

Assessment of Wind Energy Potential in Kolaka Using Era5-land Data Reanalysis

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ABSTRACT

This research aims to evaluate the potential for wind energy in Kolaka Regency using ERA5-Land reanalysis data from the output of the European Center for Medium-Range Weather Forecasts (ECMWF) model, which has a spatial resolution of 9 km with hourly temporal resolution for the period from 2001 to 2020. This research also compared the quality of ERA5-Land reanalysis wind speed data on data from nearby meteorological stations using statistical assessment methods. The analysis results reveal that the highest average wind speed was discovered at a height of 80 to 150 meters with a range of 4.99 to 5.93 m/s. The spatial distribution map of wind power density indicates that the energy potential at a height of 80 to 150 meters can reach 60 to 170 W/m². The largest wind energy potential in Kolaka Regency can be generated in the DJF period (December-January-February) with the highest average monthly wind power density in January and the JJA period (June-July-August) with the highest average in July. In general, Kolaka Regency can be classified as an area with first-class wind energy potential, so it tends to be more suitable for the development of small-scale power plants. The suitable locations for developing small-scale wind power plants in Kolaka Regency are the southern Pomalaa coast and the Tanggetada coast because both locations have better wind energy sources than other areas.

Keywords: Reanalysis data, ERA5-Land, wind power density, wind energy potential.

INTRODUCTION

Wind energy is an alternative energy to replace fossil energy which has advantages including being environmentally friendly, not polluting CO₂ emissions, unlimited resources, reliable and easy to find. (Nasiri et al., 2014; Varzaneh et al., 2014). The use of wind energy as a generator has grown very rapidly, in order to meet the need for electricity which continues to increase every year (Soufi et al., 2016).

A significant increase in global wind energy capacity occurred from 2008 to 2018. In 2008, global wind energy capacity was only 121 gigawatts (GW) and increased to 591 GW in 2018, around 568.4 GW operates onshore and the rest is offshore. This makes wind the second largest source of renewable energy after hydro energy which reaches a capacity of 1,132 GW (Hesty et al., 2021; REN21, 2019). 2020 was a historical year in the global wind energy industry, as many as 93

GW of additional new wind energy capacity were installed, growing 53% compared to 2019, bringing the total installed capacity to 742,689 GW.(Lee & Zhao, 2021).

According to Hidayat (2022), data from the General National Energy Plan (RUEN) shows that the largest wind energy potential in Indonesia is in the East Nusa Tenggara region reaching 10.19 GW, followed by East Java, West Java, Central Java, South Sulawesi and Maluku with each potential of 7.91 GW, 7.04 GW, 5.21 GW, 4.19 GW and 3.19 GW. For wind energy potential in other provinces.

Utilization of wind energy as new renewable energy (EBT) in Indonesia is still relatively low, only around 0.1% of the total wind energy potential of 60.6 GW(Directorate General of EBTKE, 2020). Of the total national generating capacity installed in 2020 of 72,750.72 MW, the contribution made was only 154.31 MW or around 0.21%(Directorate General of Electricity, 2022; Saputra et al., 2023). The minimal use of wind energy for electricity in Indonesia is due to the relatively high production prices of NRE-based power plants making it difficult to compete with fossil power plants, the lack of domestic industry support regarding NRE plant components, the difficulty of obtaining low-interest funding(DEN, 2022).

One of the regions in Indonesia that has large wind energy potential is Sidrap and Jenepono in South Sulawesi. Currently both areas have also had PLTB built and are operating commercially. Sidrap PLTB has a capacity of 75 MW from 30 installed wind turbines with a blade length of 57 meters and a turbine hub height of 80 meters(Directorate General of EBTKE, 2017). Meanwhile at Jenepono PLTB, the total installed capacity reaches 72 MW from 20 wind turbines with a blade length of 63 meters and a turbine hub height of 133 meters.(Private, 2019).

The potential of wind energy for electricity generation is very dependent on the distribution of wind speed throughout the year(Amano, 2017; Burke et al., 2019). Wind speed in Indonesia is generally between 3 and 6 m/s(EMR, 2020) and the average that can be used for small wind turbines starts from 3 m/s, above 5 m/s for medium type wind turbines, and 6 m/s for large wind turbines(Yunginger & Sune, 2015). According to Notosudjono & Adzikri (2018), areas that have an average wind speed of less than 5 m/s are more suitable for small-scale power plants using vertical axis wind turbines to produce good electricity. Feasibility of building a wind or wind power plant (PLTB) at a location, the annual average wind speed at a minimum height of 50 meters ranges from 4 m/s to 5 m/s(BSN, 2017) or a minimum wind power density of around 39 W/m² to 77 W/m².

