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Research paper

Collaboration enhanced hybrid fuzzy decision-making approach to analyze the renewable energy investment projects

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ABSTRACT

The aim of this study is to examine the cost management strategies of low-carbon renewable energy projects. This manuscript has important contributions by evaluating different cost-management to increase renewable energy investment projects. Owing to the analysis results of this study, the ways to minimize carbon emission problem can be presented. Additionally, another important contribution of this study is to generate a novel hybrid model based on Pythagorean fuzzy DEMATEL, TOPSIS and Shapley value to find appropriate policies to improve these projects. Furthermore, the accuracy of the proposed model is measured for each cooperative cost management strategy by using the VIKOR method. In addition, sensitivity analysis is also applied with 5 cases for both the TOPSIS and VIKOR methods by changing the weighting results of the criteria consecutively. It is defined that the proposed model is coherent and applicable for the further studies. Moreover, the ranking results of the sensitivity analysis are also consistent with the different cases. The results indicate that internal process has always the lowest costs for the solar energy alternatives. In addition, customer is the lowest cost factor with respect to the wind energy alternative. Thus, it is obvious that improving the qualification of the employees is essential for the improvement of the solar energy projects. Moreover, the effectiveness of the wind energy investments can be increased with the help of giving significance to the customers. Furthermore, it is also concluded that when the level of the cooperation increases, the efficiency of the investments can be higher. Another important point is that if the investors prefer to make weak or strong cooperative cost management strategy, they should primarily focus on solar energy projects because they have lower costs in comparison with other alternatives.

1. Introduction

One of the biggest causes of environmental pollution problem is carbon emissions resulting from energy consumption. Especially with the effect of factors such as industrialization and increasing population, very serious increases in carbon emissions happen. If this problem is not solved, there is a risk that many people will become sick soon (Yüksel et al., 2021a,b). On the other hand, carbon emission also leads to an increase in the problem of global warming. As a result, droughts will occur, and seasonal balances will be disturbed. This situation endangers the lives of people and animals. Because of all these negativities, it is important to take the necessary measures to reduce the carbon emission problem. In this context, one of the most prominent issues is the utilization of renewable energy alternatives in the electricity generation process. Since natural resources such as wind and sun are used in these energy types, carbon emission is realized at minimum levels.

Despite its many benefits, renewable energy sources are still not preferred at the desired level in the world because the costs of renewable energy alternatives are very high compared to fossil fuels. In addition, the amount of energy obtained from renewable energy sources varies depending on the air temperature. In other words, while more energy is obtained at some times of the day, the amount of energy may decrease in some parts of the day. This situation creates the need for energy storage, which leads to an increase in energy costs. As this situation negatively affects the profitability of energy investment projects, some investors are reluctant to invest in renewable energies. On the other hand, the technological developments that occur contribute to the cost reduction of the renewable energy investments (Kiptoo et al., 2020). Thus, the profitability of these projects will be increased, and it will be possible for investors to pay more attention to this area.

The costs of renewable energy projects must be managed effectively. Investing in different projects at the same time can

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Table 1
Multidimensional criteria of the cost management for renewable energy investments.

Criteria	Supported Literature
Customer (C1)	Hast et al. (2018); Zhou et al. (2020)
Finance (C2)	Waheed et al. (2019); Yüksel et al. (2020)
Internal Process (C3)	Yao et al. (2019); Fankhauser and Jotzo (2018)
Learning (C4)	Waheed et al. (2019); Hamilton and Kelly (2017)
Growth (C5)	Liu et al. (2020); Yüksel et al. (2020)

Table 2
Weights of the factors.

	Weights (A1)	Weights (A2)	Weights (A3)
C1	0.124	0.185	0.183
C2	0.247	0.233	0.227
C3	0.256	0.243	0.205
C4	0.174	0.156	0.178
C5	0.200	0.182	0.208

Table 3
Average and total costs.

	A1	A2	A3	Average costs	Total costs
C1	0.124	0.185	0.183	0.164	0.492
C2	0.247	0.233	0.227	0.236	0.707
C3	0.256	0.243	0.205	0.235	0.704
C4	0.174	0.156	0.178	0.169	0.508
C5	0.200	0.182	0.208	0.196	0.589

Table 4
The cooperative cost orders for weak cost management strategy.

	A1	A2	A3
C1	1	5	5
C2	4	3	2
C3	5	4	1
C4	3	2	3
C5	2	1	4

Table 5
The cooperative cost orders for fair cost management strategy.

	A1	A2	A3
C1	1	5	5
C2	4	3	2
C3	5	4	1
C4	3	1	3
C5	2	2	4

Table 6
The cooperative cost orders for strong cost management strategy.

	A1	A2	A3
C1	1	3	3
C2	4	4	4
C3	5	5	1
C4	2	1	2
C5	3	2	5

contribute to achieving this goal. Considering that some of the costs in these projects are common, it will be possible to increase the cost effectiveness by focusing on different projects at the same time. Different aspects from the financial issues such as customer retention, advertising for the promotion of the company, and training expenditures for the development of staff should also be considered in the cost analysis (Kirikkaleli and Adebayo, 2021). For example, as a result of increasing the training given to the employees, their knowledge on the subject increases. This reduces the mistakes made by the personnel during the work process. Thus, it is possible to significantly reduce the costs of the project. On the other hand, technological developments also contribute to reducing the costs of renewable energy projects. Thanks to the research and development studies, new techniques will be developed for these projects. This will help the process to be carried out at a lower cost.

