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The assessment of hydrogen production potential from wind power in Vietnam

Abstract: Hydrogen production technology from wind energy is one of the feasible methods to shift dependence on fossil fuels to clean energy in the near future. In Vietnam, the government is also developing policies and regulations to promote the development of the hydrogen industry. However, hydrogen production efficiency from areas with different potential for wind power exploitation in Vietnam has not yet been researched to provide a sufficient basis for investors to develop projects. In this paper, the hydrogen production potential from wind power systems is analysed based on the wind energy potential in each region in Vietnam with the support of SAM software and hydrogen production formulas. Phu Yen province (South Central region) and Dak Lak province (Central Highlands region) with the highest wind energy potential, have the largest hydrogen production of 45,286.1 kg/year and 42,675.4 kg/year, respectively. Wind power will help reduce large amounts of CO_2 emissions into the environment by replacing grid electricity that uses fossil fuels

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in the electrolysis process. The amount of CO_2 emission reduction is determined by corresponding to the amount of wind power produced for the hydrogen generation process. Phu Yen province has the highest CO_2 emission reduction of 1,792,968 kg/year, while Ho Chi Minh City has the lowest value of 859,233 kg/year. The study results can be referenced by managers, consultants, and investors to support the development of the green hydrogen sector in Vietnam.

KEYWORDS: hydrogen energy, wind power, electricity, CO_2 emission reduction

Nomenclature and abbreviation

AC – alternating current
DC – direct current
E_{out} – annual electrical energy output [kWh]
E_{con} – amount of the energy consumption in the electrolyzer [kWh]
$EFgrid$ – tCO_2 emission coefficient of Vietnam's power grid [tCO_2/MWh]
eff_{con} – performance of rectifier efficiency [%]
$F_{adj,j}$ – hourly adjustment factor due to various losses [h]
H – amount of hydrogen produced [Nm^3]
L – loss correction factor due to the wake losses [%]
N – number of turbines in the wind farm [unit]
$P_{wf,j}$ – electrical output of wind farm in hour j [kWh/h]
$P_{j,n}$ – Electrical output of turbine n in hour j [kWh/h]
R_{tCO2e} – Average annual CO_2 emission reduction [ton]
SAM – System Advisor Model

1. Introduction

Currently, hydrogen plays an extremely important role in socio-economic and environmental development. Hydrogen can be used to produce clean energy, helping to reduce dependence on traditional energy sources (Chelvam et al. 2024).

Green hydrogen (Hassan et al. 2024) produced from renewable electricity systems has great potential to shift dependence on fossil fuels to clean energy in the near future. Currently, hydrogen production from renewable power sources, in general, and wind power, in particular, has been receiving research attention from laboratories around the world. Flavia Franco (Franco 2020) conducted a study on a model of a hydrogen production plant from wind and solar power sources in Portugal with the help of Energy Plan software. Using MATLAB software, the researcher (Li et al. 2021) proposed a mathematical model and control system design for hydrogen production in a wind power system and gas turbines. Sedai et al. (2023) evaluated the possibility of producing hydrogen from wind energy in the US. AlZohbi et al. (2023) studied the potential of using excess wind energy to produce hydrogen in four sites located in Saudi Arabia. Xue et al. (2021) analysed the investment efficiency of hydrogen production from wind power through electrolysis and contributed to China's carbon emission reduction goal. Javaid et al. (2022) built a machine-learning method to predict hydrogen production based on wind energy in suburban environments. Wu et al. (2020) proposed a cooperative method between hydrogen fuel stations and wind turbines to optimize hydrogen production and storage efficiency. Opakhai et al. (2024) analysed the difficulty of green hydrogen energy development in Kazakhstan. Apart from this, a new hydrogen production roadmap by 2040 in Kazakhstan was proposed. Rezaei et al. (2018) investigated the economic and social aspects of using wind power systems in 3 typical cities in Iran to produce hydrogen. This study evaluated five sets with different rated capacities (from 5 to 100 kW) in 3 cities. A 60 kW wind turbine was the most suitable type with the least payback period to produce hydrogen in 3 cities. The research of Zheng et al. (2023) evaluated the economic performance of off-grid wind hydrogen systems across 112 sites in seven countries by using detailed electrolysis models. Hydrogen production systems from 4.2 MW wind turbines in China and Denmark are the best cost-competitive due to abundant resources and lower investment costs.

