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Analytical Study to Produce Green Hydrogen Via Wind Energy in Malaysia

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Abstract

Green hydrogen offers good advantages in terms of energy storage compared to conventional battery systems. Batteries face limitations in energy density, degradation over repeated charge-discharge cycles, hydrogen can be stored over long periods with low losses. This study investigates and analyzes the production of green hydrogen from wind power in Malaysia. It revolves around incorporating wind-driven electrolysis as one of the hydrogen production avenues that comply with the decarbonization targets in Malaysia. Challenges to integrating wind energy with hydrogen production include low wind speeds, limited access to specialized turbine technologies, and gaps in technical expertise. This study investigates and analyzes the production of green hydrogen from wind power in Malaysia. It focuses on using wind-driven electrolysis as a pathway for hydrogen production that aligns with the country's decarbonization goals. Challenges to integrating wind energy with hydrogen production include low wind speeds, limited access to specialized turbine technologies, and gaps in technical expertise. The study focuses on modeling wind turbines and a hydrogen plant, collecting real wind data from three Malaysian cities, and performing simulations in MATLAB Simulink to estimate hydrogen production rates. The results show that a hybrid renewable system represented with wind energy could enhance the reliability of hydrogen generation under moderate wind conditions. These findings provide valuable insights for developing a local green hydrogen infrastructure.

1.Introduction

Hydrogen is a clean and flexible energy source that can be used in many areas, including transportation, industry, electricity, and buildings. It does not produce greenhouse gases when used, making it a sustainable option. Green hydrogen is made by splitting water using electricity from renewable sources like wind or solar, resulting in almost no emissions. It has the potential to replace fossil fuels and play an important role in moving towards a low-carbon economy [1].

Wind energy is a green and renewable source of power that is produced by harnessing the wind and turning its kinetic energy into electricity with the help of wind turbines. Specifically, offshore wind has been regarded as very efficient considering the steady and high wind speed, hence suitable for producing large amounts of energy [2]. The potential use of wind energy could be, among others, in green hydrogen generation, where wind power is used to electrify the electrolysis procedure, utilizing which hydrogen and oxygen can be produced without the release of greenhouse [3]. The procedure helps to achieve the worldwide purpose of decarbonization of the energy system and provides a sustainable solution to fossil fuels, in particular, such industries as transportation and manufacturing [4]. The use of green hydrogen can be an effective mechanism to minimize carbon emissions, most notably in offshore wind power. As opposed to solar power, which is actually dependent on sunlight, wind energy is actually capable of an all-day, every-day energy output, especially in a high-wind region [5].

The countries of Denmark and some others have already used the hybrid systems of wind turbines and hydrogen successfully to produce continuous green hydrogen with a reduced cost and increased energy efficiency [6]. Research indicates that wind farms, when coupled with hydrogen plants, have the potential to create minimal environmental impact differences and ensure the long-term safety of energy [7]. Wind energy has not been developed as well as solar energy in Malaysia, but coastal regions in the Peninsula, as well as East Malaysia, exhibit favorable possibilities [5]. The issue is reduced speeds of wind, which forces a need for special turbine designs that take into consideration the local winds [8]. In order to become successful, Malaysia needs to invest in hybrid renewable systems and a set of facilitative policies, as has been done in Europe [9]. Through its experience in foreign examples and focus on technological advancement and infrastructure, Malaysia can contribute significantly to the green hydrogen market in Southeast Asia, reinforcing its position regarding sustainability and climate targets.

The study highlights the significant investment required for the deployment of renewable energy sources, particularly wind energy, to produce green hydrogen. The primary contribution of this research lies in providing a comprehensive evaluation of green hydrogen production potential from wind energy within Malaysia. By integrating real wind data from three distinct regions with modeling of wind turbines and an electrolysis-based hydrogen plant in MATLAB Simulink, the study delivers quantitative insights into hydrogen production rates under moderate wind conditions. The findings contribute to the national renewable energy discourse by demonstrating how hybrid wind-hydrogen systems can support a reliable, long-term energy storage solution that aligns with Malaysia's decarbonization ambitions.

2. Methodology

The present study attempts to assess the prospect of utilizing wind energy in green hydrogen generation in Malaysia. It tackles such issues as a lack of data about appropriate wind turbines and local wind conditions.

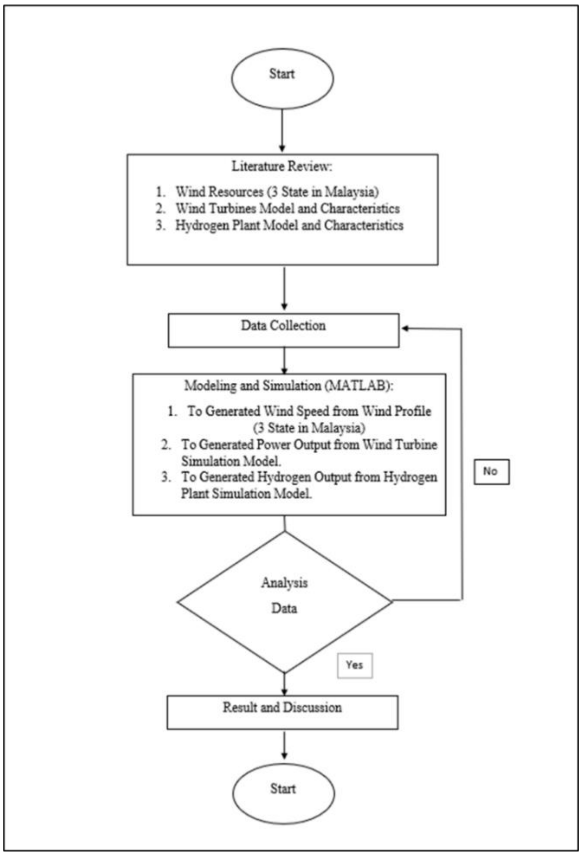


Fig. 1 : *The process of workflow for the research*

The research embraces the global standards of excellence and applies the MATLAB simulations to represent the performance of wind turbines, hydrogen production, and energy results. Through the study of wind supply and system efficiency at three cities in Malaysia, the paper offers an organized format for measuring the technological, economic, and environmental feasibility of wind-powered hydrogen systems in the country.

