

ANALYSIS OF DAILY AND ANNUAL VARIATIONS OF SOLAR RADIATION, AIR TEMPERATURE, PRECIPITATION, WIND SPEED, HUMIDITY, AND AIR PRESSURE IN LAMPUNG AS INDICATORS OF RENEWABLE ENERGY

Ayu Aprilia^{1*}, Ahmad Faruq Abdurrahman², Annisa Ananda³

^{1,2}Departement of Physics, University of Lampung, Bandar Lampung, Indonesia

³Departement of Chemistry, University of Lampung, Bandar Lampung, Indonesia

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*Corresponding author: ayu.aprilia@fmipa.unila.ac.id

Abstract

This study aims to analyze the potential for renewable energy development in Lampung Province, Indonesia, using data from NASA POWER and then integrating it with regional geographic and climate characteristics. The analysis focuses on three main types of renewable energy: solar, wind, and hydropower. In solar energy, Pesisir Barat shows significant potential with high and consistent solar radiation levels, averaging 18.61 kWh/m²/day, and stable temperature conditions, making this area suitable for solar photovoltaic (PV) systems. However, Mesuji shows lower solar radiation but remains a candidate for further exploration. Humidity patterns show minimal impact on solar radiation, while stable air pressure improves solar energy prospects in most areas. Based on the analysis, wind energy has limited potential for large-scale projects due to low wind speeds, averaging 1.0–2.5 m/s, but it can be used for micro-scale applications in coastal areas such as the Pesisir Barat and South Lampung. Hydropower presents significant opportunities, particularly in areas with high precipitation and significant topographic variation, such as West Lampung and Tanggamus, which are ideal for large-scale hydropower and micro-hydro systems. Seasonal precipitation patterns and stable air pressure support renewable energy development by providing predictable resource availability.

Keywords: Energy, Lampung, NASA POWER.

INTRODUCTION

Renewable energy has emerged as a global priority in the current era of increasing energy demand and climate change challenges. Indonesia faces declining fossil fuel reserves and aims to increase its renewable energy share to 23% by 2025 and 31% by 2050 (Setyono & Kiono, 2021). However, progress remains slow, with renewable energy accounting only 11.31% in 2020. Indonesia is exploring various renewable sources, including biomass for biogas and biodiesel production, which can reduce carbon dioxide emissions and mitigate greenhouse gas effects (Pramudiyanto & Suedy, 2020). One is solar energy, which is promising, with potential applications in electricity generation, water heating, and transportation (Dwisari, 2023). To achieve a socially just energy transition, Indonesia must address challenges such as declining oil and gas production, infrastructure integration, and economic factors while ensuring social justice in policy implementation (Lauranti & Djamhari, 2017).

Lampung province in Indonesia has significant potential for renewable energy development to reduce dependence on fossil fuels. Key renewable energy sources in the region include geothermal, biogas from livestock waste, and corn cob gasification. However, current electricity generation in Lampung remains heavily reliant on fossil fuels (Redaputri & Yusuf S Barusman, 2021). Educational initiatives, such as developing renewable energy education tourism at Sekolah Alam Lampung, can help raise awareness and promote innovation in renewable energy technologies (Irsyad & Tugiono, 2023). These efforts include practical demonstrations of wind turbines, solar panels, and water heaters, enabling students to become renewable energy ambassadors (Redaputri & Yusuf S Barusman, 2021). Lampung can contribute significantly to Indonesia's sustainable energy future by leveraging its renewable energy potential and implementing educational programs.

Research highlighting renewable energy is needed to consider its potential, especially in this study examining Lampung province. Lampung is facing increasing energy demand due to rapid development, which requires long-term energy consumption forecasting (Syafruddin et al., n.d.). Previous studies have projected energy supply using LEAP software, considering renewable sources such as geothermal, biogas, and biodiesel (Waluyo, 2020). A comprehensive biomass energy potential map has been developed, but studies on the region's and wind energy potential remain limited (Hidayati & Ekayuliana, 2022). Furthermore, a renewable energy potential map for solar energy, namely solar radiation and temperature and wind energy potential, namely wind speed, needs to be developed. This data can support the development of renewable energy in the Lampung region. In addition, Lampung has significant tourism potential due to its natural beauty, cultural heritage, and unique customs. However, these resources are still underdeveloped, requiring further study and strategic planning to maximize their benefits (Tambunan et al., 2020). This study collectively emphasizes the need for a comprehensive energy development strategy in Lampung.

Meteorological data analysis plays a vital role in optimizing renewable energy infrastructure planning. Many studies have shown that solar panel efficiency is directly proportional to solar intensity and wind speed while inversely proportional to temperature, humidity, and dew point (Sarmah et al., 2023). In addition, correlation analysis based on the Markowitz Portfolio Theory has helped determine spatially more optimal installation of wind turbines and PV panels by examining the temporal correlation of generation profiles (Surmonte et al., 2021). Furthermore, Geographic Information Systems (GIS) can analyze meteorological parameters and high-potential areas for solar and wind power generation, with low-lying areas

often showing more significant potential (Kianian et al., 2019). This study shows that location determines the quantity of energy generated. A framework for visual analytics has been developed to explore long-term solar and wind energy datasets, which facilitates the analysis of spatiotemporal patterns, variable variability, and interactive evaluation of potential installation locations (Pammi et al., 2023). These approaches collectively contribute to more efficient and effective renewable energy resource planning.