In Vietnam, the government (Prime Minister 2023, 2024) is also developing policies and regulations to promote hydrogen industry development. These policies and strategies have created the legal basis and direction for hydrogen development in Vietnam. However, many challenges still need to be resolved, such as the high cost of hydrogen production, the lack of infrastructure for producing and using hydrogen, and the competitiveness of hydrogen compared to other fossil fuels, which are still limited. Green hydrogen (Hoang et al. 2023) is a powerful solution in the global pursuit of a green future. Vietnam boosts green hydrogen production by expanding renewable energy capacity and reducing solar and wind production costs, offering great prospects (Luong 2021) with high renewable energy potential and a fast growth rate in renewable energy, especially wind power. The applications of green hydrogen in Vietnam are vast (Luong 2021). It is used in the steel and chemical industries. Vietnam has had some studies on hydrogen production from renewable energy sources (Phap et al. 2022; Phan et al. 2023). However, hydrogen production efficiency from areas with different potential for wind power exploitation in Vietnam has not yet been researched to provide a sufficient basis for investors to develop projects.

This paper analyzes the potential for hydrogen production from onshore wind power in different climate zones in Vietnam. The results also determined the reduction in CO_2 emission due to using wind power to replace fossil fuels in the electrolysis process. The research results can be referenced by managers, consultants, and investors who are considering applying to build a hydrogen production station from wind power in Vietnam.

1. Methodology

In Figure 1, the research method has a process of four steps of data collection, using SAM (System Advisor Model) software for analysis, estimation of hydrogen production, and assessment of calculation results.

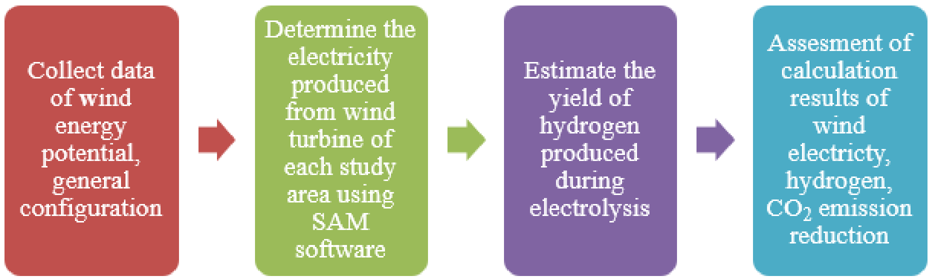


Fig. 1. The research method process

Rys. 1. Proces metody badawczej

SAM software (Freeman et al. 2014) calculates the electricity generated from the wind turbine as follows:

The hourly output is calculated by the equation (1):

$$P_{wf,j} = \frac{L}{100\%} x \sum_{n=1}^{N} P_{j,n} \tag{1}$$

where:

$P_{wf,j}$ – the electrical output of a wind farm per hour j [kWh/h],
L – the loss correction factor due to the wake losses [%],
$P_{j,n}$ – the electrical output of turbine n in hour j [kWh/h],
N – the number of turbines in the wind farm.

The annual energy output is determined by the equation (2):

$$E_{out} = \sum_{n=1}^{8760} (P_{wf,j}\, x\, F_{adj,j}) \tag{2}$$

where:

E_{out} – the annual electrical energy output [kWh],
$P_{wf,j}$ – the electrical output of the wind farm per hour j [kWh/h],
$F_{adj,j}$ – the hourly adjustment factor due to various losses,
8760 – number of hours in one year.

