To estimate the potential possessed by the specified location and the electrical energy demand to be discussed: One of the Cross Border Posts (PLBN) of Indonesia and Papua New Guinea, Kampung Pund, Waris District, Keerom Regency, Papua Province. The coordinates of PLBN Waris are 04°20'13.9 "S140°49'32.5 "E. PLBN Waris has complete facilities and services, including immigration, quarantine, customs, and trade facilities (Based on the Regulation of the Minister of Home Affairs Number 18 of 2007 concerning Standardization of Facilities, Infrastructure and Services for Cross-Border Intercountry) (Permendagri, 2007).

Figure 1. Research Location

METHODOLOGY

Data Collection: The study utilized GIS data from the NASA Prediction of Worldwide Energy Resource (POWER) to collect solar radiation and temperature data over a 5-year period (2018-2022) in the Indonesia-Papua New Guinea border region. Additionally, data on the current electricity demand at the Indonesia-Papua New Guinea border post was gathered, including constraints in meeting the electricity needs such as distance from the PLN electricity grid, geographical conditions, and budget limitations. Analysis of Solar Energy Potential: The solar radiation data was processed and analyzed to calculate the average daily solar energy potential that can be generated. Furthermore, the study identified technical, economic, social, and environmental factors that may constrain the development of solar energy

systems in the border region. Feasibility Study for Solar Power Plant: The research conducted a technical analysis to determine the appropriate solar power system design for the border area conditions. An economic and financial analysis was performed to calculate the investment, operating, and maintenance costs for the solar power plant, as well as to evaluate its economic and financial feasibility. Additionally, the study analyzed the potential social and environmental impacts of the solar power plant development. Implementation and Development Strategy: The research developed a strategic plan for the implementation of the solar power plant at the border post. It also identified the policy and regulatory support required to facilitate the development of solar energy in the border region. Finally, the study formulated steps to maximize the benefits and minimize the constraints in the development of solar energy in the border area. Efficient use of solar energy can alleviate many energy and environmental problems, as the solar energy radiating the Earth's surface (1.3×10^5 TW) exceeds current global human energy consumption (1.6×10^1 TW in 2010) by about four times (Hisatomi et al., 2014). More energy from sunlight shines on the Earth in one hour than all the energy consumed by humans in a year ago. In fact, solar energy undermines all other renewable and fossil-based energy sources combined (Zhang et al., 2013).

Global electricity consumption is increasing and there is a steady increase in demand for electricity capacity, production, distribution and efficient use of energy(Blaabjerg et al., 2004). To calculate the potential of solar electric energy by using GIS data sourced from NASA Prediction of Worldwide Energy Resources (POWER), National Aeronautics and Space Administration (NASA). The last decade has been characterized by a significant increase in the penetration of solar photovoltaic systems into energy systems worldwide. At the same time, solar irradiation has an intermittent nature. Thus, efficient management of existing and new solar photovoltaic systems requires an accurate prediction system of solar irradiation (Braga et al., 2020). Estimation of solar short wavelength radiation from curved surfaces is important in the study of solar energy use, building design work, and prediction of agricultural crop production (Harrison & Coombes, 1988). Meteorological data such as solar radiation, sunshine hours, ambient temperature, relative humidity, and amount of cloud cover are important for estimating global average solar radiation (Almasoud & Gandayh, 2015) The Research Center provides (SSE) datasets in which solar radiation and various other meteorological data are derived from earth observation satellite programs. The radiation data are systematically validated against data from the Baseline Surface Radiation Network (BSRN), World Radiation Data Centre (WRDC), Global Energy Balance Archive (GEBA), and National Solar Radiation Database (NSRD). The parameters set to obtain solar radiation data are with the climatology temporal period has Solar Flux and Radiated parameters and the selected parameter is All sky surface shortwave downward irradiance, namely with climatology the amount of solar radiation that occurs (direct and diffuse) in the horizontal plane on the earth's surface in all sky conditions. The alternative term is Global Horizontal

Irradiance or GHI, so that the measurement of solar radiation is more accurate with a period of 2018 - 2022 so obtained.