Recent studies highlight the impact of climate change on rainfall, temperature, and humidity patterns in Lampung, Indonesia, affecting agricultural planning and productivity. Rainfall in Lampung has shown a decreasing trend since the 1990s, particularly during El Niño events, leading to longer dry seasons and changes in seasonal patterns (Katarina Manik et al., n.d.). Temperature projections for Bandar Lampung indicate an upward trend, while rainfall projections show a downward tendency except during dry periods (Kusumastuty et al., 2021). Coffee production in Lampung has been significantly affected by rainfall variability, with dry months negatively correlated to production (Aisyah et al., n.d.). To adapt, farmers are planting local, tolerant coffee clones and implementing integrated plantation practices. In South Lampung, where rice cultivation is primarily rain-fed, assessing water availability is crucial for sustainable production and infrastructure development (Anika et al., 2022). These findings underscore the importance of climate data in supporting agricultural planning and adaptation strategies in Lampung.

A new study finds dynamic climate patterns in Lampung, Indonesia, and their effects on policy making. One example is the time series analysis of rainfall data from 1974 to 2004, which shows changes in seasonal patterns, indicating an increase in larger climate systems' influence on local rainfall (Katarina Manik, 2009). Other research in Bandar Lampung from 1998-2020 identified symptoms of climate change, including changes in rainfall patterns, air temperature, and impacts such as tidal floods (Pratiwi et al., n.d.). A 30-year study (1991-2020) in South Lampung showed a shift in climate variations, decreasing rainfall, and a general increase in average monthly temperatures (Hidayat & Haryanto, 2023). Although Bandar Lampung has made progress in increasing its capacity to adapt to climate change, its collaborative governance approach faces challenges (Mukhlis & Perdana, 2022). These findings underscore the importance of understanding local climate variations in developing evidence-based policies in Lampung. In the research context, it is intended to look at the potential of renewable energy.

This study aims to analyze Lampung's renewable energy potential by examining five years of meteorological data, focusing on solar radiation, wind speed, and other climatic variables. The objectives include identifying districts with the highest solar energy potential, evaluating the distribution of renewable energy resources, and offering recommendations for optimizing infrastructure development. By addressing the intersection of climate variability and renewable energy, this research aims to contribute to a sustainable energy future for Lampung and beyond.

METHODS

This study uses an integrative method by combining meteorological data from NASA POWER with local data sets related to renewable energy potential in Lampung province. The data consists of main meteorological parameters such as solar radiation, air temperature, rainfall, wind speed, humidity, and air pressure over 5 years. The 5 years is considered the basis for a comprehensive analysis. The study area covers 13 districts and 2 cities in Lampung, with 106 location points. The aim to ensure spatial coverage throughout the province for regional insights. In **Figure 1**. Flow Chart , a flow diagram is provided to make it easier to understand the research flow.

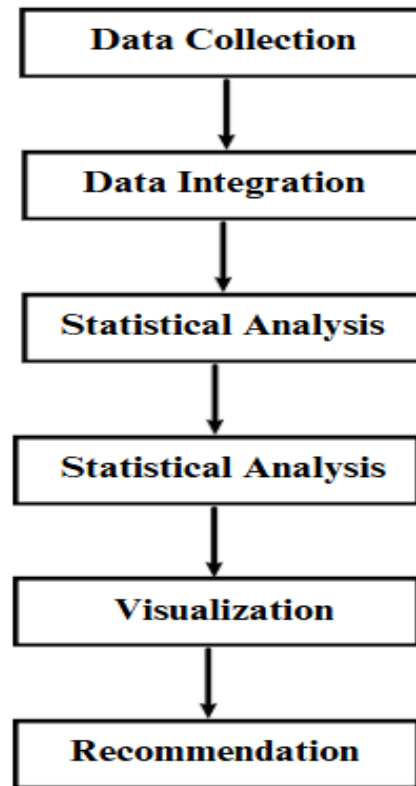


Figure 1. Flow Chart

Data Collection and Sources

The primary data source for this study is the NASA POWER (Prediction of Worldwide Energy Resources) database, which provides reliable, high-resolution meteorological data (I Gusti Ngurah Putu Dharmayasa et al., 2022). Data was taken over a 5 year period started from October 31, 2019 until October 31, 2024. Data to validate the findings and improve application at a regional scale, local data sets and information on administrative boundaries and geographic coordinates are combined (Samsonov, 2021). The integration of these components creates a detailed spatial analysis of potential locations for renewable energy development, specifically solar and wind energy. The selected meteorological variables include:

1. Solar Radiation: Evaluated as the main factor for assessing solar energy potential.
2. Air Temperature: Analyzed to determine its effect on solar panel efficiency and energy consumption patterns.
3. Precipitation: Studied to understand seasonal weather variations.
4. Wind Speed: Considered for its potential application in wind energy.
5. Humidity: Assessed for its effect on solar radiation transmission.
6. Air Pressure: Included to provide additional insight into atmospheric conditions.

Data for each region was collected in Excel and compiled into a unified dataset for further analysis using Python. The dataset underwent detailed and rigorous preprocessing to ensure its quality and reliability. Missing and invalid values were removed, and outliers were identified

and removed using the Interquartile Range (IQR) method. Local observations were compared to NASA POWER data where available to further ensure accuracy.

Data Analysis Tools and Procedures

Data analysis was performed using Python, a powerful and versatile programming language for scientific computing and data analysis. Key libraries used are Excel is a complementary tool for data validation and manual verification of statistical results, Matplotlib and Seaborn To create visualizations, including temporal and spatial trends and Pandas: For data manipulation and organization (McKinney, 2010).

Then, with the help of the Python library, Daily and annual averages for each meteorological parameter were calculated. The daily and annual averages were intended to capture temporal trends and seasonal variability. Descriptive statistics were applied to comprehensively understand the data distribution, while spatial mapping was performed to identify districts with the highest renewable energy potential. Graphical representations, including heat maps and temporal fluctuation graphs, were created to visualize patterns and trends effectively (Daly, 2006).

