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Analysis of Strategic Directions in Sustainable Hydrogen Investment Decisions

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Abstract: This study seeks to find the appropriate strategies necessary to make sustainable and effective hydrogen energy investments. Within this scope, nine different criteria are defined regarding social, managerial, and financial factors. A hesitant, interval-valued, intuitionistic fuzzy (IVIF) decision-making trial and evaluation laboratory (DEMATEL) methodology is considered to calculate the degree of importance of the criteria. Additionally, impact relation maps are also generated to visualize the causality relationship between the factors. The findings indicate that the technical dimension has the greatest importance in comparison to managerial and financial factors. Furthermore, it is also concluded that storage and logistics, research and development, and technological infrastructure are the most significant factors to be considered when defining hydrogen energy investment strategies. Hence, before investing in hydrogen energy, necessary actions should be taken to minimize the storage and logistic costs. Among them, building the production site close to the usage area will contribute significantly to this purpose. In this way, possible losses during the transportation of hydrogen can be minimized. Moreover, it is essential to identify the lowest-cost hydrogen storage method by carrying out the necessary research and development activities, thereby increasing the sustainability and effectiveness of hydrogen energy investment projects.

Keywords: sustainability; energy production; hydrogen energy; hesitant IVIF DEMATEL

1. Introduction

Energy means the power consumed while moving or working; therefore, energy is important in determining the efficiency of a job, and it is needed in all areas of life. Energy is provided in different ways and from various sources [1], and the resources used to obtain energy are divided into two kinds: renewable and non-renewable energy alternatives. Non-renewable energy sources represent sources which cannot be replenished, such as oil, natural gas, and coal [2]. These resources cause an increase in carbon emissions, which leads to a rise in environmental problems and, as a result, these energy sources are criticized by many different parties. Additionally, these resources are not found all over the world, and they are distributed unequally. This key issue paves the way for competition to dominate energy sources.

On the other hand, renewable energy sources are constantly present and renewable in nature and do not harm the environment. At the same time, they reduce foreign dependency, since every country can access renewable energy on its own [3]. Therefore, investments in renewable energy sources are crucially important. However, there are many factors that affect renewable energy investments, such as technical, economic, and social factors. In addition, there are many difficulties in renewable energy investment, including the high cost of the installation of power plants, state restrictions on this issue, and the inadequacy of the technological infrastructure used in the production of renewable energy sources, all of which cause the demand for renewable energies to decrease and create a risk for investors. Therefore, it is necessary to focus on these factors to make renewable energy investment more efficient [4]. However, around the world electricity is mainly produced by using non-renewable energy resources. In other words, only 25.6% of electricity is generated with the help of renewable energies. Moreover, this amount was 36.40% for Europe, 32.12% for America, 22.36% for Asia, and 17.78% for Africa in 2018. On the other hand, the percentage of renewable energy has been increasing, especially over the last ten years [5].

Hydrogen can be accepted as a type of renewable energy source; it is a clean, odorless, and colorless natural element. The separation of hydrogen (in the clean state) from its molecules creates hydrogen energy [6], and the use of hydrogen is important for the sustainable growth of a country. In addition, it also considers social and environmental issues, particularly [7] since the use of fossil resources and their carbon emissions harm the environment. Additionally, these resources often lead to a dependency on other countries due to a lack of reserves. Hence, to achieve sustainable growth, an energy source that does not harm the environment and reduces the dependency on foreign economies is needed. At this point, hydrogen can be a very efficient source, since it does no harm to the environment and can be carried to any area [8]. In a world where energy demand is rising and continuous energy sources are needed, hydrogen energy can meet increasing energy needs and play an important role in the development of countries. In this regard, the use of hydrogen should be encouraged [9].

However, there are many factors to consider in hydrogen investments. Firstly, managerial factors need to be considered, since several problems with managerial factors affect the use of hydrogen. In this regard, markets related to hydrogen energy should be effectively monitored, leading to new development opportunities and the identification of the appropriate expectations of customers [10]. In addition, effective coordination between top managers and employees should be achieved in companies to generate innovative ideas [11]. Moreover, incentives to employees also play a significant role, particularly since financial and administrative incentives, such as premiums and promotions, can encourage employees to improve their work performance [12]. These factors may also make a significant contribution to the generation of innovative strategies in hydrogen energy investments.

Additionally, technical factors are also important in hydrogen investments. In this context, the storage and transportation of hydrogen energy plays a significant role [13], since hydrogen occupies much more volume than other types of energy such as oil [14]. Moreover, the security of this process should also be ensured during the transportation of hydrogen, given the risk of explosion and external threats [15]. Furthermore, because hydrogen energy investments require significant engineering knowledge, the technological infrastructure of both the company and the region must be of the highest quality for the success of hydrogen investments [16,17]. It is obvious that companies should focus on necessary research and development activities and, within this context, the necessary financial resources should be provided by the companies and qualified personnel should be employed [18]. These issues contribute to the success of hydrogen energy investment projects.

Besides these issues, financial factors should be also taken into consideration. Hydrogen energy investments have differing costs, such as the initial and the variable costs encountered in the process [19]. These costs should be managed effectively for the sustainable performance of hydrogen energy projects [20]. In addition, the potential sales volume of the projects should be estimated, as this factor is very significant when making investment decisions. In fact, if the expected sales volume is not predicted to be high, the investment decisions of these projects cannot be appropriately considered [21]. Moreover, a comprehensive feasibility analysis should be conducted to identify the potential cash flow of the investment project and its profitability [22]. Hence, innovative strategies can be more appropriately generated for hydrogen energy investments.

In this paper, we aimed to determine which factor is important for sustainable hydrogen investment decisions. At this point, nine criteria were determined based on literature reviews. In the analysis process of the study, the decision-making trial and evaluation laboratory (DEMATEL) method was used to determine which criteria are more influential while generating strategies for hydrogen investment projects. Most importantly, this methodology can create impact relation maps between the items [23], allowing a causality analysis of the factors to be performed. In addition, hesitant intuitionistic fuzzy (IVIF) numbers are also considered, since uncertainty can be minimized when expert teams are unable to reach a consensus [24].

The main novelty of this study is that appropriate strategies for sustainable hydrogen energy production can be presented, and the results pave the way for both investors and policy makers to increase investments in this area. Hence, it will be possible to contribute to energy production that does not harm the environment. Moreover, higher quality and inexhaustible energy can be generated and, as a result, necessary suggestions can be identified to contribute to sustainable energy production. Another originality of the study is related to the method used in the analysis process. For the first time, the hesitant IVIF DEMATEL approach is considered in this study for hydrogen energy, thereby increasing the methodological originality. In this way, it will be possible to take advantage of both the DEMATEL method and the hesitant fuzzy numbers.

This study consists of five chapters. In the second part of the study, a literature review will be conducted and similar studies in the literature will be explained. In addition, in the third part of the study information will be given on hesitant IVIF DEMATEL, which is taken into consideration during the analysis process. In the fourth part of the study, an analysis will be performed on the subject. In the last part of the study, the results obtained will be discussed and suggestions will be given.

2. Literature Review

Hydrogen is a clean energy source that is constantly present in nature, which is important in reducing carbon dioxide emissions and meeting increasing energy demands. Therefore, the use of hydrogen energy needs to be taken into consideration. In the literature, the subject of hydrogen energy has been handled by many researchers. In this section, firstly, the literature on hydrogen energy investment is evaluated. After that, various studies regarding the methodology are also reviewed. In the final part, the results of the literature review are discussed.

2.1. Literature on Hydrogen Energy Investment

The renewable energy resources have become a significant subject of interest in recent literature. Within this framework, hydrogen energy is recognized as being capable of creating an economy where hydrogen holds a central role in the energy sector and will provide many benefits for countries on a global scale. Hydrogen energy is much higher in quality than oil and natural gas and [25] is an environmentally friendly energy source, since only water vapor is released into the atmosphere because of hydrogen production [26]. According to multiple studies, countries should give greater importance to the production of hydrogen to provide sustainable energy production [27]. Clearly, it will be beneficial for countries to minimize factors hindering hydrogen investment.

Specifically, a significant number of researchers have stated that managerial factors can be effective in investment strategies for hydrogen energy. In this context, it has been justifiably argued that market developments regarding hydrogen investments should be effectively followed [10]. Nastasi [28], Para et al. [29], and Apak et al. [16] have stated that determining current developments in the market and implementing innovative investment projects can contribute to maintaining positive growth within the sector Another important issue in this process is to determine the expectations of the customers [30,31]. If all these factors were considered, in addition to an increase in the level of awareness of top management regarding current developments in hydrogen energy, greater development and innovative strategies for these investment projects would move the industry forward.