Hydrogen production (Rezaei et al. 2019) is estimated by the formulas as below:

$$H = \left(\frac{E_{out}}{E_{con}}\right) x\, eff_{con} \tag{3}$$

where:

- H – the amount of hydrogen produced [Nm^3],
- E_{out} – the amount of wind electricity [kWh],
- eff_{con} – the performance of rectifier efficiency with the value of 95%,
- E_{con} – the amount the energy consumption of 5 kWh/Nm^3 in the electrolyzer.

Equation (4) is used to convert Nm^3 to weight [m] in kg (Rezaei et al. 2019):

$$m = \mathrm{N} \cdot m^3 \cdot \left(\frac{1\,mol}{0.022414\,Nm^3}\right) \cdot \left(\frac{0.002016\,kg}{1\,mol}\right) \tag{4}$$

The average annual CO_2 emission reduction is calculated according to the formula:

$$R_{tCO_{2e}} = E_{out} \cdot EFgrid \tag{5}$$

where:

- $R_{tCO_{2e}}$ – the average annual CO_2 emission reduction [ton],
- E_{out} – the average annual amount of wind electricity [MWh],
- $EFgrid$ – the tCO_2 emission coefficient of Vietnam's power grid (0.6766 tCO_2/MWh) (Department of Climate Change 2024).

2. Hydrogen production system using wind power

Figure 2 shows the basic block diagram of hydrogen production from a wind power system. The wind turbine generates electricity in favorable weather conditions to operate the electrolyzer. The electrolyzer is used to separate hydrogen and oxygen molecules from water molecules. The controller controls the conversion of alternating current (AC) to direct current (DC) for hydrogen production and supply to local loads. The hydrogen produced will be stored in storage for hydrogen load.

The hydrogen production station uses 1 MW wind turbine from Mitsubishi (Fig. 3) to replace grid electricity using fossil fuels in the electrolysis process. The alkaline electrolyzer system