Methodological Framework

The methodological framework integrates data collection, preprocessing, and advanced analysis to address regional variability and data discrepancies (Kavakiotis et al., 2017). By combining NASA POWER's global perspective with local data, the study contextualizes the findings with the unique conditions of Lampung Province.

The analysis involved calculating daily and annual averages for solar radiation and other parameters to comprehensively assess renewable energy potential. Solar radiation was the primary focus, with wind speed and rainfall analyzed as complementary factors to understand their impact on renewable energy applications (Moriarty & Honnery, 2023). Spatial analysis identified districts with stable and intense solar radiation throughout the year, providing actionable insights for solar energy development.

The integrated and systematic approach ensures the robustness of the findings and offers a reliable basis for energy planning and infrastructure development tailored to the climatic conditions of Lampung Province. The methodological rigor and comprehensive instrumentation used in this study contribute to advancing renewable energy strategies in the region.

RESULTS AND DISCUSSION

Solar Radiation and Air Temperature

The results of the analysis of solar radiation data from 2020 to 2024 in **Figure 2** and **Figure 3** provide information on the potential of solar energy. One of the most significant results is that the average solar radiation on Pesisir Barat is high but consistent (18.61 kWh/m²/day). This gives the Pesisir Barat area the potential to develop solar cells. Furthermore, this potential is accompanied by a variability value indicated by the maximum value (19.22 kWh/m²/day) and standard deviation (0.55). This is positive information in the development of solar energy in the Pesisir Barat area.

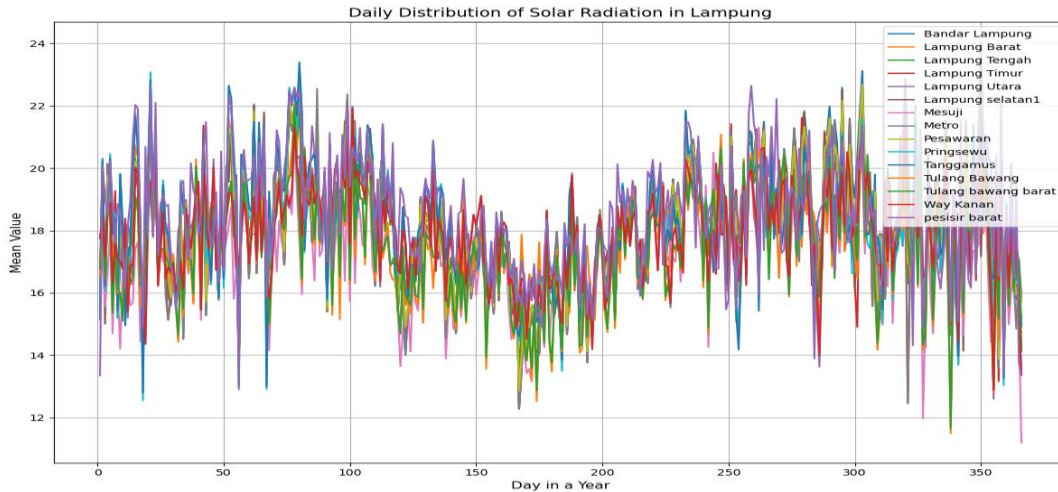


Figure 2. Time Series of Solar Radiation

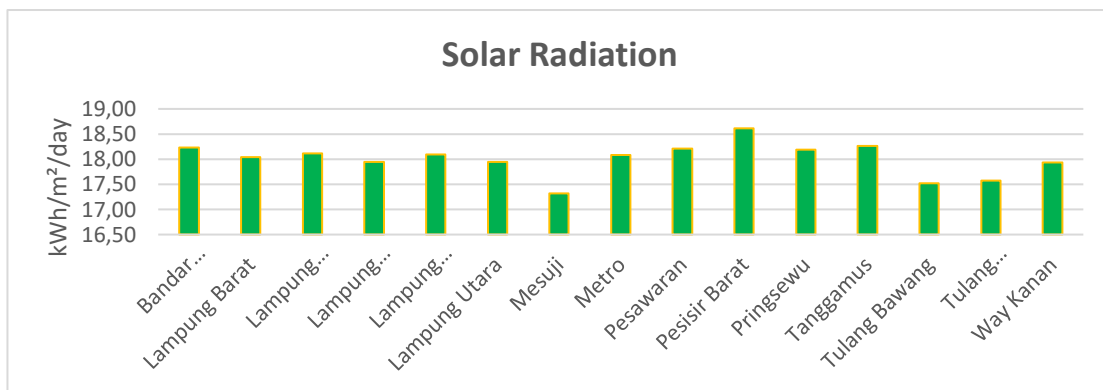


Figure 3. Average daily of Solar Radiation

Other results found that the Mesuji area had the lowest average solar radiation (17.32 kWh/m²/day) with a minimum value of 6.92 kWh/m²/day. The value does not change much, considering that Lampung is a tropical climate area. However, it can be considered if you want to build a power plant in the Mesuji area to conduct further research to choose the right location.

The results of the temperature distribution in **Figure 4** and **Figure 5** obtained aspects of climate diversity that can affect the efficiency of solar cells. In addition, high temperatures may affect the use of electrical energy, such as in the demand for air conditioning. Based on this, South Lampung has the highest temperature with an average of 27.18 °C, second place Tulang Bawang area 26.98 °C. In contrast, West Lampung shows a much lower average temperature (24.72 °C), indicating colder conditions due to altitude or local microclimate.