In addition, being open to different ideas within the company is another managerial factor that may be effective in producing an effective strategy for hydrogen energy investment. In this process, it is important to have high coordination between senior management and company employees, making it possible to reach effective investment ideas [11]. This will contribute to the development of innovative investment strategies for hydrogen projects [32,33]. Moreover, the existence of incentives within the company is another important management issue. In an environment where successful employees are rewarded with financial incentives, such as premium payments, it is obvious that employees can contribute to the company's performance [34]. Furthermore, people with high performance can be rewarded with administrative incentives like promotions [35], which would increase the motivation of the employees and contribute to the company's development of innovative strategies for hydrogen investment.

In many studies in the literature, technical factors may also be effective in hydrogen energy investment decisions. In this context, storage and logistics are the leading factors. One of the most important problems in using hydrogen is the high storage cost [13]; due to the difficult storage of hydrogen, the tanks are large in volume, which increases the cost of storage [14]. In addition, how to transfer the stored hydrogen energy to places for it to be used is another important issue in this process. Jones et al. [15] identified that it is important for the success of the project that companies try to reduce their costs while making an investment decision regarding hydrogen energy. Moreover, Cao et al. [36] and Nakayama et al. [37] determined that necessary security measures must be taken during the transportation of hydrogen energy with the help of simulation techniques. In this context, there is a risk of explosion if the necessary measures are not taken in the process of transporting the gas. Therefore, this risk should be minimized by taking the necessary precautions. Furthermore, necessary measures should also be taken for external threats that may occur during the transportation of hydrogen [38,39]; otherwise, it will not be possible to provide sustainability in hydrogen energy investments.

Some researchers have also argued that the technological infrastructure must be of high quality for the success of hydrogen investments; it is essential both for the company and for the region to be invested in [16]. Since hydrogen energy investments contain significant engineering knowledge [17], Garcia [40], Welder et al. [41], and Walker et al. [42] have claimed that it does not seem possible for companies with insufficient infrastructure to be very successful in their investments in this energy project. In addition, the technological infrastructure of the region where hydrogen energy investments will be made is important for the supply and use of hydrogen energy and should be considered when considering investment decisions. On the other hand, Bhogilla et al. [43], San Marchi et al. [44], and Arat et al. [45] have emphasized that for this infrastructure to exist, companies must continue their necessary research and development activities. Specific to this study, different methodologies were considered, such as optimization and survey.

Financial factors are also effective in hydrogen energy investment strategies, especially in calculating the cost of the project [46]. In the production of hydrogen energy, there are both initial costs and variable costs [47]. Hydrogen must be separated from a compound by a certain operation, thereby increasing the cost of providing hydrogen [48,49]. In fact, Amrouche et al. [50] and Le Duigou et al. [51] identified that the high cost of storage and transportation is one of the most important disadvantages in this process. As a result, Reddi et al. [52] underlined the importance of this issue, building on the need for simulation techniques. Therefore, when determining investment strategies for hydrogen energy these different costs need to be analyzed effectively, and if these costs cannot be managed effectively it will be very difficult for the project to be successful.

In addition to the issues mentioned, a high volume of sales of these energy projects is also integral in making profit from these investments [21]. Therefore, companies planning to invest in hydrogen energy need to make estimates to determine the potential sales volume. In this context, it would be more accurate to make an investment decision if the expected sales volume is estimated to be high. Furthermore, a comprehensive feasibility analysis should be conducted to understand the potential cash flows of this investment project [22] to better understand whether this project is profitable [53,54].

2.2. Literature on Methodology

The DEMATEL method is used to identify the most important of the different factors that affect an issue. It is considered to be superior to other similar methods, such as the analytic hierarchy process (AHP) and the analytic network process (ANP), due to the fact that it reveals the effect relationship network between the variables and performs a causality analysis of the factors [55]. In a significant portion of the studies in which the DEMATEL approach was used, selecting the best supplier was attempted. In these studies, the criteria were selected first and the most important issues were calculated with the DEMATEL method [56,57]. In addition to the issues mentioned, some researchers also preferred this method to define the factors that influence service innovation [58,59]. Moreover, the DEMATEL method has been used in some studies to increase the efficiency of energy production [60,61]. Additionally, it has been determined that some studies prefer DEMATEL together with IVIF numbers [60,61].

2.3. Literature Review Results

According to the results of the literature review, many factors are considered in hydrogen and renewable energy investment decisions. Generally, it has been seen that factors such as storage system, energy demand, cost, and technology determine the use of hydrogen energy. However, it has also been determined that renewable energy investment decisions are influenced by factors such as legal regulations, technology, incentives, capital, and country management structures. In some of the relevant studies, one country was examined, while in others country groups were included. In these studies, it was observed that technology was important in the decisions of hydrogen and renewable energy investment. Therefore, it is thought that focusing on the influencing factors of hydrogen investment can contribute to the literature. In this study, we aimed to show the significant criteria that affect hydrogen investment decisions, and it is thought that this analysis will reduce the deficiency in the literature. As a result, with respect to the factors that affect hydrogen energy investment strategies, nine different criteria are identified for three dimensions: managerial, technical, and financial. The details of these factors are demonstrated in Table 1.

Table 1. Dimensions and criteria for hydrogen investment strategies.

Dimensions	Criteria	Definitions	References
Managerial (dimension 1)	Awareness (criterion 1)	It includes the monitoring of the market in regard to hydrogen investment. Hence, it is aimed at identifying innovative strategies. Additionally, customer expectations can be defined more effectively with the help of this situation.	[10,16,28–31]
	Acceptance (criterion 2)	It explains brainstorming within the organization. It aims to generate appropriate policies for hydrogen investment. For this purpose, it is necessary to provide effective coordination between top managers and employees.	[11,32,33]
	Incentives (criterion 3)	This criterion includes rewarding employees financially and morally. In this context, those who offer an effective strategy can be given a financial incentive award. On the other hand, people with high performance can be rewarded with administrative incentives such as promotion. This stated situation will contribute to the determination of more effective strategies for hydrogen investment within the company.	[34,35]

Table 1. *Cont.*

Dimensions	Criteria	Definitions	References
Technical (dimension 2)	Storage and logistics (criterion 4)	This criterion includes the necessary points for the efficient storage of the hydrogen energy produced. In addition to this issue, it also deals with the efficient transport of this obtained hydrogen energy to the relevant locations. Another important point in this process is security. Both the fact that the hydrogen gas transported does not harm the environment and the protection of this system against external threats are evaluated within this scope.	[13–15,36–39]
	Technological infrastructure (criterion 5)	This criterion includes the quality of the technological infrastructure of both the company and the region. In this framework, it is primarily examined how technologically sufficiently the company invests in hydrogen energy. Similarly, the technological infrastructure of the region where the investment is made has an important role in the effectiveness of these energy investments.	[16,17,40–42]
	Research and development (criterion 6)	This criterion covers the research and development activities necessary for the efficient execution of complex hydrogen energy investment projects. In this context, issues such as whether the companies allocate sufficient resources for this purpose and the potential of existing personnel are evaluated.	[43–45]
Financial (dimension 3)	Costs (criterion 7)	In this framework, different cost types of hydrogen energy investments are analyzed with a primary consideration as to how the initial setup costs can be reduced. In addition, the variable costs to be encountered in the project process are also evaluated in this process.	[46–52]
	Profit (criterion 8)	It considers the possible sales volume of the hydrogen energy to be obtained. In this way, estimates can be made for the income generated. Furthermore, by examining the rate of increase in sales, it will be possible to make an analysis of the potential profit that can be obtained.	[21,22]
	Return on investment (criterion 9)	This criterion deals with the comprehensive feasibility of the hydrogen energy project. In this framework, the possible cash flow of the project is examined and, thanks to this analysis, it will be possible to determine the profitability of the project in question.	[53,54]

3. Methodology

In this section, information regarding the methodology is presented. For this purpose, firstly 2-tuple linguistic information and hesitant IVIF sets are explained. After that, the DEMATEL methodology is explained.