In summary, carbon emission is a very significant problem and renewable energy investments should be increased to overcome this problem. However, these projects have high-cost problems so that effective cost management should be performed to manage this issue. This study aims at defining the optimal cost management strategies for low-carbon renewable energy investments with a suggested model. Hence, the main research question of this study is to define key issues for the cost effectiveness of the renewable energy investment projects. In this model, firstly, the cost priorities of low-carbon renewable energy alternatives are determined with Pythagorean fuzzy DEMATEL. In this framework, balanced scorecard (BSC) perspectives are considered. Secondly, the cooperative cost management strategies are measured by Shapley values. Finally, the cooperative cost management strategies are ranked by using Pythagorean fuzzy TOPSIS. Furthermore, the accuracy of the proposed model is measured for each cooperative cost management strategy by using the VIKOR method. In addition, sensitivity analysis is also applied with 5 cases for both the TOPSIS and VIKOR methods by changing the weighting results of the criteria consecutively.

This manuscript has several important contributions. Firstly, evaluating different cost-management strategies has an important contribution to increase renewable energy investment projects. The analysis results of this study indicate the ways to minimize carbon emission problem. With the help of this situation, environmental problems can be handled more effectively. Moreover, this study has methodological novelties as well. Considering BSC perspectives to define the criteria brings many advantages. In this technique, both financial and non-financial issues are considered (Kaplan and Norton, 2007). This situation provides a broader view of cost management process. Hence, more appropriate evaluations can be performed (Dinçer et al., 2019a,b). Additionally, with the help of using coalition game theory, the impacts of each alternative can be identified (Rapoport, 2001). This situation contributes to make more reliable analysis (Straffin, 1993; Winston, 1998). Furthermore, owing to considering Pythagorean fuzzy sets, the uncertainties can be managed effectively (Cao et al., 2020; Zhu et al., 2019; Zhan et al., 2020).

In addition, using a hybrid methodology is also considered another important novelty of this suggested model. Within this context, different MCDM approaches are considered in various phases of the model (Awasthi et al., 2018; Rezaie et al., 2014). Therefore, it is obvious that considering hybrid methodology has a powerful contribution to increase objectivity (Büyüközkan and Görener, 2015). Also, DEMATEL technique measures the causality relationship between variables (Dinçer et al., 2020; Delen et al., 2020; Feng and Ma, 2020). Furthermore, both positive and negative optimal values are used in TOPSIS method (Dhiman and Deb, 2020). In this way, more sensitive results can be achieved (Ziemba et al., 2020; Dinçer and Yüksel, 2019). Moreover, making a comparative evaluation with VIKOR and performing sensitivity analysis provide opportunity to check the validity and reliability of the proposed model. The main reason of selecting VIKOR is that both the maximization of group utility and the minimization of individual regret can be taken into consideration (Kumar and Samuel, 2017; Hu et al., 2020). With the help of this situation, it can get the closest compromise solution to the optimal solution (Liang et al., 2018). Another advantage of this method is that it can deal with conflicting criteria (Titiyal et al., 2019).

Table 7
Cooperative cost rates of the low-carbon renewable energy alternatives by the cost management strategies.

Weak cooperative cost management strategy						
Alternatives	The lowest costs for the first round	The lowest costs for the second round	First round cost rate	Total cost rate	First round cost index	Total cost index
A1	C1	–				
A2	C5	C4	0.268	0.447	0.895	10.490
A3	C3	C2				
Fair cooperative cost management strategy						
Alternatives	The lowest costs for the first round	The lowest costs for the second round	First round cost rate	Total cost rate	First round cost index	Total cost index
A1	C1	–				
A2	C4	C5	0.332	0.582	0.829	10.455
A3	C3	C2				
Strong cooperative cost management strategy						
Alternatives	The lowest costs for the first round	The lowest costs for the second round	First round cost rate	Total cost rate	First round cost index	Total cost index
A1	C1	–				
A2	C4	C5	0.450	0.824	0.750	10.373
A3	C3	C2				

Table 8
Ranking results.

Weak cooperative cost management strategy				
	D+	D-	CCi	Ranks
A1	0.029	0.039	0.573	2
A2	0.022	0.039	0.639	1
A3	0.037	0.033	0.470	3
Fair cooperative cost management strategy				
	D+	D-	CCi	Ranks
A1	0.043	0.033	0.430	3
A2	0.026	0.047	0.641	1
A3	0.028	0.048	0.630	2
Strong cooperative cost management strategy				
	D+	D-	CCi	Ranks
A1	0.035	0.040	0.528	2
A2	0.023	0.044	0.653	1
A3	0.037	0.039	0.510	3

This manuscript has 7 different sections. Section 2 includes literature evaluation. Section 3 explains methodological backgrounds. Section 4 is related to the proposed model. Section 5 includes analysis results. Section 6 makes a discussion of the results by comparing the literature. Section 7 summarizes main conclusions.

2. Literature review

There is a large literature on low carbon energy. A significant number of researchers claim that there will be more sustainable economic growth by reducing carbon emissions in energy production (Hast et al., 2018; Yeh and Liao, 2017). In case the necessary measures are not taken, excessive energy use will lead to an increase in carbon emissions (Zhou et al., 2020; Waheed et al., 2019; Aye and Edoja, 2017). Therefore, there will be some losses as well as the benefits obtained because of energy production. Thus, the environment should not be harmed in the energy production process (Yao et al., 2019; Fernández-Amador et al., 2017). With the help of this issue, energy production will be able to contribute to sustainable economic development (Yüksel et al., 2020; Liu et al., 2020). Hamilton and Kelly (2017) made an evaluation about the impacts of the low-carbon energy production on the sustainable economic growth. They reached a conclusion that economic growth of these countries is strongly linked to the low-carbon energy production. Similarly, Shuai et al. (2019) examined the relationship between these items in 133 different countries by using decoupling analysis. It is concluded that to provide sustainability in economic development, carbon emission should be minimized with the help of the green energy usage. Fankhauser and Jotzo (2018) and Cheng et al. (2018) also identified similar findings in their studies.

