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Hydrogen Power Plant Site Selection Under Fuzzy Multicriteria Decision-Making (FMCDM) Environment Conditions

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Abstract: Fuel and energy are basic resources necessary to meet a country's socioeconomic development needs; further, countries rich in these resources have the best premise for meeting the inputs of an economic system; however, this also poses many political challenges and threats to national security. Vietnam is located in the Southeast Asian monsoon-humid tropical region and has diverse fuel-energy resources such as coal, petroleum, and hydropower, along with renewable energy sources such as solar energy, biomass energy, and geothermal energy. However, the reality of economic development in recent years shows complex fluctuations in fuel and energy usage, i.e., besides the export of coal and crude oil, Vietnam still has imported processed oil products. To overcome this issue, many hydrogen power plants will be built in the future. This is why we propose fuzzy multicriteria decision-making (FMCDM) for hydrogen power plant site selection in this research. All criteria affecting location selection are determined by experts and literature reviews, and the weight of all criteria are defined by a fuzzy analytic hierarchy process (FAHP). The technique for order of preference by similarity to an ideal solution (TOPSIS) is a multicriteria decision analysis method, which is used for ranking potential locations in the final stage. As a result, the decision-making unit, DMU010 (DMU010), has become the optimal solution for building hydrogen power plants in Vietnam. A multicriteria decision-making (MCDM) model for hydrogen power plant site selection in Vietnam under fuzzy environment conditions is a contribution of this study. This research also provides useful tools for other types of renewable energies in Vietnam and other countries.

Keywords: FMCDM; fuzzy logics; fuzzy environment; FAHP; TOPSIS; hydrogen power plant; site selection

1. Introduction

Vietnam has the potential to develop its available renewable energy sources. Renewable energy sources that can be exploited and used in practice that have been identified thus far are hydrogen power, wind energy, biomass energy, biogas energy (biogas), biofuel, solar, and geothermal. In the context of Vietnam's energy, demand is increasing. Further, the ability to supply domestic energy resources is limited, while Vietnam's renewable energy potential is huge. A highly effective solution for the present and the future is to consider exploitation of available renewable energy sources for electricity generation, especially hydrogen energy—an idea that is feasible both in technology and economic efficiency and environment.

Today, a new type of renewable energy source that is being exploited is hydrogen (hydrogen, H2). Hydrogen is the highest heat-burning gas of all-natural fuels, e.g., it is used as fuel to launch spacecraft. The important feature of hydrogen is that its molecules do not contain any other chemical elements, e.g., carbon (C), sulfur (S), nitrogen (N), so their combustion product is only water (H2O), which is considered the ideal clean energy resource [1]. Hydrogen is produced from water and solar energy; thus, the collected hydrogen is also called hydrogen by solar energy (solar hydrogen). Planet Earth has a surplus of water and sunshine; therefore, hydrogen, thanks to solar energy, is an endless source of fuel to ensure energy safety for human beings, without fear of exhaustion [1]. Hydrogen is considered to be the renewable energy of the future and has recently received a lot of attention [2]. Many researchers have been involved in dealing with issues to facilitate the introduction of hydrogen into the energy balance [3]. Alternative fuels, including hydrogen-rich fuels, have been studied for use in electricity production [4]. The effect of hydrogen injection as an additional fuel in gas turbine combustion chambers has been assessed [5]. Power plants that utilize hydrogen could potentially have absolutely zero emissions [2].

One of the most important aspects of renewable energy resources is site selection, as decision-makers have to evaluate all quantitative and qualitative factors of the multiple-criteria decision-making (MCDM) process. This is why we proposed a fuzzy MCDM model for hydrogen power plants in this research. MCDM is a decision-making analysis that evaluates multiple (conflicting) criteria as part of the decision-making process. The general process of site selection is shown in Figure 1.

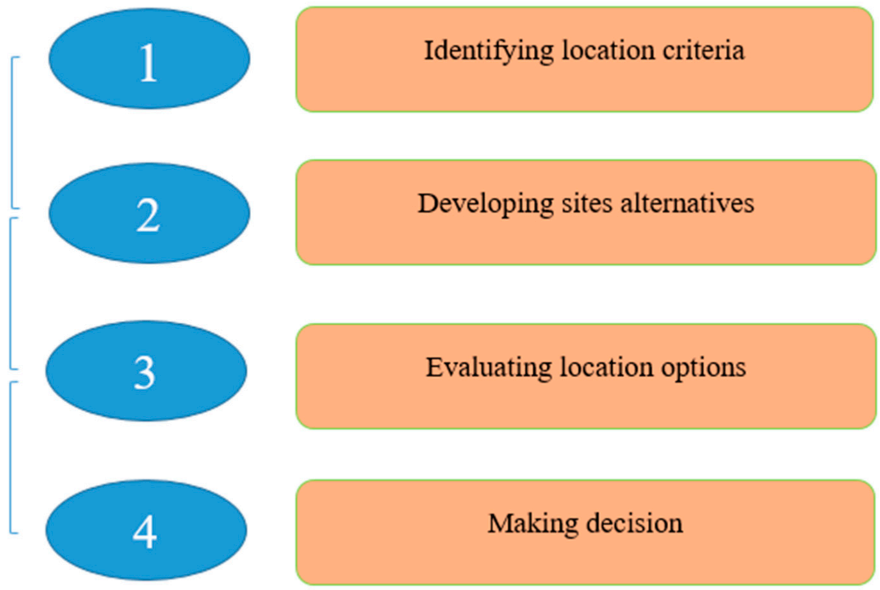

Figure 1. The general process of site selection [6,7].

The primary goal of this work is to propose a fuzzy MCDM model for hydrogen power plant site selection in Vietnam under fuzzy environment conditions. All criteria that affect the location selection are determined by experts and literature reviews, and the weight of all criteria are defined by the fuzzy analytic hierarchy process (FAHP) model. A technique for order of preference by similarity to an ideal solution (TOPSIS) is a multicriteria decision analysis method, which is used for ranking potential locations in the final stage. This research also introduces a useful tool for site selection in other types of renewable energy.