Fig.1 shows the process flow chart for the systematic research conducted in this thesis, wherein a literature review will be conducted to first appreciate the nature of renewable energy, specifically wind energy, and its contribution to the production of hydrogen. Then, data collection is structured on wind resources, and simulation is performed in MATLAB on the performance of the turbines and hydrogen plants analyzed by using the real data. The flow chart focuses on the repeated analysis wherein the inadequate outcomes give rise to adjustments of the data. In case this is good, then the research proceeds to the discussion and conclusion section and gives a logically acceptable flow of the study, starting with the initial review and concluding with the final evaluation.

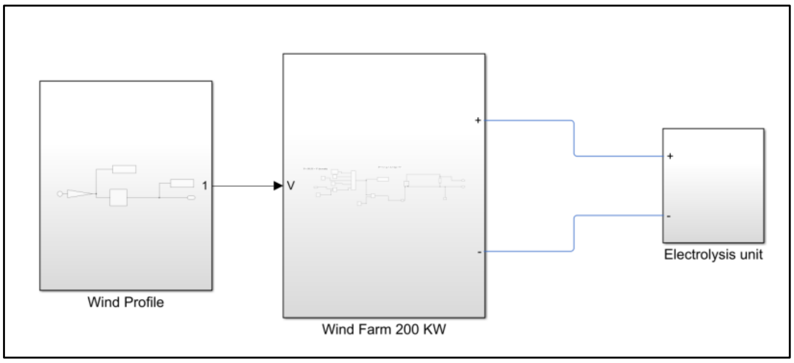


Fig. 2 *Block diagram for Green Hydrogen model in MATLAB Simulink*

The diagram in fig 2 represents a renewable hydrogen production system that combines wind turbine with an electrolysis unit. The process begins with the wind profile block, which simulates changing wind speeds over time using a real dataset. This wind data is sent to the wind farm 200 kW model, where the wind turbine system including the turbine, generator, and power electronics converts the wind energy into usable electricity. The generated electricity supplied to the electrolysis unit, which used to produce the hydrogen. This system provides a sustainable, carbon-free energy solution by continuously producing green hydrogen using renewable wind energy.

2.1 Wind Energy in Malaysia

Despite the promising global outlook for solar power, Malaysia still lags behind many countries in harnessing renewable energy. In several rural areas, wind energy also presents a suitable option for electricity generation. Numerous studies have been carried out to assess Malaysia's wind-energy potential, with most contributions coming from government agencies and local universities. Although Malaysia is not traditionally classified as a high-wind nation, recent assessments indicate that specific coastal and offshore locations experience sufficiently consistent wind speeds to support small to medium-scale power generation [10].

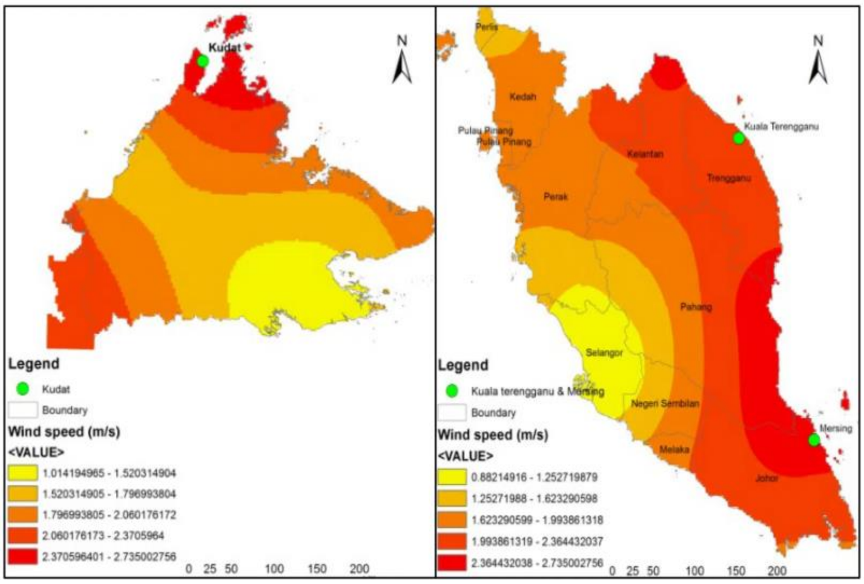


Fig. 3 *Statistics Wind speed in Malaysia [10]*

Sites such as Kota Bharu, Kudat, and Mersing have repeatedly demonstrated wind characteristics, prompting further interest in localized wind energy deployment. Fig. 3 illustrates the wind speed distribution across Malaysia. As Malaysia continues working toward its long-term sustainability goals, the expansion of wind energy research and pilot projects highlights the growing recognition of wind power as a resource in the national energy mix.

Since actual wind behaviour is complex and rarely constant, the wind profile input helps the model capture fluctuations in wind speed rather than relying on a single fixed value. This is important because wind turbines are typically designed to operate efficiently at certain wind speed ranges, and using real wind profile data ensures the simulation reflects the turbine's performance under multiple wind conditions before the generated power is supplied to the hydrogen production plant. Fig.3 represents the simulation blocks of the wind profile in MATLAB Simulink, where wind-speed data taken from real data and used to drive the wind turbine model.