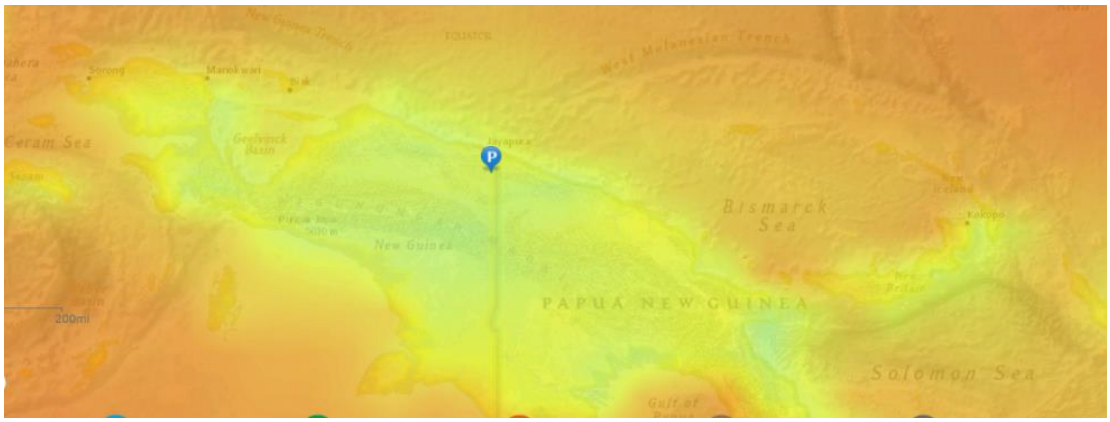


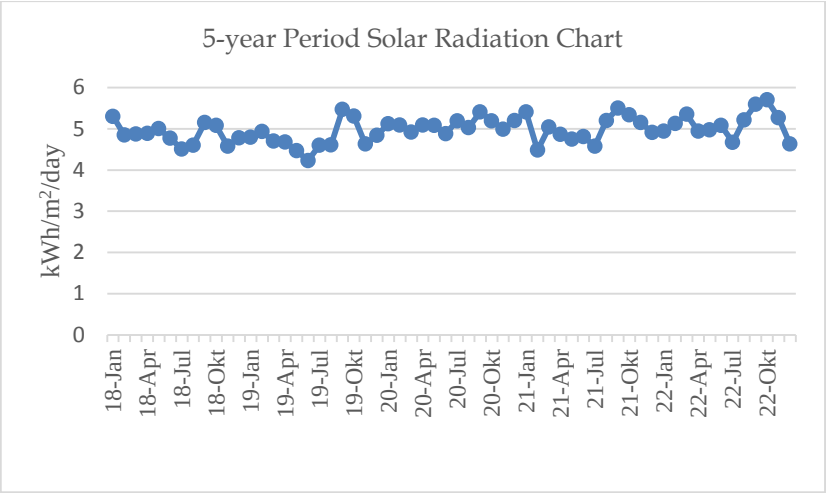
Figure 2 Surface Radian

RESEARCH RESULT

The research findings indicate that the Indonesia-Papua New Guinea border region holds significant potential for solar power generation. The GIS data analysis from NASA POWER revealed an average daily solar radiation of 4.974 kWh/m^2 over the 5-year period from 2018 to 2022, suggesting substantial solar energy resources in the area. This finding is particularly relevant given the current electricity access challenges faced by the border post, where the electricity needs are not being fully met due to the remote location, difficult geographical conditions, and limited budget availability. The feasibility study further reinforced the viability of a solar power plant solution for the border post. The technical assessment showed that a solar power system designed for the local conditions would be a suitable option to meet the electricity demand. Moreover, the economic and financial analysis demonstrated the overall feasibility of the solar power plant investment, considering the abundant solar energy resources in the region. Additionally, the social and environmental impact analysis indicated that the solar power plant development would have minimal negative impacts, while providing clean and sustainable energy to the border community. These results highlight the substantial potential for solar power generation in the Indonesia-Papua New Guinea border area and the feasibility of developing a solar power plant to address the electricity access challenges faced by the border post.

Table 1 surface Radian Period 5 Years

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Agst	Sep	Okt	Nov	Dec	Ann
2018	5.3	4.85	4.87	4.89	5	4.77	4.51	4.6	5.15	5.08	4.58	4.78	4.87
2019	4.79	4.93	4.7	4.68	4.47	4.23	4.6	4.61	5.47	5.31	4.63	4.84	4.77
2020	5.12	5.09	4.92	5.09	5.08	4.88	5.19	5.03	5.41	5.19	4.99	5.2	5.1
2021	5.41	4.48	5.04	4.86	4.75	4.81	4.58	5.2	5.5	5.34	5.15	4.91	5.01
2022	4.94	5.13	5.35	4.94	4.97	5.08	4.67	5.21	5.59	5.7	5.27	4.63	5.12



$$\text{Radiation} = \frac{\sum monthly\ solar\ radiation\ in\ 5\ years}{5} \quad \text{.....(1)}$$

$$= \frac{4{,}87+4{,}77+5{,}1+5{,}01+5{,}12}{5}$$

$$= 4{,}974\ \text{kWh/m}^2\text{/day}$$

So that the average solar radiation obtained over a 5-year period is 4.974 kWh/m²/day where 2019 experiences the lowest radiation in 2022 has the highest solar radiation. So that the PSH at the research location was 4.974 kWh/m²/day in a 5 years period. Average monthly temperature. The clear effect that the operating temperature of a photovoltaic (PV) cell/module has on its electrical efficiency has been well documented (Skoplaki & Palyvos, 2009). The sun has an effective black body temperature of 5,762 K (Kalogirou, 2004). Average monthly temperature by location, last 5 years, year (2018- 2022). Temperature data can be used to assess the potential for solar and wind energy generation at various locations. This information can be used to guide the development of renewable energy projects. The parameter used is Temperature at 2 meters maximum which means the maximum hourly air temperature at 2 meters above the earth's surface in a 5-year period.