3.1. 2-Tuple Linguistic Values and Hesitant IVIF Sets

The linguistic terms are named $S = \{s_0, \ldots, s_g\}$, and $S = S \times [-0.5, 0.5)$ gives information about 2-tuple sets. In addition, the linguistic model can be demonstrated as the function of Δ and Δ^{-1}. Details are given in Equations (1) and (2). In these equations, Δ states a bijective function whereas β indicates the term of the round. On the other side, i explains the integer number [62].

$$\Delta(\beta) = (S_i, \alpha), \text{ with } \begin{cases} i = round(\beta) \\ \alpha = \beta - i \end{cases}, \tag{1}$$

$$\Delta^{-1} : S \to [0, g] \text{ and } \Delta^{-1}(S_i, \alpha) = i + \alpha. \tag{2}$$

In addition, the membership function (S) and context-free grammar (G) are defined as in Equations (3) and (4).

$$S = \{S_0, S_1, \ldots, S_t\}, \tag{3}$$

$$G_H = (V_N, V_T, I, P), \tag{4}$$

where

$V_N = \{primary\ term, composite\ term, unary\ term, binary\ term, conjunction\};$
$V_T = \{lower\ than,\ greater\ than,\ at\ least,\ at\ most,\ between,\ and,\ S_0, S_1, \ldots, S_t\};$
$I \in V_N;$
$P = \{I\ ::= primary\ term \big| composite\ term, composite\ term; ::= composite\ term primary\ term;$
$\big| binary\ relation primary\ term conjunction primary\ term;$
$primary\ term ::= S_0 | S_1 | \ldots | S_t;$
$unary\ relation ::= lower\ than \big| greater\ than\ | at\ least\ | at\ most;$
$binary\ relation ::= between;$
$conjunction ::= and\}.$

Moreover, the hesitant linguistic fuzzy sets (h_s) and the intuitionistic fuzzy set (I) are identified in Equations (5) and (6).

$$h_S = \left\{S_i, S_{i+1}, \ldots, S_j\right\}, \tag{5}$$

$$I = \{\vartheta, \mu_I(\vartheta), n_I(\vartheta) / \vartheta \in U\}. \tag{6}$$

In addition to them, Equations (7) and (8) indicate the intuitionistic hesitant fuzzy set (H).

$$H = \{\vartheta, h_1(\vartheta), h_2(\vartheta), \vartheta \in U\}, \tag{7}$$

$$\forall \mu \in h_1(\vartheta),\ n \in h_2(\vartheta). \tag{8}$$

Finally, the interval-valued intuitionistic hesitant fuzzy set ($\widetilde{H}$) can be defined as in Equation (9). In this equation, $h_{\widetilde{H}}(\vartheta)$ represents an interval-valued intuitionistic hesitant fuzzy number.

$$\widetilde{H} = \left\{\vartheta, h_{\widetilde{H}}(\vartheta), \vartheta \in U\right\}. \tag{9}$$

3.2. DEMATEL

The DEMATEL methodology aims to define the significance degrees of different factors that affect the same issue. Additionally, a causality analysis of these factors can also be conducted in this approach. In the first step, opinions are obtained from k different experts so that a direct relation matrix can be generated, as in Equation (10). In this framework, the average values of the expert evaluations are considered [58].

$$\mathrm{A_k} = \begin{bmatrix} 0 & \cdots & a_{1nk} \\ \vdots & \ddots & \vdots \\ a_{n1k} & \cdots & 0 \end{bmatrix}. \tag{10}$$

Later, this matrix is normalized with the help of Equation (11). In this equation, b_{ij} gets a value between 0 and 1.

$$\mathrm{B} = \left[b_{ij}\right]_{n\times n} = \frac{\mathrm{A}}{max \sum_{j=1}^{n} a_{ij}}. \tag{11}$$

The next step is related to the generation of the total relation matrix (C), as in Equation (12). In this equation, "I" represents the identity matrix.

$$\mathrm{C} = \left[c_{ij}\right]_{n\times n} = \mathrm{B}(\mathrm{I} - \mathrm{B})^{-1}. \tag{12}$$

Moreover, the values of D and E are calculated with Equations (13) and (14). Within this context, (D + E) is considered to identify the weights of the factors. Furthermore, (D − E) gives information about the causality relationship between the factors. In this context, the average (D − E) value is firstly calculated, and it is compared with the values in the total relation matrix. For the values that are greater than the average value, it is identified that the first criterion influences another one [59].

$$\mathrm{D} = \left[d_{ij}\right]_{n\times 1} = \left[\sum_{j=1}^{n} c_{ij}\right]_{n\times 1}, \tag{13}$$

$$E = \left[e_{ij}\right]_{1\times n} = \left[\sum_{j=1}^{n} c_{ij}\right]_{1\times n}. \quad (14)$$

4. Analysis

In this study, we investigate what should be considered in strategies to be developed for hydrogen energy investment. To reach this goal, nine different criteria were evaluated by three different people who are experts in this field. While making an analysis with fuzzy logic, the qualification of the experts plays an essential role [63,64]. The details of the experts are demonstrated in Table 2.

Table 2. The details of the experts.

Expert Number	Education Status	Experience	Occupation	Areas of Expertise
Expert 1	PhD	23 years	Academician and top manager in hydrogen energy companies	Renewable energies, hydrogen energy, strategy development, cost management
Expert 2	PhD	15 years	Academician and middle level manager in hydrogen energy companies	Renewable energies, hydrogen energy, strategy development, new product development
Expert 3	PhD	27 years	Academician and top manager in hydrogen energy companies	Renewable energies, hydrogen energy, strategy development, cost management, new product development

Table 2 states that the experts have at least 15 years of experience in the field of hydrogen energy. These experts are middle and top managers in the industry and academics who work on hydrogen energy. Therefore, it is understood that the expert team performing the evaluation is quite competent in the strategies to be developed for hydrogen energy investment. In lots of different studies in which fuzzy multi-criteria decision-making methods are considered, three different experts made evaluations [65–68]. This situation is quite similar in most of the studies related to energy investment [69–72]. Hence, it is thought that the evaluations of three experts are quite enough in such an analysis. In other words, in these evaluations, the qualifications of the experts are more significant than the number of people. On the other side, in this study this evaluation has been performed under hesitancy. This stated approach contributes to achieving the most appropriate result when the experts do not agree with each other [73–75]. These experts consider five different linguistic evaluation scales, which are stated in Table 3.

Table 3. Linguistic scales.

Linguistic Scales	Evaluation Numbers
No influence (n)	1
somewhat influence (s)	2
medium influence (m)	3
high influence (h)	4
very high influence (vh)	5

Firstly, context-free grammar evaluations of the decision-makers for different dimensions and criteria are obtained. The details are given in the appendix (Tables A1–A4). In these tables, the dimensions are named D, criteria are represented by C, and DM gives information about the decision-makers. In the next step, boundaries of the linguistic term sets for all factors are generated and stated in Tables A5–A8. Moreover, 2-tuple values of the collective linguistic evaluations are prepared for all the dimensions and criteria, and they are demonstrated in Table 4.

Table 4. 2-tuple values of the collective linguistic evaluations.

For Dimensions						
Dimensions	D1		D2		D3	
	Optimistic	Pessimistic	Optimistic	Pessimistic	Optimistic	Pessimistic
D1			(h,−0.33)	(s,0)	(m,0)	(s,−0.33)
D2	(vh,0)	(h,−0.33)			(vh,−0.33)	(m,0)
D3	(m,0.33)	(s,−0.33)	(m,0)	(n,0.33)		
For Criteria of Dimension 1						
Criteria	C1		C2		C3	
	Optimistic	Pessimistic	Optimistic	Pessimistic	Optimistic	Pessimistic
C1			(h,0.33)	(s,0)	(h,0.33)	(s,−0.33)
C2	(vh,−0.33)	(m,−0.33)			(vh,−0.33)	(m,−0.33)
C3	(h,0.33)	(s,−0.33)	(h,0.33)	(s,−0.33)		
For Criteria of Dimension 2						
Criteria	C4		C5		C6	
	Optimistic	Pessimistic	Optimistic	Pessimistic	Optimistic	Pessimistic
C4			(vh,−0.33)	(m,0)	(vh,0)	(m,0.33)
C5	(h,0)	(s,0)			(h,0)	(s,0)
C6	(h,−0.33)	(s,0)	(m,0.33)	(s,0)		
For Criteria of Dimension 3						
Criteria	C7		C8		C9	
	Optimistic	Pessimistic	Optimistic	Pessimistic	Optimistic	Pessimistic
C7			(vh,−0.33)	(s,0.33)	(h,0.33)	(m,0)
C8	(m,0.33)	(s,0)			(vh,−0.33)	(s,0.33)
C9	(h,0.33)	(m,−0.33)	(h,0.33)	(s,0)		

In addition to them, IVIF sets for the dimensions and criteria are defined in Tables A9–A12. After defining the optimistic and pessimistic values of the linguistic evaluations, the boundaries of the linguistic terms are illustrated for the dimensions and criteria. Belonging and non-belonging degrees for the linguistic evaluations with IVIF sets are generated for constructing a hesitant 2-tuple IVIF relation matrix. In the next process, direct relation matrices are created, as in Equation (10). These are detailed in Table 5.