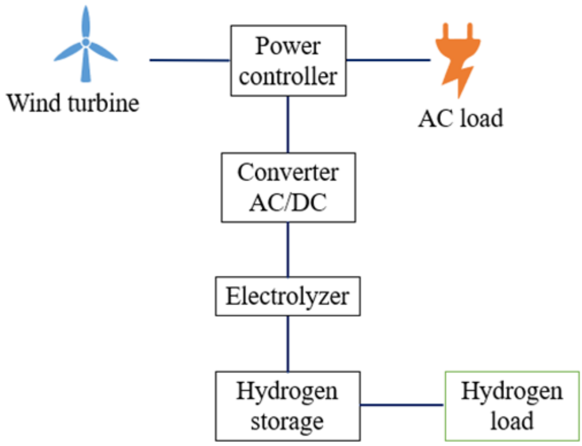


Fig. 2. Diagram of hydrogen production from a wind power system

Rys. 2. Schemat produkcji wodoru w systemie energetyki wiatrowej

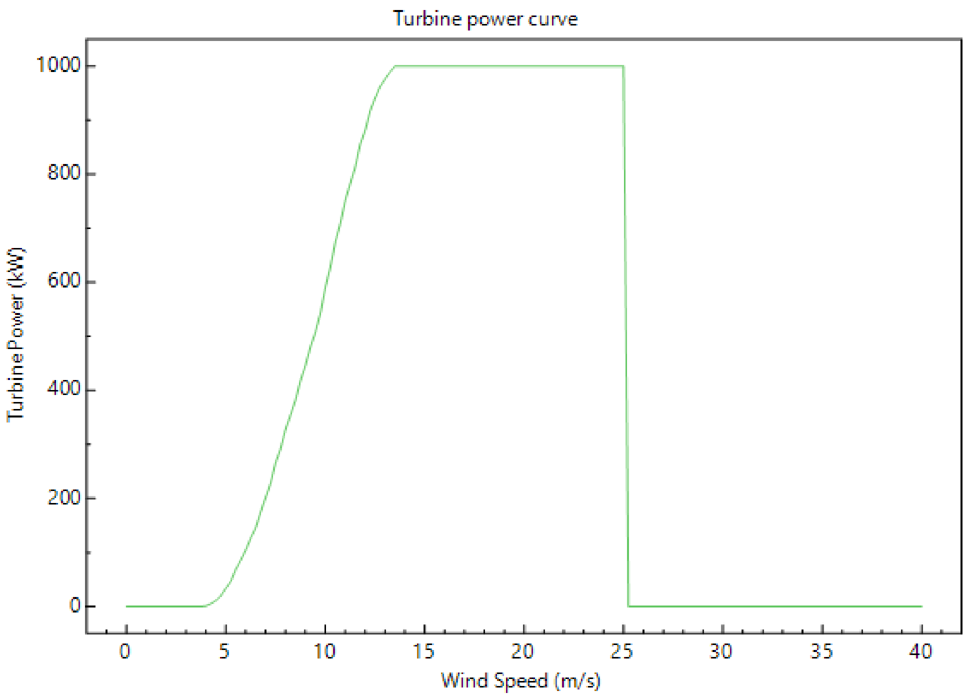


Fig. 3. 1 MW wind turbine power curve (National Renewable Energy Laboratory 2022)

Rys. 3. Krzywa mocy turbiny wiatrowej o mocy 1 MW with a total capacity of 1000 kW is used in this hydrogen production station because alkaline is the most popular type for wind electrolysis with the advantages of long life and low cost (Sharshir et al. 2024). The technical data for the wind turbine and electrolyzer simulation was used in the available database in the SAM software version 2022.11.21 (National Renewable Energy Laboratory 2022).

3. Wind power potential of case study

Vietnam is located in the tropical monsoon climate zone, with a coastline stretching over 3,000 km, so the potential for wind energy development in Vietnam is extremely large. According to World Bank survey results, Vietnam has the largest wind potential in Southeast Asia, and it is estimated that more than 39% of the total area has an average annual wind speed greater than 6 m/s in height of 65 m, equivalent to 512 GW capacity (World Bank 2021).

This study will focus on calculating the ability to produce hydrogen using wind power systems in Vietnam based on the wind energy potential in each area. The wind power stations included in the calculation have the same capacity of 1 MW. The study areas in the project include provinces representing eight geographical regions with different climatic conditions, as shown in Table 1 and Figure 4. Each province is represented by wind potential data at an altitude of 100 m based on the Global Wind Atlas.

TABLE 1. Average monthly wind speed of 8 regions at an altitude of 100 m [m/s]

TABELA 1. Średnia miesięczna prędkość wiatru w 8 regionach na wysokości 100 m [m/s]

	Bac Kan	Son La	Ha Noi	Ha Tinh	Phu Yen	Dak Lak	Ho Chi Minh	Tra Vinh
January	6.73	6.89	6.26	7.21	10.21	9.77	5.45	7.70
February	6.95	7.34	6.58	6.81	8.68	8.82	6.18	7.58
March	7.04	7.86	6.66	6.74	7.75	7.92	6.70	7.14
April	6.86	7.56	6.50	6.30	6.78	6.28	6.31	5.84
May	6.44	6.94	6.01	6.40	6.13	5.51	5.65	5.21
June	5.76	7.07	5.42	8.05	6.81	7.04	6.28	6.05
July	5.87	6.64	5.43	7.96	6.87	7.36	6.49	6.30
August	5.21	5.89	4.76	6.85	7.10	7.88	6.66	6.64
Septemper	6.00	6.16	5.31	6.47	5.77	5.97	5.84	5.79
October	6.69	6.55	5.86	8.24	8.15	7.17	4.78	5.05
November	6.49	6.28	5.70	8.34	10.94	9.73	4.87	6.40
December	6.56	6.13	5.84	7.99	11.87	10.60	4.99	7.08
Average	6.38	6.77	5.86	7.28	8.09	7.84	5.85	6.40