2. Literature Review

Numerous survey studies have recently focused on site selection problems, e.g., Wang et al. [6], who proposed an MCDM model for nuclear power plant (NPP) site selection in Vietnam. In this research, the authors applied fuzzy analytic network process (FANP) and TOPSIS for NPP location selection in Vietnam. Sedady et al. [7] introduced an MCDM model for prioritizing the construction of renewable power plants. The goal of this article is to propose a new MCDM model to define the priority of building renewable power plants considering technical, economic, social, political and environmental factors. Eveloy and Gebreegziabher [8] have considered technical, economic and environmental assessments of projected power-to-gas deployment scenarios on a distributed- to national-scale, as well as their extensions to nuclear-assisted renewable hydrogen.

Biswal and Shukla [9] have developed algorithms for the selection of appropriate locations for the installation of wind turbines. Pamucar et al. [10] combined the use of Geographical Information Systems (GIS) with multi-criteria techniques of Best-Worst method (BWM) and Multi Attributive Ideal-Real Comparative Analysis (MAIRCA) for wind farm location selection. Nicotra et al. [11] presented equivalent small hydropower: A simple method to evaluate energy production by small turbines in collective irrigation systems. Noorollahi [12] proposed multi-criteria decision support system for wind farm site selection using GIS. In this research, the authors considered technical, environmental, economic and geographic standards.

Borah et al. [13], using GIS, developed an analytical framework in which fuzzy logic was used to evaluate suitable sites for turbines for optimum energy output. The factors for a suitable site for energy optimization are environmental, physical and human factors. Öztürk et al. [14] applied GIS for wind turbine location selection in Balikesir, Northwest Turkey. This research identified 12 geographical criteria; the effects and weights of these criteria were defined by considering the relevant literature and field conditions, and various analyses were conducted on these factors with the help of GIS. Mytilinou and Kolios [15] introduced a multi-objective optimization approach applied to offshore wind farm location selection.

Wang et al. [16] proposed an MCDM model for solar power plant location selection in Vietnam. In this research, the authors used fuzzy analytic hierarchy process (FAHP), data envelopment analysis (DEA) to find the best location for building a solar power plant based on both quantitative and qualitative factors. Wang et al. [17] applied an MCDM model for solid waste to energy plant location selection in Vietnam. In this research, the authors applied FANP and TOPSIS for ranking all potential locations. Aktas et al. [18] proposed a hybrid hesitant fuzzy decision-making model for solar power plant location selection. Akkas et al. [19] applied an MCDM model for site selection for a solar power plant in the Central Anatolian Region of Turkey.

All the factors that affect hydrogen power plant location selection are defined by literature reviews and experts, these criteria as shown in Table 1.

Table 1. All criteria affect to location selection.

Main Criteria	Subcriteria	Literature Review
F.1. Social (SOC)	F.1.1. Public acceptance (SOC1)	[20]
	F.1.2. Protection law (SOC)	[16]
	F.1.3. Legal and Regulation compliance (SOC3)	[16,20]
F.2. Environmental (ENV)	F.2.1. Availability of water (EVN1)	[21]
	F.2.2. Water storage (EVN2)	[21]
	F.2.3. Water head (EVN3)	[21]
	F.2.4. Environment affect (EVN4)	[21]
F.3. Technological (TEC)	F.3.1. Distance from major road (TEC1)	[22–26]
	F.3.2. Distance from power network (TEC2)	[17,22–27]
	F.3.3. Potential demand (TEC3)	[16,22]
F.4. Economic (ECO)	F.4.1. Construction cost. (EOC1)	[16,24,28]
	F.4.2. Operation and management cost (EOC2)	[16,20,23]
	F.4.3. New feeder cost (EOC3)	[23]
F.5. Site Characteristics (SIC)	F.5.1. Land use (SIC1)	[24–26,29–31]
	F.5.2. Ecology (SIC2)	[16]

3. Methodology

3.1. Research Development

In this study, we proposed fuzzy MCDM approaches, including an FAHP and TOPSIS approach, for hydrogen power plant site selection. This study has three main stages, as shown in Figure 2.