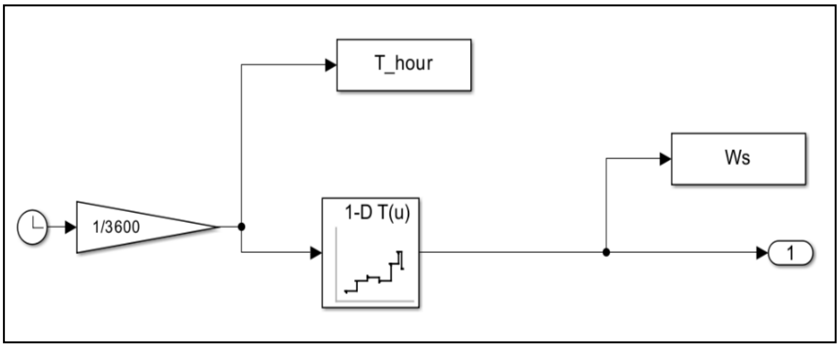


Fig. 4 *Wind profile blocks in MATLAB Simulink*

2.2 Horizontal-axis Wind Turbine Model

The horizontal-axis wind turbine model represents a key technology in renewable energy generation and an important component in integrated hydrogen-production systems. The turbine captures wind energy through its rotor blades, which rotate when exposed to sufficient wind flow. This rotational motion is transmitted through the hub to the nacelle, where a generator converts the mechanical energy into electrical power. The produced electricity is supplied to the electrolyzer [11]. MATLAB will be used to compile and analyze wind-speed data from various locations across Malaysia to evaluate the feasibility of producing green hydrogen. Wind turbine models will be developed to estimate power output based on real data of local wind characteristics, air density, and other relevant parameters. This generated energy will then be supplied to a simulated electrolysis system to assess hydrogen production performance. The simulation results will provide an estimate of the amount of green hydrogen that can be produced from wind energy in selected cities in Malaysia. The insights gained from this analysis will help identify the potential role of green hydrogen in the country's energy landscape and contribute to a clear understanding of Malaysia's pathway toward a more sustainable and renewable energy future.

Equation 1 is used to model the wind energy data and calculate the corresponding power output based on the turbine's operating characteristics. The parameters required for this model, air-density values, and performance coefficients, are summarized in Table 1. These parameters ensure that the simulation accurately reflects the behavior of the selected wind turbine under varying wind conditions, providing reliable input for the subsequent analysis.

$$P = \frac{1}{2} \times \rho \times A \times V^3 \times C_p \qquad (1)$$

This model encompasses the turbine, generator, and associated power-electronics components responsible for generating usable electricity. The produced electrical power is supplied to the electrolysis unit, where it drives the splitting of water into hydrogen and oxygen via electrolysis. The wind turbine system used in this study is illustrated in Fig. 5.

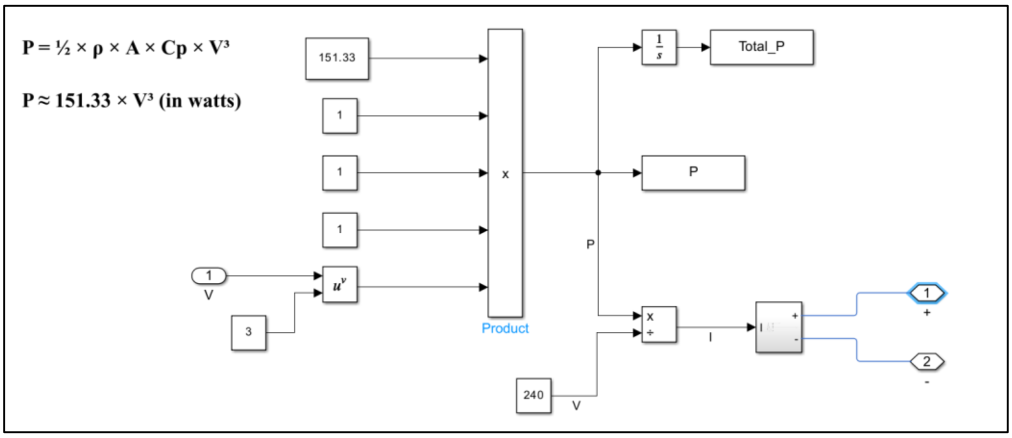


Fig. 5 *Wind turbine model in MATLAB Simulink*

Table 1 *Wind turbine parameters for wind farm 200KW in MATLAB Simulink*

Symbol	Parameter
P	estimated power output (in watts).
ρ	air density (1.225 kg/m^3).
A	rotor swept area ($\pi \times R^2$).
C_p	power coefficient (0.48).
V	wind speed in m/s.
Rated Power	200 kW
Rotor Radius (R)	12.8 m
Swept Area (A)	$\pi \times R^2 \approx 514.7\ m^2$
Air Density (ρ)	1.225 kg/m^3 (sea level standard)
Power Coefficient (C_p)	0.48 (optimized for λ ≈ 8.1)
Tip Speed Ratio (λ)	8.1
Wind Speed (V)	Hourly values in m/s (from dataset)

2.3 Electrolyze Model in MATLAB Simulink

In this research, the green hydrogen generation and storage subsystem is modeled using a Simscape Electrical electrolyzer framework. The model couples a renewable wind turbine to supply electrical energy. The electrolyzer block captures the electrochemical reactions, including water consumption and hydrogen output. Fig. 6 represents a MATLAB Simulink model of a hydrogen (H_2) generation and storage system. The process begins with a water tank, whose parameters such as level and temperature, are continuously monitored using a temperature-level sensor (TL). The water mass flow rate ($\dot{m}_{h2o}$) is controlled by a pump, which delivers water into a reactor chamber. Within the reactor, electrical energy is applied to a heating resistor, generating the necessary heat for water electrolysis. Temperature and current feedback loops (i_heat = f(θ), I_sensor, V_sensor) are used to regulate the process to ensure stable and efficient operation.