To identify the assessment of wind energy potential and determine the optimal turbine hub height, characterization of the vertical wind speed profile is required(Giani et al., 2020; Lantz et al., 2019) because wind power density (WPD) varies exponentially with the cube of the wind speed(Lu et al., 2009). Wind energy assessments are usually carried out at different turbine hub heights and most potential wind speed characterizations are based on vertical extrapolation of surface wind speed at a height of 10 m assuming stable neutral conditions(Aboobacker et al., 2021; Langodan et al., 2016; Ren et al., 2020; Yip et al., 2016). In extrapolating a 10 m wind speed, this research uses the Power Law method to estimate wind speed at turbine hub heights of 30, 50, 80, 100, and 150 m.

According to Ahmad et al (2022), accurate measurement and collection of in situ data over a long period of time is an important requirement for assessment studies of a region's wind energy potential. Collecting in situ wind speed data requires large costs and challenges, especially over a long period of time (Nezhad et al., 2021). As an alternative, due to the limited number of meteorological stations and anemometer equipment installed in the research area, reanalysis data is used. The quality of accuracy of reanalysis data varies depending on location, so before use it needs to be evaluated against measured data (Ahmad et al., 2022) by using statistical parameters.

The use of ERA5 or ERA-Interim data from the European Center for Medium-Range Weather Forecasts (ECMWF) reanalysis model has been widely used in studies assessing the potential for offshore and onshore wind energy in several countries. (Gualtieri, 2019; Nezhad et al., 2021), including Poland (Jurasz et al., 2021), Qatar (Aboobacker et al., 2021), Oman (Al-Hinai et al., 2021), Colombia (Gil Ruiz et al., 2021), Ethiopia (Nefabas et al., 2021), Brazil (Tavares et al., 2020), Scotland (Ulazia et al., 2019), and Lebanon (Ibarra-Berastegi et al., 2019).

Meanwhile, in this research, the ECMWF reanalysis data used to evaluate the assessment of wind energy potential is ERA5-Land. Utilization of ERA5-Land reanalysis wind speed data in research Marinšek & Bajt (2020) and Arregocés et al (2024) used respectively to improve the accuracy of wind turbine power predictions up to 24 hours ahead at the Fântânele-Cogealac wind farm site in Romania and identify wind energy potential at a height of 90 meters in the Northern South American region. On research Marinšek & Bajt (2020), in determining wind speed at a turbine hub height of 100 meters, vertical extrapolation of wind speed from a height of 10 meters was carried out. The same thing is also done in research Arregocés et al (2024) to calculate the approximate wind speed at a height of 90 meters.

According to Muñoz-Sabater et al (2021), the advantage of ERA5-Land reanalysis data compared to ERA5 and ERA-Interim is that it has a global horizontal resolution of up to 9 km, better than ERA5 which only has a resolution of 31 km and 80 km for resolution in ERA-Interim. Apart from that, ERA5-Land also has a much higher spatial resolution than the ERA5 and ERA-Interim generations, reaching $0.1^\circ \times 0.1^\circ$ with hourly temporal resolution, and is the first reanalysis product to focus on land surface variables in the series. ERA.

Due to the limited number of meteorological stations and Automatic Weather Station (AWS) observations, as well as the high cost of direct measurements, ERA5-Land data from the ECMWF reanalysis model is a relevant alternative for studying wind energy potential in Kolaka Regency. ERA5-Land data offer higher spatial and temporal resolution than previous generations of reanalysis. The research entitled "Assessment of Wind Energy Potential in Kolaka Using Era5-Land Reanalysis Data" aims to assess the quality of ERA5-Land reanalysis wind speed data on Sangia Nibandera Kolaka Meteorological Station data, estimating wind power density at altitudes 10, 30, 50, 80, 100, and 150 meters, and evaluate the spatial distribution of wind energy potential at the same height. It is hoped that this research can increase confidence in reanalysis data, identify potential wind resource locations in Kolaka, and contribute to planning for the development of

wind energy as renewable energy, as well as enriching literature studies and motivating relevant parties to carry out further evaluations.

RESEARCH METHODS

This research is a quantitative descriptive study which aims to provide an overview of the potential of wind energy in Kolaka Regency. With a quantitative approach, this research collects and analyzes numerical data through ERA5-Land reanalysis data for wind variables, and involves statistical analysis to evaluate wind energy potential. The research was carried out for eight months, from October 2023 to May 2024, in Kolaka Regency which is located at coordinates 3°36'-4°45' South Latitude and 120°45'-121°52' East Longitude, with a land area of 3,283.59 km². The data used includes observations of wind direction and speed at a height of 10 meters during the period 1 January 2001 to 31 December 2020 converted from knots to m/s, obtained from the Sangia Nibandera Kolaka Meteorological Station. In addition, hourly ERA5-Land reanalysis data for the u (Eastward) and v (Northward) wind components at a height of 10 meters during the same period as well as a map of the Kolaka Regency subdistrict administrative area were also used. Supporting tools in this research include Notebook, Microsoft Excel, Visual Studio Code, WRPlot View, and Quantum GIS (QGIS). Data processing procedures include calculating wind direction and speed at a height of 10 meters, comparing reanalysis data with observation data using statistical metrics RMSE, MAE, MBE, and STDE, as well as calculating and interpolating wind power density at various heights using QGIS. Data analysis techniques involve comparison of graphic patterns and statistical test values between observation data and reanalysis data, analysis of monthly and seasonal average wind speeds across the grid, evaluation of wind power density, and identification of potential areas for wind resources.

