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Research paper

An Integrated Pythagorean fuzzy soft computing approach to environmental management systems for sustainable energy pricing

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ABSTRACT

This study aims to analyse environmental management systems for sustainable energy price. For this purpose, a new fuzzy multi-criteria decision-making (MCDM) model is generated. First, seven different criteria are defined with supported literature. After that, these factors are weighted by considering decision making trial and evaluation laboratory (DEMATEL) methodology based on 2-tuple hesitant interval-valued Pythagorean fuzzy sets (HIVPFs). Furthermore, different pricing strategies are also ranked by using HIVPF technique for order preference by similarity to ideal solution (TOPSIS) and Vise Kriterijumska Optimizacija I Kompromisno Resenje (VIKOR). Also, a sensitivity analysis is also performed by considering six different conditions. The main contribution of this study is proposing a new mathematical model to solve a significant problem regarding energy prices. It is concluded that the results of both TOPSIS and VIKOR are quite similar. On the other side, it is also understood that the results of six different cases are almost the same. This situation explains that analysis results are reliable and coherent. The findings indicate that safety incidence and waste management are the most crucial factors for the sustainability of the energy price. In addition, skimming is the best pricing strategy for the energy industry. Within this framework, energy companies should firstly offer high prices to the market. After that, the price should be reduced when there is a decrease in the demand.

1. Introduction

Energy is a very important input for industrial production. Therefore, energy prices are also effective on many sectors. In other words, rapid increases in energy prices can unexpectedly raise the costs of the sectors (Braunholtz-Speight et al., 2020). This situation both causes financial difficulties for companies and increases the economic fragility of countries. Therefore, the stability of energy prices has a very key role for the economic improvement. Thus, the situation is a little easier for countries that have their own energy resources. Thanks to the available resources, these countries can be affected much less by possible price increases (Biggar and Söderberg, 2020). On the other hand, countries that are dependent on foreign countries for energy are adversely affected by the rapidly increasing prices.

It is possible to talk about many different factors that affect the stability of energy prices. The amount of energy supply is one of the most important aspects in this process. If the energy supply is insufficient, prices increase very rapidly (Shah and Sosvilla-Rivero, 2021). On the other hand, the energy supply must also rise in line with the increasing energy demand. In addition, political problems between countries also destabilize energy prices. For example, war between countries causes significant problems in energy supply (Boute, 2020). This situation will negatively affect the prices.

Some environmental factors also have a major impact on the stability of energy prices. For example, radioactive waste needs to be managed effectively. Otherwise, this will adversely affect price stability as it will increase costs (Tavakoli et al., 2020). On the other hand, meeting customers' expectations also has a very positive effect on prices. Similarly, the high financial performance of energy companies will also positively affect this process (Shah et al., 2020). Safety incidence is also a crucial factor in this process because previous accidents in the energy production make people nervous.

As it can be understood from these points, it is not easy to identify the important factors affecting the stability of energy prices. In other words, it is vital to determine how to ensure price stability in energy markets (Hoayek et al., 2020). On the other hand, it is equally important to prioritize which of the many different variables that may affect price stability in the energy market (Bollino and Galkin, 2021). It is not possible to improve all the factors affecting the stability of energy prices at the same time (Dalheimer et al., 2021; Husaini and Lean, 2021). Therefore, it is

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essential to conduct a priority analysis regarding this issue. In this context, it is necessary to carry out a comprehensive analysis by taking into account different factors at the same time (Kahyaoglu and Kahyaoglu, 2021). In this way, it will be possible to produce specific strategies to ensure stability in energy prices. This will contribute significantly to the development of energy markets.

In this study, environmental factors that have an impact on the stability of the energy prices are examined. In this context, the main research question is which factors should be mainly considered to provide stable prices in the energy market. With the help of this situation, it is aimed to provide appropriate pricing strategy to provide sustainable energy prices. In the process of weighting the environmental factors, HIVPF DEMATEL is considered. Moreover, HIVPF TOPSIS approach is also used to find appropriate pricing strategy for sustainable energy prices. HIVPF VIKOR is also considered to rank the alternatives so that the proposed model can be validated. Also, a sensitivity analysis is also performed by considering six different conditions.

The main contribution of this study is proposing a new mathematical model to solve a significant problem regarding energy prices. Because the topic is quite significant and complex, a detailed evaluation should be conducted. Due to this situation, a new model is generated to understand main influencing factors of energy prices stability. Owing to the analysis results, specific strategies can be created to solve this important problem. These issues can pave the way for both investors and policy makers. This proposed model has also some advantages. Firstly, by considering a hybrid methodology, more objective results can be achieved. Furthermore, Pythagorean fuzzy sets provide an opportunity to represent uncertainties in a more effective way (Bakioglu and Atahan, 2021; Thao, 2020). Additionally, the data loss can be reduced in the conversion of linguistic term sets (Zhang et al., 2019a,b; Liu and Chen, 2018). Also, considering hesitant fuzzy sets decreases the inconsistency in this regard (Yu et al., 2019; Liao et al., 2018).

Another novelty of this proposed model is using DEMATEL to weight the factors. The causal relationship of the items can be examined with the help of this methodology (Meng et al., 2021a,b). In this study, environmental factors that have an impact on the energy prices are evaluated, such as customer expectations and waste management (Kalkavan et al., 2021). Because these factors may affect each other significantly, considering DEMATEL methodology is quite appropriate with the subject of the study (Jun et al., 2021). On the other side, both TOPSIS and VIKOR methods are used to rank the pricing strategies so that the coherency of the analysis results can be evaluated (Shang et al., 2021; Fang et al., 2021).

This study consists of five different parts. Section 2 focuses on the details in the literature regarding this subject. Section 3 includes the details of methodology. Section 4 explains analysis results. In Section 5, the discussions and conclusions are presented.

2. Literature review

This part focuses on the sustainable energy pricing literature. Next, the literature on MCDM modelling for energy industry is discussed. Finally, the significant points are presented.

2.1. Literature on Sustainable Energy Pricing

Sustainable energy pricing has been discussed in the literature from many different perspectives. In some of the studies, it has been stated that technological competence is very important in this process. As a result of the companies having the necessary technological developments, energy generation process can be more effective (Gamtessa and Olani, 2018). This will contribute to increasing the stability in energy prices. On the other hand, if companies do not have sufficient technological developments, costs in the energy production process will increase (Rehmatulla and Smith, 2020). This situation will negatively affect both the profitability of the company and the efficiency of the process. Because of this situation, stability in energy prices will deteriorate (Zhang et al., 2019a,b). Murad et al. (2019) focused on the relationship between energy price and technological improvements. They underlined the significance of the technological development to have sustainable energy price. Additionally, Yang et al. (2019) tried the identify influencing factors of energy technical innovation in China. They concluded that technological innovations have a positive influence on the sustainability of the energy pricing. Furthermore, Barkhordari and Fattahi (2017) evaluated this relationship for Iran with the help of ARDL approach. It is identified that companies should follow technological improvements to increase sustainability in the energy prices.

Another factor affecting the stability in energy prices is the adequacy of the regulations. Due to the vast majority of energy production in a country being dependent on fossil fuels, serious environmental problems will occur in the country (Mikayilov et al., 2020; Yüksel et al., 2020). Since this situation will create many different problems in a long time, it is obvious that it will destabilize energy prices (Du et al., 2020; Liu et al., 2021a,b). Therefore, many researchers have advocated the introduction of a carbon tax on fossil fuels (Lin and Jia, 2018). For example, Chan (2020) and Lin and Xu (2019) examined the essential indicators of the energy pricing. They reached a conclusion that carbon tax plays a key role for the sustainability of the energy prices. On the other hand, speculative movements regarding energy prices should also be prevented. Therefore, it is important for governments to establish effective regulations for this process (Shi and Sun, 2017). In this regard, Amann et al. (2021) focused on the energy market in Oman and defined that regulations play an important role for the effectiveness of the energy pricing. Similarly, Ju et al. (2017) evaluated the energy prices in China and highlighted the significance of the same issue.

On the other hand, the financial performance of energy companies is also very effective in price stability. For sustainable energy prices, there should be no problems in the performance of energy companies. In case energy companies experience financial problems, there may be disruptions in energy production (Khalid et al., 2018). As a result, stability in energy prices will be adversely affected. Therefore, it is very important for energy companies to experience financial problems for sustainable energy prices (Yang et al., 2020). On the other hand, energy investments are long-term projects with high costs. In this context, providing some incentives to energy companies by the state will contribute to the financial performance of companies (Jalilzadehazhari et al., 2020). Rentschler and Kornejew (2017) focused on the energy price variation and competitiveness. For this purpose, Indonesian energy market is taken into consideration. They claimed that the financial performance of the energy companies has a significant impact on the stability of the energy prices. Additionally, Huuki et al. (2021) examined the residential solar power profitability by considering carbon-corrected energy prices and highlighted the importance of the financial performances of the energy companies in this regard.