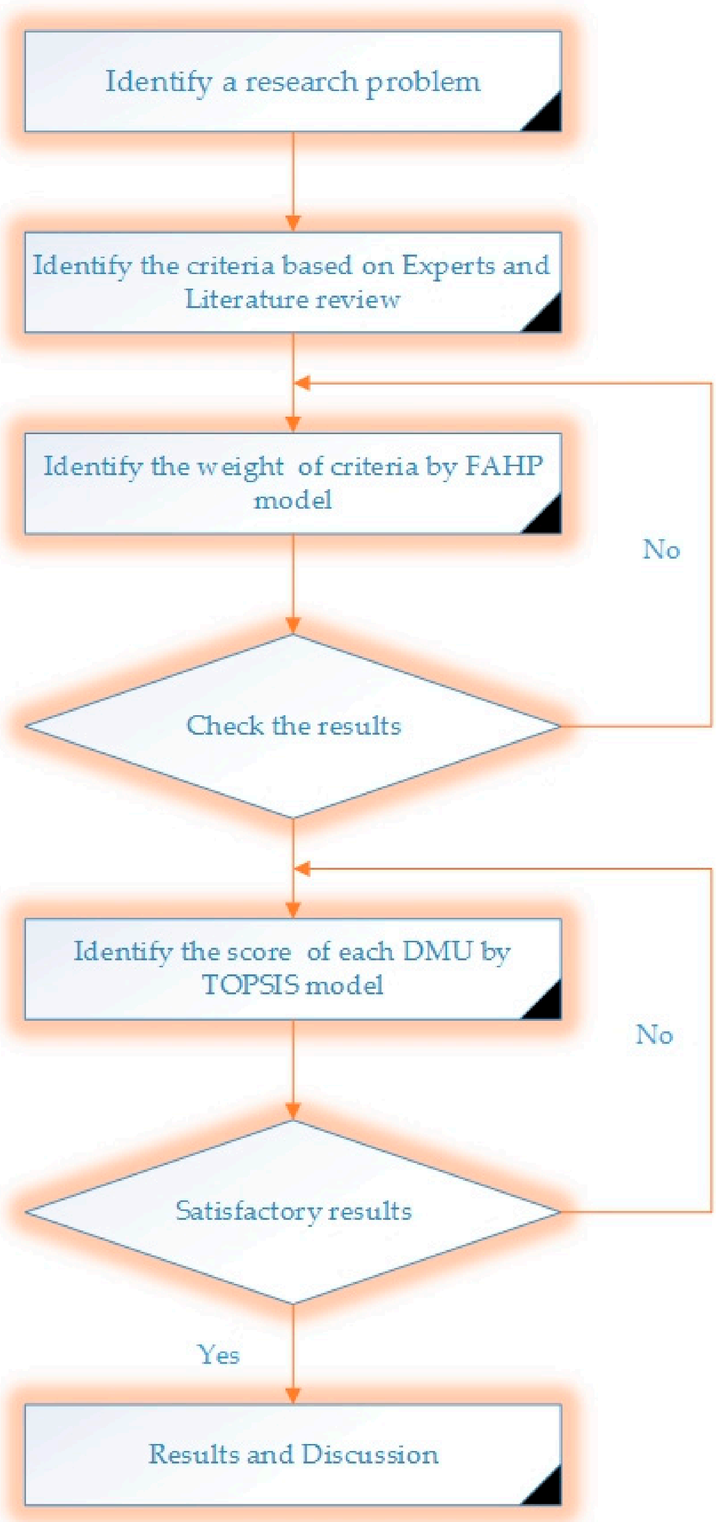

Figure 2. Research methodology.

Step 1: Identify the main criteria and subcriteria. All criteria for hydrogen power plants will be defined through experts and literature reviews.

Step 2: Using the FAHP approach. In this step, an FAHP is used to identify the weight of subcriteria.

Step 3: Ten potential locations can be highly effective for building hydrogen power plants in Vietnam. The TOPSIS approach is used in this stage for ranking all potential locations in this step. The optimal location will be shown based on positive ideal solution (PIS) and negative ideal solution (NIS) value.

3.2. Fuzzy Sets, AHP and TOPSIS Model

3.2.1. Triangular Fuzzy Number (TFN)

The TFN can be defined as (c, d, e) with $c \le d \le e$.

The general function of TFN is as follows:

$$\mu\left(\frac{x}{\widetilde{M}}\right) = \begin{cases} 0, & x < d, \\ \frac{x-c}{d-c} & c \le x \le d, \\ \frac{e-x}{e-d} & d \le x \le e, \\ 0, & x > e, \end{cases} \tag{1}$$

The basic calculations of fuzzy numbers are shown in:

$$\widetilde{M} = (M^{o(y)}, M^{i(y)}) = [c + (d-c)y,\ e + (d-e)y], y\ \in [0,1] \tag{2}$$

$o(y)$, $i(y)$ indicates both the left side and the right side of a fuzzy number as:

$$(c_1,\ d_1,\ e_1) + (c_2,\ d_2,\ e_2) = (c_1 + c_2,\ d_1 + d,\ e_1 + e_2) \tag{3}$$

$$(c_1,\ d_1,\ e_1) - (c_2,\ d_2,\ e_2) = (c_1 - c_2,\ d_1 - d_2,\ e_1 - e_2)$$

$$(c_1,\ d_1,\ e_1) \times (c_2,\ d_2,\ e_2) = (c_1 \times c_2,\ d_1 \times d_2,\ e_1 \times e_2)$$

$$\frac{(c_1,\ d_1,\ e_1)}{(c_2,\ d_2,\ e_2)} = (c_1/c,\ d_1/d_2, e_1/e_2)$$

To calculate the priority in the process of pairwise comparisons matrix, that are quantified using a $1 \div 9$ scale.

3.2.2. Analytic Hierarchy Process (AHP) model

AHP is introduced by Saaty [32], this is an MCDM that simplifies complex issues by sorting factors and alternatives in a hierarchical structure by using a pairwise comparison metric [33].

Let D = $\{D_b | b\ = 1, 2,\ \ldots,\ m\}$ be the set of criteria. The pair-wise comparisons metrics on m criteria will be shown in an m × m evaluation matrix, E, in which every element, k_{ab}, is the quotient of weights of the criteria, as shown in (1):

$$\mathrm{E}\ = (k_{ab}), a, b =\ 1 \tag{4}$$

The relative priorities are given by the Eigenvector (u) corresponding to the largest eigenvector (λ_{max}) as:

$$E_u = \lambda_{max}\ u \tag{5}$$

The consistency is determined by the relation between the entries of E and Consistency Index (CI):

$$CI = \frac{(\lambda_{max} - m)}{(m-1)} \tag{6}$$

Consistency Ratio (*CR*) is calculated as the ratio of the *CI* and the Random Consistency Index (*RI*), as shown in (7):

$$CR = \frac{CI}{RI} \tag{7}$$

$CR \leq 0.1$. If the $CR > 0.1$, the evaluation needs to be repeated again for improving consistency.

3.2.3. Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)

Hwang et al. introduced the TOPSIS model [34]. There are five main steps as follows [35].

- Determining TOPSIS requires performance ranking in every option. This can be seen from the formula below:

$$\mathrm{e_{ij}} = \frac{\mathrm{X_{ij}}}{\sqrt{\sum_{\mathrm{i=1}}^{\mathrm{m}} \mathrm{X_{ij}^2}}} \tag{8}$$

  with $i = 1, 2, \ldots, m$; and $j = 1, 2, \ldots, n$;
- Calculate the normalized weighted decision matrix.

$$\mathrm{S_{ij}} = \mathrm{W_i e_{ij}} \tag{9}$$

  with $i = 1, 2, \ldots, m$; and $j = 1, 2, \ldots, n$;
- Calculate PIS A^+ matrix and NIS A^- matrix.

$$\begin{aligned} A^+ &= s_1^+,\ s_2^+, \ldots, s_n^+ \\ A^- &= s_1^-,\ s_2^-, \ldots, s_n^-; \end{aligned} \tag{10}$$

  where:

$$s_j^+ = \begin{cases} Max\ s_{ij}\ if\ j\ is\ an\ advantage\ factor \\ Min\ s_{ij}\ if\ j\ is\ an\ cost\ factor \end{cases}$$

$$s_j^- = \begin{cases} Max\ s_{ij}\ if\ j\ is\ an\ advantage\ factor \\ Min\ s_{ij}\ if\ j\ is\ an\ cost\ factor \end{cases}$$

- Identifing the gap between the values of each options with (positive ideal solution) PIS matrix and (negative ideal solution) NIS matrix.