Table 5. Direct relation matrices.

For Dimensions			
Dimensions	D1	D2	D3
D1	0.00	0.62	0.42
D2	1.17	0.00	0.97
D3	0.55	0.36	0.00
For the Criteria of Dimension 1			
Criteria	C1	C2	C3
C1	0.00	0.68	0.75
C2	0.93	0.00	0.93
C3	0.75	0.65	0.00
For the Criteria of Dimension 2			
Criteria	C4	C5	C6
C4	0.00	0.97	1.13
C5	0.65	0.00	0.65
C6	0.62	0.58	0.00
For the Criteria of Dimension 3			
Criteria	C7	C8	C9
C7	0.00	0.90	0.93
C8	0.58	0.00	0.90
C9	0.90	0.78	0.00

Moreover, these matrices are normalized by considering Equation (11). They are summarized in Table 6.

Table 6. Normalized direct relation matrixes.

For Dimensions			
Dimensions	**D1**	**D2**	**D3**
D1	0.00	0.29	0.20
D2	0.55	0.00	0.45
D3	0.26	0.17	0.00
For the Criteria of Dimension 1			
Criteria	**C1**	**C2**	**C3**
C1	0.00	0.37	0.40
C2	0.50	0.00	0.50
C3	0.40	0.35	0.00
For the Criteria of Dimension 2			
Criteria	**C4**	**C5**	**C6**
C4	0.00	0.46	0.54
C5	0.31	0.00	0.31
C6	0.29	0.28	0.00
For the Criteria of Dimension 3			
Criteria	**C7**	**C8**	**C9**
C7	0.00	0.49	0.51
C8	0.32	0.00	0.49
C9	0.49	0.43	0.00

In addition, total relation matrices are generated by using Equation (12). The details are demonstrated in Tables A13–A16. By considering these values, the weights of the dimensions and criteria can be identified. They are summarized in Table 7.

Table 7. Weights of the criteria and dimensions for hydrogen investment strategies.

Dimensions	Weights	Criteria	Local Weights	Global Weights
Managerial (dimension 1)	0.342	Awareness (criterion 1)	0.332	0.114
		Acceptance (criterion 2)	0.338	0.116
		Incentives (criterion 3)	0.329	0.113
Technical (dimension 2)	0.370	Storage and logistics (criterion 4)	0.356	0.132
		Technological infrastructure (criterion 5)	0.317	0.117
		Research and development (criterion 6)	0.327	0.121
Financial (dimension 3)	0.288	Costs (criterion 7)	0.333	0.096
		Profit (criterion 8)	0.321	0.092
		Return on investment (criterion 9)	0.347	0.100

Table 7 indicates that the technical dimension has the highest weight, while the lowest weight belongs to the financial dimension. Moreover, it is also determined that storage and logistics (criterion 4) are the most significant factors regarding hydrogen investment strategies. Like this situation, research and development (criterion 6) and technological infrastructure (criterion 5) are other essential issues in this framework. On the other side, cost (criterion 7) and profit (criterion 8) have the weakest importance in this regard. After calculating, the weights of the factors and impact relation maps are also generated. In this context, the average (D − E) value is calculated by using Equations (13) and (14). After that, it is compared with the values of the total relation matrix. In this regard, for values that are greater than the average value, the first criterion influencing another was identified. Figure 1 gives information about the causality relationship between the dimensions.

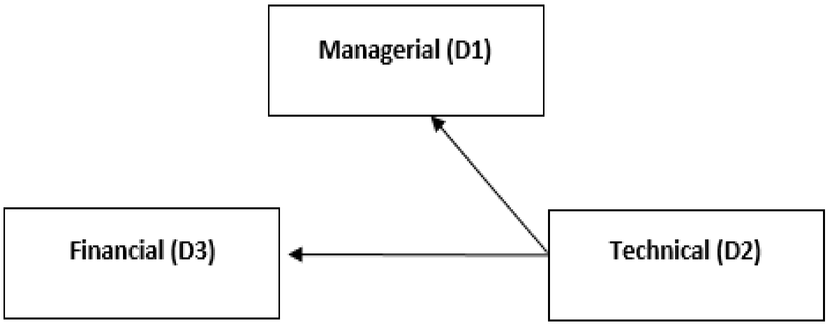

Figure 1. Impact and relation map for the dimensions.

Figure 1 shows that the technical dimension has a powerful impact on both the managerial and financial dimensions. However, it is not influenced by other factors. Parallel to this situation, Figure 2 indicates the impact relation map for the criteria under dimension 1.

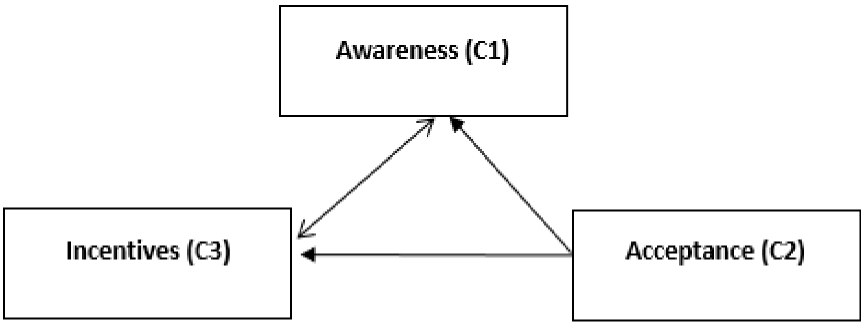

Figure 2. Impact and relation map for the criteria of dimension 1.

Figure 2 states that acceptance is the influencing criterion because it affects all other two factors. On the other side, there is also a mutual relationship between the incentives and awareness. Additionally, the relationship between the criteria of dimension 2 is illustrated in Figure 3.

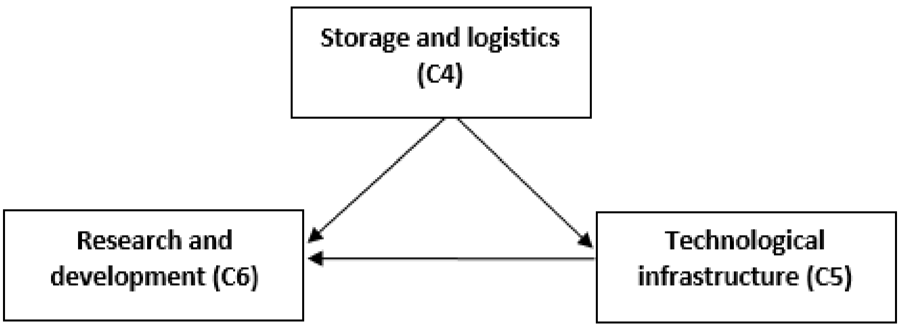

Figure 3. Impact and relation map for the criteria of dimension 2.

In Figure 3, it can be understood that storage and logistics are the influencing criterion, since they affect all other items. In contrast, research and development are the influencing factor because both of the other two criteria have an impact on it. Furthermore, Figure 4 explains the relationship of the factors of dimension 3.

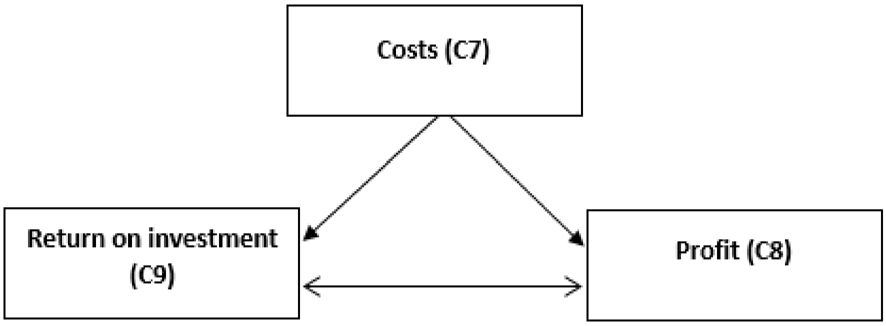

Figure 4. Impact and relation map for the criteria of dimension 3.

Figure 4 gives the information that the criterion of cost affects both the return on investment and the profit. However, this item is not influenced by others. Another important point is that there is a mutual relationship between the return on investment and profit.