Overpopulation is another factor that has an impact on energy prices. The population is increasing significantly in the world. Parallel to this, the demand for energy is also increasing (Bissing et al., 2019). The increase in this population more than expected causes fluctuations in energy prices (Wang and Nie, 2018). This situation negatively affects the price stability (Gbatu et al., 2019). On the other hand, some researchers have focused on the impact of renewable energy investments on energy prices. Thanks to the increase in renewable energy projects, there is a significant increase in energy supply (Wu et al., 2020). Thanks to increased energy production, the effect of supply-based shocks in energy prices can be minimized (Liu et al., 2020; Maji et al., 2017). On the other side, a summary table is created in the appendix (Table A.1) for the studies regarding energy price stability.

2.2. Literature on MCDM modelling for energy industry

Fuzzy MCDM models are frequently preferred in energy literature. In some of the studies, these approaches have been used with triangular fuzzy numbers. Saraswat and Digalwar (2021) evaluated energy alternatives for sustainable development of energy sector in India. In this study, fuzzy Entropy methodology was considered. Similarly, Yüksel and Ubay (2021) aimed to determine the optimal financial government incentives in wind energy investments. In order to reach this objective, DEMATEL methodology is used with triangular fuzzy numbers. Çolak and Kaya (2020) examined energy storage technologies with the help of fuzzy MCDM modelling. Wang et al. (2020a,b) focused on the renewable energy resources selection for Pakistan by using fuzzy AHP approach. Additionally, Wang et al. (2021) ranked renewable energy production capabilities with fuzzy TOPSIS methodology. Moreover, Deveci et al. (2020a,b,c) focused on offshore wind farms with a fuzzy approach. Similarly, Deveci et al. (2021b) examined offshore wind farm site selection using interval rough numbers based Best Worst Method and MARCOS.

Moreover, some researchers also preferred to use MCDM models with trapezoidal fuzzy numbers for the energy subject. Li et al. (2020) aimed to identify innovation strategies for renewable energy alternatives. In this context, interval type-2 fuzzy DEMATEL and TOPSIS approaches were taken into consideration. Shukla et al. (2020) focused on the energy efficiency with the same models. Qiu et al. (2020) analysed risk factors regarding renewable energy investment decisions in emerging countries by considering IT2F DEMATEL, VIKOR and TOPSIS. Furthermore, Gong et al. (2021) examined the renewable energy accommodation potential evaluation of distribution network with similar methodology. Also, Li et al. (2021) defined strategic priorities of customer expectations for renewable energy investments with IT2 fuzzy modelling. Additionally, Deveci et al. (2020a,b,c) generated a MCDM model based on IT2 fuzzy sets for offshore wind farm development in Ireland. Du et al. (2020) used this methodology in order to evaluate coal energy investments. Also, Liu et al. (2021a,b) made a comparative evaluation by using triangular, trapezoidal and Gaussian fuzzy numbers to analyse energy efficiency in the emerging economies. Additionally, Deveci et al. (2021a) considered type-2 neutrosophic number based multi-attributive border approximation area comparison (MABAC) approach regarding the offshore wind farm site selection in USA.

In addition to these studies, interval valued intuitionistic fuzzy sets were also preferred in many studies related to the energy investments. Deveci et al. (2020a,b,c) tried to select the optimal renewable energy investment alternative for Turkey by considering this methodology. Haiyun et al. (2021) analysed the innovation strategies for green supply chain management in the energy industry using interval valued intuitionistic fuzzy decision approach. Hu et al. (2020) considered IVIF sets for the aim of assessing technology portfolios of clean energy investments. Qi et al. (2020) generated an IVIF hybrid model to measure the sustainability in energy industry of emerging economies. Furthermore, Davoudabadi et al. (2021) and Yuan et al. (2020) tried to identify quality improvement strategies of energy investments by using the interval-valued fuzzy decision-making approach.

On the other hand, Spherical fuzzy sets were also considered especially in the recent literature with respect to the energy investments. Gündoğdu and Kahraman (2020) evaluated renewable energy investments with the help of the analytic hierarchy process based on Spherical fuzzy sets. Yuan et al. (2021) used this methodology regarding the green nuclear energy investments. Moreover, Onar et al. (2020) examined wind energy investments by considering Spherical fuzzy sets. On the other side, Cheng et al. (2020) focused on new service development process for renewable energy investment projects by using these fuzzy sets. In addition, Sharaf (2021) made a study for geothermal energy investment projects with fuzzy PROMETHEE approach based on Spherical fuzzy numbers.

2.3. Literature review results

Some issues come to the fore as a result of the literature review. First, there are many studies on the issue of the sustainability of energy prices. In these studies, the importance of many issues such as population, regulations, technological competence, and financial performance has been evaluated. On the other hand, it is seen that a small number of variables are considered throughout the studies. However, there is a need for a comprehensive study that affects the sustainability of energy prices and considers many variables at the same time. In addition to them, it is understood that fuzzy MCDM models are frequently preferred in energy literature. In these studies, it is generally aimed to produce strategies for renewable energy investments. On the other hand, it is observed that the use of these approaches in studies on energy price stability is limited.

In this study, the factors affecting sustainable energy prices are tried to be determined. For this purpose, a very comprehensive set of criteria has been generated. This criteria set can lead academicians for further studies. Additionally, these factors can also be considered for the evaluated of other studies. Furthermore, it is aimed to identify which of the different pricing strategies are more effective. There are lots of influencing factors of energy price stability. However, it is quite difficult to focus on all these factors at the same time. Hence, in order to increase the efficiency in this process, the priority analysis should be conducted. Therefore, it is obvious that this study makes a contribution to the literature in this framework. On the other hand, in this process, a new model is established by considering the hybrid fuzzy MCDM models. Finding optimal strategies for energy price stability is a very complex process because a lot of different criteria should be taken into consideration at the same time. Owing to this issue, in this study, a new hybrid model is created to solve this problem effectively.

3. Methodology

In this section, different methodologies will be explained.

3.1. Linguistic 2-tuple information

The symbolic translation is represented by $s_i \in S = \{s_0, \ldots, s_g\}$. It can take value of *[-0.5, 0.5)*. Also, $\beta \in$ *[0, g]* indicates the information of a symbolic aggregation operation whereas *round (·)* shows the usual round operation. The details are demonstrated in Eq. (1) (Wang et al., 2018)

$$\Delta: [0, g] \to S \times (-0.5, .5)\ \boldsymbol{\Delta}(\boldsymbol{\beta}) = (\boldsymbol{s_i}, \boldsymbol{\alpha}),$$
$$\text{with} \left\{ \begin{array}{cc} s_i & i = round(\beta) \\ \alpha = \beta - i & \alpha \in [-0.5, 0, 5) \end{array} \right. , \tag{1}$$

Additionally, Fig. 1 illustrates 2-tuple linguistic term sets (Zhang et al., 2018).

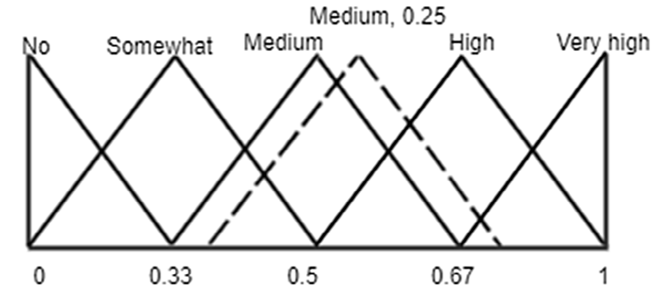

Fig. 1. 2-tuple sets.