Moreover, some studies also identified that high cost is a significant barrier to reduce carbon emission. Fossil fuels have a much lower cost compared to renewable energy alternatives (Lai and Locatelli, 2021; Salehi et al., 2017). Due to this advantage, most of the investors prefer fossil fuels to increase their profitability (Härtel and Korpås, 2021; Adler et al., 2017). This situation causes a significant increase in carbon emissions (Setyowati, 2021; Sun et al., 2017). Therefore, to minimize the carbon emission problem, financial problems must first be solved. In this context, investors are required to make their financial analysis effectively (Lizana et al., 2017). In this process, the needed funds should be obtained in the most optimal way and thus the costs must be reduced (Mao et al., 2017). On the other hand, the cash flows of the project should be evaluated effectively, and the company's potential liquidity risk should be minimized (Qian et al., 2019). Geddes et al. (2018) examined the low-carbon energy finance in Australia, the UK and Germany. They identified that the state investment banks have a significant role to lower the costs of these projects. Additionally, King and Van Den Bergh (2018) also evaluated the financial issues that impacts low carbon energy. They determined that carbon emission problem can be decreased when the cost of the low carbon transition can be reduced.

On the other hand, it has been stated in some studies that government support is essential to reduce the carbon emission problem. Taking actions to reduce carbon emissions is necessary in this respect (Bush et al., 2017). Also, companies may not be willing in this regard, as these applications involve significant costs. This is an obstacle to solving environmental pollution (Peters and Geden, 2017). In this framework, the support of states in this process is of vital importance (Rogge and Johnstone, 2017). In this context, governments can provide financial support to companies regarding practices to reduce carbon emissions. This helps companies to adapt more easily to applications such as carbon capture technology (Shen and Xie, 2018). In addition, legal procedures need to be developed to make carbon emission applications

Table 9
Comparative ranking results with sensitivity analysis.

	Case 1		Case 2		Case 3		Case 4		Case 5	
Weak cooperative cost management strategy										
	TOPSIS	VIKOR	TOPSIS	VIKOR	TOPSIS	VIKOR	TOPSIS	VIKOR	TOPSIS	VIKOR
A1	2	2	2	2	2	2	2	3	3	3
A2	1	1	1	1	1	1	1	1	1	1
A3	3	3	3	3	3	3	3	2	2	2
Fair cooperative cost management strategy										
	Case 1		Case 2		Case 3		Case 4		Case 5	
	TOPSIS	VIKOR	TOPSIS	VIKOR	TOPSIS	VIKOR	TOPSIS	VIKOR	TOPSIS	VIKOR
A1	3	3	3	3	3	3	3	3	3	3
A2	1	1	1	1	1	1	1	1	1	1
A3	2	2	2	2	2	2	2	2	2	2
Strong cooperative cost management strategy										
	Case 1		Case 2		Case 3		Case 4		Case 5	
	TOPSIS	VIKOR	TOPSIS	VIKOR	TOPSIS	VIKOR	TOPSIS	VIKOR	TOPSIS	VIKOR
A1	2	2	2	3	2	3	2	2	2	2
A2	1	1	1	1	1	1	1	1	1	1
A3	3	3	3	2	3	2	3	3	3	3

mandatory by the government (Monasterolo and Raberto, 2019). This will increase the use of these applications and contribute to solving the carbon emission problem more easily. Feldman and Hart (2018) examined low-carbon energy policies in the United States. They identified that the government should give priority to this issue and for this purpose, necessary legislation should be prepared. Furthermore, Warbroek and Hoppe (2017) tried to evaluate the low-carbon emission initiatives in the Dutch region. It is determined that governments should provide necessary supports in order to solve carbon emission problem.

MCDM models are used in the field of energy. For instance, Alkan and Albayrak (2020), Gündoğdu and Kahraman (2020) and Rani et al. (2020) ranked the renewable energy sources by using different MCDM methods, such as COPRAS, MULTIMOORA, AHP and TOPSIS. Some other researchers also preferred DEMATEL and TOPSIS approaches together to evaluate sustainable energy investment projects (Zhou et al., 2020; Li et al., 2020; Sangaiah et al., 2017; Rahimdel and Bagherpour, 2018; Peng et al., 2020). Moreover, Zhao and Li (2021), Jahangiri et al. (2020) and Zhu et al. (2020) defined the strategic directions in sustainable hydrogen investment decisions by considering VIKOR, TOPSIS and DEMATEL. Furthermore, in some studies, a specific renewable type was evaluated. Li et al. (2021) examined customer expectations for solar energy projects by DEMATEL and TOPSIS approaches. Qiu et al. (2020) considered the same methods to define risk-based investment strategies regarding the wind energy projects. Moreover, Meng et al. (2018), Chamodrakas and Martakos (2011) and Zhao and Li (2021) focused on the energy efficiency by considering TOPSIS approach. On the other hand, Wang et al. (2015) and Wu et al. (2017) made an evaluation regarding energy storage with the help of VIKOR methodology.