A purge logic controller is implemented to periodically release gases, maintaining safe reactor conditions. During electrolysis, water is decomposed, liberating hydrogen ($\dot{m}_{h2}$) while water vapor and other gases may also be emitted (pH, volPurging). The produced hydrogen is measured by an H_2 sensor and directed to a mass flow rate source before being stored in a dedicated H_2 storage tank. This model provides a detailed framework for simulating hydrogen production and storage, facilitating performance analysis and system optimization within MATLAB Simulink.

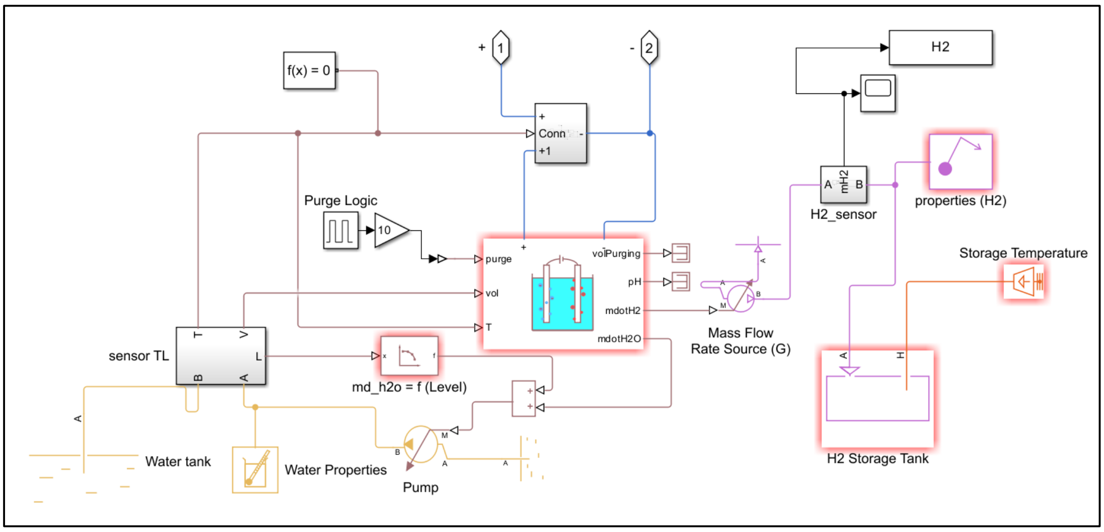
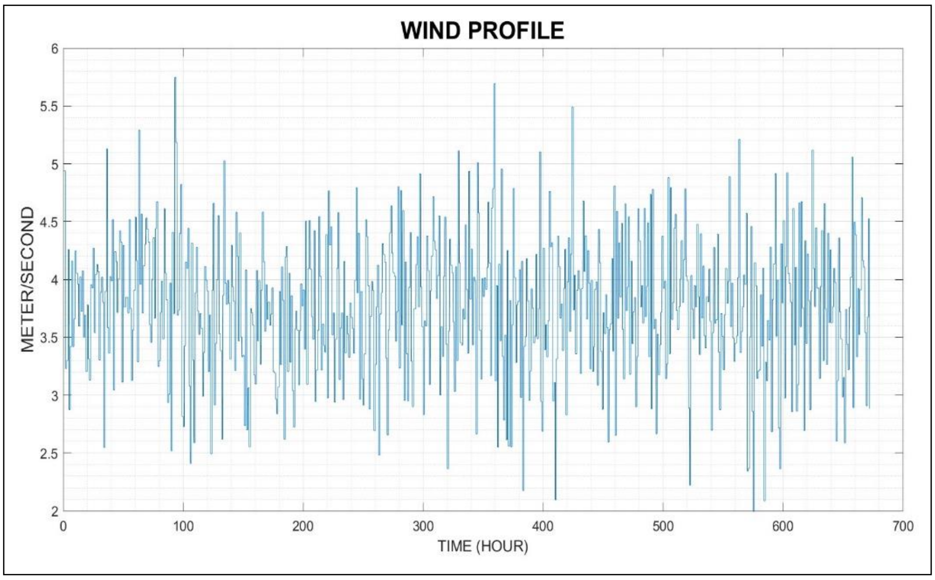


Fig. 6 *The model of the electrolyser in MATLAB Simulink [12]*

3. Results and discussion

This study explores the potential for producing green hydrogen in Malaysia by implementing wind energy as a clean energy source. While wind power is less developed than solar energy in the country, coastal and offshore regions offer untapped resources that could support energy variation. The study aims to evaluate the integration of wind energy into hydrogen production systems using tailored models of wind turbines and electrolyzers optimized for Malaysia's moderate wind conditions. A key challenge addressed is the limited local knowledge regarding the suitability and efficiency of different turbine technologies under Malaysian climate conditions. Results indicate that selected areas, with moderate-to-high wind speeds, can sustain continuous hydrogen production when electrolyzer systems are properly implemented.

