IDENTIFIKASI POTENSI ENERGI ANGIN DI DAERAH PESISIR PALOH MENGGUNAKAN METODE KOMPUTASI DINAMIKA FLUIDA

(Identification of Wind Energy Potential in Coastal Areas of Paloh District Using Computational Fluid Dynamic Method)

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PROGRAM STUDI GEOFISIKA
FAKULTAS MATEMATIKA DAN ILMU PENGETAHUAN ALAM
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Sebagai salah satu syarat untuk memperoleh gelar
Sarjana Sains pada Program Studi Geofisika

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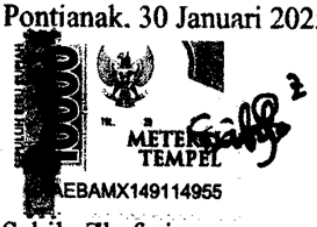
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Identifikasi Potensi Energi Angin di Daerah Pesisir Paloh Menggunakan Metode Komputasi Dinamika Fluida

Abstrak

Seiring dengan adanya peningkatan pemakaian minyak bumi dan penurunan ketersediaannya maka diperlukan sumber energi alternatif. Provinsi Kalimantan Barat memiliki banyak daerah pesisir, salah satunya daerah pesisir yang berada di Kabupaten Sambas, Kecamatan Paloh. Daerah pesisir merupakan salah satu daerah yang memiliki potensi energi angin (bayu). Pemodelan potensi energi angin di daerah pesisir Kecamatan Paloh digunakan dengan metode *Computational Fluid Dynamics* (CFD). Penelitian ini bertujuan untuk membangun dan menganalisis pemodelan 3D aliran angin sehingga dapat diidentifikasi potensi energi angin yang ada di daerah pesisir Paloh. Identifikasi dilakukan dengan menghitung daya listrik berdasarkan nilai kecepatan angin dari simulasi 3D pada beberapa lokasi penelitian. Pemodelan aliran angin dibangun berdasarkan data kecepatan angin selama 15 tahun (2009-2023) dan disimulasikan menggunakan perangkat lunak *open-source* OpenFOAM. Model referensi aliran angin berdasarkan literatur ilmiah dengan menggunakan kasus aliran angin pada medan datar dan berbukit. Selanjutnya dibangun model aliran angin berdasarkan tiga lokasi di pesisir Kecamatan Paloh. Berdasarkan hasil pemodelan yang sudah dilakukan, diperoleh kesimpulan bahwa kecepatan angin meningkat siring bertambahnya ketinggian. Oleh karena itu pembangunan ladang angin lebih optimal dilakukan di daerah berbukit dibandingkan dengan daerah yang datar.

Kata kunci: Energi Baru Tebarukan, Energi Angin, Pesisir Paloh, CFD, LES- K equation, OpenFOAM

Identification of Wind Energy Potential in Coastal Areas of Paloh District Using Computational Fluid Dynamic Method

Abstract

As the use of petroleum increases and its availability decreases, alternative energy sources are needed. West Kalimantan Province has many coastal areas in Sambas Regency, Paloh District. Coastal areas are among those that have wind energy potential. The wind energy potential modelling in the coastal area of Paloh District is carried out using the Computational Fluid Dynamics (CFD) method. This study aims to build and analyze a 3D wind flow model to identify the wind energy potential in the coastal area of Paloh. The identification is done by calculating the electrical power based on the wind speed values from the 3D simulation at several research location. The wind flow modelling is based on 15 years of wind speed data (2009-2023) and simulated using the open-source software OpenFOAM. The reference wind flow model is based on scientific literature, using wind flow cases over flat and hilly terrains. Subsequently, a wind flow model is built for three locations in the coastal area of Paloh District. The outcomes of the modelling suggest that wind speed increases with elevation. Therefore, wind farms are optimally constructed in hilly areas compared to flat regions.