3.2. HFLTS

HFLTS (H_S) can be identified in Eq. (2). In this equation, $S = \{s_0, \ldots, s_\tau\}$ represents a linguistic term set (Montserrat-Adell et al., 2019).

$$H_S = \left\{s_i, s_{i+1}, \ldots, s_j\right\}, s_k \in S, k \in \{i, \ldots, j\} \tag{2}$$

,

Furthermore, the context-free grammars are shown as $G_H = (V_N, V_T, I, P)$. Additionally, following expressions are taken into consideration (Wei et al., 2017).

$$V_N = \{\langle primary\ term\rangle, \langle composite\ term\rangle, \langle unary\ term\rangle, \langle binary\ term\rangle, \langle conjunction\rangle\}$$

$$V_T = \{lowerthan, greaterthan, atleast, atmost, between, and, S_0, S_1, \ldots, S_t\}$$

$$I \in V_N$$

$$P = \{I ::= \langle primary\ term\rangle | \langle composite\ term\rangle, \langle composite\ term\rangle ::= \langle composite\ term\rangle \langle primary\ term\rangle$$

$$|\langle binary\ relation\rangle \langle primary\ term\rangle \langle conjunction\rangle \langle primary\ term\rangle,$$

$$\langle primary\ term\rangle ::= S_0 | S_1 | \ldots | S_t,$$

$$\langle unary\ relation\rangle ::= lower\ than | greater\ than | at\ least | at\ most,$$

$$\langle binary\ relation\rangle ::= between,$$

$$\langle conjunction\rangle ::= and\}$$

On the other side, E_{G_H} defines the transformation function. It is used to convert the linguistic expressions into HFLTS as in Eq. (3). In this process, S_{ll} gives information about the expression domain generated by G_H (Lin et al., 2019).

$$E_{G_H} : S_{ll} \to H_s \tag{3}$$

Additionally, fuzzy linguistic variables ($F(H_s)$ can be modelled by the trapezoidal fuzzy numbers *(a, b, c, d)* as in Eq. (4) (Tüysüz and Şimşek, 2017).

$$F(H_s) = T\,(a, b, c, d) \tag{4}$$

3.3. Interval valued intuitionistic and Pythagorean fuzzy sets

Interval-valued intuitionistic fuzzy set (I) was generated as a new fuzzy set (Ejegwa, 2020; Dogan et al., 2019; Mohagheghi et al., 2020). In this context, membership ($\mu_I(\vartheta)$ and non-membership ($n_I(\vartheta)$ degrees are considered as in Eq. (5). The sum of these parameters can be between 0 and 1.

$$I = \{\langle \vartheta, \mu_I(\vartheta), n_I(\vartheta)\rangle / \vartheta \epsilon U\} \tag{5}$$

Eqs. (6) and (7) also explain the details of these fuzzy sets. In this context, the upper and lower values of $\mu_I(\vartheta)$ are given by ($\mu_{IU}(\vartheta)$, $\mu_{IL}(\vartheta)$. On the other hand, $n_{IU}(\vartheta)$ and $n_{IL}(\vartheta)$ identify the upper and lower values of $n_I(\vartheta)$ (Lin et al., 2021).

$$I = \{\vartheta, [\mu_{IL}(\vartheta), \mu_{IU}(\vartheta)], [n_{IL}(\vartheta), n_{IU}(\vartheta)] / \vartheta \epsilon U\} \tag{6}$$

$$0 \le \mu_{IU}(\vartheta) + n_{IU}(\vartheta) \le 1 \tag{7}$$

$\mu_{IL}(\vartheta) \ge 0, n_{IL}(\vartheta) \ge 0(7)$

Moreover, unknown degree is shown as in Eq. (8) (Molla et al., 2021).

$$\tau_I(\vartheta) = 1 - \mu_I(\vartheta) - n_I(\vartheta) \tag{8}$$

Also, Eq. (9) defines the elements of *I*. Within this scope, $\mu_{IL}(\vartheta)$, $\mu_{IU}(\vartheta)$, $n_{IL}(\vartheta)$, $n_{IU}(\vartheta)$ are demonstrated by *a, b, c* and *d*.

$$I = ([a, b], [c, d]) \tag{9}$$

On the other side, Pythagorean fuzzy sets (P) are given in Eq. (10) (Yager and Abbasov, 2013).

$$P = \{\langle \vartheta, \mu_P(\vartheta), n_P(\vartheta)\rangle / \vartheta \epsilon U\} \tag{10}$$

Furthermore, μ_P and n_P indicate the membership and non-membership degrees and the condition in Eq. (11) can be satisfied (Thao, 2020).

$$(\mu_P(\vartheta))^2 + (n_P(\vartheta))^2 \le 1 \tag{11}$$

Eq. (12) defines the degree of indeterminacy ($\pi_P(\vartheta)$) (Ejegwa, 2020).

$$\pi_P(\vartheta) = \sqrt{1 - (\mu_P(\vartheta))^2 - (n_P(\vartheta))^2} \tag{12}$$

Also, Eqs. (13)–(17) show the mathematical operations of *P* (Lin et al., 2021; Gou et al., 2016).

$$P_1 = \left\{\left\langle \vartheta, P_1(\mu_{P_1}(\vartheta), n_{P_1}(\vartheta))\right\rangle / \vartheta \epsilon U\right\}\ and\ P_2 = \left\{\left\langle \vartheta, P_2(\mu_{P_2}(\vartheta), n_{P_2}(\vartheta))\right\rangle / \vartheta \epsilon U\right\} \tag{13}$$

$$P_1 \oplus P_2 = P\left(\sqrt{\mu_{P_1}^1 + \mu_{P_2}^2 - \mu_{P_1}^1 \mu_{P_2}^2}, n_{P_1} n_{P_2}\right) \tag{14}$$

$$P_1 \otimes P_2 = P\left(\mu_{P_1}\mu_{P_2}, \sqrt{n_{P_1}^2 + n_{P_2}^2 - n_{P_1}^2 n_{P_2}^2}\right) \tag{15}$$

$$P_1 \ominus P_2 = P\left(\sqrt{\frac{\mu_{P_1}^2 - \mu_{P_2}^2}{1 - \mu_{P_2}^2}}, \frac{n_{P_1}}{n_{P_2}}\right), \quad \mu_{P_1} \ge \mu_{P_2}\ and\ n_{P_1} \le n_{P_2}\ and\ n_{P_2} \ge 0 \tag{16}$$

$$P_1 \oslash P_2 = P\left(\frac{\mu_{P_1}}{\mu_{P_2}}, \sqrt{\frac{n_{P_1}^2 - n_{P_2}^2}{1 - n_{P_2}^2}}\right), \quad \mu_{P_1} \le \mu_{P_2}\ and\ n_{P_1} \ge n_{P_2}\ and\ \mu_{P_2} \ge 0 \tag{17}$$

$$\lambda P = P\left(\sqrt{1 - \left(1 - \mu_p^2\right)^\lambda}, \left(n_p\right)^\lambda\right), \lambda > 0 \tag{18}$$

$$P^\lambda = P\left(\left(\mu_p\right)^\lambda, \sqrt{1 - \left(1 - n_p^2\right)^\lambda}\right), \lambda > 0 \tag{19}$$

and

Additionally, interval valued Pythagorean fuzzy sets *(IP)* are detailed in Eqs. (20)–(22) (Garg, 2016). In these equations, a, b, c, d are shown as $\mu_P^L(\vartheta), \mu_P^U(\vartheta), \upsilon_P^L(\vartheta), \upsilon_P^U(\vartheta)$.

$$IP = \left\{\left\langle \vartheta, \left[\mu_P^L(\vartheta), \mu_P^U(\vartheta)\right], \left[\upsilon_P^L(\vartheta), \upsilon_P^U(\vartheta)\right]\right\rangle / \vartheta \epsilon U\right\} \tag{20}$$

$$0 \le \mu_P^L(\vartheta) \le \mu_P^U(\vartheta) \le 1 \le \upsilon_P^L(\vartheta) \le \upsilon_P^U(\vartheta) \le 1\ \text{and}\ \left(\mu_P^U(\vartheta)\right)^2 + \left(\upsilon_P^U(\vartheta)\right)^2 \le 1 \tag{21}$$

$$IP = \langle [a, b], [c, d] \rangle \tag{22}$$

and

Finally, defuzzified values are explained in Eq. (23) (Garg, 2016, 2017).

$$S(\vartheta) = \frac{\left(\left(a^2-c^2\right)\left(1+\sqrt{1-a^2-c^2}\right)+\left(b^2-d^2\right)\left(1+\sqrt{1-b^2-d^2}\right)\right)}{2} \quad (23)$$

3.4. DEMATEL

The steps of DEMATEL methodology are given below.