Options to PIS.

$$D_i^+ = \sqrt{\sum_{\mathrm{j=1}}^{m} \left(s_{ij} - s_i^+\right)^2};\ \mathrm{i} = 1, 2, \ldots, \mathrm{m} \tag{11}$$

Options to NIS.

$$D_i^- = \sqrt{\sum_{\mathrm{j=1}}^{m} \left(s_{ij} - s_i^-\right)^2};\ \mathrm{i} = 1, 2, \ldots, m \tag{12}$$

where D_i^+ is the distance to the PIS for *i* option and D_i^- is the distance to the NIS.

- Calculating the preference value for every alternative (G_i)

$$G_i = \frac{D_i^-}{D_i^- + D_i^+} \quad i = 1, 2, \ldots, m \tag{13}$$

4. Case Study

The energy demand in Vietnam increased by 7.5% annually from 2015 to 2025 because it remains among one of Asia's fastest-growing economies. This study estimates that gas and hydrogen will become the largest sources of energy and will increase to more than 50% of Vietnam's power structure over the next two decades [36]. To support this rapid economic growth, it is necessary that Vietnam continuously supplies new power plant capacity to meet demand. While Vietnam has reserves of oil and coal that provide considerable capacity, traditional hydropower has provided an alternative low-cost base energy source. This study estimates that gas and hydrogen will become the largest energy source by 2015 and will increase to more than 50% in Vietnam's power structure over the next two decades. Vietnam's power generation mix (TWh) is shown in Figure 3.

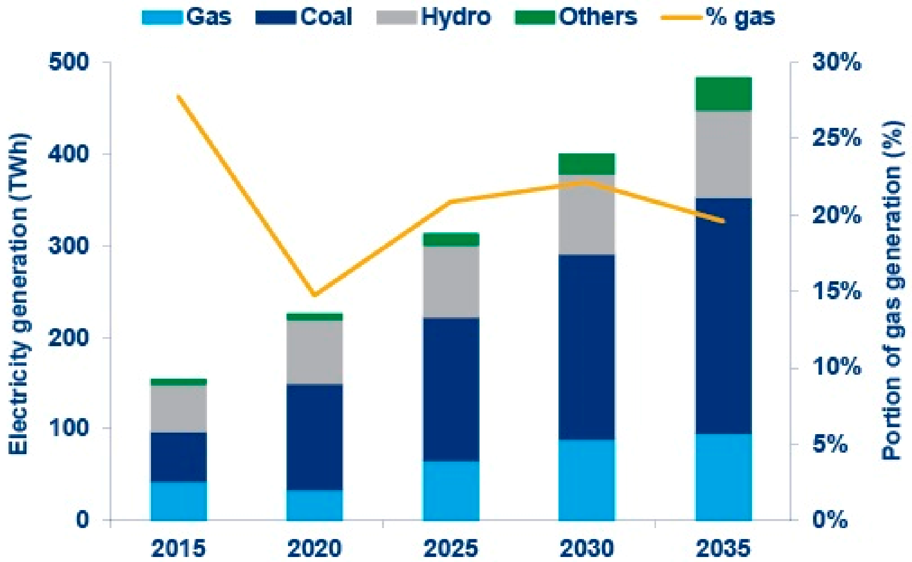

Figure 3. Vietnam power generation mix (TWh). Source: Wook Mackenie.

In recent years, the direction of development of the hydrogen energy industry has changed dramatically. Until now, hydrogen has been mainly used as fuel for automobile transport. It is thought that this will allow a significant reduction in the concentration of toxic substances in the atmosphere—not just carbon dioxide (CO_2) but a combination of toxic wastes when burning carbon-containing fuels. Hydrogen is the simplest and most abundant element on the Earth's surface. Although hydrogen does not exist in nature as monoatomic, by separating hydrogen from other elements, hydrogen can become a perfect energy carrier.

Another advantage is that the process of generating energy does not create any substance other than water. Currently, many available technologies can take advantage of hydrogen to provide energy. The ability to use hydrogen as an efficient fuel source has many advantages, e.g., it not only strengthens national energy safety but also reduces environmental pollution.

An MCDM model based on fuzzy set theory is an effective tool to solve complex selection problems, including many criteria (qualitative and quantitative) with many options [37]. Qualitative standards often have ambiguous characteristics, which are difficult to define correctly, making it difficult to synthesize assessment results according to criteria and decision-making. The fuzzy MCDM method will quantify these criteria, calculate the total scores of the weighted testers of each standard, and help decision-makers obtain a more solid and accurate basis. The assessment of a location is also carried out on such qualitative criteria; thus, the fuzzy MCDM model can be considered as an effective tool to assess site selection. Many studies have applied fuzzy MCDM in the location selection model, e.g., TOPSIS, AHP, ANP, DEA, The Preference Ranking Organization METHod for Enrichment of Evaluations (PROMETHEE). Thus, the authors proposed fuzzy multicriteria decision-making (FMCDM) for hydrogen power plant site selection in this research. All criteria affecting the location selection are determined by experts and literature reviews, and the weight of all criteria are defined by FAHP. The TOPSIS is a multicriteria decision analysis method, which is used for ranking potential locations in the final stage.

Ten potential locations are able to invest in hydrogen power plants, as shown in Table 2 and in Figure 4.