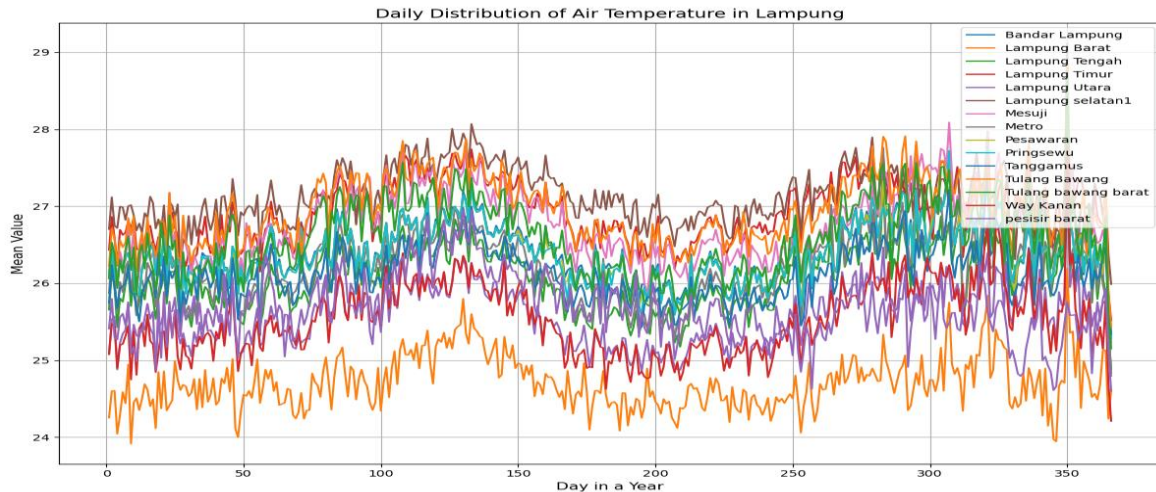


Figure 4. Time Series of Air Temperature

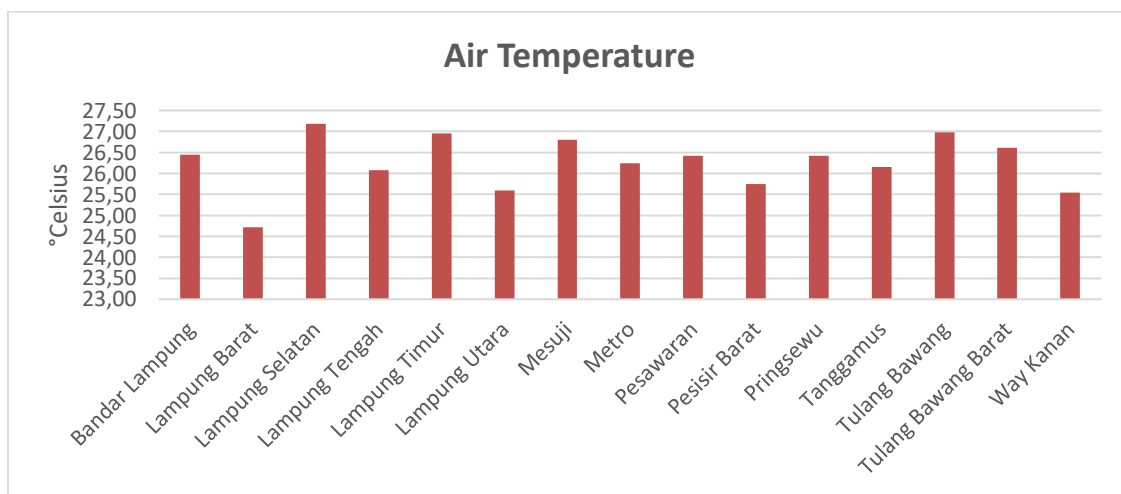


Figure 5. Average Daily of Air Temperature

This study provides information that the Pesisir Barat area recorded the lowest standard deviation value of temperature (0.33). The relatively low-temperature difference can make it easier to predict solar energy system modelling. In addition, with fairly good solar radiation and fairly stable temperatures, the Pesisir Barat area has great potential for developing solar energy.

Patterns and Variability Solar radiation and temperature patterns highlight the importance of considering climate and environmental factors in renewable energy planning. Solar radiation that occurs in the dry season provides an opportunity to maximize solar energy harvesting. Furthermore, air temperature shows a gradual and predictable pattern like the rainy and dry seasons. This stability provides advantages regarding energy demand modelling and solar energy resource development planning.

Humidity and Wind Speed

The humidity graph successfully shows in **Figure 6** and **Figure 7** a clear seasonal trend pattern for various regions in Lampung Province. From the first graph, the daily humidity values in various regions in Lampung Province show a clear seasonal trend. High humidity occurs during the middle

of the year, in accordance with the pattern of tropical climate areas. Humidity values for all regions range from 17% to 21%. Bandar Lampung and Pringsewu have higher humidity and consistency. Furthermore, when associated with precipitation, it shows a linear value with humidity during the rainy season.