RESULTS AND DISCUSSION

Research result

1. Wind Speed Data Quality Test Reanalysis ERA5-Land

To measure the quality of the ERA5-Land reanalysis wind speed data against meteorological station observation data, validation of the average wind speed at a height of 10 meters was carried out over a 20 year period (2001-2020). Validation was carried out by comparing the distribution pattern of ERA5-Land reanalysis data with observation data from the Sangia Nibandera Kolaka Meteorological Station. In addition, the statistical metric parameter values RMSE, MAE, MBE, and STDE were calculated to measure the deviation or error values of the observation data.

a. Comparison $\bar{u}_{10}$ reanalysis ERA5-Land and observations

To compare observation data with the ERA5-Land reanalysis, grids 661, 699, and 736 were chosen because they have the closest distance to the location of the Sangia Nibandera Kolaka Meteorological Station, which is less than 15 km (see Figure 3.1). Value comparison $\bar{u}_{10}$ between grids 661, 699, 736 with observations.

The graphic pattern in Figure 4.1b shows $\bar{u}_{10}$. The lowest and highest seasonality at the Sangia Nibandera Kolaka Meteorological Station compared to other seasonal periods occurs at MAM and SON with an average value of 1.28 m/s and 1.73 m/s. For $\bar{u}_{10}$, the lowest and highest monthly occurred in April and September (Figure 4.1a) with average values reaching 1.23 m/s and 1.83 m/s respectively.

On *grids* ERA5 reanalysis-Land studied, the lowest seasonality occurred at MAM for the location $\bar{u}_{10}$ *grids* 661 and 736 as well as SON for location *grids* 699 with average values reaching 1.44 m/s, 1.96 m/s and 1.38 m/s respectively.

b. Wind direction comparison reanalysis ERA5-Land and observations

To compare the distribution of wind direction at a height of 10 meters from observations with ERA5-Land reanalysis, the data used is only for the period 2014 to 2020. This is due to the availability of data from hourly wind direction observations at the Sangia Nibandera Kolaka Meteorological Station. The ERA5-Land reanalysis wind direction data compared to observational data in this study is data at grid locations 661, 699, and 736.

The percentage level of dominance of the West wind direction reached 21.51% and the East wind direction reached 20.01% for observations from the Sangia Nibandera Kolaka Meteorological Station. Meanwhile, the ERA5-Land reanalysis wind direction on grids 661, 699, and 736, the percentage of dominance of the West wind direction reached 33.65%, 37.39%, and 34.44% respectively and the East direction reached 20.24% respectively. , 26.19%, and 30.90%, as shown.

c. Statistical test analysis of wind speed ERA5-Land reanalysis

Evaluation of the performance of the average wind speed at a height of 10 meters from the ERA5-Land reanalysis was carried out using statistical tests to measure error values against reference data from meteorological stations. Analysis of statistical metrics such as RMSE, MAE, MBE, and STDE shows that STDE values of more than 0.5 m/s only occur in January and June in some grids, with the highest value in grid 736 in January. The highest RMSE and MAE metrics were also found in the JJA period in all grids, with the highest value in grid 736. In general, the average STDE value for the seasonal period at the three grid locations was below 0.5 m/s, while the MBE value showed that ERA5-Land wind speed tends to be overestimated compared to observational data.

2. ERA5-Land Reanalysis Wind Speed Extrapolation

ERA5-Land reanalysis estimation results for the 2001-2020 period for the entire grid in the Kolaka Regency area. Seasonal increases across the ERA5-Land reanalysis grid generally occur at DJF and JJA with the highest average wind speeds reaching 2.58 m/s and 2.68 m/s at grid locations 736 and 621, respectively. $\bar{u}_{10}$ $\bar{u}_{10}$ highest monthly period DJF and JJA occurred in January and July respectively reaching average values of 2.87 m/s and 2.82 m/s for grid locations 736 and 621.

Seasonal declines occurred in MAM and SON, as seen in Figure 4.5b. $\bar{u}_{10}$ $\bar{u}_{10}$ The lowest seasonality occurs at grid locations 506 and 505, respectively, the average value reaches 0.77 m/s and 0.93 m/s. For the lowest

monthly periods MAM and SON occurred in April and November reaching average values of 0.74 m/s and 0.85 m/s $\bar{u}_{10}$ occurred at grid locations 506 and 505, respectively.