Step 1: Direct relation matrix (A_k) is created by considering the expert evaluations as in Eq. (24). Within this context, a_{ij} defines the impact of factor i on the factor j (Meng et al., 2021a,b).

$$A_k = \begin{bmatrix} 0 & \cdots & a_{1nk} \\ \vdots & \ddots & \vdots \\ a_{n1k} & \cdots & 0 \end{bmatrix} \quad (24)$$

Step 2: Normalized matrix *(B)* is calculated with Eq. (25). In this process, b_{ij} can get value between 0 and 1 (Xie et al., 2021).

$$B = \left[b_{ij}\right]_{nxn} = \frac{A}{max\sum_{j=1}^{n} a_{ij}} \quad (25)$$

Step 3: Total relation matrix (C) is obtained by Eq. (26). The identity matrix is defined by I (Jun et al., 2021).

$$C = \left[c_{ij}\right]_{nxn} = B\left(I-B\right)^{-1} \quad (26)$$

Step 4: The sums of all vector rows (D) and columns (E) are computed with Eqs. (27) and (28) (Meng et al., 2021a,b).

$$D = \left[d_{ij}\right]_{nx1} = \left[\sum_{j=1}^{n} c_{ij}\right]_{nx1} \quad (27)$$

$$E = \left[e_{ij}\right]_{1xn} = \left[\sum_{j=1}^{n} c_{ij}\right]_{1xn} \quad (28)$$

3.5. TOPSIS

TOPSIS approach is used to rank different alternatives. The normalized values (r_{ij}) are considered as in Eq. (29). In this context, X gives information about the expert evaluations (Kou et al., 2021).

$$\boldsymbol{r_{ij}} = \frac{\boldsymbol{X_{ij}}}{\sqrt{\sum_{i=1}^{m} \boldsymbol{X_{ij}^2}}}\, \boldsymbol{i} = 1, 2, 3, \ldots, \boldsymbol{m\ and\ j} = 1, 2, 3, \ldots, \boldsymbol{n} \quad (29)$$

After that, the values are weighted by considering Eq. (30). In this framework, w represents the weights and s identifies the weighted values (Zhao et al., 2021).

$$\boldsymbol{s_{ij}} = \boldsymbol{w_{ij}} \times \boldsymbol{r_{ij}} \quad (30)$$

The positive (A^+) and negative (A^-) ideal solutions are computed as in Eqs. (31) and (32) (Mahmoud et al., 2021).

$$A^+ = \left\{s_{1j}, \ldots, s_{mj}\right\} = \left\{\max s_{1j}\ for\ \forall j \in n\right\} \quad (31)$$

$$\boldsymbol{A^-} = \left\{\boldsymbol{s_{1j}}, \ldots, \boldsymbol{s_{mj}}\right\} = \left\{\mathbf{min} s_{1j}\ \boldsymbol{for}\ \forall \boldsymbol{j} \in \boldsymbol{n}\right\} \quad (32)$$

The distances to the best and worst factors (D_i^+ and D_i^-) are calculated by considering Eqs. (33) and (34) (Solangi et al., 2021).

$$\boldsymbol{D_i^+} = \sqrt{\sum_{j=1}^{n}\left(\boldsymbol{s_{ij}} - \boldsymbol{A_j^+}\right)^2} \quad (33)$$

$$D_i^- = \sqrt{\sum_{j=1}^{n}\left(s_{ij} - A_j^-\right)^2} \quad (34)$$

The relative closeness (RC_i) is considered to rank the alternatives as in Eq. (35) (Shang et al., 2021).

$$\boldsymbol{RC_i} = \frac{\boldsymbol{D_i^-}}{\boldsymbol{D_i^+} + \boldsymbol{D_i^-}} \quad (35)$$

3.6. VIKOR

VIKOR is also used to rank alternatives. Fuzzy best and worst values ($\tilde{f}_j^*, \tilde{f}_j^-$) are used as in Eq. (36) (Bakioglu and Atahan, 2021).

$$\boldsymbol{\tilde{f}_j^*} = \mathbf{max}_i \boldsymbol{\tilde{x}_{ij}},\ \text{and}\ \boldsymbol{\tilde{f}_j^-} = \mathbf{min}_i \boldsymbol{\tilde{x}_{ij}} \quad (36)$$

and

Eqs. (37) and (38) are used to calculate mean group utility ($\tilde{S}_i$) and maximal regret ($\tilde{R}_i$). In this scope, $\tilde{w}_j$ demonstrates fuzzy weights (Tian et al., 2021).

$$\boldsymbol{\tilde{S}_i} = \sum_{i=1}^{n} \boldsymbol{\tilde{w}_j} \frac{\left(\left|\boldsymbol{\tilde{f}_j^*} - \boldsymbol{\tilde{x}_{ij}}\right|\right)}{\left(\left|\boldsymbol{\tilde{f}_j^*} - \boldsymbol{\tilde{f}_j^-}\right|\right)} \quad (37)$$

$$\tilde{R}_i = \max_j \left[\tilde{w}_j \frac{\left(\left|\tilde{f}_j^* - \tilde{x}_{ij}\right|\right)}{\left(\left|\tilde{f}_j^* - \tilde{f}_j^-\right|\right)}\right] \quad (38)$$

The value of $\tilde{Q}_i$ is computed with Eq. (39). The strategy weights are shown with v whereas *1-v* indicates the regret (Fang et al., 2021).

$$\boldsymbol{\tilde{Q}_i} = \boldsymbol{v}\left(\boldsymbol{\tilde{S}_i} - \boldsymbol{\tilde{S}^*}\right)/\left(\boldsymbol{\tilde{S}^-} - \boldsymbol{\tilde{S}^*}\right) + (1-\boldsymbol{v})\left(\boldsymbol{\tilde{R}_i} - \boldsymbol{\tilde{R}^*}\right)/\left(\boldsymbol{\tilde{R}^-} - \boldsymbol{\tilde{R}^*}\right) \quad (39)$$

S, Q and R values are considered to rank the alternatives.

3.7. Proposed methodology

In this study, a novel model is created to understand the important factors which have an influence on the sustainability of the energy prices. Firstly, six different environmental factors are defined by considering ISO-14001. Secondly, these factors are weighted by HIVPF DEMATEL. Thirdly, the causality analysis is made by using impact relation map of DEMATEL analysis. Fourthly, optimal energy pricing strategies are identified by using HIVPF TOPSIS. Finally, these strategies are also ranked with HIVPF VIKOR to validate the analysis results. The flowchart of the proposed model is given in Fig. 2.

The proposed model is constructed in two stages. The first stage is to weight the criteria of the environmental management systems. In this stage, seven steps including the procedures of HIVPF and DEMATEL are applied for evaluating the weights and directions of the criteria. The second stage is to rank the alternatives of energy pricing strategy. At the second stage, the computation steps contain the operations of HIVPF and TOPSIS respectively. The analysis results are represented at the following sections in detail.

This proposed model has significant benefits. Firstly, in this model, a hybrid methodology is preferred. Therefore, more objective results can be achieved. Another important benefit of this model is that uncertainties can be represented in a stronger manner with the help of Pythagorean fuzzy sets (Thao, 2020; Lin et al., 2021; Molla et al., 2021; Bakioglu and Atahan, 2021; Deveci

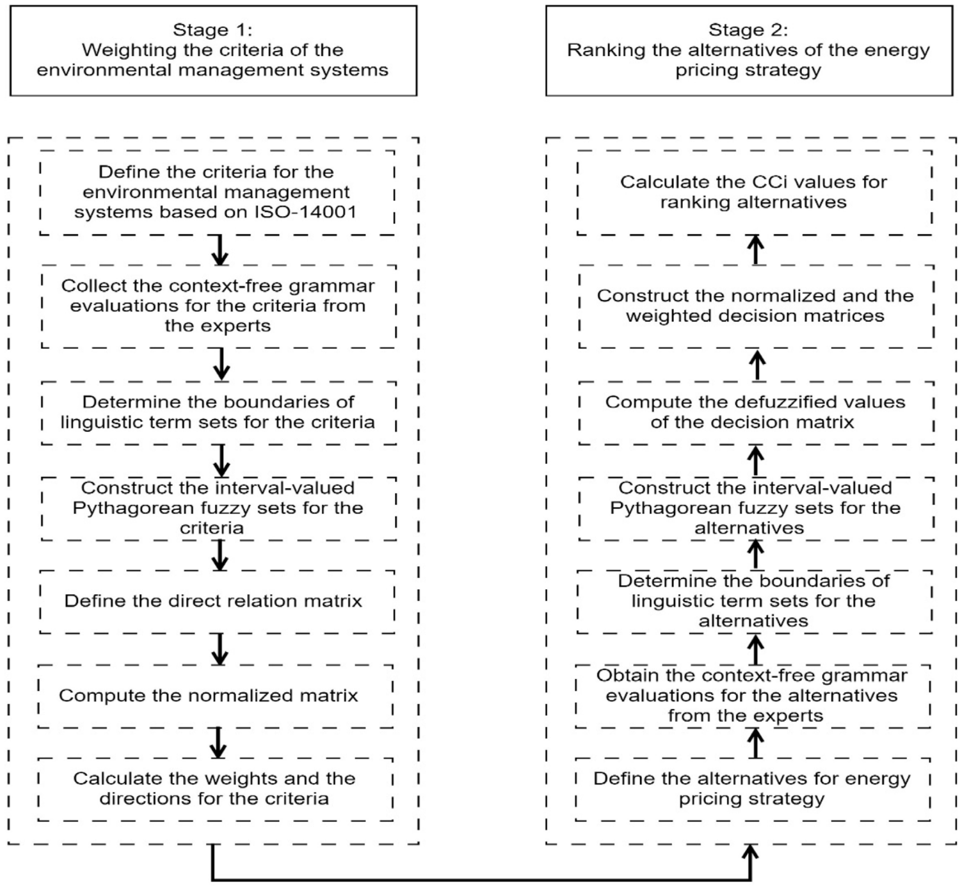

Fig. 2. The flowchart of the proposed model.