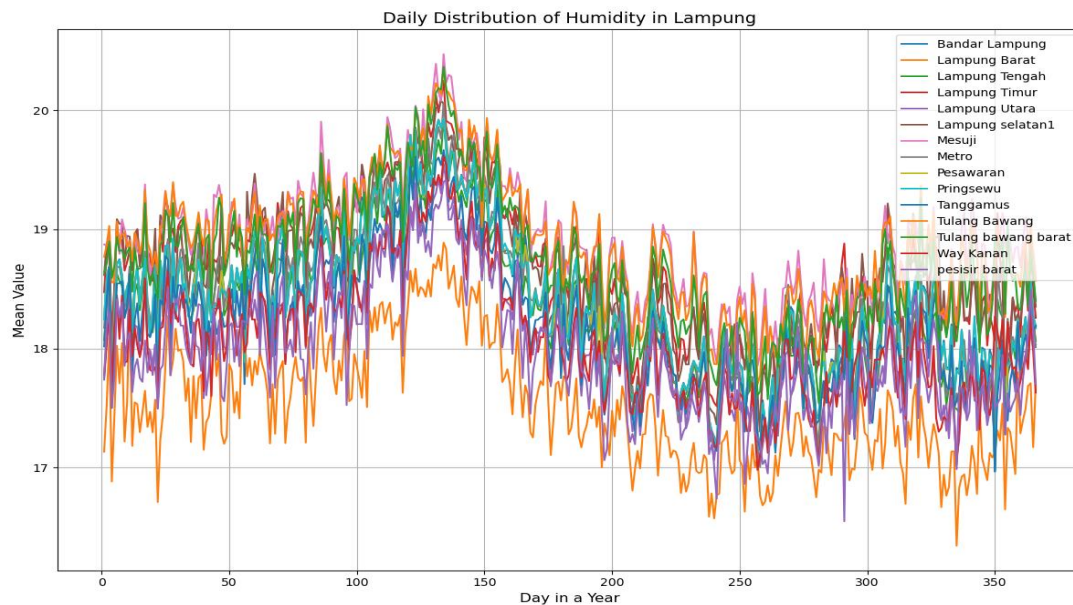


Figure 6. Time Series of Humidity

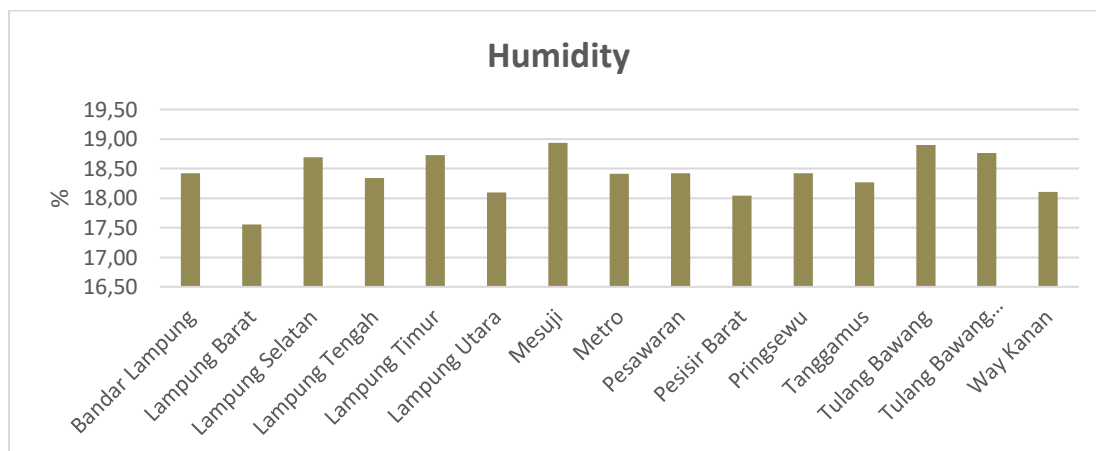


Figure 7. Average Daily of Humidity

Based on **Figure 8** and **Figure 9** the wind speed graph shows that daily wind speeds vary throughout the year, with an average range of 1.0 m/s to 2.5 m/s. Furthermore, areas with higher wind speeds are obtained, namely coastal areas such as the Pesisir Barat and South Lampung. This is due to the possibility of their proximity to the sea. If observed, the seasonal pattern for wind speeds peaks during the transition season, indicating the influence of the rainy season.

Integrating Results with Renewable Energy Potential. In solar energy, consistent humidity levels do not significantly hinder solar radiation levels. The dataset shows an average annual solar radiation of around 18-19 MJ/m², confirming the strong potential for solar energy development in Lampung. Furthermore, for wind energy, wind speed data shows limited potential for large-scale

wind power due to its generally low speed (below 3 m/s). However, micro-scale wind projects, especially in coastal areas, may still be feasible.