The main point of the literature analysis is that the popularity of the carbon emission increases especially in the last years. Most of the studies aimed to define key issues to reduce carbon emission problems. Another important situation is that MCDM models were considered in lots of the studies in the literature related to the energy. However, it is thought that there is a need for a more specific study which presents strategies to reduce costs of these projects. In this study, appropriate cost management strategies are aimed to be defined for low-carbon renewable energy alternatives by suggesting a new model based on fuzzy MCDM techniques.

3. Methodology

This section includes model description. At first, strategic outlook is given for the cooperation. Later, Pythagorean fuzzy sets are defined. Next, DEMATEL approach is explained. After that, TOPSIS methodology is defined.

3.1. Strategic outlook for the cooperation

Rational decisions could have several conflicts of interest in the complex decision-making environment and need for some strategies to reach the highest utility in the group game. Games of strategy and strategic conflicts should be redefined at the level of game-theoretic analysis. Accordingly, the concept of the game theory is portrayed by considering the possibilities and risks against the rational competitors and the cooperative strategies should be illustrated by including the potential of the market actors. So, the right and most appropriate decisions could be obtained with the comprehensive information of the cooperative strategies (Rapoport, 2001).

The cooperative games generally include more than two players entitled n-person games and the modern economic and social behaviors are constructed with the difficult interconnections among several competitors. For that, n-person games widely used for solving the complex decision problems of the global business and economic environment (Straffin, 1993).

The set of players are defined as $N = \{1, 2, \ldots n\}$ and S is the subset of N. The characteristic function v of a game is $v(S)$ and gives information about the competitive situation. The members of S can be sure of receiving if they act together and form a coalition. However, $x = (x\_1, x\_2, \ldots x\_n)$ is a reward vector that is an imputation. v(N) group rationality and individual rationality $v(i)$ are presented as in Eqs. (1) and (2) (Tullberg, 2006; Corchon and Puy, 1998).

$$v(N) = \sum_{i=1}^{i=n} x_i \tag{1}$$

$$x_i \geq v(\{i\}) \text{ for each } i \in N \tag{2}$$

The imputation $y = (y_1, y_2, \ldots, y_n)$ dominates x with a coalition S as in Eq. (3).

$$\sum_{i \in S} y_i \leq v(S) \text{ for all } i \in S, y_i > x_i \tag{3}$$

Table A.1
The linguistic evaluations for the criteria of low-carbon renewable energy alternatives.

A1															
Criteria	DM1					DM2					DM3				
	C1	C2	C3	C4	C5	C1	C2	C3	C4	C5	C1	C2	C3	C4	C5
C1		SML	SML	SML	MEM		MEM	HGH	SML	HGH		MEM	HGH	MEM	SML
C2	SML		HGH	SML	HGH	HGH		HGH	SML	HGH	HGH		HGH	MEM	HGH
C3	SML	HGH		SML	M	M	HGH		SML	SML	MEM	HGH		SML	MEM
C4	HGH	HGH	HGH		HGH	M	MEM	HGH		HGH	HGH	MEM	SML		HGH
C5	SML	MEM	HGH	SML		HGH	MEM	HGH	MEM		SML	MEM	HGH	MEM	
A2															
Criteria	DM1					DM2					DM3				
	C1	C2	C3	C4	C5	C1	C2	C3	C4	C5	C1	C2	C3	C4	C5
C1		MEM	HGH	MEM	MEM		MEM	HGH	SML	HGH		MEM	HGH	MEM	SML
C2	HGH		HGH	MEM	MEM	HGH		HGH	SML	HGH	HGH		HGH	MEM	HGH
C3	MEM	HGH		SML	MEM	MEM	HGH		SML	SML	MEM	HGH		SML	MEM
C4	MEM	HGH	HGH		HGH	MEM	MEM	HGH		HGH	HGH	MEM	SML		HGH
C5	HGH	MEM	HGH	MEM		HGH	MEM	HGH	MEM		SML	MEM	HGH	MEM	
A3															
Criteria	DM1					DM2					DM3				
	C1	C2	C3	C4	C5	C1	C2	C3	C4	C5	C1	C2	C3	C4	C5
C1		MEM	MEM	HGH	HGH		MEM	HGH	SML	HGH		MEM	HGH	MEM	SML
C2	HGH		HGH	MEM	HGH	HGH		HGH	SML	HGH	HGH		HGH	MEM	HGH
C3	SML	MEM		SML	MEM	MEM	HGH		SML	SML	MEM	HGH		SML	MEM
C4	MEM	HGH	HGH		HGH	MEM	MEM	HGH		HGH	HGH	MEM	SML		HGH
C5	HGH	MEM	MEM	HGH		HGH	MEM	HGH	MEM		SML	MEM	HGH	MEM	

Small: SML; high: HGH; medium: MEM.

Table A.2
Pythagorean fuzzy relation matrices for the low-carbon renewable energy alternatives.