Table 2. List of 10 potential locations.

No.	DMUs	Symbol
1	Can Tho	DMU-001
2	Soc Trang	DMU-002
3	Bac Lieu	DMU-003
4	Hau Giang	DMU-004
5	Tra Vinh	DMU-005
6	Vinh Long	DMU-006
7	Kien Giang	DMU-007
8	Long An	DMU-008
9	An Giang	DMU-009
10	Ca Mau	DMU-010

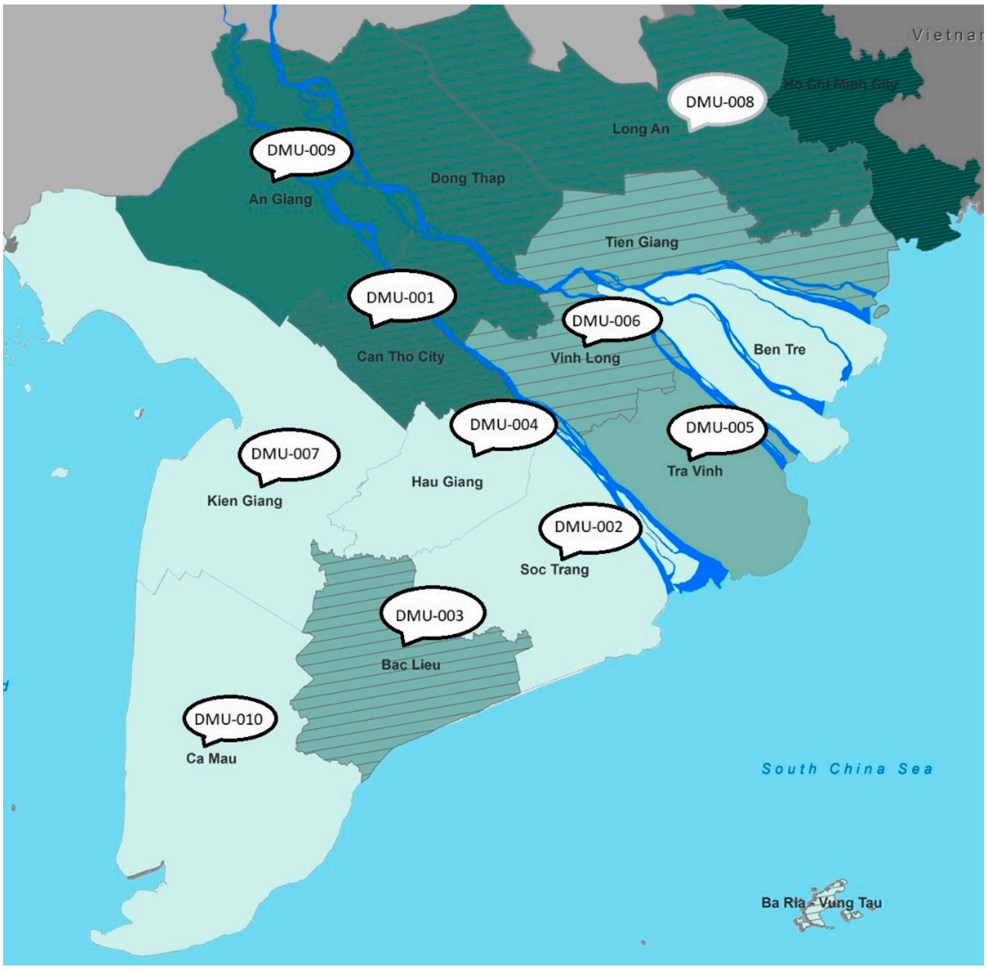

Figure 4. Ten potential locations on the map of Vietnam.

Finding an optimal location is among the most important factors affecting the time at which the project reaches completion. In order to select a good site, the decision-maker must first understand the criteria of site evaluation. Based on experts and literature reviews, the decision-maker must consider social factors, environmental criteria, technological factors, economic criteria and also characteristic factors. The hierarchy of the objectives of this work is shown in Figure 5.

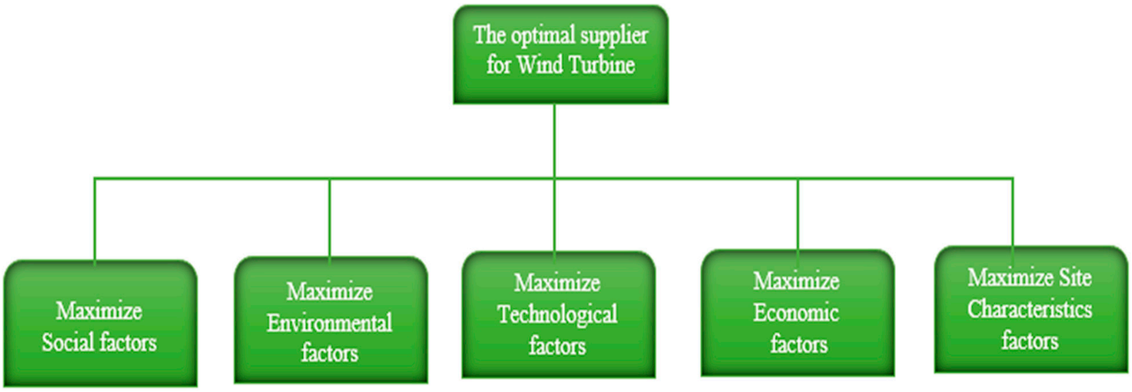

Figure 5. The objectives hierarchy.

The fuzzy comparison matrix of Goal from the FAHP model is shown in Table 3.

Table 3. Fuzzy comparison matrices for GOAL.