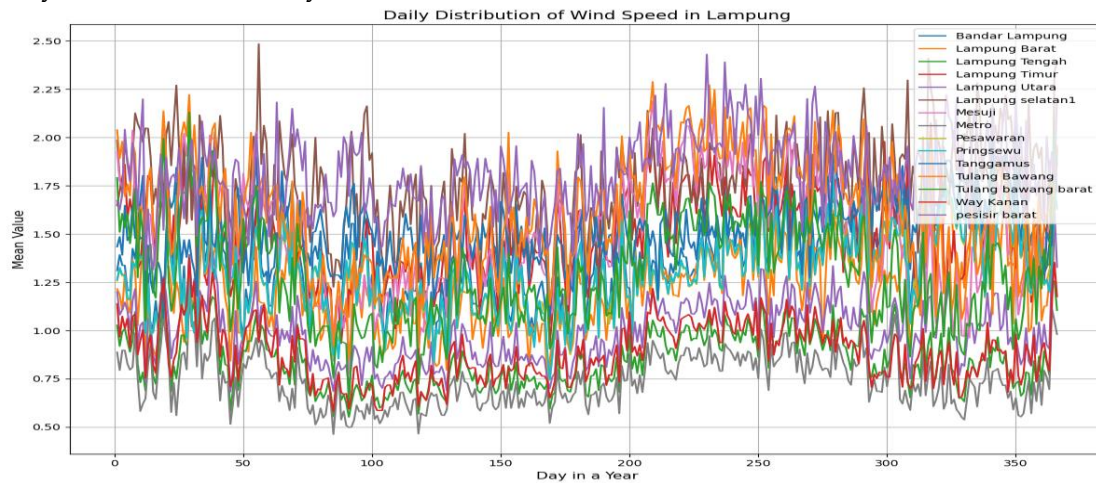


Figure 8. Time Series of Wind Speed

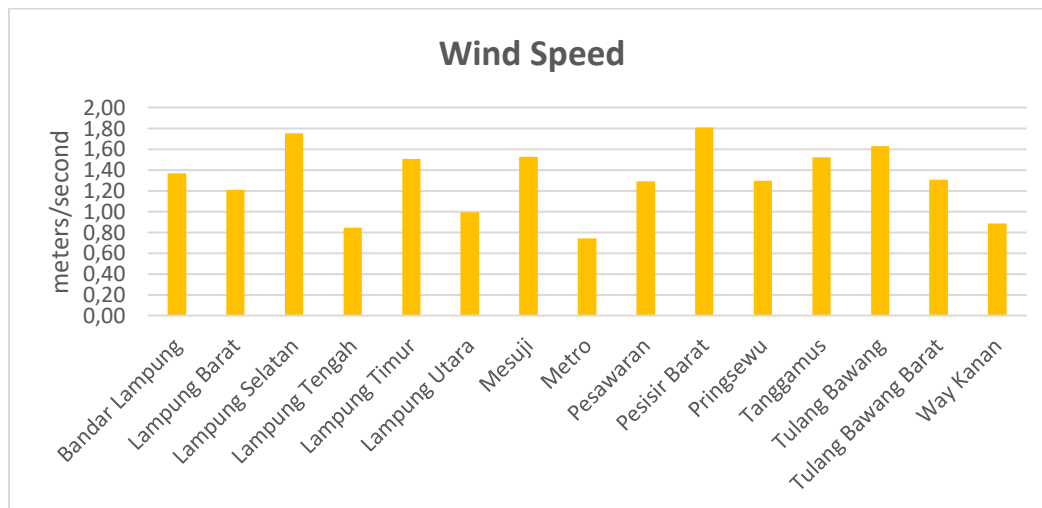


Figure 9. Average Daily of Wind Speed

Precipitation and Air Pressure

The results of the daily distribution show in **Figure 10** and **Figure 11** that the highest precipitation usually occurs at the beginning and end of the year, reflecting the cycle of the Indonesian rainy season. Most areas of Lampung have precipitation of 5-10 mm/day. This is consistent in the annual average. Then, areas such as Bandar Lampung and West Lampung experience much higher precipitation during certain periods, which is in line with the annual maximum value of 11.91 mm/day.