5. Discussions and Conclusions

Energy plays a vital role in the social and economic development of countries, as it meets the individual needs of people and is the most important raw material in the industry. On the other hand, the reserves of energy resources such as oil and natural gas are significantly decreasing. This stated situation has caused the search for new energy resources. Hydrogen energy is a type of energy that can be produced both from fossil fuels and renewable energy alternatives. Since it does not emit carbon gas into the atmosphere [25], it does not harm the environment and its content is higher quality than other alternatives, such as oil and natural gas [26]. Thus, hydrogen energy is very important for a sustainable energy supply. On the other hand, there are some disadvantages of hydrogen energy. The most important problem in using hydrogen as fuel is the storage cost. In addition to the mentioned issue, another difficulty in hydrogen energy is that this element is not found in its pure form in natural conditions. In other words, hydrogen must be separated from compounds to be obtained [76,77].

Considering these issues, a detailed analysis is required to develop a strategy for hydrogen energy investments. In this context, it is important to determine a correct strategy by considering many different issues at the same time. In this study, we investigated which issues are more important in investment strategies for hydrogen energy. First, a comprehensive literature review was performed. As a result, nine different criteria have been identified that may have an impact on these strategies. An analysis has been carried out using the hesitant IVIF DEMATEL method to determine which of the relevant criteria are more important. In addition to the issues mentioned, it was also possible to determine the causality relationships between these criteria with the help of the relevant analysis.

It was concluded that the technical dimension has the greatest importance in comparison with the managerial and financial dimensions. Moreover, the most important criterion for a hydrogen energy investment strategy is storage and logistics. In addition, research and development and technological infrastructure also play a significant role when generating these strategies. On the other hand, cost, profit and return on investment have lower weights in comparison with others. These results were supported by various researchers in the literature. Uyar and Beşikci [49] claimed that an effective storage system is the key factor in the effectiveness of hydrogen energy investment. Parallel to this study, Gkanas et al. [78] also added that the lack of energy storage reduces the success of hydrogen energy investment projects. Some other researchers have also stated that logistics is the key issue for the effectiveness of these investments. In particular, Maghami et al. [79] reached the conclusion that the power of the logistic system has an important contribution to the success of the hydrogen energy investment project.

Furthermore, impact-relations maps have also been created to find causality relationships between the factors. The technical dimension has a powerful impact on both the managerial and financial dimensions, meaning that if the company has necessary technical power, it affects the managerial and financial situations. Similarly, it is also obvious that managerial factors such as awareness can also be improved. Nagasawa et al. [80] evaluated the sustainability of hydrogen energy investments and concluded that technical developments have the highest importance in this regard. Valente et al. [81] also supported this situation by considering 71 hydrogen energy case studies. Additionally, the technological infrastructure, storage, and logistics have an influence on research and development. Moreover, cost affects both the return on investment and profit criteria.

Considering the findings, for the success of hydrogen energy investments, both the storage and logistics costs should be reduced. In this context, the fact that the production area is close to the point of use will also contribute to the reduction in costs. The main reason for this is that, due to its nature, the storage and transportation of hydrogen is very difficult compared to that of fossil fuels. Additionally, hydrogen can be stored in underground caves, cars, and vehicle tanks. On the other hand, hydrogen can be stored in the form of compressed gas, liquid, or a metal hybrid. In this framework, it is important to determine the lowest cost storage method of hydrogen by carrying out the necessary research and development activities. In addition, hydrogen can be transported in underground pipelines in hydrogen gas or liquid form, or it can be transported by tankers or ships. Therefore, a detailed analysis to determine the most effective method will contribute to a reduction in costs and a more successful investment.

The biggest limitation of this study is the focus only on hydrogen energy. In fact, other types of renewable energy, such as wind, solar, and hydroelectricity, are at least as important as hydrogen energy. Therefore, in a future study, it will be beneficial to make a comparative analysis of all renewable energy types. In addition, this study focused only on hydrogen energy investment strategies. Moreover, more specific studies can be conducted regarding the efficiency of hydrogen energy. For instance, how storage costs can be reduced for hydrogen energy should be examined. In the analysis process of the study, DEMATEL, one of the multi-criteria decision-making methods, was taken into consideration. On the other hand, calculations were made with IVIF numbers. In a new study, a comparative analysis should be made with trapezoidal or Gaussian fuzzy numbers, which might be preferred to methods such as AHP and ANP in calculating the weights of the criteria.

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Appendix A

Table A1. Context-free grammar evaluations of the decision-makers for dimensions.

Dimensions	D1			D2			D3		
	DM1	DM2	DM3	DM1	DM2	DM3	DM1	DM2	DM3
D1				between "s" and "h"	at most "m"	between "m" and "h"	between "s" and "m"	at most "m"	between "s" and "m"
D2	at least "h"	at least "m"	at least "h"				greater than "m"	at least "h"	at most "h"
D3	at most "m"	between "s" and "m"	between "s" and "h"	between "s" and "m"	between "s" and "h"	at most "m"			

Table A2. Context-free grammar evaluations of the decision-makers for the criteria of dimension 1.

Criteria	C1			C2			C3		
	DM1	DM2	DM3	DM1	DM2	DM3	DM1	DM2	DM3
C1				at most "m"	between "s" and "vh"	at least "m"	between "s" and "vh"	at most "m"	between "s" and "vh"
C2	greater than "m"	at most "h"	at least "m"				at least "h"	at least "m"	at most "h"
C3	at least "m"	at most "h"	at most "h"	between "s" and "vh"	at most "m"	between "s" and "vh"			

Table A3. Context-free grammar evaluations of the decision-makers for the criteria of dimension 2.

Criteria	C4			C5			C6		
	DM1	DM2	DM3	DM1	DM2	DM3	DM1	DM2	DM3
C4				at least "h"	at least "h"	at most "h"	between "m" and "vh"	at least "m"	between "h" and "vh"
C5	at least "m"	between "s" and "h"	at most "m"				between "s" and "h"	at least "m"	at most "m"
C6	greater than "s"	between "s" and "m"	at most "m"	between "m" and "h"	at most "m"	between "s" and "m"			

Table A4. Context-free grammar evaluations of the decision-makers for the criteria of dimension 3.

Criteria	C7			C8			C9		
	DM1	DM2	DM3	DM1	DM2	DM3	DM1	DM2	DM3
C7				at least "h"	at least "s"	at most "h"	between "m" and "vh"	between "m" and "h"	between "m" and "h"
C8	between "h" and "vh"	at most "m"	lower than "m"				at most "h"	between "m" and "vh"	at least "m"
C9	between "m" and "vh"	at most "m"	greater than "m"	between "s" and "h"	at least "m"	at least "m"			

Table A5. Boundaries of the linguistic term sets for the dimensions.

Dimensions	D1			D2			D3		
	DM1	DM2	DM3	DM1	DM2	DM3	DM1	DM2	DM3
D1				[s, h]	[n, m]	[m, h]	[s, m]	[n, m]	[s, m]
D2	[h, vh]	[m, vh]	[h, vh]				[h, vh]	[h, vh]	[n, h]
D3	[n, m]	[s, m]	[s, h]	[s, m]	[n, m]	[n, m]			

Table A6. Boundaries of the linguistic term sets for the criteria of dimension 1.

Criteria	C1			C2			C3		
	DM1	DM2	DM3	DM1	DM2	DM3	DM1	DM2	DM3
C1				[n, m]	[s, vh]	[m, vh]	[s, vh]	[n, m]	[s, vh]
C2	[h, vh]	[n, h]	[m, vh]				[h, vh]	[m, vh]	[n, h]
C3	[m, vh]	[n, h]	[n, h]	[s, vh]	[n, m]	[s, vh]			

Table A7. Boundaries of the linguistic term sets for the criteria of dimension 2.

Criteria	C4			C5			C6		
	DM1	DM2	DM3	DM1	DM2	DM3	DM1	DM2	DM3
C4				[h, vh]	[h, vh]	[n, h]	[m, vh]	[m, vh]	[h, vh]
C5	[m, vh]	[s, h]	[n, m]				[s, vh]	[m, vh]	[n, m]
C6	[m, vh]	[s, m]	[n, m]	[m, h]	[n, m]	[s, m]			

Table A8. Boundaries of the linguistic term sets for the criteria of dimension 3.