Criteria	EIC	ENV	EOC	SOC	TEC
EIC	(1,1,1)	(1/3,1/4,1/5)	(1/3,1/4,1/5)	(1/2,1/3,1/4)	(1,2,3)
ENV	(3,4,5)	(1,1,1)	(1,2,3)	(1,2,3)	(3,4,5)
EOC	(5,4,3)	(1/3,1/2,1)	(1,1,1)	(4,5,6)	(3,4,5)
SOC	(4,3,2)	(1/3,1/2,1)	(1/6,1/5,1/4)	(1,1,1)	(3,4,5)
TEC	(1/3,1/2,1)	(1/5,1/4,1/3)	(1/5,1/4,1/3)	(1/5,1/4,1/3)	(1,1,1)

We have the coefficients $\alpha = 0.5$ and $\beta = 0.5$, and
$g_{0.5,0.5}(\overline{a_{EIC,TEC}}) = [(0.5 \times 1.5) + (1 - 0.5) \times 2.5] = 2$
$f_{0.5}(L_{EIC,TEC}) = (2 - 1) \times 0.5 + 1 = 1.5$
$f_{0.5}(U_{EIC,TEC}) = 3 - (3 - 2) \times 0.5 = 2.5$
$g_{0.5,0.5}(\overline{a_{TEC,EIC}}) = \frac{1}{2}$
The real number priority when comparing the main criteria pairs is shown in Table 4.

Table 4. Real number priority.

Criteria	EIC	ENV	EOC	SOC	TEC
EIC	1	1/4	1/4	1/3	2
ENV	4	1	2	2	4
EOC	4	1/2	1	5	4
SOC	3	1/2	1/5	1	4
TEC	1/2	1/4	1/4	1/4	1

Calculating the maximum individual value is achieved as follows:

$$M1 = (1 \times 1/4 \times 1/4 \times 1/3 \times 2)^{1/5} = 0.5$$

$$M2 = (4 \times 1 \times 2 \times 2 \times 4)^{1/5} = 2.3$$

$$M3 = (4 \times 1/2 \times 1 \times 5 \times 4)^{1/5} = 2.1$$

$$M4 = (3 \times 1/2 \times 1/5 \times 1 \times 4)^{1/5} = 1.04$$

$$M5 = (1/2 \times 1/4 \times 1/4 \times 1/4 \times 1)^{1/5} = 0.38$$

$$\sum M = 6.32$$

$$\omega_1 = \frac{0.5}{6.32} = 0.08$$

$$\omega_2 = \frac{2.3}{6.32} = 0.36$$

$$\omega_3 = \frac{2.1}{6.32} = 0.33$$

$$\omega_4 = \frac{1.04}{6.32} = 0.16$$

$$\omega_5 = \frac{0.38}{6.32} = 0.06$$

$$\begin{bmatrix} 1 & 1/4 & 1/4 & 1/3 & 2 \\ 4 & 1 & 2 & 2 & 4 \\ 4 & 1/2 & 1 & 5 & 4 \\ 3 & 1/2 & 1/5 & 1 & 4 \\ 1/2 & 1/4 & 1/4 & 1/4 & 1 \end{bmatrix} \times \begin{bmatrix} 0.08 \\ 0.36 \\ 0.33 \\ 0.16 \\ 0.06 \end{bmatrix} = \begin{bmatrix} 0.43 \\ 1.9 \\ 1.87 \\ 0.89 \\ 0.31 \end{bmatrix}$$

$$\begin{bmatrix} 0.43 \\ 1.9 \\ 1.87 \\ 0.89 \\ 0.31 \end{bmatrix} / \begin{bmatrix} 0.08 \\ 0.36 \\ 0.33 \\ 0.16 \\ 0.06 \end{bmatrix} = \begin{bmatrix} 5.4 \\ 5.3 \\ 5.7 \\ 5.56 \\ 5.17 \end{bmatrix}$$

$n = 5$, $\lambda_{\max}$ and CI are calculated as follows:

$$\lambda_{max} = \frac{5.4 + 5.3 + 5.7 + 5.56 + 5.17}{5} = 5.426$$

$$CI = \frac{\lambda_{max} - n}{n - 1} = \frac{5.136 - 5}{5 - 1} = 0.1065$$

To calculate the CR value, we get $RI = 1.12$ with $n = 4$.

$$CR = \frac{CI}{RI} = \frac{0.1065}{1.12} = 0.0951$$

Because $CR = 0.0951$, which is ≤ 0.1, it does not need to be re-evaluated. The weight of all critera are defined by fuzzy AHP are shown in Table 5.

Table 5. The weight of subcriteria.

No.	Criteria	Weight
1	SOC1	0.0199
2	SOC2	0.0593
3	SOC3	0.1329
4	ENV1	0.0290
5	ENV2	0.0478
6	ENV3	0.0681
7	ENV4	0.1293
8	TEC1	0.1106
9	TEC2	0.0392
10	TEC3	0.0208
11	EOC1	0.0396
12	EOC2	0.0227
13	EOC3	0.1037
14	SIC1	0.0354
15	SIC2	0.1418

The normalized matrix and normalized weight matrix, obtained from the TOPSIS model, are shown in Tables 6 and 7.

Table 6. Normalized matrix.

Subcriteria	DMU-1	DMU-2	DMU-3	DMU-4	DMU-5	DMU-6	DMU-7	DMU-8	DMU-9	DMU-10
SOC1	0.2851	0.3258	0.3665	0.3665	0.2851	0.2443	0.3258	0.2851	0.3665	0.2851
SOC2	0.2782	0.3180	0.3180	0.2782	0.3180	0.3577	0.2385	0.3180	0.3577	0.3577
SOC3	0.2825	0.3229	0.3229	0.3229	0.3229	0.2825	0.3632	0.2825	0.2825	0.3632
ENV1	0.3269	0.2860	0.3269	0.3269	0.3677	0.3269	0.3269	0.2860	0.2452	0.3269
ENV2	0.2584	0.3015	0.3015	0.3446	0.3446	0.3015	0.3877	0.3015	0.3015	0.3015
ENV3	0.3269	0.3677	0.3269	0.2860	0.3677	0.2860	0.2860	0.2860	0.2860	0.3269
ENV4	0.3780	0.2940	0.3360	0.2940	0.2940	0.3360	0.2940	0.2940	0.3360	0.2940
TEC1	0.2860	0.3269	0.2860	0.2860	0.3677	0.2860	0.3269	0.2860	0.3269	0.3677
TEC2	0.3671	0.3263	0.3263	0.3263	0.3671	0.2855	0.3263	0.2855	0.2447	0.2855
TEC3	0.3052	0.3052	0.3052	0.3488	0.2616	0.3924	0.3052	0.3052	0.2616	0.3488
ECO1	0.3780	0.2940	0.3360	0.2940	0.2940	0.3360	0.2940	0.2940	0.3360	0.2940
ECO2	0.2860	0.3269	0.2860	0.2860	0.3677	0.2860	0.3269	0.2860	0.3269	0.3677
ECO3	0.3671	0.3263	0.3263	0.3263	0.3671	0.2855	0.3263	0.2855	0.2447	0.2855
SIC1	0.3269	0.2860	0.3269	0.3269	0.3677	0.3269	0.3269	0.2860	0.2452	0.3269
SIC2	0.2584	0.3015	0.3015	0.3446	0.3446	0.3015	0.3877	0.3015	0.3015	0.3015