Next, the ERA5-Land reanalysis wind speed at a height of 10 meters is extrapolated for heights of 30, 50, 80, 100, and 150 m using equations (2.4) and (2.7). Average wind speed ERA5- reanalysisLandThe extrapolation results were analyzed based on monthly and seasonal variations during the 2001-2020 period. In this study, the average wind speed at altitude30, 50, 80, 100 and 150 meach is denoted by $\bar{u}_{30}$, $\bar{u}_{50}$, , , And $\bar{u}_{80}$, $\bar{u}_{100}$, $\bar{u}_{150}$

a. Monthly average wind speed

Extrapolated monthly average wind speed at heights of 30, 50, 80, 100 and 150 m during the 2001-2020 period. The highest average wind speed in January and March at heights of 30, 50, 80, 100, and 150 m occurred at grid location 736. $\bar{u}_{30}$, $\bar{u}_{50}$, , , And $\bar{u}_{80}$, $\bar{u}_{100}$, $\bar{u}_{150}$ January reached an average of 3.84 m/s, 4.40 m/s, 4.98 m/s, 5.29 m/s and 5.89 m/s. Meanwhile, in March the average values reached 2.88 m/s, 3.35 m/s, 3.84 m/s, 4.10 m/s and 4.62 m/s. The highest wind speed in February occurred at grid location 811 (Figure 4.6b) with an average wind speed of each at height30, 50, 80, 100, and 150 m reach 3.33 m/s, 3.84 m/s, 4.39 m/s, 4.67 m/s, and 5.24 m/s.

The highest average wind speed from April to June during the 2001-2020 period at heights of 30, 50, 80, 100, and 150 m occurred at grid location 621. The average wind speed in April reached 2.41 m/s, 2.82 m/s, 3.27 m/s, 3.51 m/s, and 3.99 m/s for , , , , and $\bar{u}_{30}$, $\bar{u}_{50}$, $\bar{u}_{80}$, $\bar{u}_{100}$, $\bar{u}_{150}$. Wind speed in May at altitude30, 50, 80, 100, and 150 m at grid location 621 reach average values of 2.96 m/s, 3.45 m/s, 3.96 m/s, 4.23 m/s respectively. s, and 4.78 m/s. Meanwhile in June, the average wind speed reached 3.47 m/s, 4.01 m/s, 4.58 m/s, 4.87, and 5.47 m/s respectively for , , , , And $\bar{u}_{30}$, $\bar{u}_{50}$, $\bar{u}_{80}$, $\bar{u}_{100}$, $\bar{u}_{150}$ Kwind speedhighest averageJuly-Septemberat height30, 50, 80, 100, and 150 m occurred at grid location 621. The average wind speed in July at grid location 621 reached 3.81 m/s, 4.38 m/s, 4.99 m/s, 5.30 m/s, and 5.93 m/s for , , , , and , respectively. For August, respectively, it reached 3.63 m/s, 4.18 m/s, 4.76 m/s, 5.07 m/s and 5.68 m/s. Meanwhile, , , , , and $\bar{u}_{30}$, $\bar{u}_{50}$, $\bar{u}_{80}$, $\bar{u}_{100}$, $\bar{u}_{150}$ September at grid location 621 respectively reached 3.14 m/s, 3.64 m/s, 4.17 m/s, 4.45 m/s, and 5.01 m/s KThe highest average wind speed in October-Decemberat height30, 50, 80, 100, and 150 m occur at grid location 736. , , , , and $\bar{u}_{30}$, $\bar{u}_{50}$, $\bar{u}_{80}$, $\bar{u}_{100}$, $\bar{u}_{150}$ October on grid 736 respectively reached 2.90 m/s, 3.37 m/s, 3.87 m/s, 4.13 m/s and 4.66 m/s.

For November, the average wind speed values reached 2.82 m/s, 3.28 m/s, 3.77 m/s, 4.03 m/s, and 4.55 m/s respectively for $\bar{u}_{30}$, $\bar{u}_{50}$, , , And $\bar{u}_{80}$, $\bar{u}_{100}$, $\bar{u}_{150}$. Meanwhile, the average wind speed in December at grid location is 736 for height30, 50, 80, 100, and 150 m reach 3.33 m/s, 3.84 m/s, 4.38 m/s, 4.66 m/s, and 5.23 m/s respectively .

b. Seasonal average wind speed

Histogram during the DJF period, the highest ERA5-Land reanalysis seasonal average wind speed in the Kolaka Regency area for heights of 30, 50, 80, 100, and 150 m occurred at grid location 736 with , , , , and each reached an average

value -averages of 3.48 m/s, 4.01 m/s, 4.56 m/s, 4.85 m/s, and 5.43 m/s. $\bar{u}_{30}$, $\bar{u}_{50}$, $\bar{u}_{80}$, $\bar{u}_{100}$, $\bar{u}_{150}$