Criteria	C7			C8			C9		
	DM1	DM2	DM3	DM1	DM2	DM3	DM1	DM2	DM3
C7				[h, vh]	[s, vh]	[n, h]	[m, vh]	[m, h]	[m, h]
C8	[h, vh]	[n, m]	[n, s]				[n, h]	[m, vh]	[m, vh]
C9	[m, vh]	[n, m]	[h, vh]	[s, h]	[n, h]	[m, vh]			

Table A9. Interval-valued intuitionistic fuzzy sets for the dimensions.

Dimensions	D1	D2	D3
D1		((0.40,0.53), (0.10,0.20))	((0.20,0.40), (0.10,0.13))
D2	((0.60,0.80), (0.40,0.53))		((0.60,0.73), (0.20,0.40))
D3	((0.40,0.47), (0.10,0.13))	((0.20,0.40), (0.05,0.07))	

Table A10. Interval-valued intuitionistic fuzzy sets for the criteria of dimension 1.

Criteria	C1	C2	C3
C1		((0.40,0.67), (0.10,0.20))	((0.60,0.67), (0.10,0.13))
C2	((0.60,0.73), (0.20,0.33))		((0.60,0.73), (0.20,0.33))
C3	((0.60,0.67), (0.10,0.13))	((0.40,0.67), (0.10,0.13))	

Table A11. Interval-valued intuitionistic fuzzy sets for the criteria of dimension 2.

Criteria	C4	C5	C6
C4		((0.60,0.73), (0.20,0.40))	((0.60,0.80), (0.40,0.47))
C5	((0.40,0.60), (0.10,0.20))		((0.40,0.60), (0.10,0.20))
C6	((0.40,0.53), (0.10,0.20))	((0.40,0.47), (0.10,0.20))	

Table A12. Interval-valued intuitionistic fuzzy sets for the criteria of dimension 3.

Criteria	C7	C8	C9
C7		((0.60,0.73), (0.20,0.27))	((0.60,0.67), (0.20,0.40))
C8	((0.40,0.47), (0.10,0.20))		((0.60,0.73), (0.20,0.27))
C9	((0.60,0.67), (0.20,0.33))	((0.60,0.67), (0.10,0.20))	

Table A13. Total relation matrix and values of D and E for the dimensions.

Dimensions	D1	D2	D3	D	E	D + E	D − E	Weights
D1	0.39	0.48	0.49	1.37	1.92	3.29	−0.55	0.342
D2	1.00	0.43	0.84	2.27	1.28	3.56	0.99	0.370
D3	0.53	0.37	0.27	1.16	1.60	2.76	−0.44	0.288

Table A14. Total relation matrix and weights for the criteria of dimension 1.

Criteria	C1	C2	C3	D	E	D + E	D − E	Weights
C1	1.44	1.50	1.73	4.67	5.22	9.89	−0.55	0.332
C2	2.07	1.48	2.07	5.63	4.44	10.07	1.19	0.338
C3	1.70	1.47	1.42	4.59	5.22	9.81	−0.63	0.329

Table A15. Total relation matrix and weights for the criteria of dimension 2.

Criteria	C4	C5	C6	D	E	D + E	D − E	Weights
C4	0.74	1.16	1.30	3.20	2.23	5.43	0.98	0.356
C5	0.76	0.60	0.91	2.27	2.55	4.83	−0.28	0.317
C6	0.72	0.79	0.63	2.14	2.84	4.99	−0.70	0.327

Table A16. Total relation matrix and weights for the criteria of dimension 3.

Criteria	C7	C8	C9	D	E	D + E	D − E	Weights
C7	3.02	3.60	3.81	10.44	9.05	19.49	1.39	0.333
C8	2.84	2.81	3.32	8.98	9.82	18.80	−0.84	0.321
C9	3.19	3.40	3.29	9.88	10.43	20.31	−0.55	0.347

References

1. Destek, M.A.; Aslan, A. Renewable and non-renewable energy consumption and economic growth in emerging economies: Evidence from bootstrap panel causality. *Renew. Energy* **2017**, *111*, 757–763. [CrossRef]
2. Destek, M.A.; Sinha, A. Renewable, non-renewable energy consumption, economic growth, trade openness and ecological footprint: Evidence from organisation for economic Co-operation and development countries. *J. Clean. Prod.* **2020**, *242*, 118537. [CrossRef]
3. Kath, C.; Nitka, W.; Serafin, T.; Weron, T.; Zaleski, P.; Weron, R. Balancing Generation from Renewable Energy Sources: Profitability of an Energy Trader. *Energies* **2020**, *13*, 205. [CrossRef]
4. Saganeiti, L.; Pilogallo, A.; Faruolo, G.; Scorza, F.; Murgante, B. Territorial Fragmentation and Renewable Energy Source Plants: Which Relationship? *Sustainability* **2020**, *12*, 1828. [CrossRef]
5. Enerdata Global Energy Statistical Yearbook (2019). Available online: https://www.enerdata.net/publications/world-energy-statistics-supply-and-demand.html (accessed on 18 May 2020).
6. Wang, B.; Mi, Z.; Nistor, I.; Yuan, X.C. How does hydrogen-based renewable energy change with economic development? Empirical evidence from 32 countries. *Int. J. Hydrogen Energy* **2018**, *43*, 11629–11638. [CrossRef]
7. Armeanu, D.Ş.; Vintilă, G.; Gherghina, Ş.C. Does renewable energy drive sustainable economic growth? Multivariate panel data evidence for EU-28 countries. *Energies* **2017**, *10*, 381. [CrossRef]
8. Baykara, S.Z. Hydrogen: A brief overview on its sources, production and environmental impact. *Int. J. Hydrogen Energy* **2018**, *43*, 10605–10614. [CrossRef]
9. Sivagurunathan, P.; Kumar, G.; Bakonyi, P.; Kim, S.H.; Kobayashi, T.; Xu, K.Q.; Bélafi-Bakó, K. A critical review on issues and overcoming strategies for the enhancement of dark fermentative hydrogen production in continuous systems. *Int. J. Hydrogen Energy* **2016**, *41*, 3820–3836. [CrossRef]
10. Fernández, R.Á.; Cilleruelo, F.B.; Martínez, I.V. A new approach to battery powered electric vehicles: A hydrogen fuel-cell-based range extender system. *Int. J. Hydrogen Energy* **2016**, *41*, 4808–4819. [CrossRef]
11. Nasri, S.; Slama, S.B.; Yahyaoui, I.; Zafar, B.; Cherif, A. Autonomous hybrid system and coordinated intelligent management approach in power system operation and control using hydrogen storage. *Int. J. Hydrogen Energy* **2017**, *42*, 9511–9523. [CrossRef]
12. Mattioda, R.A.; Fernandes, P.T.; Casela, J.L.; Junior, O.C. Social Life Cycle Assessment of Hydrogen Energy Technologies. In *Hydrogen Economy*; Academic Press: Cambridge, MA, USA, 2017; pp. 171–188.
13. Zhang, F.; Zhao, P.; Niu, M.; Maddy, J. The survey of key technologies in hydrogen energy storage. *Int. J. Hydrogen Energy* **2016**, *41*, 14535–14552. [CrossRef]
14. Nojavan, S.; Zare, K.; Mohammadi-Ivatloo, B. Application of fuel cell and electrolyzer as hydrogen energy storage system in energy management of electricity energy retailer in the presence of the renewable energy sources and plug-in electric vehicles. *Energy Convers. Manag.* **2017**, *136*, 404–417. [CrossRef]
15. Jones, J.; Genovese, A.; Tob-Ogu, A. Hydrogen vehicles in urban logistics: A total cost of ownership analysis and some policy implications. *Renew. Sustain. Energy Rev.* **2020**, *119*, 109595. [CrossRef]
16. Apak, S.; Atay, E.; Tuncer, G. Renewable hydrogen energy and energy efficiency in Turkey in the 21st century. *Int. J. Hydrogen Energy* **2017**, *42*, 2446–2452. [CrossRef]
17. Bessarabov, D.; Human, G.; Kruger, A.J.; Chiuta, S.; Modisha, P.M.; Du Preez, S.P.; Ren, J. South African hydrogen infrastructure (HySA infrastructure) for fuel cells and energy storage: Overview of a projects portfolio. *Int. J. Hydrogen Energy* **2017**, *42*, 13568–13588. [CrossRef]
18. Zhou, L.; Zhou, Y.; Sun, Y. Enhanced storage of hydrogen at the temperature of liquid nitrogen. *Int. J. Hydrogen Energy* **2004**, *29*, 319–322. [CrossRef]
19. Yang, C.; Ogden, J. Determining the lowest-cost hydrogen delivery mode. *Int. J. Hydrogen Energy* **2007**, *32*, 268–286. [CrossRef]