Table 1
Motivations of environmental management systems based on ISO-14001.

Criteria (CRT)	References
Customer expectations (CRT1)	Tavakoli et al. (2020)
Investment performance (CRT2)	Shah et al. (2020)
Waste management (CRT3)	Gamtessa and Olani (2018)
Competitive cost (CRT4)	Murad et al. (2019)
Safety incidence (CRT5)	Chan (2020)
Employee health (CRT6)	Ju et al. (2017)

et al., 2021c). Owing to 2-tuple fuzzy linguistic sets, linguistic term sets can be converted without any loss (Deng and Gao, 2019; Zhang et al., 2019a,b). Additionally, considering hesitant fuzzy sets helps to minimize inconsistency (Yu et al., 2019; Liao et al., 2018).

Considering DEMATEL to weight the environmental factors is another advantage of this proposed model. Different from other similar MCDM, the causal relationship of the items can be examined by using this approach (Jun et al., 2021; Meng et al., 2021a,b). Similarly, TOPSIS methodology considers the negative optimal result in addition to the positive ideal solution (Kou et al., 2021). Thus, TOPSIS provides more reliable results (Solangi et al., 2021). Finally, the pricing strategies are also ranked by VIKOR so that the coherency of the analysis results can be measured (Ning and Junwen, 2021).

On the other side, this proposed model is also quite appropriate with the subject of the study. For example, environmental factors that have an impact on the energy prices are evaluated, such as customer expectations, investment performance and waste management. It is obvious that these factors can have powerful effects on each other. Because of this issue, using DEMATEL approach is suitable in the proposed model. Moreover, identifying the optimal pricing strategy is a very critical issue. The main reason is that it has a significant impact on the performance of the energy investments. Thus, considering both TOPSIS and VIKOR in this process helps to reach more coherent results.

4. Analysis

This study aims to find the significant environmental factors that affect the sustainability of the energy prices. Additionally, it is also aimed to find appropriate pricing strategy. Hence, the main research question is which factors should be mainly considered to provide stable prices in the energy market. In this process, firstly, influencing factors of energy price stability are defined based on ISO-14001 and literature review. Secondly, these criteria are weighted by using HIVPF DEMATEL. For this purpose, the evaluations of three different experts are taken into consideration. In this framework, 5 different scales are taken into consideration. Thirdly, the cause-and-effect relationship between the items is identified with the help of impact relation map. Fourthly, five different energy pricing strategy alternatives are ranked by using HIVPF TOPSIS. Fifthly, the proposed model is validated with HIVPF VIKOR. The main missing part in the literature is that there is a need for a comprehensive study that affects the sustainability of energy prices and considers many variables at the same time. Therefore, in this study, a very comprehensive set of criteria has been created to contribute to the literature. Additionally, it is not easy to focus on all influencing factors of energy price stability at the same time. Due to this condition, the priority

Table 2
CFGE.

	CRT1			CRT2			CRT3		
	EXP1	EXP2	EXP3	EXP1	EXP2	EXP3	EXP1	EXP2	EXP3
CRT1				bwn “m” and “h”	bwn “m” and “h”	bwn “m” and “h”	bwn “m” and “vh”	atl “m”	atl “h”
CRT2	atm “h”	atl “m”	lot “m”				atl “m”	atl “m”	atm “h”
CRT3	atl “m”	atm “h”	atl “m”	atm “h”	bwn “m” and “vh”	bwn “m” and “h”			
CRT4	atl “m”	grt “m”	atm “h”	atl “m”	atl “h”	bwn “m” and “vh”	bwn “m” and “vh”	grt “m”	bwn “m” and “vh”
CRT5	bwn “m” and “h”	atm “h”	atl “h”	atm “h”	atm “h”	grt “m”	atm “h”	bwn “m” and “vh”	bwn “s” and “m”
CRT6	atl “m”	atl “m”	atm “h”	bwn “m” and “h”	atl “m”	bwn “m” and “vh”	bwn “s” and “m”	grt “m”	atm “h”
	CRT4			CRT5			CRT6		
	EXP1	EXP2	EXP3	EXP1	EXP2	EXP3	EXP1	EXP2	EXP3
CRT1	bwn “m” and “vh”	bwn “m” and “vh”	bwn “s” and “m”	bwn “m” and “vh”	atl “m”	bwn “m” and “vh”	bwn “m” and “vh”	bwn “m” and “vh”	grt “m”
CRT2	atl “m”	atm “h”	grt “h”	bwn “h” and “vh”	atm “h”	atl “m”	atl “m”	atl “m”	bwn “s” and “m”
CRT3	bwn “m” and “vh”	grt “m”	atm “h”	grt “m”	atl “h”	atm “h”	atl “h”	bwn “m” and “vh”	atm “h”
CRT4				bwn “m” and “vh”	atm “h”	bwn “m” and “h”	bwn “s” and “m”	atm “h”	bwn “s” and “m”
CRT5	bwn “m” and “h”	bwn “m” and “vh”	lot “m”				grt “s”	atm “m”	atl “m”
CRT6	lot “h”	lot “m”	atl “m”	bwn “m” and “vh”	atl “m”	lot “m”			

Between: bwn; At least: atl; Lower than: lot; Greater than: grt; At most; atm

analysis should be conducted to increase the efficiency in this process. Hence, it is thought that identifying the key influencing factor of energy price stability and finding the optimal price strategy for the energy market is another novelty of this study. Finally, a new hybrid model is generated to solve this problem because finding optimal strategies for energy price stability is a very complex process. With the help of this hybrid MCDM model based on HIVPF DEMATEL, TOPSIS and VIKOR, it is aimed to reach more appropriate results. In this section, analysis results will be presented in five different subtitles.

4.1. Defining criteria

Environmental factors are identified based on ISO-14001 as in Table 1.

The fact that customers' expectations are met has a positive effect on the energy prices. It is also very important that the financial performance of the investments made is high. If the profitability of investments is low, energy prices will be adversely affected. One of the most important issues in the use of energy is the efficient management of radioactive wastes. Any failure in this process will cause energy prices to change dramatically. On the other hand, the prices offered to customers should also be affordable. Safety incidence is also a vital factor in this process. Previous accidents in the energy production make people nervous. Failure to take necessary measures for this situation will adversely affect energy prices. Finally, taking measures to protect the health of the employees may create a positive perception in the market.

4.2. Weighting criteria

Three different experts (EXP) evaluated these six different criteria. In this process, 5 different scales are considered that are “5” for very high influence (vh), “4” for high influence (h), “3” for medium influence (m), “2” for somewhat influence (s), and “1” for no influence (n). Within this framework, an interview has been conducted with these people between February and April 2021. In this context, the data for the analysis can be obtained for the analysis. Context-free grammar evaluations (CFGE) are illustrated on Table 2.

After that, boundaries are defined as in Table 3.

Interval-valued Pythagorean fuzzy sets are indicated in Table 4.

Table 5 states the direct relation matrix (DRM).

Normalized matrix (NM) is presented in Table 6.

Table 7 demonstrates the weighted results.

Table 7 gives information that safety incidence (CRT5) has the greatest weight (0.184). Additionally, the second highest weight (0.170) belongs to the waste management (CRT3). On the other hand, customer expectations (CRT1) and employee health (CRT6) have the lowest weights. It is identified that safety and waste management conditions have a strong impact on the energy prices.

4.3. Causality relationship between criteria

By considering the values of “D-E” in Table 7, the directions among the criteria can be defined. Fig. 3 shows the details of this relationship.

Fig. 3 illustrates that waste management is the most influencing factor. It has a direct impact on all other criteria. In addition, customer expectations and employee health are the influenced variables. Moreover, there is also bidirectional relationship between investment performance and safety incidence.

4.4. Finding optimal energy pricing strategy

In this section, firstly, five different energy pricing strategy alternatives are defined that are penetration (ALT1), skimming (ALT2), promotional (ALT3), destroyer (ALT4) and demand based (ALT5). With respect to the penetration pricing strategy, the companies aim to increase market share with the help of initially offering low prices. On the other side, regarding skimming pricing strategy, the companies firstly offer high prices to the market. After that, the price is reduced when there is a decrease in the

Table 3
Boundaries of linguistic term sets.