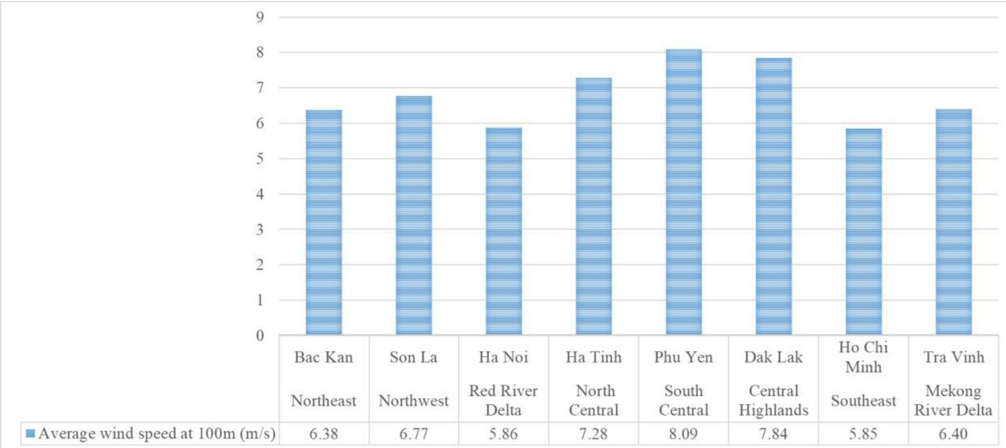


Fig. 4. Average annual wind speed of 8 regions at an altitude of 100 m

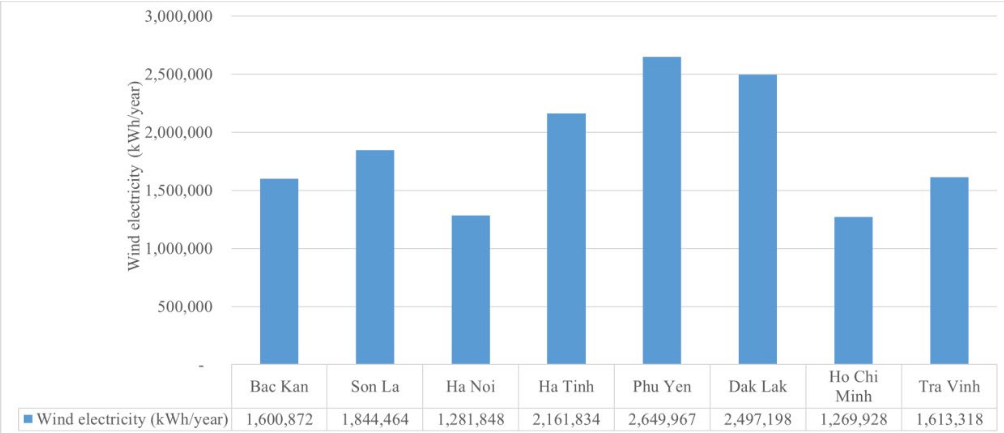
Rys. 4. Średnia roczna prędkość wiatru w 8 regionach na wysokości 100 m

The average wind speed at an altitude of 100 m in Vietnam ranges from 6 to 7 m/s, the average wind speed tends to be higher in the Central regions and down to the Central Highlands and Mekong Delta. The highest average speed is in the South Central region, with a value of 8.09 m/s. The area with the lowest average wind speed is in the Red River Delta and the Southeast region, with an average speed of approximately 5.9 m/s.