20. Maleki, A.; Pourfayaz, F.; Ahmadi, M.H. Design of a cost-effective wind/photovoltaic/hydrogen energy system for supplying a desalination unit by a heuristic approach. *Sol. Energy* **2016**, *139*, 666–675. [CrossRef]
21. Stamatakis, E.; Zoulias, E.; Tzamalis, G.; Massina, Z.; Analytis, V.; Christodoulou, C.; Stubos, A. Metal hydride hydrogen compressors: Current developments early markets. *Renew. Energy* **2018**, *127*, 850–862. [CrossRef]
22. Shah, S.A.A. Feasibility study of renewable energy sources for developing the hydrogen economy in Pakistan. *Int. J. Hydrogen Energy* **2019**, in press. [CrossRef]
23. Dinçer, H.; Yüksel, S. Defining the Strategic Impact-Relation Map for the Innovative Investments Based on IT2 Fuzzy DEMATEL: Evidence from the European Tourism Sector. In *Handbook of Research on Creating Sustainable Value in the Global Economy*; IGI Global: Hershey, PA, USA, 2020; pp. 103–124.
24. Liu, Y.; Alcantud, J.C.R.; Rodríguez, R.M.; Qin, K.; Martínez, L. Intertemporal Hesitant Fuzzy Soft Sets: Application to Group Decision Making. *Int. J. Fuzzy Syst.* **2020**, *22*, 1–17. [CrossRef]
25. Li, J.; Yin, Y.; Zhang, X.; Liu, J.; Yan, R. Hydrogen-rich gas production by steam gasification of palm oil wastes over supported tri-metallic catalyst. *Int. J. Hydrogen Energy* **2009**, *34*, 9108–9115. [CrossRef]
26. Maggio, G.; Nicita, A.; Squadrito, G. How the hydrogen production from RES could change energy and fuel markets: A review of recent literature. *Int. J. Hydrogen Energy* **2019**, *44*, 11371–11384. [CrossRef]
27. Ishimoto, Y.; Kurosawa, A.; Sasakura, M.; Sakata, K. Significance of CO2-free hydrogen globally and for Japan using a long-term global energy system analysis. *Int. J. Hydrogen Energy* **2017**, *42*, 13357–13367. [CrossRef]
28. Nastasi, B. Hydrogen policy, market, and R&D projects. In *Solar Hydrogen Production*; Academic Press: Cambridge, MA, USA, 2019; pp. 31–44.
29. Parra, D.; Valverde, L.; Pino, F.J.; Patel, M.K. A review on the role, cost and value of hydrogen energy systems for deep decarbonisation. *Renew. Sustain. Energy Rev.* **2019**, *101*, 279–294. [CrossRef]
30. Walter, S.; Ulli-Beer, S.; Wokaun, A. Assessing customer preferences for hydrogen-powered street sweepers: A choice experiment. *Int. J. Hydrogen Energy* **2012**, *37*, 12003–12014. [CrossRef]
31. Zohuri, B. Hydrogen Energy Technology, Renewable Source of Energy. In *Hybrid Energy Systems*; Springer: Cham, Switzerland, 2018; pp. 135–179.
32. Baetcke, L.; Kaltschmitt, M. Hydrogen Storage for Mobile Application: Technologies and Their Assessment. In *Hydrogen Supply Chains*; Academic Press: Cambridge, MA, USA, 2018; pp. 167–206.
33. Bellaby, P.; Upham, P.; Flynn, R.; Ricci, M. Unfamiliar fuel: How the UK public views the infrastructure required to supply hydrogen for road transport. *Int. J. Hydrogen Energy* **2016**, *41*, 6534–6543. [CrossRef]
34. Moradi, M. Economic Assessment of Hydrogen Energy Production in Norway—An Economic Analysis of Strategies for Implementation of Hydrogen Fuel Produced by Renewable Energies in Norway. Master's Thesis, NTNU, Trondheim, Norway, 2018.
35. Acar, C.; Beskese, A.; Temur, G.T. Sustainability analysis of different hydrogen production options using hesitant fuzzy AHP. *Int. J. Hydrogen Energy* **2018**, *43*, 18059–18076. [CrossRef]
36. Cao, Y.; Guo, J.; Hu, K.; Xie, L.; Li, B. Effect of ignition location on external explosion in hydrogen–air explosion venting. *Int. J. Hydrogen Energy* **2017**, *42*, 10547–10554. [CrossRef]
37. Nakayama, J.; Kasai, N.; Shibutani, T.; Miyake, A. Security risk analysis of a hydrogen fueling station with an on-site hydrogen production system involving methylcyclohexane. *Int. J. Hydrogen Energy* **2019**, *44*, 9110–9119. [CrossRef]
38. Hienuki, S.; Hirayama, Y.; Shibutani, T.; Sakamoto, J.; Nakayama, J.; Miyake, A. How Knowledge about or Experience with Hydrogen Fueling Stations Improves Their Public Acceptance. *Sustainability* **2019**, *11*, 6339. [CrossRef]
39. Verfondern, K.; Yan, X.; Nishihara, T.; Allelein, H.J. Safety concept of nuclear cogeneration of hydrogen and electricity. *Int. J. Hydrogen Energy* **2017**, *42*, 7551–7559. [CrossRef]
40. Garcia, D.A. Analysis of non-economic barriers for the deployment of hydrogen technologies and infrastructures in European countries. *Int. J. Hydrogen Energy* **2017**, *42*, 6435–6447. [CrossRef]
41. Welder, L.; Stenzel, P.; Ebersbach, N.; Markewitz, P.; Robinius, M.; Emonts, B.; Stolten, D. Design and evaluation of hydrogen electricity reconversion pathways in national energy systems using spatially and temporally resolved energy system optimization. *Int. J. Hydrogen Energy* **2019**, *44*, 9594–9607. [CrossRef]
42. Walker, S.B.; Mukherjee, U.; Fowler, M.; Elkamel, A. Benchmarking and selection of Power-to-Gas utilizing electrolytic hydrogen as an energy storage alternative. *Int. J. Hydrogen Energy* **2016**, *41*, 7717–7731. [CrossRef]