Table 7. Normalized weight matrix.

Subcriteria	DMU-1	DMU-2	DMU-3	DMU-4	DMU-5	DMU-6	DMU-7	DMU-8	DMU-9	DMU-10
SOC1	0.0261	0.0298	0.0336	0.0336	0.0261	0.0224	0.0298	0.0261	0.0336	0.0261
SOC2	0.0376	0.0430	0.0430	0.0376	0.0430	0.0484	0.0323	0.0430	0.0484	0.0484
SOC3	0.0472	0.0539	0.0539	0.0539	0.0539	0.0472	0.0607	0.0472	0.0472	0.0607
ENV1	0.0257	0.0225	0.0257	0.0257	0.0289	0.0257	0.0257	0.0225	0.0193	0.0257
ENV2	0.0230	0.0268	0.0268	0.0306	0.0306	0.0268	0.0345	0.0268	0.0268	0.0268
ENV3	0.0197	0.0221	0.0197	0.0172	0.0221	0.0172	0.0172	0.0172	0.0172	0.0197
ENV4	0.0367	0.0286	0.0327	0.0286	0.0286	0.0327	0.0286	0.0286	0.0327	0.0286
TEC1	0.0312	0.0357	0.0312	0.0312	0.0401	0.0312	0.0357	0.0312	0.0357	0.0401
TEC2	0.0395	0.0351	0.0351	0.0351	0.0395	0.0307	0.0351	0.0307	0.0263	0.0307
TEC3	0.0197	0.0197	0.0197	0.0225	0.0169	0.0254	0.0197	0.0197	0.0169	0.0225
ECO1	0.0150	0.0116	0.0133	0.0116	0.0116	0.0133	0.0116	0.0116	0.0133	0.0116
ECO2	0.0065	0.0074	0.0065	0.0065	0.0083	0.0065	0.0074	0.0065	0.0074	0.0083
ECO3	0.0381	0.0338	0.0338	0.0338	0.0381	0.0296	0.0338	0.0296	0.0254	0.0296
SIC1	0.0116	0.0101	0.0116	0.0116	0.0130	0.0116	0.0116	0.0101	0.0087	0.0116
SIC2	0.0365	0.0426	0.0426	0.0486	0.0486	0.0426	0.0547	0.0426	0.0426	0.0426

5. Results and Discussion

Owing to its the geographical position, climate and agricultural activities are present in Vietnam; thus, there is a plentiful and quite diverse potential of renewable energy sources, which can be exploited and used as hydrogen power and biomass, wind, solar, geothermal, biofuel, and other new energy sources. In the context of a growing shortage in the domestic energy supply and demand and unpredictable developments, there will certainly be a major impact on supply and demand, along with the prices of traditional energy sources. Thus, exploiting and using renewable energy sources in a considerable and appropriate quantity are urgent requirements.

In this study, the author proposed a fuzzy MCDM model using hybrid FAHP and TOPSIS for site selection of hydrogen power plant projects in Vietnam. Ten potential locations were considered and judged based on five main criteria and 15 subcriteria. All criteria affecting location selection were determined by experts and literature reviews, and the weight of all criteria were defined by FAHP. The TOPSIS was used for ranking potential locations in the final stage. Results are shown in Figures 6 and 7; further, the decision-making unit DMU010 (DMU010) was found to be an optimal solution for building hydrogen power plants in Vietnam.