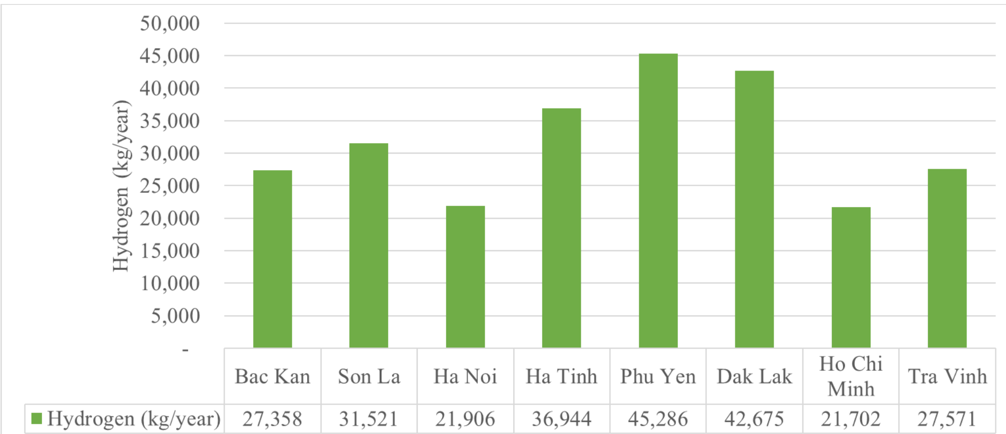
4. Results and discussion

The annual average amount of wind electricity and hydrogen are depicted in Figure 5. The study results show that the amount of wind power produced at Phu Yen province (South Central region) and Dak Lak province (Central Highlands region) have the highest values of 2,649,967 and 2,497,198 kWh/year, respectively. These are all areas with average to high annual wind speeds and are relatively stable, especially in the Central regions, which are exposed to a long coastline receiving wind resources blowing mostly from offshore to the mainland. Next, Ha Tinh province (North Central region) also has a relatively high output of 2,161,834 kWh/year.

Son La province (Northwest region) has the highest average wind speed among the three localities in the Northern area, so the wind electricity output in the Son La province is the largest, with a value of 1,844,464 kWh/year, followed by Bac Kan province (Northeastern region) with an output of 1,600,872 kWh/year. Hanoi city (Red River Delta region) has the lowest result with an output of 1,281,848 kWh/year because this is a flat and plain terrain area, the variation in wind speed is not high, and climate change between seasons is obvious, so wind speed is not stable.



a. Wind electricity



b. Hydrogen

Fig. 5. Annual average amount of wind electricity (a) and hydrogen (b)

Rys. 5. Średnia roczna ilość energii elektrycznej z wiatru (a) i wodoru (b)

In the Southern area, Tra Vinh province (Mekong Delta) has high results with a yearly output of 1,613,318 kWh/year. Ho Chi Minh City (Southeastern region) has an electricity output of 1,269,928 kWh/year, the lowest value in the Southern area.

The amount of wind electricity generated corresponds to the amount of hydrogen produced. The study results show that Phu Yen province (South Central region) and Dak Lak province (Central Highlands region) have the highest average annual hydrogen production of 45,286.1 and 42,675.4 kg/year, respectively. Ha Tinh province (North Central region) has hydrogen production of 36,944.3 kg/year. Furthermore, the regions from the North Central region down to the Southeast provinces have great potential for green hydrogen consumption because of key industrial production facilities such as petrochemical refineries, chemicals, and fertilizers. Thus, high hydrogen output will create favorable conditions for the above industries in the regions.

Son La province (Northwest region) and Bac Kan province (Northeast region) also produced relatively good results, with a hydrogen output of 31,520.6 and 27,357.8 kg/year, respectively. Hanoi City (Red River Delta) has the lowest hydrogen output of 21,905.9 kg/year. In the Southern area, Tra Vinh province (Mekong Delta) and Ho Chi Minh City (Southeast region) have hydrogen production of 27,570.5 and 21,702.2 kg/year, respectively.

Figure 6 presents rthe electricity consumption of an electrolyzer to produce hydrogen from the clean electricity of a 1 MW wind turbine. Ho Chi Minh City has the smallest electricity consumption amount of an electrolyzer of about 1,206,643 kWh/year, followed by Hanoi City with a value of nearly 1,217,969 kWh/year.