Fig. 7 (a) illustrates the wind speed profile at Kota Bharu for February 2025, covering a total observation period of twenty-eight days, or 672 hours. The wind speed exhibits noticeable variations throughout the observation period, ranging from a minimum of approximately 2 m/s to a maximum of 5.5 m/s, with occasional dips and spikes. Most values are concentrated between 3 m/s and 4.5 m/s, indicating an overall pattern of moderately steady to intermittent wind conditions. The wind profile serves as the input for a wind turbine model, where the wind speed data is converted into electrical power output. Fluctuations in wind speed directly affect turbine performance: higher wind speeds generate more power, whereas lower wind speeds result in reduced output.



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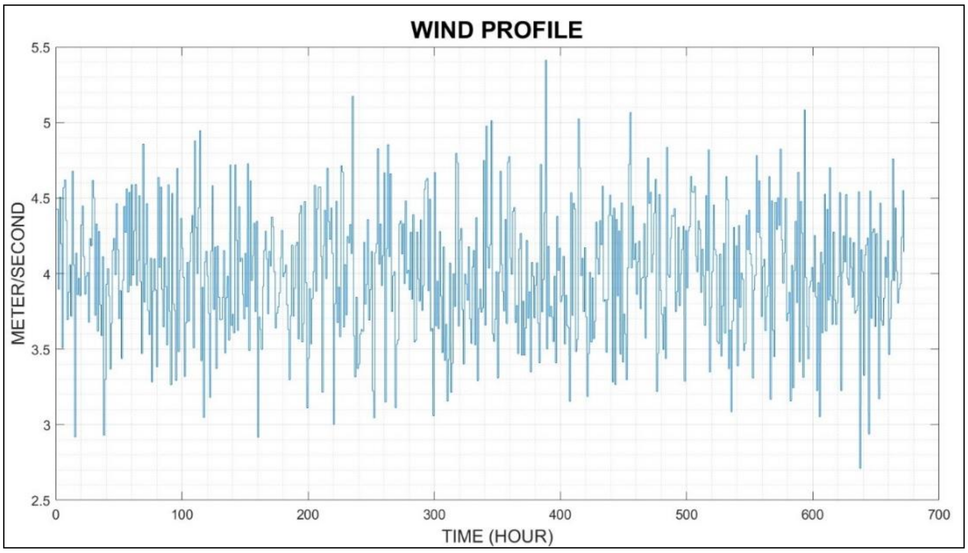

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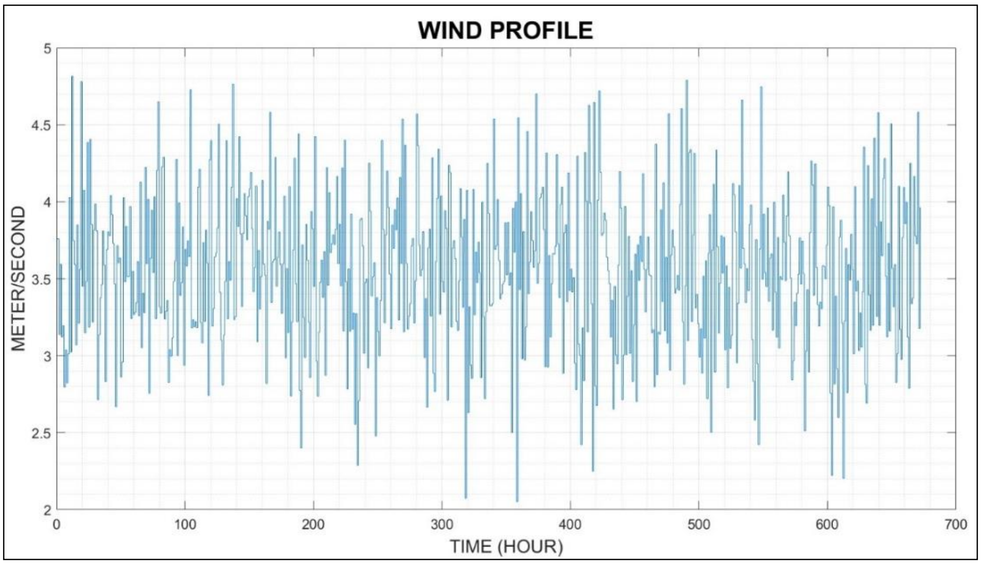


(c)

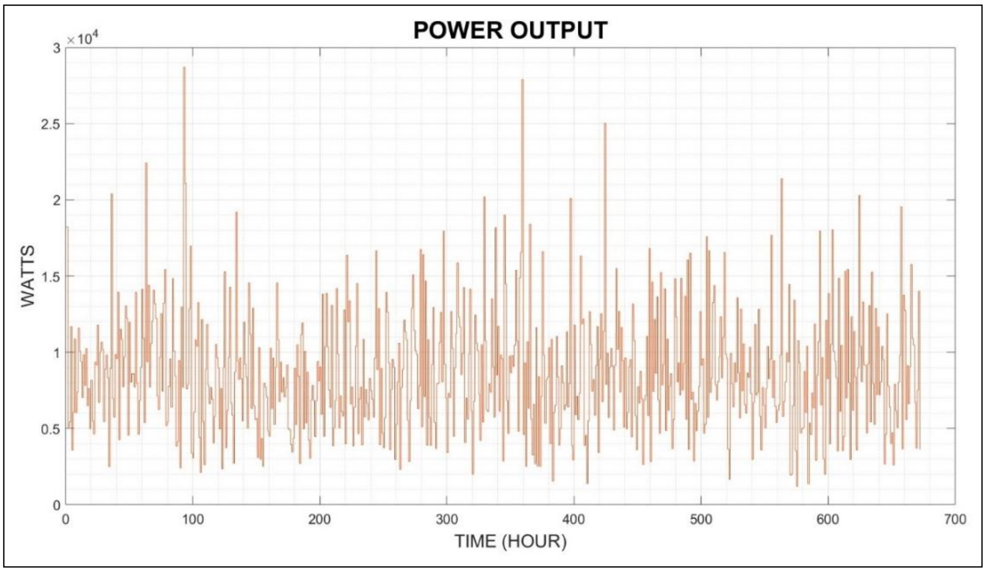
Fig. 7 *The wind speed profile in February 2025 at (a) Kota Bharu; (b) Kudat; (c) Mersing*