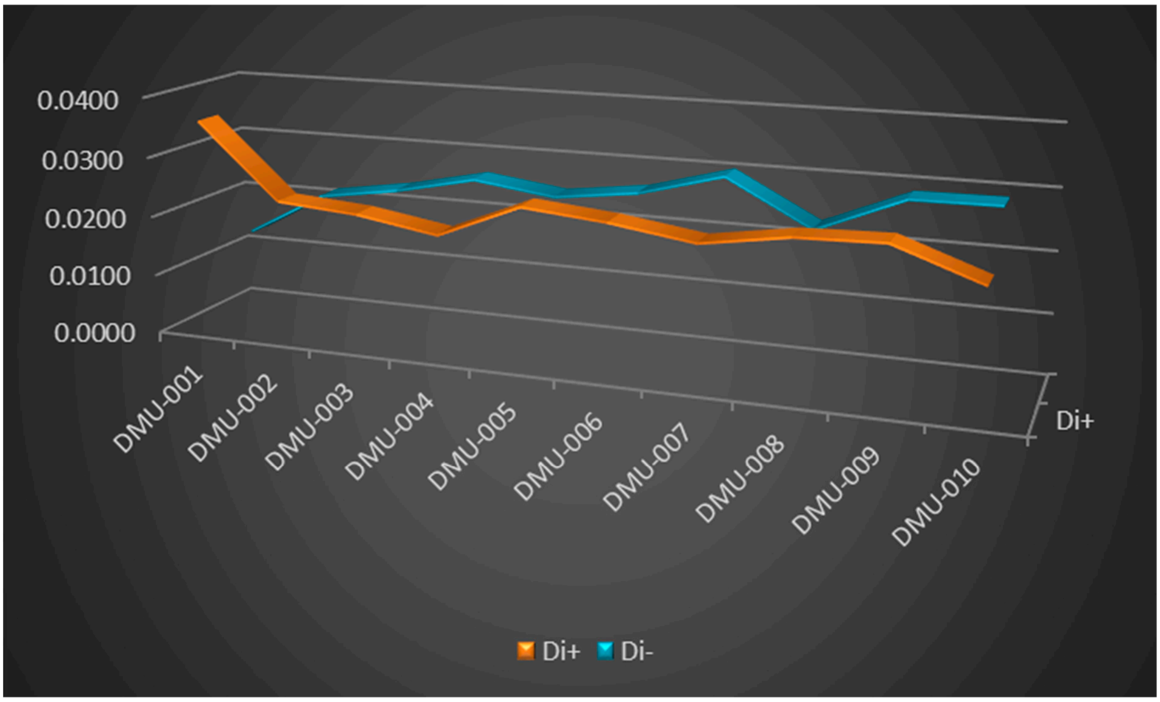

Figure 6. Negative ideal solution (NIS) and positive ideal solution (PIS) value.

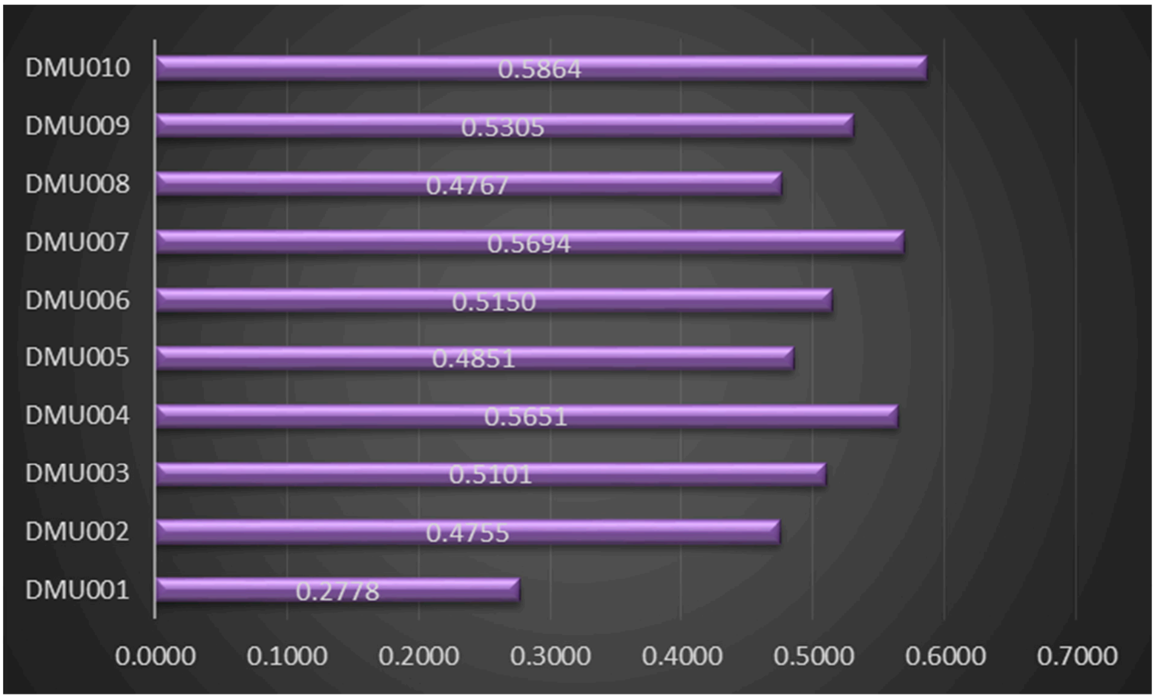

Figure 7. Final ranking score.

6. Conclusions

Energy plays an important role in human life. Industrialization processes have increased the energy demand. Fossil fuels are the main sources of energy for the global economy. However, this fuel is limited and causes environmental problems and climate change; thus, people have found new sources of alternative energy called “renewable energy”. Further, this energy source is continuously supplemented by natural processes, including wind power, solar energy, biofuels, hydrogen power, wave energy, and tidal energy, which can be exploited at any time to meet the development needs of the world.

The advantages of Vietnam's natural and climate conditions, such as its coastline of more than 3000 km, rivers and lakes, and tidal energy sources, hydrogen energy, abundant wave energy, and wind energy, have created abundant raw materials for the development of renewable energy. Therefore, the study and access to technologies to maximize and efficiently utilize these energy sources are important tasks for the country toward building sustainable and environmentally friendly energy in the future. Hydrogen is one of the most important energy sources that will increasingly contribute to the world's energy output. Vietnam is an ideal country for investment and expansion of hydrogen power production capacity, thanks to its highly skilled labor force and future development of the energy sector. Site selection is an important issue in renewable energy projects in that a decision-maker must consider qualitative and quantitative factors. Choosing the right location is among the key success factors of renewable energy projects in general and hydrogen power plant projects in particular. Site selection is an MCDM process in which decision-makers have to evaluate qualitative and quantitative factors. Although some studies have applied MCDM approaches for location selection in renewable energy projects, few studies, to the best of our knowledge, have used the MCDM model for hydrogen power plant location selection in fuzzy environment conditions. This is a reason why we proposed an FMCDM model for hydrogen power plant location selection in Vietnam. As a result, decision-making unit DMU010 (DMU010) has become an optimal solution for building hydrogen power plants in Vietnam.

The contribution of this work is to propose an MCDM model for hydrogen power plants site selection in Vietnam under fuzzy environment conditions. The advantages of this proposed model also reside in the evolution of a new approach that is flexible and practical to the decision-maker. This research also provides a useful tool for other types of renewable energies in Vietnam and other countries.

For future study, this FMCDM model can also be used for location selection for other types of renewable energy resources. In addition, different approaches, such as FANP, PROMETHEE, etc., could also be combined for different scenarios.

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