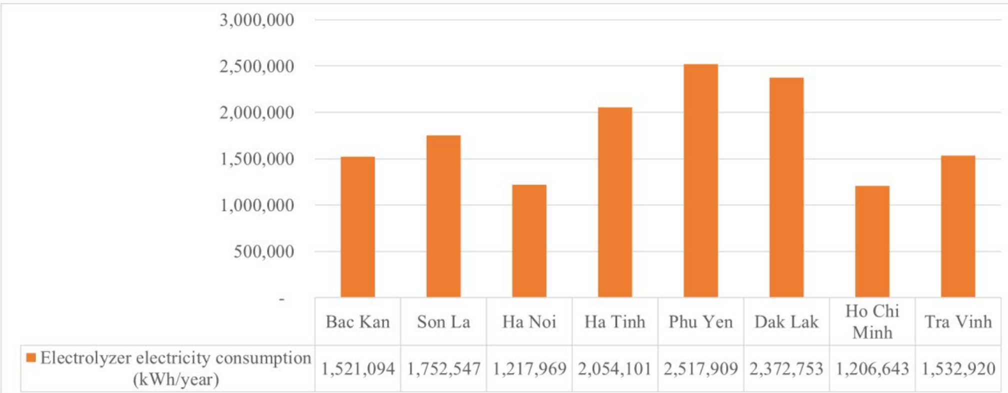


Fig. 6. Electrolyzer electricity consumption

Rys. 6. Zużycie energii elektrycznej przez elektrolizer

Environmental analysis results in Figure 7 and Table 2 present that the use of wind power for hydrogen production will help reduce large amounts of CO_2 emissions into the environment because it has replaced grid electricity using fossil fuels in the electrolysis process. The reduction in CO_2 emission is determined by the amount of wind power produced during the hydrogen generation process. Phu Yen province has the highest CO_2 emission reduction of 1,792,968 kg/year, while Ho Chi Minh City has the smallest value of 859,233 kg/year.

At present, hydrogen production technology from wind power systems is a viable energy conversion trend globally and a potential technology in Vietnam. The country needs to consider accessing and researching new technologies in production, analysing and clarifying the hydrogen market in the region, and building and upgrading necessary infrastructure for wind power projects. To overcome those challenges, the Vietnamese government also needs to consider strong, specific, and clear support solutions and policies on roadmaps and orientations to help develop

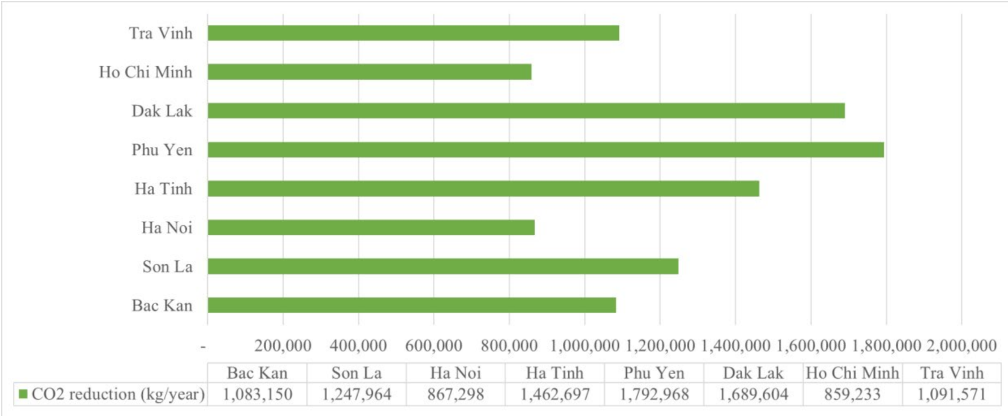


Fig. 7. CO_2 emission reduction output in 1 year

Rys. 7. Efekt redukcji emisji CO_2 w ciągu 1 roku

Table 2. Output results compared between localities

Tabela 2. Porównanie wyników wyjściowych pomiędzy miejscowościami

City/Province	Average wind speed at 100 m [m/s]	Electricity [kWh/year]	Hydrogen [kg/year]	CO_2 reduction [kg/year]
Bac Kan	6.38	1,600,872	27,357.8	1,083,150
Son La	6.77	1,844,464	31,520.6	1,247,964
Ha Noi	5.86	1,281,848	21,905.9	867,298
Ha Tinh	7.28	2,161,834	36,944.3	1,462,697
Phu Yen	8.09	2,649,967	45,286.1	1,792,968
Dak Lak	7.84	2,497,198	42,675.4	1,689,604
Ho Chi Minh	5.85	1,269,928	21,702.2	859,233
Tra Vinh	6.40	1,613,318	27,570.5	1,091,571