Fig. 7 (b) shows the wind speed variations in Mersing throughout February 2025. The data was used as input for a MATLAB Simulink wind turbine simulation to assess its suitability for green hydrogen production. The wind speeds range from 2.0 to 5.0 m/s, with most values between 3.0 and 4.0 m/s. There are brief variations in the wind profile, but no sharp or protracted peaks. These wind speeds are within the typical operating range of small to medium-sized turbines, suggesting that they have the capacity to generate hydrogen with a steady energy production throughout the month. Fig. 7 (c) presents the wind speed profile of Kudat, Sabah, for February 2025 over 28 days. The wind speeds range from 2.5 to 5.5 m/s, with most values between 4.0 and 4.5 m/s.

3.1 Power Output in MATLAB Simulink.

Fig. 8 illustrates the simulated wind-derived power output for February 2025 at Kota Bharu, Kudat, and Mersing, generated using hourly wind speed profiles over 28 days (672 hours) in MATLAB Simulink. At Kota Bharu, power outputs varied widely from near 0 W to approximately 30 kW, with average hourly values between 5 and 15 kW and intermittent peaks exceeding 20 kW. This variability reflects the fluctuating wind conditions at the site and indicates that energy storage or power regulation may be necessary to maintain a stable supply for hydrogen production. Mersing exhibited lower outputs overall, fluctuating between 0 and 17 kW, with most values below

13 kW, demonstrating the intermittent nature of its wind resource and the challenges of sustaining consistent hydrogen generation without supplementary systems. In contrast, Kudat showed higher and more stable generation, averaging 8–20 kW with peaks regularly surpassing 24 kW, highlighting its suitability for continuous wind-to-hydrogen conversion. The differences among these sites emphasize the importance of site-specific wind assessment and turbine selection, as well as the potential integration of energy storage or power conditioning to buffer natural fluctuations.



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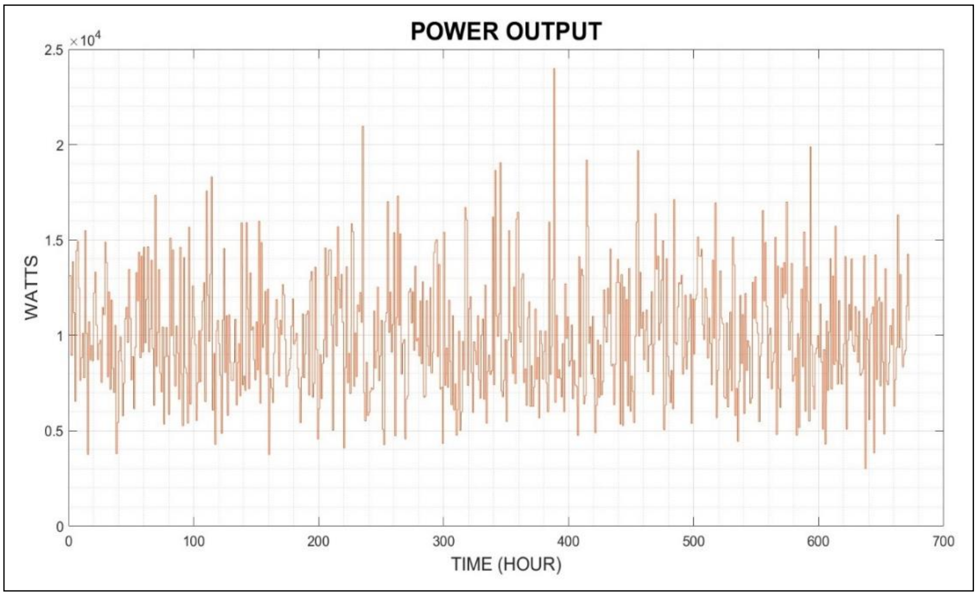

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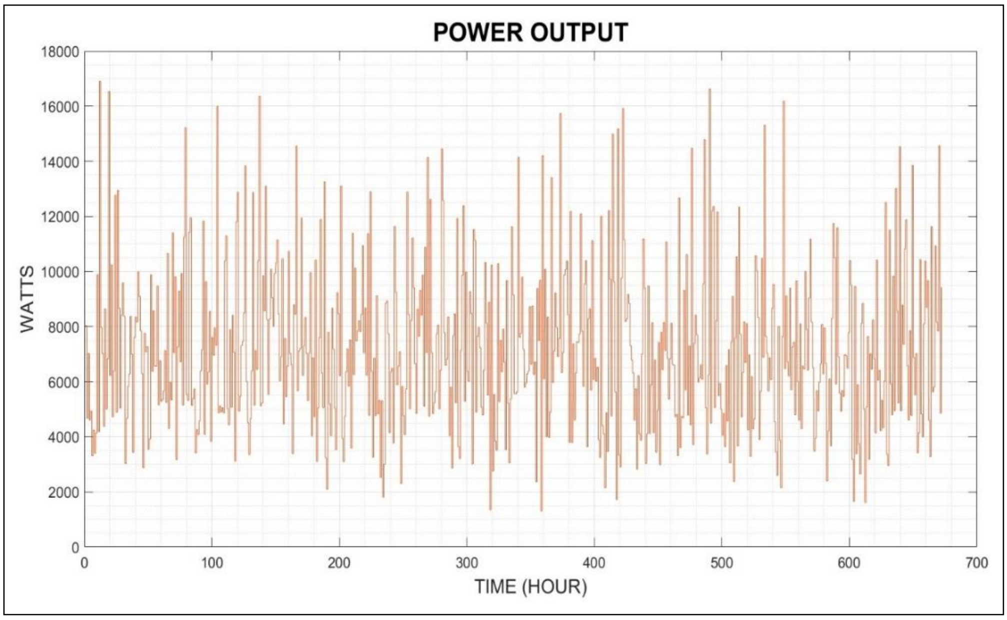