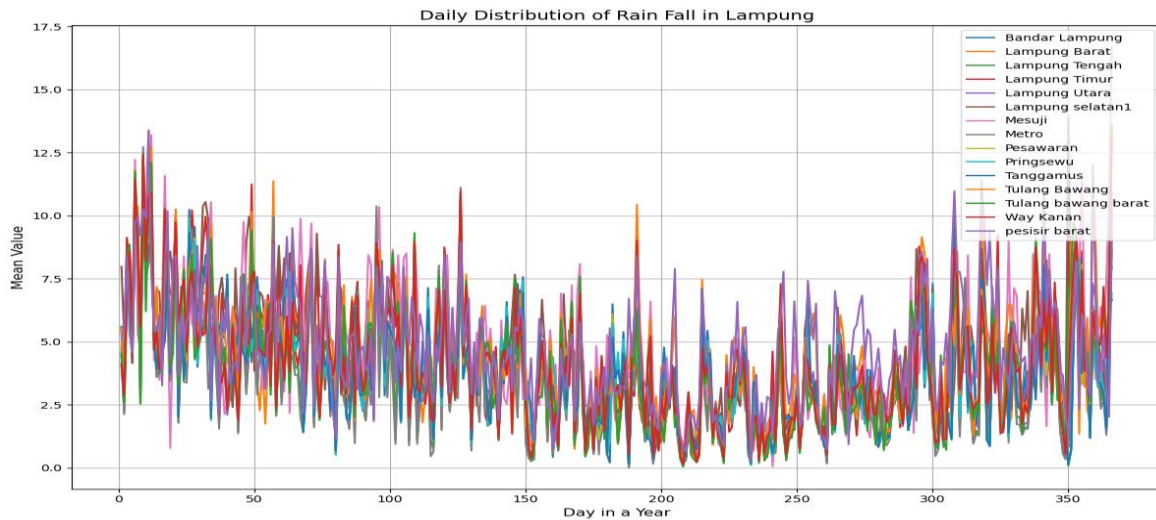


Figure 10. Time Series of Precipitation

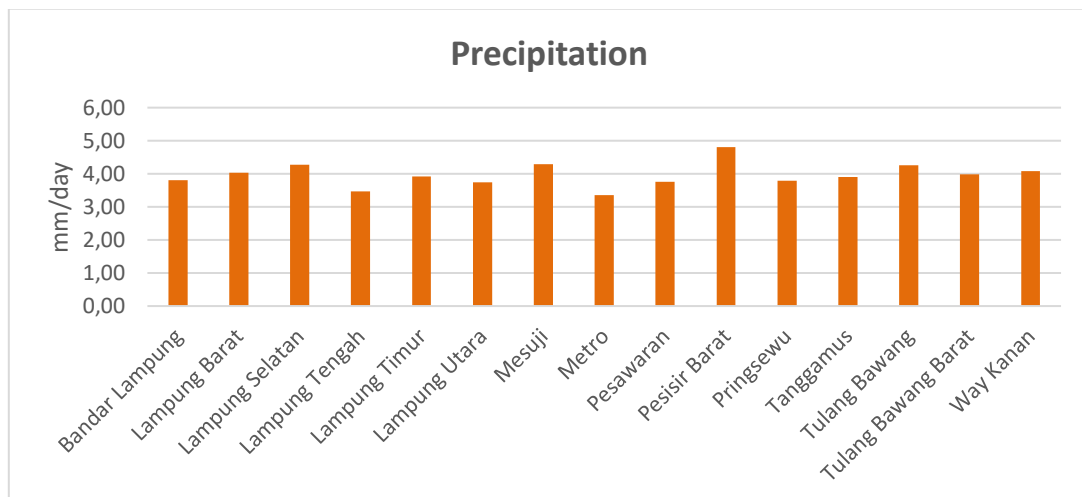


Figure 11. Average Daily of Precipitation

The daily air pressure distribution in **Figure 12** and **Figure 13** consistently ranges from 99–101 kPa, which is in line with the annual average. Areas such as Pesawaran and Pringsewu show very stable air pressure values, indicating minimal atmospheric disturbance. Higher elevations, such as West Lampung, show slightly lower pressure values (~96 kPa), reflecting the influence of topography.

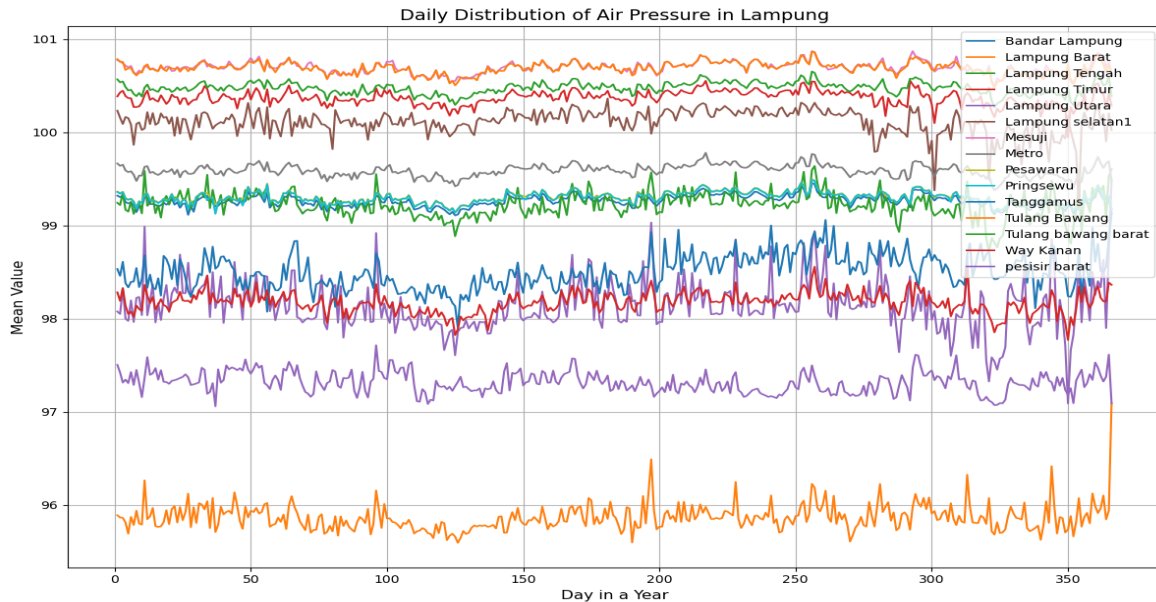


Figure 10. Time Series of Air Pressure

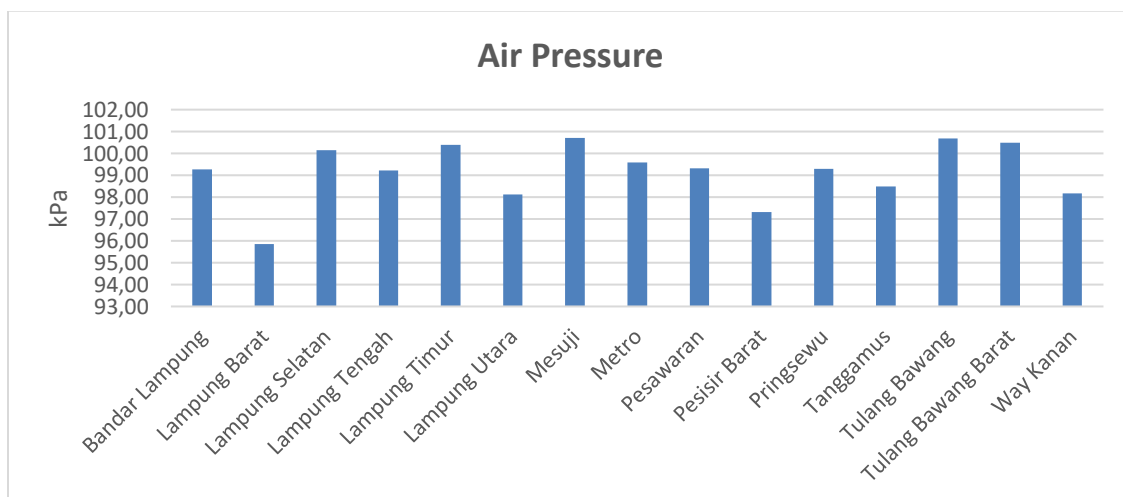


Figure 11. Average Daily of Air Pressure

Correlation Between Precipitation, Air Pressure, and Renewable Energy Potential

1. Solar Energy

Air Pressure Stability: Consistent air pressure (99–101 kPa) in most areas ensures that solar radiation can penetrate the atmosphere effectively. This stability, coupled with periods of lower precipitation (e.g., 3.69 mm/day during the dry season), makes Lampung a good location for solar photovoltaic (PV) systems. **Precipitation Impact:** While heavy precipitation during the rainy season can temporarily reduce solar power generation due to cloud cover, it also naturally cleans the solar panels, increasing efficiency during the dry season. Areas such as Pesawaran and Pringsewu, with moderate precipitation and stable air pressure, are ideal for solar farms.