Keywords: *Renewable Energy, Wind Energy, Coastal Area of Paloh, CFD, LES K-equation, openFOAM*

FOREWORD

Praise and gratitude be to Allah Subhanahu wa Ta'ala for His blessings and grace, enabling the compilation of this thesis titled "Identification of Wind Energy Potential in Coastal Areas of Paloh District Using Computational Fluid Dynamic Method" on time. Peace and salutations are extended to the Prophet Muhammad Shalallahu Alaihi Wassalam, his family, companions, and followers. This thesis is submitted as a requirement for obtaining a bachelor's degree in the Geophysics Program at the Department of Mathematics and Natural Science, Tanjungpura Univerity. Throughout the author's academic journey and research process, I received invaluable guidance, encouragement, and support from many individuals and institutions. Therefore, I would like to express my heartfelt appreciation to:

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Pontianak, 30 Januari 2025

Sabila Zhafarina

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CHAPTER I
INTRODUCTION

1.1 Background

The depletion of petroleum reserves has necessitated a global shift towards renewable energy sources (Ellabban *et al.*, 2014). As one of the world's oldest oil-producing nations, Indonesia faces a significant challenge due to its relatively small oil reserves compared to domestic demand. In 2021, the Ministry of Energy and Mineral Resources recorded Indonesia's oil reserves at 3.95 billion barrels, comprising 2.25 billion barrels of proven reserves and 1.7 billion barrels of potential reserves. Given the increasing consumption of petroleum and dwindling supplies, Indonesia has committed to a sustainable transition towards environmentally friendly energy, as outlined in Presidential Regulations No. 22 of 2017 on the National General Energy Plan. Renewable Energy (RE) sources are derived from natural processes and are replenished continuously, unlike fossil fuels such as coal, petroleum, and natural gas, which are finite (Mohammed, 2021). Indonesia possesses significant RE potential, including geothermal, hydropower, bioenergy, solar, and wind energy. However, the utilization of RE in Indonesia remains suboptimal due to several factors, such as limited policies, high costs, and the challenges associated with exploring and exploiting new energy sources (Sekretariat Jenderal Dewan Energi Nasional (DEN), 2022). Further research is crucial to provide more comprehensive information that can facilitate exploration and exploitation in these areas to maximize the utilization of RE.

Located in northern West Kalimantan, Paloh is influenced by complex atmospheric processes, including the Borneo vortex, a mesoscale system that influences surface wind patterns through cyclonic circulation. This vortex, which forms due to sea breeze interactions, caused localized changes in wind speed and direction (Isnoor *et al*., 2019). Additionally, downdrafts of 'downdrolling' events distrupt surface wind patterns, generating turbulence. These downdrafts can enhance vertical mixing, leading to stronger wind speeds at ideal wind turbines height. Coastal regions offer substantial potential for wind energy exploitation.

Wind energy is one example of a renewable energy source, harnessing the kinetic energy of wind through wind turbines, and converting it into electrical energy (Alkhalidi *et al.*, 2019). Coastal regions are promising for such conversions due to their consistent wind patterns. Paloh District in Sambas Regency, is a prime example of such a region.

Coastal regions in Paloh District have an extensive coastline bordering the North Natuna Sea (Firdaus & Rahadian, 2018). Coastal zones are transitional areas that connects terrestrial and marine environments, significantly shaped by processes like sea breezes, tides, and saltwater intrusion (Aldrian, 2008). Wind plays a crucial role in coastal dynamics, driving changes in coastal conditions and ocean circulation patterns (Ma'arif & Hidayah, 2020). Coastal regions typically experience more consistent and intense wind patterns than inland areas, primarily attributed to the ocean's stabilizing effect on atmospheric circulations (Wu *et al*., 2018). Detailed wind speed and direction analysis in coastal zones enables the identification of climate patterns, providing essential data for weather prediction and climate modelling. Computational Fluid Dynamics (CFD) is a numerical modelling technique for analyzing fluid flow that can be used to determine the wind energy potential in coastal regions (Dhunny *et al.*, 2017). CFD simulations can model complexities, featuring complex terrains, including hills, valleys, and water bodies, and providing detailed insights and information on wind flows through these environments (Blocken *et al.*, 2015).