Table 2 Temperature 5 years Period

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Agst	Sep	Okt	Nov	Dec	Ann
2018	29.65	29.4	29.72	29.73	29.45	28.96	28.91	29.19	29.9	31.86	31.47	30.15	31.86
2019	29.06	29.27	29.48	30.04	29.26	28.91	29.36	29.09	30.91	31.49	31.06	32.12	32.12
2020	32.55	31.47	32.06	30.46	30.24	29.83	30.6	31.82	33.08	33.24	32.11	31.4	33.24
2021	32.32	29.04	28.95	29.4	29.61	28.89	28.99	30.06	31.95	31.49	31.75	29.94	32.32
2022	29.05	29.77	29.64	29.87	29.76	30.01	31.98	33.43	34.74	34.73	33.95	31.62	34.74

$$\text{Temperature} = \frac{\sum Monthly\ temperature\ in\ 5\ years}{5} \quad \text{.....(2)}$$

$$= \frac{31{,}86+32{,}12+33{,}24+32{,}32+34{,}74}{5}$$

$$= 32,\ 85^{o}\ \text{C}$$

So the average temperature in a 5-year period is 32.85°C, and experiences the lowest temperature in 2018 and the highest temperature in 2022.

DISCUSSION

The research findings and insights provide valuable perspectives on the potential for utilizing solar energy to address the electricity access challenges in the Indonesia-Papua New Guinea border region. The significant solar energy potential identified in the border area presents a valuable opportunity to leverage renewable energy resources and reduce the reliance on traditional fossil fuel-based electricity generation. Developing a solar power plant at the border post can not only provide a reliable and sustainable electricity supply but also contribute to the broader goals of promoting renewable energy and sustainable development in the region.

The discussion further emphasizes the importance of an integrated approach to the successful implementation of the solar power project. Addressing the technical, economic, social, and environmental considerations holistically will be crucial for ensuring the long-term viability and sustainability of the solar power plant. Stakeholder collaboration, supportive policy and regulatory frameworks, and a comprehensive deployment and operational strategy will be essential elements in this integrated approach. By adopting such a holistic perspective, the solar power plant can become a transformative solution that not only meets the electricity needs of the border post but also contributes to the overall development and connectivity of the Indonesia-Papua New Guinea border region.

CONCLUSIONS AND RECOMMENDATIONS

From the research that has been done, it can be concluded that at the border location, namely the Cross Border Post (PLBN) of Indonesia and Papua New Guinea, Kampung Pund, Waris District, Keerom Regency, Papua Province, there is very high potential for the construction of solar power plants because of the relatively high solar radiation each year in a 5-year period, and the temperature is also relatively constant so that the potential of the area is 4.974 kWh/m^2/day. So that it can meet the electricity needs at the border post and can be used according to its needs. However, the estimated solar power potential (theoretical potential) is significantly reduced when technical, economic, social and environmental factors that limit the deployment of solar energy systems are considered.

The research findings and analysis provide a strong foundation for several key recommendations to further strengthen the feasibility and long-term sustainability of the solar power plant project in the Indonesia-Papua New Guinea border region. To start, a more detailed site assessment and design optimization process should be undertaken, including comprehensive measurements of solar radiation, temperature, and other environmental factors to refine the system configuration and maximize energy generation efficiency. Engaging with key stakeholders, such as local authorities, border post operators, and the community, will also be crucial, along with implementing capacity-building programs to ensure sustainable management of the solar power plant by local personnel. Additionally, the research recommends working closely with policymakers to develop supportive regulations and incentives that facilitate the deployment of renewable energy projects in these

remote border areas, as well as exploring innovative financing mechanisms to secure the necessary resources for the investment. Finally, establishing a robust monitoring and evaluation framework will be essential to track the performance, operational efficiency, and societal impacts of the solar power plant over time, allowing for continuous improvement and optimization of the system's contribution to the border region's sustainable development. By holistically addressing these recommendations, the solar power plant project can be further strengthened and positioned as a transformative solution to improve electricity access, environmental sustainability, and socioeconomic progress in the Indonesia-Papua New Guinea border communities.

ADVANCED RESEARCH

The research was limited by its reliance on GIS data that may not fully capture local microclimatic conditions, as well as its focus on technical and economic factors without an in-depth analysis of social and cultural considerations. Additionally, the scope was confined to the Indonesia-Papua New Guinea border region, potentially constraining the transferability of the findings. To address these limitations, future research should prioritize comprehensive on-site solar resource measurements to obtain more accurate data for system design optimization. Furthermore, the research should incorporate a deeper analysis of the social and cultural factors that may impact project acceptance and sustainability, through meaningful engagement with local stakeholders. Expanding the research to compare multiple border regions would enable a more comprehensive understanding of the viability and replicability of solar power solutions. Investigating existing energy planning frameworks and providing policy recommendations to better integrate renewable energy in border areas would also be valuable. Finally, establishing long-term monitoring and evaluation systems to track performance and inform future initiatives could significantly enhance the impact and applicability of the research findings. By addressing these limitations and exploring these research directions, future studies can build upon the foundations of this work and develop more context-specific, impactful solutions for leveraging solar energy in border regions.

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