	CRT1			CRT2			CRT3		
	EXP1	EXP2	EXP3	EXP1	EXP2	EXP3	EXP1	EXP2	EXP3
CRT1				[m, h]	[m, h]	[m, h]	[m, vh]	[m, vh]	[h, vh]
CRT2	[n, h]	[m, vh]	[n, m]				[m, vh]	[m, vh]	[n, h]
CRT3	[m, vh]	[n, h]	[m, vh]	[n, h]	[m, vh]	[m, h]			
CRT4	[m, vh]	[h, vh]	[n, h]	[h, vh]	[h, vh]	[m, vh]	[m, vh]	[m, vh]	[m, vh]
CRT5	[m, h]	[n, h]	[h, vh]	[n, h]	[n, h]	[h, vh]	[n, h]	[m, vh]	[s, m]
CRT6	[h, vh]	[m, vh]	[n, h]	[m, h]	[m, vh]	[m, vh]	[s, m]	[h, vh]	[n, h]
	CRT4			CRT5			CRT6		
	EXP1	EXP2	EXP3	EXP1	EXP2	EXP3	EXP1	EXP2	EXP3
CRT1	[m, vh]	[m, vh]	[s, m]	[m, vh]	[m, vh]	[m, vh]	[m, vh]	[m, vh]	[vh, vh]
CRT2	[m, vh]	[n, h]	[vh, vh]	[h, vh]	[n, h]	[m, vh]	[m, vh]	[m, vh]	[s, m]
CRT3	[m, vh]	[h, vh]	[n, h]	[h, vh]	[h, vh]	[n, h]	[h, vh]	[m, vh]	[n, h]
CRT4				[m, vh]	[n, h]	[m, h]	[s, m]	[n, h]	[s, m]
CRT5	[m, vh]	[m, vh]	[n, s]				[m, vh]	[n, m]	[m, vh]
CRT6	[n, m]	[n, s]	[m, vh]	[m, vh]	[m, vh]	[n, s]			

Table 4
Interval-valued Pythagorean fuzzy sets.

	CRT1	CRT2	CRT3	CRT4	CRT5	CRT6
CRT1		([.40,.60], [.20,.40])	([.60,.80], [.40,.47])	([.60,.67], [.20,.33])	([.60,.80], [.20,.40])	([.60,.80], [.40,.53])
CRT2	([.40,.60], [.10,.13])		([.60,.73], [.20,.27])	([.60,.73], [.20,.40])	([.60,.73], [.20,.33])	([.60,.67], [.20,.33])
CRT3	([.60,.73], [.20,.27])	([.60,.67], [.20,.27])		([.60,.73], [.20,.33])	([.60,.73], [.20,.40])	([.60,.73], [.20,.33])
CRT4	([.60,.73], [.20,.33])	([.60,.80], [.40,.53])	([.60,.80], [.40,.47])		([.60,.67], [.20,.27])	([.40,.47], [.10,.13])
CRT5	([.60,.67], [.20,.33])	([.60,.67], [.10,.20])	([.40,.60], [.10,.20])	([.40,.60], [.20,.27])		([.60,.67], [.20,.27])
CRT6	([.60,.73], [.20,.33])	([.60,.73], [.20,.40])	([.40,.60], [.20,.27])	([.40,.47], [.10,.13])	([.40,.60], [.20,.27])	

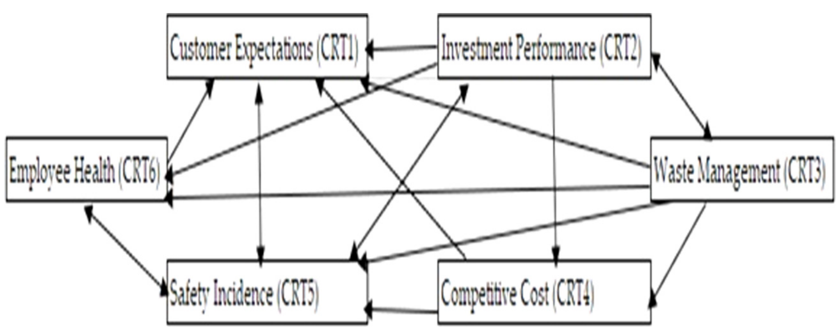

Fig. 3. Directions of environmental management systems for sustainable energy prices.

demand. On the other hand, in promotional pricing strategy, the price is reduced mainly for the aim of attracting the attentions of the customers. Furthermore, as for the destroyer pricing strategy, customers aim to drive competitors out of the market by decreasing the prices. Finally, in the demand-based pricing strategy, customer expectations are taken into consideration while defining the prices. TOPSIS methodology is used to rank these alternatives for the energy industry. Table 8 gives information about the CFGE for alternatives.

The boundaries for the alternatives are demonstrated on Table 9.

Pythagorean fuzzy sets for alternatives are given in Table 10.

Table 11 demonstrates the defuzzified decision matrix (DM).

This matrix is normalized as in Table 12.

Weighted DM is given in Table 13.

Table 14 states the significant values for alternatives.

Table 14 explains that skimming (ALT2) is the best pricing strategy for the energy industry because it has the highest CC_i value (0.744). Similarly, destroyer (ALT2) is another important energy pricing strategy with CC_i value of 0.742.

Table 5
Direct relation matrix.

	CRT1	CRT2	CRT3	CRT4	CRT5	CRT6
CRT1	.00	.28	.46	.56	.63	.40
CRT2	.45	.00	.66	.58	.62	.56
CRT3	.66	.60	.00	.62	.58	.62
CRT4	.62	.40	.46	.00	.60	.33
CRT5	.56	.66	.43	.37	.00	.60
CRT6	.62	.58	.37	.33	.37	.00

4.5. Validation of the proposed model

In order to validate the results of the proposed model, a different analysis is also made with the help of VIKOR. Additionally, sensitivity analysis has also been performed by considering six different cases. Table 15 identifies the analysis results.

Table 7
Weighted results.

	CRT1	CRT2	CRT3	CRT4	CRT5	CRT6	D	E	D+E	D-E	Weights
CRT1	.75	.75	.76	.80	.90	.77	4.74	2.93	7.67	1.81	.153
CRT2	1.04	.80	.94	.94	1.05	.96	5.73	2.55	8.29	3.18	.165
CRT3	1.14	1.00	.80	1.00	1.09	1.01	6.04	2.50	8.54	3.53	.170
CRT4	.95	.79	.78	.67	.92	.78	4.89	3.41	8.30	1.48	.166
CRT5	.99	.91	.82	.83	.81	.90	5.25	3.95	9.20	1.30	.184
CRT6	.90	.80	.72	.73	.82	.65	4.63	3.52	8.15	1.10	.163

Table 8
CFGE for alternatives.

	ALT1			ALT2			ALT3		
	EXP1	EXP2	EXP3	EXP1	EXP2	EXP3	EXP1	EXP2	EXP3
CRT1	bwn “p” and “f”	atl “f”	grt “f”	bwn “f” and “g”	atl “f”	bwn “f” and “b”	bwn “f” and “b”	bwn “f” and “g”	grt “f”
CRT2	bwn “f” and “b”	bwn “f” and “b”	grt “f”	bwn “p” and “f”	atl “f”	bwn “f” and “b”	bwn “f” and “b”	grt “f”	bwn “f” and “b”
CRT3	atm “g”	atl “f”	bwn “f” and “b”	bwn “f” and “g”	bwn “f” and “b”	bwn “f” and “b”	grt “f”	bwn “g” and “b”	bwn “f” and “b”
CRT4	bwn “p” and “f”	atl “f”	bwn “f” and “b”	atl “g”	bwn “p” and “f”	bwn “f” and “b”	bwn “f” and “b”	atm “g”	bwn “g” and “b”
CRT5	bwn “f” and “g”	bwn “f” and “b”	grt “f”	atm “g”	bwn “g” and “b”	grt “f”	atm “g”	atm “g”	bwn “g” and “b”
CRT6	atl “g”	bwn “p” and “f”	bwn “f” and “b”	bwn “f” and “b”	atl “g”	atm “g”	bwn “f” and “b”	bwn “g” and “b”	grt “f”
	ALT4			ALT5					
	EXP1	EXP2	EXP3	EXP1	EXP2	EXP3			
CRT1	bwn “f” and “b”	bwn “f” and “g”	atl “f”	bwn “f” and “b”	bwn “f” and “b”	bwn “g” and “b”			
CRT2	atl “f”	grt “f”	atm “g”	bwn “g” and “b”	grt “f”	bwn “g” and “b”			
CRT3	bwn “f” and “b”	bwn “g” and “b”	atm “g”	grt “f”	bwn “g” and “b”	atm “g”			
CRT4	bwn “f” and “g”	atm “g”	atm “g”	bwn “g” and “b”	bwn “g” and “b”	bwn “g” and “b”			
CRT5	grt “f”	atm “g”	bwn “f” and “b”	grt “f”	bwn “g” and “b”	bwn “g” and “b”			
CRT6	bwn “f” and “b”	bwn “g” and “b”	bwn “f” and “b”	bwn “g” and “b”	bwn “g” and “b”	bwn “g” and “b”			

Between: bwn; At least: atl; Lower than: lot; Greater than: grt; At most: atm

Table 9
Boundaries of linguistic term sets for alternatives.