43. Bhogilla, S.S.; Ito, H.; Kato, A.; Nakano, A. Research and development of a laboratory scale totalized hydrogen energy utilization system. *Int. J. Hydrogen Energy* **2016**, *41*, 1224–1236. [CrossRef]
44. San Marchi, C.; Hecht, E.S.; Ekoto, I.W.; Groth, K.M.; LaFleur, C.; Somerday, B.P.; James, C.W. Overview of the DOE hydrogen safety, codes and standards program, part 3: Advances in research and development to enhance the scientific basis for hydrogen regulations, codes and standards. *Int. J. Hydrogen Energy* **2017**, *42*, 7263–7274. [CrossRef]
45. Arat, H.T.; Baltacioglu, M.K.; Tanç, B.; Sürer, M.G.; Dincer, I. A perspective on hydrogen energy research, development and innovation activities in Turkey. *Int. J. Energy Res.* **2020**, *44*, 588–593. [CrossRef]
46. Bayrak, Z.U.; Bayrak, G.; Ozdemir, M.T.; Gencoglu, M.T.; Cebeci, M. A low-cost power management system design for residential hydrogen solar energy based power plants. *Int. J. Hydrogen Energy* **2016**, *41*, 12569–12581. [CrossRef]
47. Zhou, L. Progress and problems in hydrogen storage methods. *Renew. Sustain. Energy Rev.* **2005**, *9*, 395–408. [CrossRef]
48. Shehzad, M.F.; Abdelghany, M.B.; Liuzza, D.; Glielmo, L. Modeling of a Hydrogen Storage Wind Plant for Model Predictive Control Management Strategies. In Proceedings of the IEEE 18th European Control Conference (ECC), New York, NJ, USA, 25–28 June 2019; pp. 1896–1901.
49. Uyar, T.S.; Beşikci, D. Integration of hydrogen energy systems into renewable energy systems for better design of 100% renewable energy communities. *Int. J. Hydrogen Energy* **2017**, *42*, 2453–2456. [CrossRef]
50. Amrouche, S.O.; Rekioua, D.; Rekioua, T.; Bacha, S. Overview of energy storage in renewable energy systems. *Int. J. Hydrogen Energy* **2016**, *41*, 20914–20927. [CrossRef]
51. Le Duigou, A.; Bader, A.G.; Lanoix, J.C.; Nadau, L. Relevance and costs of large scale underground hydrogen storage in France. *Int. J. Hydrogen Energy* **2017**, *42*, 22987–23003. [CrossRef]
52. Reddi, K.; Elgowainy, A.; Rustagi, N.; Gupta, E. Impact of hydrogen refueling configurations and market parameters on the refueling cost of hydrogen. *Int. J. Hydrogen Energy* **2017**, *42*, 21855–21865. [CrossRef]
53. Manoharan, Y.; Hosseini, S.E.; Butler, B.; Alzhahrani, H.; Senior, B.T.F.; Ashuri, T.; Krohn, J. Hydrogen fuel cell vehicles; current status and future prospect. *Appl. Sci.* **2019**, *9*, 2296. [CrossRef]
54. de Jongh, P.E.; Adelhelm, P. Nanosizing and nanoconfinement: New strategies towards meeting hydrogen storage goals. *ChemSusChem* **2010**, *3*, 1332–1348. [CrossRef]
55. Dincer, H.; Yuksel, S. IT2-based fuzzy hybrid decision making approach to soft computing. *IEEE Access* **2019**, *7*, 15932–15944. [CrossRef]
56. Li, Y.; Diabat, A.; Lu, C.C. Leagile supplier selection in Chinese textile industries: A DEMATEL approach. *Ann. Oper. Res.* **2020**, *287*, 303–322. [CrossRef]
57. Chen, Z.; Ming, X.; Zhou, T.; Chang, Y. Sustainable supplier selection for smart supply chain considering internal and external uncertainty: An integrated rough-fuzzy approach. *Appl. Soft Comput.* **2020**, *87*, 106004. [CrossRef]
58. Feng, G.C.; Ma, R. Identification of the factors that influence service innovation in manufacturing enterprises by using the fuzzy DEMATEL method. *J. Clean. Prod.* **2020**, *253*, 120002. [CrossRef]
59. Sadeghi-Niaraki, A. Industry 4.0 Development Multi-Criteria Assessment: An Integrated Fuzzy DEMATEL, ANP and VIKOR Methodology. *IEEE Access* **2020**, *8*, 23689–23704. [CrossRef]
60. Mangla, S.K.; Luthra, S.; Jakhar, S.; Gandhi, S.; Muduli, K.; Kumar, A. A step to clean energy-Sustainability in energy system management in an emerging economy context. *J. Clean. Prod.* **2020**, *242*, 118462. [CrossRef]
61. Wu, Y.; Wu, C.; Zhou, J.; Zhang, B.; Xu, C.; Yan, Y.; Liu, F. A DEMATEL-TODIM based decision framework for PV power generation project in expressway service area under an intuitionistic fuzzy environment. *J. Clean. Prod.* **2020**, *247*, 119099. [CrossRef]
62. Qi, W.; Huang, Z.; Dinçer, H.; Korsakienė, R.; Yüksel, S. Corporate Governance-Based Strategic Approach to Sustainability in Energy Industry of Emerging Economies with a Novel Interval-Valued Intuitionistic Fuzzy Hybrid Decision Making Model. *Sustainability* **2020**, *12*, 3307. [CrossRef]
63. Fatrias, D.; Hendrawan, D.; Fithri, P.; Rusman, M. An Application of Combined Fuzzy MCDM Techniques in Structuring Disaster Resilience Indicators for Small and Medium Enterprises: A Case Study. In Proceedings of the 2019 IEEE 6th International Conference on Industrial Engineering and Applications (ICIEA), Tokyo, Japan, 12–15 April 2019; pp. 639–643.
64. Jahangiri, M.; Molaeifar, H.; Rajabi, F.; Banaee, S. Occupational stressors among farmers in Iran using fuzzy multiple criteria decision-making methods. *J. Agromedicine* **2020**, *25*, 28–37. [CrossRef] [PubMed]

65. Farhadinia, B.; Herrera-Viedma, E. Multiple criteria group decision making method based on extended hesitant fuzzy sets with unknown weight information. *Appl. Soft Comput.* **2019**, *78*, 310–323. [CrossRef]
66. Qu, G.; Zhang, Z.; Qu, W.; Xu, Z. Green Supplier Selection Based on Green Practices Evaluated Using Fuzzy Approaches of TOPSIS and ELECTRE with a Case Study in a Chinese Internet Company. *Int. J. Environ. Res. Public Health* **2020**, *17*, 3268. [CrossRef]
67. Fei, L.; Deng, Y.; Hu, Y. DS-VIKOR: A new multi-criteria decision-making method for supplier selection. *Int. J. Fuzzy Syst.* **2019**, *21*, 157–175. [CrossRef]
68. Komsiyah, S.; Wongso, R.; Pratiwi, S.W. Applications of the Fuzzy ELECTRE Method for Decision Support Systems of Cement Vendor Selection. *Procedia Comput. Sci.* **2019**, *157*, 479–488. [CrossRef]
69. Zhou, P.; Zhou, P.; Yüksel, S.; Dinçer, H.; Uluer, G.S. Balanced Scorecard-Based Evaluation of Sustainable Energy Investment Projects with IT2 Fuzzy Hybrid Decision Making Approach. *Energies* **2020**, *13*, 82. [CrossRef]
70. Wang, S.; Liu, Q.; Yuksel, S.; Dincer, H. Hesitant linguistic term sets-based hybrid analysis for renewable energy investments. *IEEE Access* **2019**, *7*, 114223–114235. [CrossRef]
71. Tang, Z.; Dinçer, H. Selecting the House-of-Quality-Based Energy Investment Policies for the Sustainable Emerging Economies. *Sustainability* **2019**, *11*, 3514. [CrossRef]
72. Qiu, D.; Dinçer, H.; Yüksel, S.; Ubay, G.G. Multi-Faceted Analysis of Systematic Risk-Based Wind Energy Investment Decisions in E7 Economies Using Modified Hybrid Modeling with IT2 Fuzzy Sets. *Energies* **2020**, *13*, 1423. [CrossRef]
73. Torra, V. Hesitant fuzzy sets. *Int. J. Intell. Syst.* **2010**, *25*, 529–539. [CrossRef]
74. Hosseini, B.; Kiani, K. A big data driven distributed density based hesitant fuzzy clustering using Apache spark with application to gene expression microarray. *Eng. Appl. Artif. Intell.* **2019**, *79*, 100–113. [CrossRef]
75. Bai, K.; Zhu, X.; Zhang, R.; Gao, J. Linguistic Reasoning Petri Nets Using q-Rung Orthopair Fuzzy Linguistic Sets and Weighted Ordered Weighted Averaging Operators. *IEEE Access* **2019**, *7*, 103167–103183. [CrossRef]
76. Solovev, M.V.; Chashchikhin, O.V.; Dorovatovskii, P.V.; Khrustalev, V.N.; Zyubin, A.S.; Zyubina, T.S.; Dobrovolsky, Y.A. Hydrolysis of Mg (BH4) 2 and its coordination compounds as a way to obtain hydrogen. *J. Power Sources* **2018**, *377*, 93–102. [CrossRef]
77. dos Santos, K.G.; Eckert, C.T.; De Rossi, E.; Bariccatti, R.A.; Frigo, E.P.; Lindino, C.A.; Alves, H.J. Hydrogen production in the electrolysis of water in Brazil, a review. *Renew. Sustain. Energy Rev.* **2017**, *68*, 563–571. [CrossRef]
78. Gkanas, E.I.; Christodoulou, C.N.; Tzamalis, G.; Stamatakis, E.; Chroneos, A.; Deligiannis, K.; Stubos, A.K. Numerical investigation on the operation and energy demand of a seven-stage metal hydride hydrogen compression system for Hydrogen Refuelling Stations. *Renew. Energy* **2020**, *147*, 164–178. [CrossRef]
79. Maghami, M.R.; Hassani, R.; Gomes, C.; Hizam, H.; Othman, M.L.; Behmanesh, M. Hybrid energy management with respect to a hydrogen energy system and demand response. *Int. J. Hydrog. Energy* **2020**, *45*, 1499–1509. [CrossRef]
80. Nagasawa, K.; Davidson, F.T.; Lloyd, A.C.; Webber, M.E. Impacts of renewable hydrogen production from wind energy in electricity markets on potential hydrogen demand for light-duty vehicles. *Appl. Energy* **2019**, *235*, 1001–1016. [CrossRef]
81. Valente, A.; Iribarren, D.; Dufour, J. Harmonising the cumulative energy demand of renewable hydrogen for robust comparative life-cycle studies. *J. Clean. Prod.* **2018**, *175*, 384–393. [CrossRef]