A1					
	C1	C2	C3	C4	C5
C1		[0.225,0.3875]	[0.225,0.3875]	[0.225,0.3875]	[0.45,0.275]
C2	[0.225,0.3875]		[0.675,0.1625]	[0.225,0.3875]	[0.675,0.1625]
C3	[0.225,0.3875]	[0.675,0.1625]		[0.225,0.3875]	[0.45,0.275]
C4	[0.675,0.1625]	[0.675,0.1625]	[0.675,0.1625]		[0.675,0.1625]
C5	[0.225,0.3875]	[0.45,0.275]	[0.675,0.1625]	[0.225,0.3875]	
A2					
	C1	C2	C3	C4	C5
C1		[0.45,0.275]	[0.675,0.1625]	[0.45,0.275]	[0.45,0.275]
C2	[0.675,0.1625]		[0.675,0.1625]	[0.45,0.275]	[0.45,0.275]
C3	[0.45,0.275]	[0.675,0.1625]		[0.225,0.3875]	[0.45,0.275]
C4	[0.45,0.275]	[0.675,0.1625]	[0.675,0.1625]		[0.675,0.1625]
C5	[0.675,0.1625]	[0.45,0.275]	[0.675,0.1625]	[0.45,0.275]	
A3					
	C1	C2	C3	C4	C5
C1		[0.45,0.275]	[0.45,0.275]	[0.675,0.1625]	[0.675,0.1625]
C2	[0.675,0.1625]		[0.675,0.1625]	[0.45,0.275]	[0.675,0.1625]
C3	[0.225,0.3875]	[0.45,0.275]		[0.225,0.3875]	[0.45,0.275]
C4	[0.45,0.275]	[0.675,0.1625]	[0.675,0.1625]		[0.675,0.1625]
C5	[0.675,0.1625]	[0.45,0.275]	[0.45,0.275]	[0.675,0.1625]	

Shapley value is a unique reward vector that gives more equitable solutions for n-person games. This value shows the effects of cooperation in the interchanges the players' rewards. Group rationality is considered, and additional value of each player is measured for all coalitions of cooperative games. The reward of the ith player x_i is presented by using Eq. (4) and $|S|$ demonstrates the number of players in S and for $n \geq 1$ (Winston, 1998).

$$x_i = \sum_{all\ S\ for\ which\ i\ is\ not\ in\ S} \frac{|S|!\,(n-|S|-1)!}{n!} \left[v\left(S \cup \{i\}\right) - v(S)\right] \tag{4}$$

3.2. Pythagorean fuzzy sets (P)

Pythagorean fuzzy sets (P) is the extension of intuitionistic fuzzy sets. In these sets, some new conditions are presented. In this framework, a wider definition range is offered. According to this new condition, the sum of the squares of the membership and non-membership values must be at most 1. P is identified in Eq. (5) and ϑ indicates universal set (Cao et al., 2020).

$$P = \{\langle \vartheta, \mu_P(\vartheta), n_P(\vartheta)\rangle \,/\, \vartheta \epsilon U\} \tag{5}$$

The membership and non-membership functions are represented by μ_P and n_P: $U \to [0, 1]$ as in Eq. (6) (Zhu et al., 2019).

$$(\mu_P(\vartheta))^2 + (n_P(\vartheta))^2 \leq 1 \tag{6}$$

After that, Eq. (7) is considered to compute the degree of indeterminacy.

$$\pi_P(\vartheta) = \sqrt{1 - (\mu_P(\vartheta))^2 - (n_P(\vartheta))^2} \tag{7}$$

Table A.3
DFR.

A1					
	C1	C2	C3	C4	C5
C1		0.043	0.219	0.033	0.127
C2	0.219		0.429	0.033	0.429
C3	0.043	0.429		0.100	0.043
C4	0.320	0.219	0.219		0.429
C5	0.043	0.127	0.429	0.043	
A2					
	C1	C2	C3	C4	C5
C1		0.127	0.429	0.043	0.127
C2	0.429		0.429	0.043	0.320
C3	0.127	0.429		0.100	0.043
C4	0.219	0.219	0.219		0.429
C5	0.219	0.127	0.429	0.127	
A3					
	C1	C2	C3	C4	C5
C1		0.127	0.320	0.127	0.219
C2	0.429		0.429	0.043	0.429
C3	0.043	0.320		0.100	0.043
C4	0.219	0.219	0.219		0.429
C5	0.219	0.127	0.320	0.219	

Table A.4
Normalized matrix.

A1					
	C1	C2	C3	C4	C5
C1	0.000	0.036	0.185	0.027	0.107
C2	0.185	0.000	0.361	0.027	0.361
C3	0.036	0.361	0.000	0.084	0.036
C4	0.269	0.185	0.185	0.000	0.361
C5	0.036	0.107	0.361	0.036	0.000
A2					
	C1	C2	C3	C4	C5
C1	0.000	0.104	0.351	0.035	0.104
C2	0.351	0.000	0.351	0.035	0.262
C3	0.104	0.351	0.000	0.081	0.035
C4	0.179	0.179	0.179	0.000	0.351
C5	0.179	0.104	0.351	0.104	0.000
A3					
	C1	C2	C3	C4	C5
C1	0.000	0.095	0.240	0.095	0.165
C2	0.323	0.000	0.323	0.032	0.323
C3	0.032	0.240	0.000	0.075	0.032
C4	0.165	0.165	0.165	0.000	0.323
C5	0.165	0.095	0.240	0.165	0.000

Also, Eqs. (8)–(12) show the calculations details (Zhan et al., 2020).

$$P_1 = \left\{\left\langle \vartheta, P_1(\mu_{P_1}(\vartheta), n_{P_1}(\vartheta))\right\rangle / \vartheta \epsilon U\right\} \text{ and } P_2 = \left\{\left\langle \vartheta, P_2(\mu_{P_2}(\vartheta), n_{P_2}(\vartheta))\right\rangle / \vartheta \epsilon U\right\} \quad (8)$$

$$P_1 \oplus P_2 = P\left(\sqrt{\mu_{P_1}^1 + \mu_{P_2}^2 - \mu_{P_1}^1 \mu_2^2}, n_{P_1} n_{P_1}\right) \quad (9)$$

$$P_1 \otimes P_2 = P\left(\mu_{P_1}\mu_{P_2}, \sqrt{n_{P_1}^2 + n_{P_2}^2 - n_{P_1}^2 n_{P_2}^2}\right) \quad (10)$$

$$\lambda P = P\left(\sqrt{1 - \left(1 - \mu_p^2\right)^{\lambda}}, \left(n_p\right)^{\lambda}\right), \lambda > 0 \quad (11)$$

$$P^{\lambda} = P\left(\left(\mu_p\right)^{\lambda}, \sqrt{1 - \left(1 - n_p^2\right)^{\lambda}}\right), \lambda > 0 \quad (12)$$

Finally, Eq. (13) is used for the calculation of the score function (S) which is considered in the defuzzification process (Ali and Sarwar, 2021; Liu et al., 2021; Ohlan, 2021).