	ALT1			ALT2			ALT3		
	EXP1	EXP2	EXP3	EXP1	EXP2	EXP3	EXP1	EXP2	EXP3
CRT1	[p, f]	[f, b]	[g, b]	[f, g]	[f, b]	[f, b]	[f, b]	[p, f]	[g, b]
CRT2	[f, b]	[f, b]	[g, b]	[p, f]	[f, b]	[f, b]	[f, b]	[g, b]	[f, b]
CRT3	[w, g]	[f, b]	[f, b]	[f, g]	[f, b]	[f, b]	[g, b]	[g, b]	[f, b]
CRT4	[p, f]	[f, b]	[f, b]	[g, b]	[p, f]	[f, b]	[f, b]	[f, b]	[g, b]
CRT5	[f, g]	[f, b]	[g, b]	[w, g]	[g, b]	[g, b]	[w, g]	[w, g]	[g, b]
CRT6	[g, b]	[p, f]	[f, b]	[f, b]	[g, b]	[w, g]	[f, b]	[f, b]	[g, b]
	ALT4			ALT5					
	EXP1	EXP2	EXP3	EXP1	EXP2	EXP3			
CRT1	[f, b]	[f, g]	[f, b]	[f, b]	[f, b]	[g, b]			
CRT2	[f, b]	[g, b]	[w, g]	[g, b]	[g, b]	[g, b]			
CRT3	[f, b]	[g, b]	[w, g]	[g, b]	[g, b]	[w, g]			
CRT4	[f, g]	[w, g]	[w, g]	[g, b]	[g, b]	[g, b]			
CRT5	[g, b]	[w, g]	[f, b]	[g, b]	[g, b]	[g, b]			
CRT6	[f, b]	[g, b]	[f, b]	[g, b]	[g, b]	[g, b]			

Table 15 states that the results of both TOPSIS and VIKOR are quite similar. On the other side, it is also understood that the results of six different cases are almost the same. This situation explains that analysis results are reliable and coherent. The details of the analysis results are also illustrated in Fig. 4.

5. Conclusions and discussions

In this study, environmental management systems are evaluated with the aim of finding appropriate energy pricing strategy. A novel fuzzy MCDM model is created for this purpose. First of all, by the help of the comprehensive literature review, seven different environmental criteria are identified. HIVPF DEMATEL

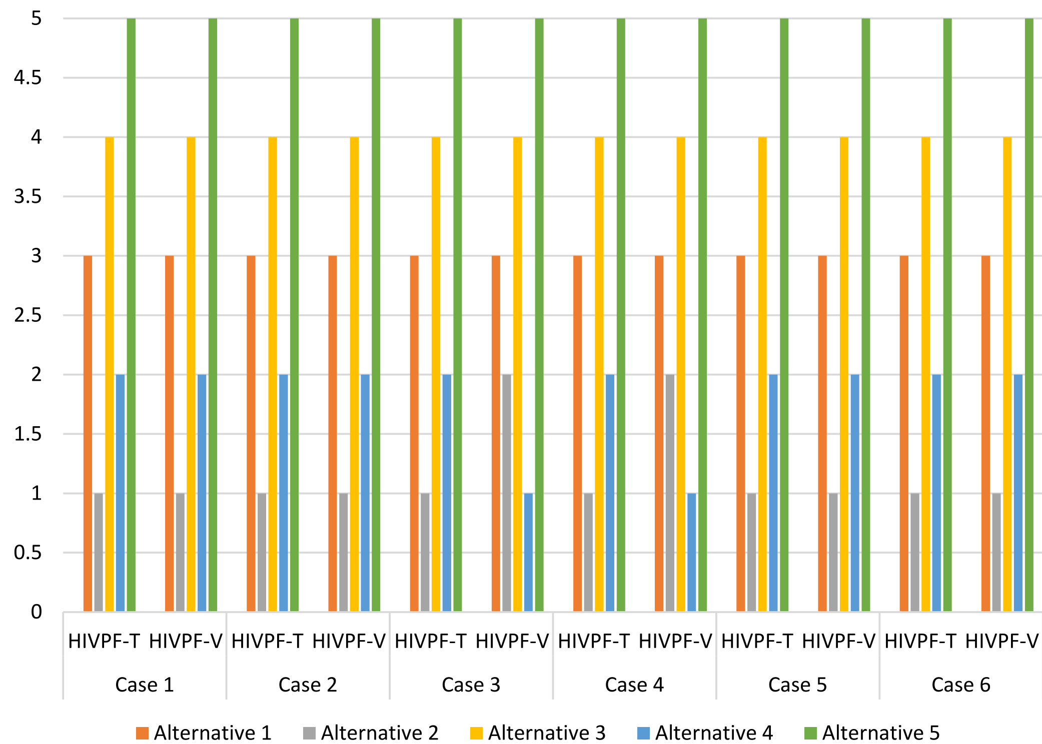

Fig. 4. Sensitivity analysis results.

Table 6
NM.

	CRT1	CRT2	CRT3	CRT4	CRT5	CRT6
CRT1	.00	.09	.15	.18	.20	.13
CRT2	.15	.00	.21	.19	.20	.18
CRT3	.21	.19	.00	.20	.19	.20
CRT4	.20	.13	.15	.00	.19	.11
CRT5	.18	.21	.14	.12	.00	.19
CRT6	.20	.19	.12	.11	.12	.00

Table 10
IVPFs for alternatives.

	ALT1	ALT2	ALT3	ALT4	ALT5
CRT1	([.60,.67], [.20,.40])	([.40,.73], [.20,.40])	([.60,.67], [.20,.40])	([.60,.73], [.20,.40])	([.60,.80], [.40,.47])
CRT2	([.60,.80], [.40,.47])	([.60,.67], [.20,.33])	([.60,.80], [.40,.47])	([.60,.73], [.20,.33])	([.60,.73], [.40,.60])
CRT3	([.60,.73], [.20,.27])	([.60,.73], [.20,.40])	([.60,.80], [.40,.53])	([.60,.73], [.20,.33])	([.60,.73], [.20,.40])
CRT4	([.60,.67], [.20,.33])	([.60,.67], [.20,.40])	([.60,.80], [.40,.47])	([.40,.60], [.10,.33])	([.60,.73], [.40,.60])
CRT5	([.60,.73], [.40,.47])	([.60,.73], [.20,.40])	([.60,.67], [.10,.20])	([.60,.73], [.20,.33])	([.60,.73], [.40,.60])
CRT6	([.60,.67], [.20,.40])	([.60,.73], [.20,.33])	([.60,.80], [.40,.47])	([.60,.80], [.40,.47])	([.60,.73], [.40,.60])

Table 11
Defuzzified DM.

	CRT1	CRT2	CRT3	CRT4	CRT5	CRT6
ALT1	.516	.460	.663	.562	.408	.516
ALT2	.406	.562	.577	.516	.577	.624
ALT3	.516	.460	.396	.460	.661	.460
ALT4	.577	.624	.624	.449	.624	.460
ALT5	.460	.284	.577	.284	.284	.284

Table 12
Normalized DM.

	CRT1	CRT2	CRT3	CRT4	CRT5	CRT6
ALT1	.463	.418	.516	.542	.344	.479
ALT2	.365	.511	.449	.497	.486	.579
ALT3	.463	.418	.308	.444	.558	.427
ALT4	.518	.567	.485	.433	.526	.427
ALT5	.413	.258	.449	.274	.240	.264

Table 13
Weighted DM.