the renewable energy industry, creating favorable conditions for investors, promoting research and application of new technologies, and supporting the promotion of hydrogen use.

In addition, the shortage of highly skilled and specialised workers is also a major obstacle to the development of the hydrogen industry in Vietnam. The use of foreign personnel will increase production costs. Thus, government, management agencies, businesses, educational institutions, and social organizations need to improve training quality, improve the facilities of academic institutions and businesses, increase investment in research and development of hydrogen production technology, etc.

Conclusions

This study presented hydrogen production potential in different regions in Vietnam. The results showed that the annual production of hydrogen depends strongly on the wind power potential. It can be seen that Phu Yen province (South Central region) and Dak Lak province (Central Highlands region), with the highest wind energy potential, have the largest hydrogen production of 45,286.1 and 42,675.4 kg/year, respectively. In contrast, hydrogen production potentials in Hanoi City (Red River Delta region) and Ho Chi Minh City (Southeast region) are the lowest, with a value of 21,905.9 and 21,702.2 kg/year, respectively, because of the lowest wind power output.

Carbon emissions can be reduced by utilising wind power generated instead of grid power in the electrolysis process. Therefore, Phu Yen province has the highest CO_2 emission reduction of 1,792,968 kg/year, while Ho Chi Minh City has the lowest value of 859,233 kg/year.

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The Authors have no conflicts of interest to declare.

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Ocena potencjału produkcji wodoru z elektrowni wiatrowych w Wietnamie

Streszczenie

Technologia produkcji wodoru z energii wiatrowej jest jedną z wykonalnych metod przejścia od zależności od paliw kopalnych do czystej energii w niedalekiej przyszłości. W Wietnamie rząd opracowuje również polityki i przepisy mające na celu promowanie rozwoju przemysłu wodorowego. Jednak efektywność produkcji wodoru z obszarów o różnym potencjale wykorzystania energii wiatrowej w Wietnamie nie została jeszcze zbadana, aby zapewnić inwestorom wystarczającą podstawę do rozwijania projektów. W tym artykule potencjał produkcji wodoru z systemów energetyki wiatrowej jest analizowany na podstawie potencjału energii wiatrowej w każdym regionie Wietnamu przy wsparciu oprogramowania SAM i wzorów produkcji wodoru. Prowincja Phu Yen (region południowo-centralny) i prowincja Dak Lak (region Central Highlands) o największym potencjale energii wiatrowej mają największą produkcję wodoru, odpowiednio 45 286,1 i 42 675,4 kg/rok. Energia wiatrowa pomoże zmniejszyć duże ilości emisji CO_2 do środowiska poprzez zastąpienie energii elektrycznej z sieci, która wykorzystuje paliwa kopalne w procesie elektrolizy. Ilość redukcji emisji CO_2 jest określana na podstawie ilości energii wiatrowej wytworzonej w procesie wytwarzania wodoru. Prowincja Phu Yen ma najwyższą redukcję emisji CO_2 wynoszącą 1 792 968 kg/rok, podczas gdy Ho Chi Minh ma najniższą wartość wynoszącą 859 233 kg/rok. Wyniki badania mogą być wykorzystywane przez menedżerów, konsultantów i inwestorów w celu wsparcia rozwoju sektora zielonego wodoru w Wietnamie.

Słowa kluczowe: wodór, emisja CO_2, elektryczność, energia wiatrowa