Meanwhile, , , , and the lowest occurred at grid location 506 with seasonal average wind speeds reaching 1.20 m/s, 1.46 m/s, 1.75 m/s, 1.91 m/s, and 2.23 m/s. For the MAM period, the lowest and highest seasonal average wind speeds also occur at the same grid locations as the DJF period, namely grids 506 and 736. During the MAM period, the lowest average wind speeds are at heights 30, 50, 80, 100, and 150 meters were recorded at 1.18 m/s, 1.44 m/s, 1.72 m/s, 1.88 m/s, and 2.19 m/s respectively, while the highest speed at the same height the same reaching 2.71 m/s, 3.16 m/s, 3.64 m/s, 3.90 m/s, and 4.41 m/s. During the JJA period, there was an increase in average wind speed, with the highest values at heights of 30, 50, 80, 100 and 150 meters reaching 3.63 m/s, 4.19 m/s, 4.77 m/s, 5.08 m/s, and 5.69 m/s, and the lowest at 1.45 m/s, 1.75 m/s, 2.08 m/s, 2.26 m/s, and 2.63 m/s. For the SON period, the average wind speed decreased compared to JJA, with the highest values at 2.92 m/s, 3.39 m/s, 3.90 m/s, 4.16 m/s, and 4.69 m/s and the lowest at 1.39 m/s, 1.67 m/s, 1.99 m/s, 2.16 m/s, and 2.51 m/s. $\bar{u}_{30}$, $\bar{u}_{50}$, $\bar{u}_{80}$, $\bar{u}_{100}$, $\bar{u}_{150}$

3. Wind Power Density at Height 10, 30, 50, 80, 100, and 150 m

In this research, the wind power density or WPD that will be studied is WPD_{10} , WPD_{30} , WPD_{50} , WPD_{80} , , and respectively for WPD_{100} , WPD_{150} heights of 10, 30, 50, 80, 100, and 150 m during the 2001-2020 period which were calculated based on wind speed at the ERA5-Land reanalysis grid location in the Kolaka Regency area.

To calculate the WPD amount at a height of 10 meters or WPD_{10} Equation (2.12) is used and the results are used as a reference in predict WPD_{30} , WPD_{50} , WPD_{80} , , and by using WPD_{100} , WPD_{150} equation (2.13). Monthly and seasonal average yields for , WPD_{10} , WPD_{30} , WPD_{50} , WPD_{80} , , And . WPD_{100} , WPD_{150}

a. Monthly average WPD_{10} , WPD_{30} , WPD_{50} , WPD_{80} , , And WPD_{100} , WPD_{150}

The highest WPD in January and March occurred at grid location 736. WPD_{10} , WPD_{30} , WPD_{50} , WPD_{80} , , and January on WPD_{100} , WPD_{150} grids 736 respectively reaching 16.7 W/m², 40.3 W/m², 60.9 W/m², 89.0 W/m², 106.6 W/m², and 147.9 W/m². Meanwhile, in March it reached 6.6 W/m², 17.3 W/m², 27.2 W/m², 41.3 W/m², 50.3 W/m², and 72.2 W/m². For February, the highest WPD occurred at grid location 811 with value WPD_{10} , WPD_{30} , WPD_{50} , WPD_{80} , , And WPD_{100} , WPD_{150} respectively reaching 10.4 W/m², 26.4 W/m², 40.6 W/m², 60.5 W/m², 73.2 W/m², and 103.3 W/m².

Meanwhile, the highest WPD for the April-June period occurred at grid location 621. April WPD reached 3.1 W/m², 9.0 W/m², 14.7 W/m², 23.1 W/m², 28.6 W/m², and 42.4 W/m² respectively for WPD_{10} , WPD_{30} , WPD_{50} , WPD_{80} , , And . For the month of May, , WPD_{100} , WPD_{150} , WPD_{10} , WPD_{30} , WPD_{50} , WPD_{80} , , and each achieves WPD_{100} , WPD_{150} 6.5 W/m², 17.2 W/m², 27.3 W/m², 41.5 W/m², 50.7 W/m², and 73.0 W/m². Whereas June reaches 10.5 W/m², 26.9 W/m², 41.6 W/m², 62.3 W/m², 75.4 W/m², and 106.7 W/m² respectively for WPD_{10} , WPD_{30} , WPD_{50} , WPD_{80} , , And . WPD_{100} , WPD_{150}

During the MAM period, the lowest average wind speeds at heights of 30, 50, 80, 100, and 150 meters were recorded at 1.18 m/s, 1.44 m/s, 1.72 m/s, 1.88 m/s, and 2.19 m/s, while the highest speed at the same height reached 2.71 m/s, 3.16 m/s, 3.64 m/s, 3.90 m/s, and 4.41 m/s. During the JJA period, there was an increase in average wind speed, with the highest values at heights of 30, 50, 80, 100 and 150 meters reaching 3.63 m/s, 4.19 m/s, 4.77 m/s, 5.08 m/s, and 5.69 m/s, and the lowest at 1.45 m/s, 1.75 m/s, 2.08 m/s, 2.26 m/s, and 2.63 m/s. For the SON period, the average wind speed decreased compared to JJA, with the highest values at 2.92 m/s, 3.39 m/s, 3.90 m/s, 4.16 m/s, and 4.69 m/s and the lowest at 1.39 m/s, 1.67 m/s, 1.99 m/s, 2.16 m/s, and 2.51 m/s.