	CRT1	CRT2	CRT3	CRT4	CRT5	CRT6
ALT1	.071	.069	.088	.090	.063	.078
ALT2	.056	.084	.076	.082	.089	.094
ALT3	.071	.069	.052	.073	.102	.069
ALT4	.079	.094	.083	.072	.097	.069
ALT5	.063	.043	.076	.045	.044	.043

methodology is considered to weight these items. Additionally, five different pricing strategies are examined by using both HIVPF TOPSIS and VIKOR. Also, a sensitivity analysis is also performed by considering six different conditions. It is defined that the results of both TOPSIS and VIKOR are similar. On the other side, it is also seen that the results of six different cases are almost the same. This situation gives information that analysis results of the proposed model are reliable and coherent. It is identified that safety incidence and waste management are the most crucial factors for the sustainability of the energy price. Furthermore, skimming is found as the best pricing strategy for the energy industry.

It has been observed that security factors have a great impact on the continuity of energy prices. Therefore, it is of vital importance to take the necessary security measures in power generation facilities. This stated situation is independent of energy types. In case of accidents due to the lack of security measures in energy production facilities, the damage to be obtained will seriously reduce the profitability of energy investments. As a

Table 14
Significant values for alternatives.

	D^+	D^-	CC_i
ALT1	.050	.076	.604
ALT2	.031	.091	.744
ALT3	.053	.076	.590
ALT4	.032	.091	.742
ALT5	.105	.025	.193

result, there will be significant fluctuations in energy prices in the market. In order to prevent this problem, periodic inspections should be made whether the necessary security measures have been taken or not. In this way, it will be possible to minimize the risk of accidents that may occur in energy production facilities. Chung et al. (2017), Taghizadeh-Hesary et al. (2019) and Filipović et al. (2018) also focused on the influencing factors of energy price stability. In this context, they stated that security measures should be made for the sustainability of the energy prices.

It is also defined that skimming is the best pricing strategy for the energy industry. It is understood that energy companies should primarily present high prices to the market. With the help of this situation, high earnings can be obtained owing to some parts of the market demand. However, there is a high possibility that the market demand can decrease after a point because of high prices. In this framework, energy companies should reduce the prices. This situation increases the efficiency of the energy investments so that it can be much easier to provide sustainability in the energy prices. Zu and Zeng (2020), Chan et al. (2018), Yan and Han (2021) and Chen et al. (2020) also recommended skimming pricing strategy for the energy industry.

The main contribution of this study is proposing a new mathematical model to solve a significant problem regarding energy prices. In this fuzzy hybrid MCDM model, the criteria are weighted with HIVPF DEMATEL. There are also different MCDM models to weight the factors according to their significance, such as AHP and ANP. Within this context, Dinçer and Yüksel (2018) created a model to define new service development competencies in Turkish banking sector. In this study, balanced scorecard-based factors are weighted with fuzzy AHP model. Similarly, Silahtaroğlu et al. (2021) defined the significant factors of the currency exchange rate risks by the same methodology. Moreover, Wang et al. (2020a,b) and Bakir and Atalik (2021) generated a fuzzy model by using AHP approach. In these models, although the criteria can be weighted, the causal relationship between these factors cannot be identified. Nevertheless, because DEMATEL method is preferred in the proposed model of this study, impact relation map of the criteria can also be defined.

Additionally, in the proposed model of this study, a hybrid fuzzy modelling is preferred. In this context, different MCDM techniques are used in all stages of the analysis. In other words, DEMATEL is used to weight the criteria and alternatives are ranked by considering TOPSIS and VIKOR. In some non-hybrid models in the literature, only one MCDM method is used to rank the alternatives. For instance, Rostampour (2012) aimed to rank internet web browsers. In this study, TOPSIS methodology was taken into consideration to evaluate the alternatives. However, the weights of the criteria are assumed as equal. Also, Hájek et al. (2018) integrated balanced scorecard and fuzzy TOPSIS methodology to make innovation performance analysis. Similarly, the criteria weights are accepted as equal by the authors. It is obvious that in the proposed model of this study, more objective evaluations can be made by using a hybrid methodology.

The analysis results can pave the way for both academicians, policy makers and investors. In this study, a novel hybrid fuzzy MCDM model has been generated to find influencing factors of energy price stability. In the future studies, this model can be extended by the researchers. For instance, Spherical fuzzy numbers can be taken into consideration. With the help of this situation, the results of the different models can be compared. Similarly, academicians can prefer to use different MCDM techniques for the future studies, such as COPRAS and MOORA. On the other side, the results of these study can be very helpful for the policy makers. Because energy investments play a key role for the sustainable economic development of the countries, the government aim to generate appropriate policies to increase these investments. Hence, based on the analysis results of this study, it is recommended that the governments should make legal arrangements for the safety incidence and waste management issued. Owing to this situation, effectiveness in the energy market can be provided. Finally, energy investors can also benefit from the analysis results of this study. In this framework, they can implement skimming pricing strategy to increase the efficiency.

However, the biggest limitation of this study is to make evaluation regarding energy prices in a general manner. In the future studies, different renewable energy types can be examined, such as renewable energy prices and nuclear energy prices. With the help of this situation, more unique strategies can be generated for the special type of the energy investments. In other words, this situation provides a more specific focus for the sustainability of the energy prices. Additionally, fuzzy MCDM modelling is preferred in this study. Nonetheless, different approaches can be used in the analysis process, such as regression or cointegration analysis. This situation provides an opportunity to make comparative analysis between different methodologies. It is also possible to mention some limitations of the proposed model of this study. During the evaluation process of the criteria, the decision makers were not given the opportunity to not evaluate. Therefore, the evaluators had to give a score even though they could not have detailed information about some criteria. In future studies, experts may be given the opportunity not to make evaluations. Missing evaluations can be analysed by considering the incomplete preferences approach. This will help reduce uncertainties in the decision-making process.

Table 15
Comparative ranking results with sensitivity analysis.

	Case 1		Case 2		Case 3		Case 4		Case 5		Case 6	
	HIVPF-T	HIVPF-V	HIVPF-T	HIVPF-V	HIVPF-T	HIVPF-V	HIVPF-T	HIVPF-V	HIVPF-T	HIVPF-V	HIVPF-T	HIVPF-V
ALT1	3	3	3	3	3	3	3	3	3	3	3	3
ALT2	1	1	1	1	1	2	1	2	1	1	1	1
ALT3	4	4	4	4	4	4	4	4	4	4	4	4
ALT4	2	2	2	2	2	1	2	1	2	2	2	2
ALT5	5	5	5	5	5	5	5	5	5	5	5	5

HIVPF-T: Hesitant Interval-valued Pythagorean Fuzzy TOPSIS; HIVPF-V: Hesitant Interval-valued Pythagorean Fuzzy VIKOR

Table A.1
Literature review table for the studies regarding energy price stability.

Authors	Results
Gamtessa and Olani (2018)	Technological developments contribute the energy generation process
Rehmatulla and Smith (2020)	Technological developments reduce the costs of energy investments
Zhang et al. (2019a,b)	Technological improvements increase the energy price stability
Murad et al. (2019)	There is a strong relationship between energy price and technological improvements.
Yang et al. (2019)	They concluded that technological innovations have a positive influence on the sustainability of the energy pricing
Barkhordari and Fattahi (2017)	Companies should follow technological improvements to increase sustainability in the energy prices.
Chan (2020)	Carbon tax plays a key role for the sustainability of the energy prices.
Lin and Xu (2019)	They advocated the introduction of a carbon tax on fossil fuels.
Shi and Sun (2017)	Governments should establish effective regulations to reduce carbon emission.
Amann et al. (2021)	Regulations play an important role for the effectiveness of the energy pricing.
Ju et al. (2017)	Governments should create necessary regulations to increase stability for energy prices.
Khalid et al. (2018)	In case energy companies experience financial problems, there may be disruptions in energy production.
Yang et al. (2020)	It is very important for energy companies to experience financial problems for sustainable energy prices
Jalilzadehazhari et al. (2020)	Providing some incentives to energy companies by the state will contribute to the financial performance of companies
Rentschler and Kornejew (2017)	They claimed that the financial performance of the energy companies has a significant impact on the stability of the energy prices.
Huuki et al. (2021)	They highlighted the importance of the financial performances of the energy companies for energy price stability.
Bissing et al. (2019)	Parallel to growing population in the world, the demand for energy is also increasing which causes problems for energy price stability.
Gbatu et al. (2019)	Radically increasing energy demand negatively affects energy price stability.
Wu et al. (2020)	Thanks to the increase in renewable energy projects, there is a significant increase in energy supply which improves energy price stability.
Liu et al. (2020)	Thanks to increased energy production, the effect of supply-based shocks in energy prices can be minimized

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CRediT authorship contribution statement

Zhaohan Ding: Conceptualization, Methodology, Software, Data curation, Writing – original draft. **Serhat Yüksel:** Supervision, Visualization, Investigation, Data curation, Methodology, Conceptualization. **Hasan Dinçer:** Supervision, Software, Validation, Methodology, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A

See Table A.1.

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