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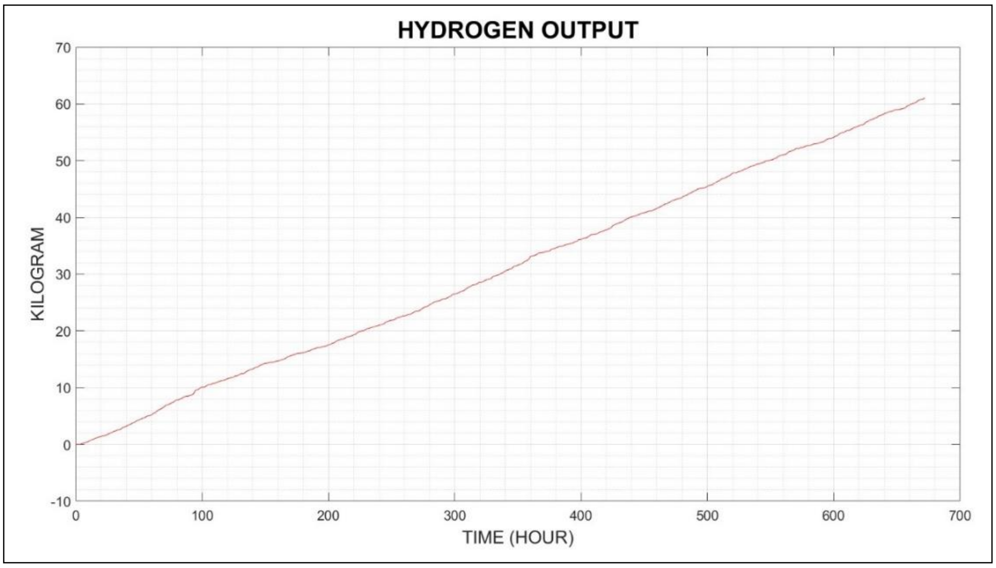
Fig. 8 *The estimated wind-derived power during February 2025at (a) Kota Bharu; (b) Kudat; (c) Mersing*

3.2 Hydrogen Output in MATLAB Simulink

This section focuses on hydrogen production via the electrolysis model in MATLAB Simulink. The electrical power generated by the wind turbines, serves as the input to the electrolyzer, where water molecules are split into hydrogen (H_2) and oxygen (O_2). The volume of hydrogen produced is directly influenced by the magnitude, duration, and stability of the supplied electrical power. Fig. 9 represents the estimated hydrogen production the three studied locations considered in this research,

The simulation spans 672 hours in February 2025. For Kota Bharu, the simulation yielded a total hydrogen production of approximately 62 kg. The site's wind profile exhibited significant hourly fluctuations, causing turbine power outputs to vary between 5 kW and 15 kW, occasionally peaking at 20 kW. The simulated results for the hydrogen production at Mersing indicated the lowest output among the three studied locations. Over the 28 days, less than 33 kg of hydrogen was produced. The wind profile at Mersing was highly variable and often weak, resulting in turbine power outputs ranging from 0 W to 13 kW, with occasional peaks up to 17 kW. The hydrogen production results at Kudat in February 2025 demonstrated the highest hydrogen production among the three sites, totaling approximately 135 kg over 672 hours. The consistently strong wind profile allowed the turbine model to generate stable and high power, ranging from 8 kW to 20 kW, with frequent peaks.



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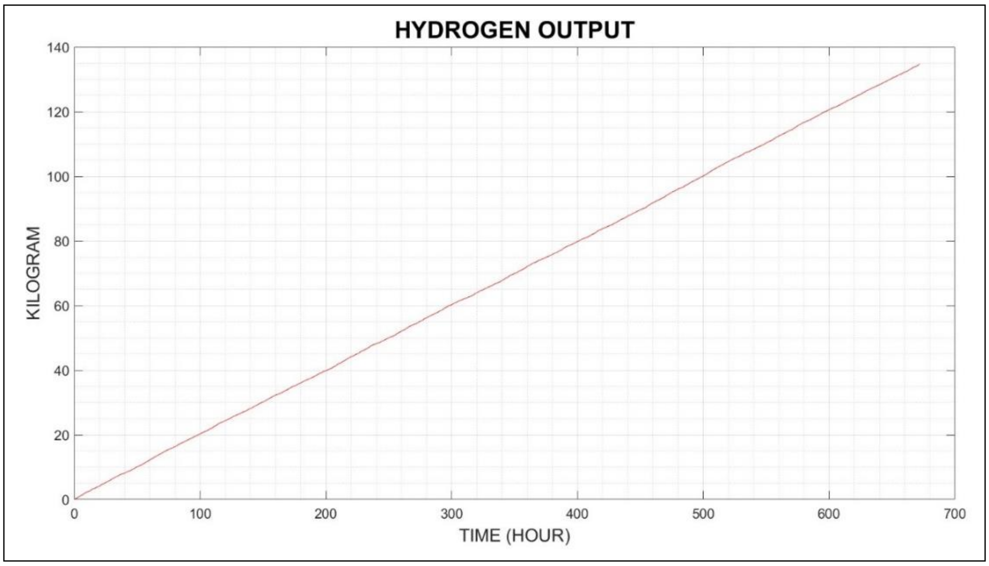