Kurnia (2024) investigated the wind energy potential in Mempawah Regency's coastal areas using a CFD-based 3D wind flow simulation with the RANS k-omega turbulence model. This study simulated wind flow and calculated power generation at various heights and locations. The result showed that power generated from the western direction (during the transitional season) at all locations and heights of 10 m, 30 m, 50 m, and 80 m was categorized as low, with specific power below 100 watts. Power from the southern direction (during the east monsoon) at locations 1 and 3 was categorized as moderate, producing more than 100 watts, at location 2 power was categorized as low, producing less than 100 watts. Power from the northern direction (during the west monsoon) at location 3 and a height of 10 m was

categorized as high, producing more than 150 watts, at heights of 30 m, 50 m, and 80 m, it was categorized as moderate. At locations 1 and 2, power was categorized as moderate, producing less than 150 watts.

Dhunny *et al.,* (2015) studied high-resolution wind energy potential mapping in Mauritius using CFD, producing contour maps of wind velocity and power at 500 m resolution. In a follow-up study, Dhunny *et al.* (2017) assessed wind energy in complex terrains on Mauritius Island. Their findings showed that the wind energy potential was highest in the Southeast (300 km²), lower center plateau (144 km²) and Southwest (375 km²) regions throughout the year. In 2023, Zhou and Ishihara conducted a numerical study on neutral atmospheric boundary layer (ABL) flows over flat terrain and three-dimensional hills, incorporating the effects of the Coriolis force. They developed a new formula to describe the mean wind profiles for neutral ABL flows over flat terrain with varying surface roughness, using the LLS k-ε model. The study also revealed that the velocity deficit in the hill wake recovers faster when the Coriolis force is considered, particularly as the hill slope and height ratio increase.

Blockhen *et al.,* (2015) performed a numerical study to simulate wind flow velocities in a natural complex terrain using CFD, validated by field measurements from Ria de Ferrol, Galicia, Spain. Their results indicated that wind speeds increased due to a funneling effect when blowing from 60° and 90°, while other directions caused the wind to slow down. The 3D RANS model with the k-ε model accurately predicts complex wind patterns and the funelling effect caused by the surrounding terrain. Based on the previous research, this study aims to identify the wind energy potential in the coastal area of Paloh District using CFD. Leveraging a dataset of wind speed and direction spanning 15 years (2009-2023) from Paloh meteorological station, the research will employ the Large Eddy Simulation (LES) k-equation model within the OpenFOAM software to conduct three-dimensional wind flow simulations. The simulated results will be used to estimate potential power generation for the development of wind energy potential.

1.2 Problem Statement

The problem statement of this study are as follows:

1) How to analyze the magnitude and direction of wind in the coastal area of Paloh District?
2) How to model wind flow in the coastal area of Paloh District using the CFD method?
3) How to identify potential locations of wind energy in Paloh District based on the CFD method?

1.3 Objectives of the Study

The objectives of this study are as follows:

1) To analyze the magnitude and direction of wind in the coastal area of Paloh District
2) To model wind flow in the coastal area of Paloh District using the CFD method
3) To identify potential locations of wind energy in Paloh District based on the CFD method

1.4 Scope of the Study

The limitations of this study are as follows:

1) The validation data used in this study was obtained from the meteorological station in Paloh District, for a period of 15 years (2009-2023)
2) The modelling in this study was conducted using the OpenFOAM software where the computational domain was constructed based on real-world conditions using Blender GIS software
3) The determination of wind flow direction was conducted based on an analysis of wind direction data from the meteorological station in Paloh District, for a period of 15 years (2009-2023)
4) The turbulence model employed in this study is the LES k-equation model
5) The modelling in this study will be applied to three specific locations within the Paloh District with varying topography

1.5 Benefits

The anticipated benefits of this study are as follows:

1) To provide information about wind speed and direction in the coastal area of Paloh District
2) To provide a comprehensive review of private wind energy studies conducted in similar environments
3) To provide information on the wind energy potential in the coastal area of Paloh District
4) To facilitate the management of renewable energy potential for the benefit of the government and surrounding communities
5) To provide a deeper understanding of wind energy characteristics through numerical investigations, especially on CFD simulations.