4. Spatial Distribution of Wind Energy Potential at Height 10, 30, 50, 80, 100, and 150 m

The results of wind power density or WPD calculations on each ERA5-Land reanalysis grid (Figure 3.1) are interpolated using the QQIS application for heights of 10, 30, 50, 80, 100 and 150 m so that monthly average spatial distribution patterns can be depicted. and seasonality of wind energy potential in Kolaka Regency.

a. WPD at a height of 10 meters

Spatially, most areas of Kolaka Regency show that the monthly and seasonal average wind power density at a height of 10 meters is below 10 W/m². The highest average, both monthly and seasonal, was identified as reaching 10-20 W/m² in January, June, July and August as well as during the DJF and JJA periods. Locations with wind power density of 10-20 W/m² in January include Padamarang Island, Wundulako, Pomalaa, Tanggetada, Watubangga, Polinggona and Toari Districts. In June, the area includes Padamarang Island, Pomalaa Coast, Tanggetada Coast, and the Samaturu border with Latambaga. During July, the area with dense wind power extends to the Samaturu Coast, Wundulako, Padamarang Island, Pomalaa, Tanggetada, Watubangga, Toari, and the western part of Polinggona. In August, these areas include the Toari Coast to Pomalaa, the western part of Polinggona, Padamarang Island, and the Samaturu border with Latambaga. For the DJF and JJA periods, the highest seasonal wind power density reaches 10-20 W/m² on the Tanggetada Coast and the Watubangga, Tanggetada and Pomalaa Coasts.

b. WPD at a height of 30 meters

The monthly average wind power density at a height of 30 meters in Kolaka Regency reaches the highest 40-50 W/m² in January and July, with the main areas on the Tanggetada Coast in January and the southern part of the Pomalaa Coast as well as Padamarang Island to Maniang Island in Wundulako District in July. Seasonally, the highest average wind power density of 20-30 W/m² occurs during the DJF and JJA periods, with distribution in the DJF covering Padamarang Island, Maniang Island in Wundulako District, Pomalaa, Tanggetada, Watubangga, Polinggona, and Toari, while in JJA, the area with this value extends along the coast from Samaturu to Baula, and includes Padamarang Island, Maniang Island, Pomalaa, Tanggetada, Polinggona, Watubangga and Toari.

c. WPD at a height of 50 meters

At a height of 50 meters, the highest monthly average wind power density occurs in January and July, reaching 60-70 W/m², with the main areas on the Tanggetada Coast and around the Pomalaa border with Tanggetada in January, as well as on Padamarang Island to Maniang Island in Wundulako District, and the southern part of the Pomalaa Coast to Tanggetada in July. Seasonally, the highest wind power density only reaches 40-50 W/m² in the DJF and JJA periods, with distribution in the DJF covering the Pomalaa and Tanggetada borders, the Tanggetada Coast to Watubangga, and in the JJA identified on the Samaturu and Latambaga border coast, eastern part of the island Padamarang to Maniang Island in Wundulako District, the southern part of the Pomalaa Coast, as well as the Tanggetada Coastal area to Watubangga, the border of Watubangga and Toari, and the western part of Polinggona.

d. WPD at a height of 80 meters

There is a monthly average wind power density at a height of 80 meters which reaches 90-100 W/m², namely in January and July. The average size in January reaches 90-100 W/m² on the Tanggetada Coast. Apart from the Tanggetada Coast, there are areas with an average of 90-100 W/m² in July, namely the southern Pomalaa Coast and Padamarang Island to Maniang Island, Wundulako District. WPD₈₀ WPD₈₀

The amount reaching 60-70 W/m² occurs during the DJF and JJA seasons. The area in Kolaka Regency which has the highest average of 60-70 W/m² in both seasonal periods is the same as the area which has the highest seasonal average wind power density at a height of 50 meters. WPD₈₀ WPD₈₀

e. WPD at a height of 100 meters

Based on the area in Kolaka Regency that has the highest monthly average wind power density at a height of 100 meters is the Tanggetada Coast which was identified in January. Meanwhile, locations identified as having the highest average in July include the southern part of the Pomalaa Coast and Padamarang Island to Maniang Island, Wundulako District and the Tanggetada Coast, as shown in Figure 4.20. These locations were identified as having an average of 110-120 W/m². WPD₁₀₀ WPD₁₀₀

For seasonal averages, the highest average in Kolaka Regency reaching 70-80 W/m² was identified as occurring during the DJF and JJA seasons, as seen in Figure 4.21. Figure 4.21 shows that there are areas that have an average of 70-80 W/m² in the DJF period, including the southern part of the Pomalaa Coast, the Tanggetada to Watubangga Coast, the border of Watubangga and Toari, and the western part of Polinggona. WPD₁₀₀ WPD₁₀₀

Meanwhile, during the JJA period, it was found on the border coast of Samaturu and Latambaga, Padamarang Island to Maniang Island, Wundulako District, the southern part of the Pomalaa Coast, the Tanggetada, Watubangga and Toari Coasts, as well as the western part of Polinggona.

f. WPD at a height of 150 meters

Based on spatial distribution maps WPD₁₅₀ The monthly average in Figure 4.22 shows that the highest wind power density can reach 150-160 W/m² in January

and 160-170 W/m² in July. Figure 4.22 shows areas that have WPD₁₅₀ the average reaches 150-160 W/m² in January from the Tanggetada Coast to the Pomalaa border. Meanwhile, in July it is found on the border coast of Samaturu and Latambaga, the western part of Padamarang Island, the southern part of the Pomalaa Coast and the Tanggetada Coast.