Table A.5
TRM.

A1					
	C1	C2	C3	C4	C5
C1	0.082	0.214	0.375	0.075	0.234
C2	0.349	0.402	0.822	0.139	0.624
C3	0.209	0.576	0.396	0.151	0.335
C4	0.455	0.562	0.739	0.114	0.681
C5	0.169	0.386	0.633	0.112	0.221
A2					
	C1	C2	C3	C4	C5
C1	0.348	0.488	0.800	0.167	0.354
C2	0.827	0.584	10.110	0.240	0.624
C3	0.507	0.684	0.582	0.208	0.361
C4	0.684	0.693	0.948	0.199	0.707
C5	0.577	0.564	0.913	0.253	0.329
A3					
	C1	C2	C3	C4	C5
C1	0.224	0.321	0.532	0.232	0.397
C2	0.613	0.353	0.784	0.268	0.649
C3	0.235	0.381	0.270	0.172	0.258
C4	0.468	0.451	0.609	0.209	0.632
C5	0.394	0.348	0.568	0.304	0.294

$$S(\vartheta) = (\mu_P(\vartheta))^2 - (n_P(\vartheta))^2 \text{ where } S(\vartheta) \in [-1, 1] \quad (13)$$

3.3. DEMATEL

DEMATEL method is a technique used to choose the best one among the complex factors. On the other hand, a structural model that shows the causal relationships between these factors can also be created. In other words, it can be understood which factor is more effective on the others. In the first step, the evaluations are obtained from the expert team. Next, the direct relation matrix (A) is created as in Eq. (14) (Kumar et al., 2021; Dinçer et al., 2020).

$$A = \begin{bmatrix} 0 & a_{12} & a_{13} & & \cdots & a_{1n} \\ a_{21} & 0 & a_{23} & & \cdots & a_{2n} \\ a_{31} & a_{32} & 0 & & \cdots & a_{3n} \\ \vdots & \vdots & \vdots & \ddots & & \vdots \\ a_{n1} & a_{n2} & a_{n3} & & \cdots & 0 \end{bmatrix} \quad (14)$$

In this matrix, a_{ij} demonstrates the effect of item i on the factor j. Later, the normalized matrix (B) is created with Eqs. (15) and (16) (Delen et al., 2020).

$$B = \frac{A}{\max_{1 \le i \le n} \sum_{j=1}^{n} a_{ij}} \quad (15)$$

$$0 \le b_{ij} \le 1 \quad (16)$$

Total relation matrix (C) is generated with B and identity matrix (I) as in Eq. (17) (Feng and Ma, 2020)

$$C = B(I - B)^{-1} \quad (17)$$

Moreover, the sums of columns and rows (E and D) are defined by Eqs. (18) and (19).

$$D = \left[\sum_{j=1}^{n} e_{ij}\right]_{nx1} \quad (18)$$

$$E = \left[\sum_{i=1}^{n} e_{ij}\right]_{1xn} \quad (19)$$

In this process, $D + E$ is considered to weight the criteria. The causality analysis is performed with $D - E$. In this scope,

Table A.6
Weak cooperative costs and Shapley values (SV).

C1			
Orders	Cooperative costs		
	A1	A2	A3
1,2,3	0.124	0.176	0.000
1,3,2	0.124	0.000	0.176
2,1,3	0.115	0.185	0.000
2,3,1	0.000	0.185	0.115
3,1,2	0.117	0.000	0.183
3,2,1	0.000	0.117	0.183
SV	0.080	0.111	0.109
C2			
Orders	Cooperative costs		
	A1	A2	A3
1,2,3	0.247	0.053	0.000
1,3,2	0.247	0.000	0.053
2,1,3	0.067	0.233	0.000
2,3,1	0.000	0.233	0.067
3,1,2	0.073	0.000	0.227
3,2,1	0.000	0.073	0.227
SV	0.106	0.099	0.096
C3			
Orders	Cooperative costs		
	A1	A2	A3
1,2,3	0.256	0.044	0.000
1,3,2	0.256	0.000	0.044
2,1,3	0.057	0.243	0.000
2,3,1	0.000	0.243	0.057
3,1,2	0.095	0.000	0.205
3,2,1	0.000	0.095	0.205
SV	0.111	0.104	0.085
C4			
Orders	Cooperative costs		
	A1	A2	A3
1,2,3	0.174	0.126	0.000
1,3,2	0.174	0.000	0.126
2,1,3	0.144	0.156	0.000
2,3,1	0.000	0.156	0.144
3,1,2	0.122	0.000	0.178
3,2,1	0.000	0.122	0.178
SV	0.102	0.093	0.104
C5			
Orders	Cooperative costs		
	A1	A2	A3
1,2,3	0.200	0.100	0.000
1,3,2	0.200	0.000	0.100
2,1,3	0.118	0.182	0.000
2,3,1	0.000	0.182	0.118
3,1,2	0.092	0.000	0.208
3,2,1	0.000	0.092	0.208
SV	0.102	0.093	0.106

threshold value (α) is considered as in Eq. (20) (Mahdiraji et al., 2021; Karaşan et al., 2021).