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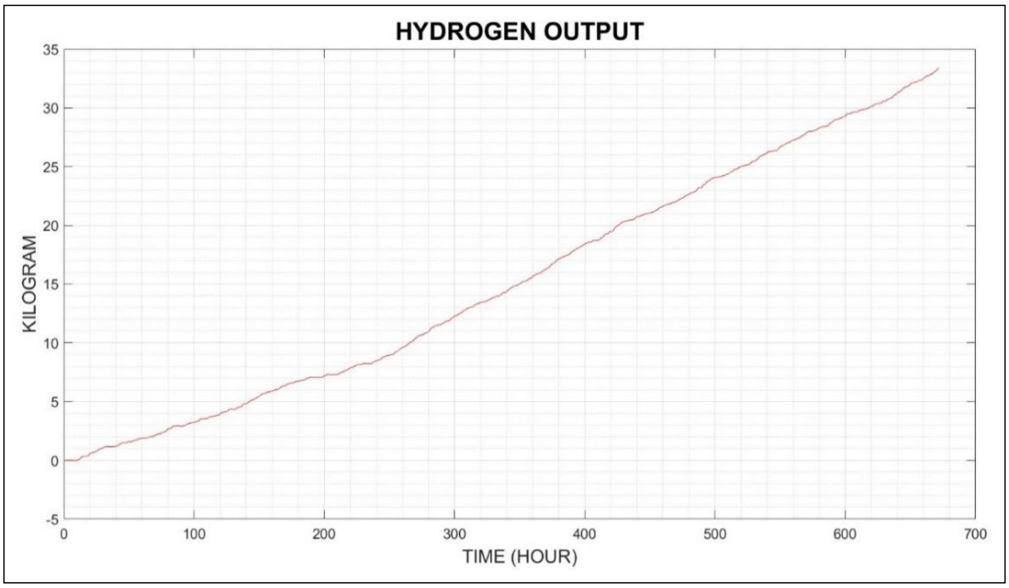

(c)

Fig. 9 *The estimated hydrogen production during February 2025 at (a) Kota Bharu; (b) Kudat; (c) Mersing*

The findings highlight Kudat's favorable coastal wind climate and its suitability for large-scale wind-to-hydrogen projects. The simulation confirms both the technical feasibility and environmental potential of developing a green hydrogen infrastructure in this location, making it the most promising site for sustainable hydrogen generation in Malaysia.

Table 2 summarize a comparative analysis of the hydrogen output based on the simulation results, there is a notable difference in hydrogen production performance among the three studied locations: Kudat, Kota Bharu, and Mersing. Kudat exhibited the highest cumulative production of approximately 135 kg over 672 hours in February 2025, with a consistently linear and steep production trend of about 20 kg per 100 hours. This reflects a stable and strong wind profile throughout the month, enabling the wind turbines to deliver sufficient and reliable power for continuous electrolyzer operation. In comparison, Kota Bharu achieved 62 kg of hydrogen, characterized by a moderate and more fluctuating production curve due to variable wind speeds, which caused intermittent power supply and reduced electrolyzer efficiency. Nevertheless, Kota Bharu remains a viable location for hydrogen production if supported with energy storage or power smoothing systems to buffer the variability. Mersing recorded the lowest output at 33 kg, with slow and irregular hydrogen accumulation, reflecting weaker and highly intermittent wind conditions. Overall, the results highlight the critical influence of local wind regimes on hydrogen yield and emphasize the importance of site-specific assessment and system integration strategies to maximize renewable hydrogen production in Malaysia.

Table 2 *Comparative Analysis of Hydrogen production across cites*

Time (Hour)	Hydrogen Kudat (Kg)	Hydrogen Kota Bharu (Kg)	Hydrogen Mersing (Kg)
0	0	0	0
100	20	9	4.5
200	40	18	8.5
300	60	27	13
400	80	36	18
500	100	45	24
600	120	54	29
672	135	62	33

4. Conclusion

Based on the analysis of wind profiles, power generation, and hydrogen production across the three cities Kudat, Mersing, and Kota Bharu, it is evident that Kudat offers the most favorable conditions for wind-driven hydrogen production. The wind data for February 2025 show that Kudat consistently recorded higher and more stable wind speeds, which directly resulted in greater power output and the highest cumulative hydrogen production at 135 kg. In comparison, Mersing and Kota Bharu exhibited occasional peaks in wind speed and power generation, but their overall averages were significantly lower, leading to reduced hydrogen yields of 34 kg and 58 kg, respectively. These findings highlight that sustained and reliable wind conditions are more critical than short-duration high-speed events for achieving efficient green hydrogen production. Therefore, Kudat stands out as the most promising location for wind-based hydrogen generation in Malaysia.

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Conflict of Interest

The authors declare no conflicts of interest in this article.

Author Contribution

The authors confirm contribution to the paper as follows: study conception and design: Muhamad Amirun Aqil Zainuren, Taha Mohammed Ahmed Sadeq; data collection: Muhamad Amirun Aqil Zainuren; analysis and interpretation of results Muhamad Amirun Aqil Zainuren and Taha Mohammed Ahmed Sadeq; draft manuscript preparation: Muhamad Amirun Aqil Zainuren and Taha Mohammed Ahmed Sadeq. All authors reviewed the results and approved the final version of the manuscript

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