For areas in Kolaka Regency that are identified as having WPD₁₅₀ the average reaches 160-170 W/m² in July for the eastern part of Padamarang Island to Maniang Island, Wundulako District, the southern part of the Pomalaa Coast, and the Tanggetada Coast.

WPD₁₅₀ seasonal average in the Kolaka Regency area. The highest average occurred in the DJF and JJA periods, respectively reaching WPD₁₅₀ 100-110 W/m² and 110-120 W/m². In the DJF period, regions that have WPD₁₅₀ average reach 100-110 W/m², including the southern part of the Pomalaa coast, the Tanggetada coast, the Watubangga coast to the Toari border, and the western part of Polinggona.

For regions that have WPD₁₅₀ average reach 100-110 W/m² in the JJA period was found on the border coast of Samaturu and Latambaga, Padamarang Island to Maniang Island, Wundulako District, the southern part of the Pomalaa Coast, the Tanggetada, Watubangga and Toari Coasts, and the western part of Polinggona. Whereas WPD₁₅₀ highest average to reach 110-120 W/m² in the JJA period, only found on the Tanggetada Coast to the southern part of the Pomalaa Coast.

Discussion

1. Wind Speed Data Quality Reanalysis ERA5-Land

Based on the graph in Figure 4.1a, the monthly average fluctuation of wind speed at a height of 10 meters for the three ERA5-Land reanalysis grid locations is different from the observation results, namely from August to December. Figure 4.1a shows a pattern of decreasing average wind speed at the three ERA5-Land reanalysis grid locations which occurred from August to November and increased in December. Meanwhile, data from the Sangia Nibandera Kolaka Meteorological Station shows that the increase occurred from August to September and decreased from October to December.

For the seasonal pattern in graph Figure 4.1b, the average wind speed from the ERA5-Land reanalysis data has a pattern almost similar to the distribution pattern from the average wind speed data from the Sangia Nibandera Kolaka Meteorological Station. Significant differences in average wind speed fluctuations occur during the SON period, namely during the transition from the dry season (JJA) to the rainy season (DJF).

Differences in ERA5-Land reanalysis wind speed fluctuations compared to monthly and seasonal average Sangia Nibandera Meteorological Station observations indicate the inability of the ERA5-Land reanalysis model to capture topographic effects and surface roughness that influence surface wind circulation patterns and local weather interactions that occur in the Regency. Kolaka is entering the transition from the dry season to the rainy season or during the period from August to December.

The results of the evaluation of wind direction in Kolaka Regency at a height of 10 meters are dominated by the West and East directions. This can be seen from

the windrose diagram comparison between Sangia Nibandera Meteorological Station data and ERA5-Land reanalysis data (Figure 4.2). The dominance of the two wind directions is also reinforced by the high percentage of frequency distribution in the West and East directions when compared to other directions.

Analysis of the performance of the wind speed model at the ERA5-Land reanalysis grid locations, namely grids 661, 699, and 736, the highest RMSE and MAE values in the monthly and seasonal periods range from 0.50 m/s to 1.31 m/s respectively. and 0.46 m/s to 1.01 m/s. This value is still below the error threshold for wind speed models of ≤ 2 m/s. The average MBE values for the three ERA5-Land reanalysis grid locations tested were 0.12 m/s, 0.10 m/s, and 0.77 m/s, respectively. The MBE is positive, meaning that the ERA5-Land reanalysis data tends to overestimate the observation data.

2. Average Wind Power Density at ERA5-Land Reanalysis Grid Locations

The wind speed distribution pattern in Kolaka Regency based on ERA5-Land reanalysis wind speed shows that an increase in wind speed occurs in January and July (Figure 4.1a). Meanwhile, the seasonal period occurs during DJF and JJA (Figure 4.1b). This shows that the greatest potential for wind resources in Kolaka Regency can be generated during that time period.

The largest monthly average wind power density at heights of 10, 30, 50, 80, 100, and 150 m from the ERA5-Land reanalysis grid data occurs in January and July. The locations with the highest wind energy potential that month in Kolaka Regency are located on grids 736 and 621.