$$\alpha = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n}\left[e_{ij}\right]}{N} \tag{20}$$

3.4. TOPSIS

TOPSIS method is used to select the most optimal among different alternatives. In this method, distances from positive and negative ideal solutions are considered. In this way, it is possible to determine the ideal solutions. TOPSIS approach ranks different alternatives with respect to their significance. Firstly, Eq. (21) is considered to obtain normalized values (Dhiman and Deb, 2020).

$$r_{ij} = \frac{X_{ij}}{\sqrt{\sum_{i=1}^{m} X_{ij}^2}} i = 1, 2, 3, ..m \text{ and } j = 1, 2, 3, ..n \tag{21}$$

Secondly, Eq. (22) is taken into consideration to weight these values (Ziemba et al., 2020).

$$v_{ij} = w_{ij} \times r_{ij} \tag{22}$$

After that, with the help of Eqs. (23) and (24), the positive and negative (A^+, A^-) optimal solutions are identified.

$$A^+ = \left\{v_{1j}, v_{2j}, \ldots, v_{mj}\right\} = \left\{\max\ v_{1j} \text{ for } \forall j \in n\right\} \tag{23}$$

$$A^- = \left\{v_{1j}, v_{2j}, \ldots, v_{mj}\right\} = \left\{\min\ v_{1j} \text{ for } \forall j \in n\right\} \tag{24}$$

Later, the distances to the best and the worst solutions (D_i^+, D_i^-) are computed as in Eqs. (25) and (26) (Dinçer and Yüksel, 2019).

$$D_i^+ = \sqrt{\sum_{j=1}^{n}\left(v_{ij} - A_j^+\right)^2} \tag{25}$$

$$D_i^- = \sqrt{\sum_{j=1}^{n}\left(v_{ij} - A_j^-\right)^2} \tag{26}$$

Eq. (27) is considered to compute the relative closeness to the ideal solution (RC_i) so that alternatives can be ranked (Phate et al., 2021; Kurdyś-Kujawska et al., 2021; Jiang et al., 2021).

$$RC_i = \frac{D_i^-}{D_i^+ + D_i^-} \tag{27}$$

4. Proposed model

While considering the techniques emphasized above, a new model is generated. The phases and steps of this novel model are depicted in Fig. 1.

The proposed model consists of 3 different phases. Firstly, the cost priorities of low-carbon renewable energy alternatives are determined with Pythagorean fuzzy DEMATEL. In this phase, primarily, the criteria and alternatives are defined for the cost management strategies of the low-carbon renewable energy investments. Next, the linguistic evaluations of the decision makers are obtained for the criteria of the low-carbon renewable energy alternatives. Later, the Pythagorean fuzzy relation matrix is constructed. After the defuzzification and normalization process, the total relation matrix is created. By using the values in this matrix, the weights of the criteria can be calculated. In the second phase, the cooperative cost management strategies are measured for the low-carbon renewable energy alternatives: (i) These strategies are defined; (ii) The Shapley values of the multidimensional criteria are calculated for the cooperative cost management strategies; (iii) Low-carbon renewable energy alternatives are listed, and the cooperative cost rates are then computed. The final phase includes the ranking of the cooperative cost management strategies for the low-carbon renewable energy alternatives with TOPSIS. First, the decision matrix is constructed with the Shapley values for the cooperative cost management strategies. After that, normalized and weighted decision matrices are generated. Consequently, the low-carbon renewable energy alternatives by the cooperative cost management strategies are ranked. Additionally, the accuracy of the proposed model is measured for each cooperative cost management strategy by using the VIKOR method. Accordingly, sensitivity analysis is also applied with 5 cases for both the TOPSIS and VIKOR methods by changing the weighting results of the criteria consecutively.