2. Hydropower (Hydropower and Microhydropower)

Relevance of Precipitation: With an average annual precipitation of 6.51 mm/day, Lampung has great potential for hydropower development. Areas with high precipitation such as West Lampung can maintain river flow throughout the year, supporting large-scale hydropower generation. **Topographic Advantages:** Areas such as Tanggamus and West Lampung, with significant elevation differences and high precipitation, are well suited for microhydropower systems. These smaller systems can power rural communities, offering a cost-effective solution to decentralized energy needs.

CONCLUSION

Analysis of renewable energy in Lampung Province highlights the favorable potential in various renewable energy sources. For solar energy potential, the Pesisir Barat region stands out for its high and consistent solar radiation, with an average of 18.61 kWh/m²/day, a maximum of 19.22 kWh/m²/day, and a low standard deviation of 0.55. This stability makes it ideal for solar cell development. On the other hand, Mesuji has the lowest average solar radiation of 17.32 kWh/m²/day, although its potential requires further investigation. Temperature distribution also plays an important role in solar energy efficiency. Meanwhile, the cooler average temperature in West Lampung is 24.72 °C, offering favorable conditions for consistent solar energy production. Seasonal stability in solar radiation and temperature further supports effective solar energy system modeling and planning.

Humidity patterns and wind speeds add another dimension to renewable energy considerations. Humidity in Lampung shows a clear seasonal trend, with values ranging from 17% to 21%, with areas such as Bandar Lampung and Pringsewu showing higher consistency. These humidity levels do not significantly block solar radiation, thus ensuring the continuity of solar energy. Wind speed data reveal limited potential for large-scale wind energy projects due to their generally low speeds (1.0–2.5 m/s). However, coastal areas such as Pesisir Barat and Lampung Selatan, where wind speeds are slightly higher, may be suitable for micro-scale wind energy projects, especially during peak seasons.

Precipitation and air pressure also influence renewable energy planning. The precipitation pattern in Lampung, with an annual average of 5–10 mm/day and peaking during the rainy season, is in line with hydropower potential. West Lampung and Bandar Lampung, with higher precipitation, could support large-scale hydropower projects, while small-scale micro-hydro systems could be developed in rural areas. Stable air pressure in most areas (99–101 kPa) ensures effective solar radiation penetration, with areas such as Pesawaran and Pringsewu particularly suitable for solar photovoltaic systems due to their moderate precipitation and stable atmospheric conditions. Higher elevations such as West Lampung experience slightly lower pressure values (~96 kPa), reflecting topographic influences.

Overall, Lampung Province shows good potential for renewable energy development. Stability of solar radiation and temperature, coupled with precipitation patterns and air pressure conditions, provide an excellent foundation. Areas with high precipitation and topographic advantages, such as West Lampung and Tanggamus, are ideal for hydropower and micro-hydro projects. Furthermore, wind energy potential is limited to micro-scale applications in coastal areas, but remains a viable option. These findings underscore the significant renewable energy opportunities available in Lampung, supporting sustainable energy development in the region.

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ANALISIS VARIASI HARIAN DAN TAHUNAN RADIASI MATAHARI, SUHU UDARA, CURAH HUJAN, KECEPATAN ANGIN, KELEMBABAN, DAN TEKANAN UDARA DI PROVINSI LAMPUNG SEBAGAI INDIKATOR ENERGI TERBARUKAN

Abstrak

Studi ini bertujuan untuk menganalisis potensi pengembangan energi terbarukan di Provinsi Lampung, Indonesia, dengan menggunakan data dari NASA POWER dan kemudian mengintegrasikannya dengan karakteristik geografis dan iklim regional. Analisis difokuskan pada tiga jenis utama energi terbarukan: tenaga surya, angin, dan tenaga air. Dalam energi surya, Pesisir Barat menunjukkan potensi yang signifikan dengan tingkat radiasi surya yang tinggi dan konsisten, rata-rata 18,61 kWh/m²/hari, dan kondisi suhu yang stabil, menjadikan wilayah ini cocok untuk sistem fotovoltaik surya (PV). Namun, Mesuji menunjukkan radiasi surya yang lebih rendah tetapi tetap menjadi kandidat untuk eksplorasi lebih lanjut. Pola kelembapan menunjukkan dampak minimal pada radiasi surya, sementara tekanan udara yang stabil meningkatkan prospek energi surya di sebagian besar wilayah. Berdasarkan analisis, energi angin memiliki potensi terbatas untuk proyek skala besar karena kecepatan angin yang rendah, rata-rata 1,0–2,5 m/s, tetapi dapat digunakan untuk aplikasi skala mikro di wilayah pesisir seperti Pesisir Barat dan Lampung Selatan. Pembangkit listrik tenaga air menawarkan peluang yang signifikan, terutama di daerah dengan curah hujan tinggi dan variasi topografi yang signifikan, seperti Lampung Barat dan Tanggamus, yang ideal untuk sistem pembangkit listrik tenaga air dan mikrohidro skala besar. Pola curah hujan musiman dan tekanan udara yang stabil mendukung pengembangan energi terbarukan dengan menyediakan ketersediaan sumber daya yang dapat diprediksi.

Kata kunci: Energi, Lampung, NASA POWER.