The highest average wind power density in January at heights of 10, 30, 50, 80, 100, and 150 m respectively reached 16.7 W/m², 40.3 W/m², 60.9 W/m², 89.0 W/m², 106.6 W/m², and 147.9 W/m² with average wind speeds of 2.87 m/s, 3.84 m/s, 4.40 m/s, 4.98 m/s, 5.29 m/s, and 5.89 m/s. For July at the same altitude, the highest average wind power density reached 14.1 W/m², 35.2 W/m², 53.7 W/m², 79.4 W/m², 95.6 W/m², and 133.9 W/m² with average wind speeds of 2.82 m/s, 3.81 m/s, 4.38 m/s, 4.99 m/s, 5.30 m/s, and 5.93 m/s.

In the seasonal period, the largest wind energy potential in Kolaka Regency at heights of 10, 30, 50, 80, 100 and 150 m is produced during the DJF and JJA periods. The ERA5-Land reanalysis grid location which has the highest average wind power density in the season period is located in the same grid location as before, namely grids 736 and 621.

The average wind speed for the DJF period at heights of 10, 30, 50, 80, 100, and 150 m respectively reached 2.58 m/s, 3.48 m/s, 4.01 m/s, 4.56 m/s, 4.85 m/s, and 5.43 m/s which produces an average wind power density of 11.2 W/m², 28.3 W/m², 43.7 W/m², 65.2 W/m², 78.8 W/m², and 111.3 W/m². In the JJA period, the average wind power density reached 12.0 W/m², 30.3 W/m², 46.7 W/m², 69.5 W/m², 84.0 W/m², and 118.5 W/m² with an average wind speed at each height of 2.68 m/s, 3.63 m/s, 4.19 m/s, 4.77 m/s, 5.08 m/s, and 5.69 m/s.

Based on rThe lowest wind power throughout the year in Kolaka Regency at altitudes of 10, 30, 50, 80, 100, and 150 m is in the northern region, precisely at grid location 504 located in Iwoimendaa District, grids 505, 506, 543, and 544 are located at Wolo District, as well as grid 545 are located in Samaturu District.

Meanwhile, the highest wind power density is at grid locations 621 and 736 around the central part of Kolaka Regency, respectively located in Latambaga and Pomalaa Districts.

3. Analysis of the Spatial Distribution of Wind Energy Potential in Kolaka Regency

Based on spatial distribution maps of monthly (Figures 4.13, 4.15, 4.17, 4.19, 4.21, and 4.23) and seasonal (Figures 4.14, 4.16, 4.18, 4.20, 4.22, and 4.24) average wind power density at heights 10, 30, 50, 80, 100, and 150 m, it was identified that the largest wind energy potential in Kolaka Regency occurs in January and July and during the DJF and JJA seasons.

The wind power density distribution map shows the highest monthly average WPD magnitudes in Kolaka Regency at heights of 10, 30, 50, 80, 100, and 150 m respectively reaching 10-20 W/m², 40-50 W/m², 60-70 W/m², 90-100 W/m², 110-120 W/m², and 150-170 W/m². Meanwhile, during the season it reaches 10-20 W/m², 20-30 W/m², 40-50 W/m², 60-70 W/m², 70-80 W/m², and 100-120 W/m². In general, the height that has quite large energy potential in Kolaka Regency is at an altitude of 80 to 150 meters with an average WPD reaching 60 W/m² to 170 W/m².

The evaluation results based on wind energy potential for heights of 10, 30 and 50 m in Kolaka Regency are classified as class 1 type with the very poor category because the average WPD values at these heights are respectively included in the 0-100 W/m², 0-160 W/m², and 0-200 W/m² (Baloch et al., 2017). Meanwhile, according to Oh et al (2012) if at a height of 80 meters the WPD value is < 240 W/m² and at a height of 100 meters the WPD value is < 260 W/m², then the wind energy potential at that height is also classified as very poor or class 1 type.

From the monthly and seasonal average WPD spatial distribution map at heights of 10, 30, 50, 80, 100, and 150 m, locations with sufficient wind energy potential that are suitable for the development of small-scale wind power plants in Kolaka Regency are located in the area Southern Pomalaa Coast and Tanggetada Coast. Meanwhile, the northern areas of Kolaka Regency, such as Wolo and Iwoimendaa, are less suitable for developing wind power plants because they have low average wind speeds.

CONCLUSION

Based on the analysis of data processing results, the conclusions of this research are: first, the ERA5-Land reanalysis data is quite representative for the study of wind energy potential in Kolaka Regency, with wind speed distribution patterns similar to Sangia Nibandera Kolaka Meteorological Station data and adequate statistical metric test results, although tends to overestimate. Second, the highest wind power density is found at grid locations 736 and 621, with the highest values at heights of 80, 100, and 150 m, indicating an increase in wind power density as altitude and wind speed increase. Third, the greatest potential for wind energy in Kolaka Regency occurs in January and July as well as the DJF and JJA periods, with a class 1 or very poor category, so it is more suitable for small-scale

power generation, with the southern part of the Pomalaa Coast and the Tanggetada Coast having more potential. compared to the North. Suggestions for further research include using data with better resolution and adding parameters that influence wind energy potential such as air density, topography and land cover. This research can also be a basis for consideration for planning the development of wind power plants in Kolaka Regency.

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