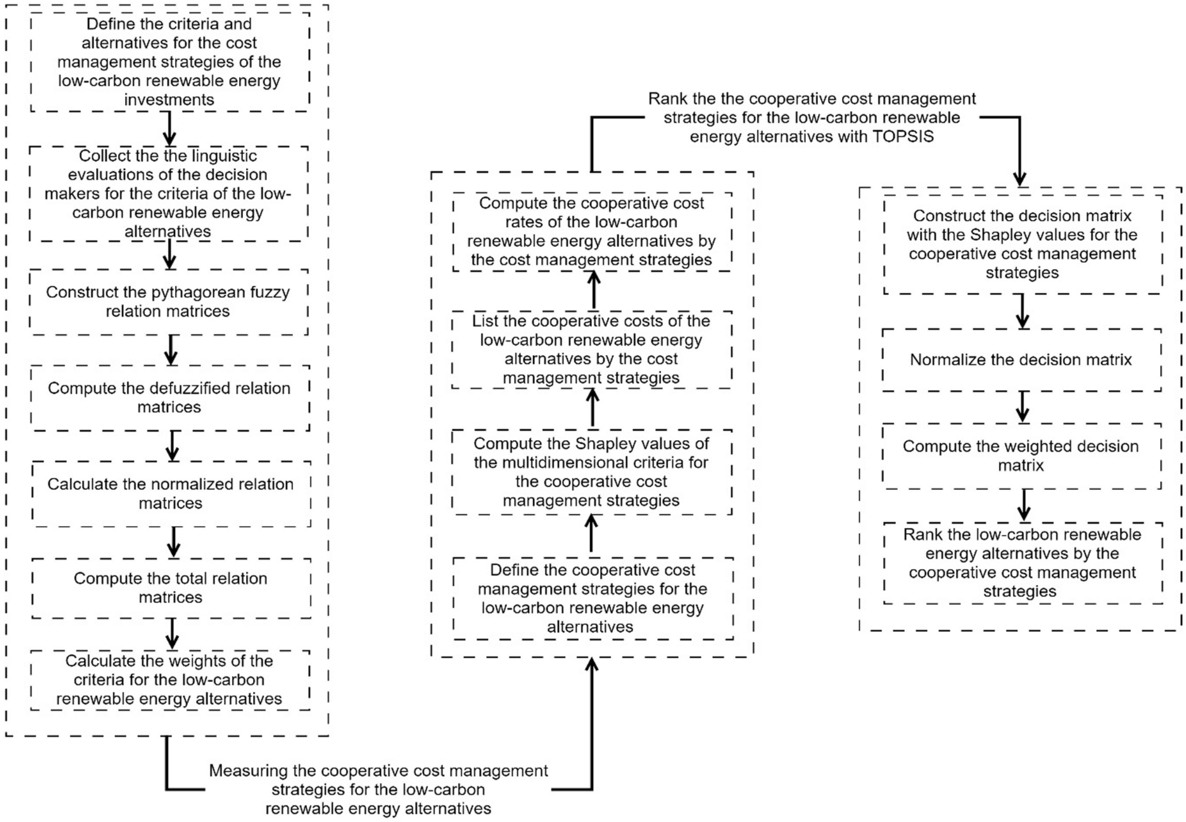

Fig. 1. The phases of the model.

This model has some novelties by comparing with other models in the literature. Firstly, a hybrid model is created by considering DEMATEL and TOPSIS in all stages. In other words, subjective weights are not used in the analysis process. This situation has a positive contribution on the objectivity of the analysis results. However, in some models in the literature, the criteria weights are assumed to be equal (Janic and Reggiani, 2002; Zeleny, 1992). On the other side, in this model, Pythagorean fuzzy sets are taken into consideration. This situation has a positive impact on the effectiveness on the decision-making problems. Problems in the real world become very complex and because of this situation, finding appropriate solutions is quite difficult. Hence, many different researchers use MCDM models with fuzzy sets to handle uncertainty in this process in a better way. In the literature, some MCDM models are created without considering fuzzy sets (Yüksel et al., 2020; Lyu et al., 2020; Ricardo et al., 2021; Kalkavan et al., 2021). Also, some researchers use triangular fuzzy sets in their models (Bakır and Atalık, 2021; Arif et al., 2021; Sadat et al., 2021). Therefore, the main superiority of the proposed model in this manuscript is that membership, non-membership and hesitancy parameters are considered in the analysis process with the help of Pythagorean fuzzy sets. Thus, more effective and appropriate evaluations can be conducted.

Criteria for the cost management strategies of the low-carbon renewable energy investments are identified as in Table 1.

Table 1 shows 5 different criteria. In this context, these criteria are selected by considering balanced scorecard perspectives. The main advantage of the balanced scorecard approach is that it focuses on both financial and nonfinancial issues (Mio et al., 2021). With the help of this situation, better management information can be assessed (Pietrzak, 2021). In addition to this situation, balanced scorecard approach has also positive contribution to the improvement of the knowledge and skills of the employees. Hence, it can be possible to make better strategy planning (Oliveira et al., 2021). Customer (C1) shows the costs incurred to retain customers. For the renewable energy projects to be effective, customer expectations should be satisfied. On the other hand, finance (C2) includes issues such as investment and equipment installation costs. The main reason is that when the costs can be minimized, the profitability of the renewable energy investments can be increased. Additionally, the internal process (C3) provides information about company-specific costs, such as employee wages. If these costs cannot be controlled, it will be very difficult to increase the efficiency of these investments. Moreover, learning (C4) focuses on research and development costs. For the profitability of renewable energy investments to be continuous, the expenditure allocated to research and development studies should not be uncontrolled. Otherwise, it will be difficult to manage the costs of these investments. Furthermore, growth (C5) indicates the expenditures made to increase the market share in the market such as advertising expenditures. Additionally, three different alternatives are identified regarding low-carbon renewable energy types which are wind (A1), hydroelectricity (A2), solar (A3). On the other side, geothermal energy and biomass energy are not considered in low-carbon renewable energy types. The main reason is that these energy types have higher carbon emission in comparison with wind, hydroelectricity, and solar energies (Shahzad et al., 2021; Bilgili et al., 2020; Field and Shen, 2008; Adewuyi and Awodumi, 2017).

5. Analysis results

5.1. Weighting the criteria

Next, the linguistic evaluations are obtained. In this scope, 3 decision makers (DM) evaluated these factors. This expert team consists of people from two top managers in the energy industry and one academician in the area of renewable energy investments. One top manager has graduate degree whereas other top manager has doctoral degree. They have sufficient background regarding strategic management, carbon emission reduction, energy investments. On the other hand, the academician has lots of qualified publications regarding energy economics, low carbon projects, carbon emissions and renewable energy investments. These people have at least 20-year experience in this area. Thus, it is thought that the expert team has necessary and sufficient knowledge to assess the criteria and alternatives with respect to the renewable energy investment projects. The details of the linguistic evaluations are given in the Appendix part (Table A.1). These items are normalized as in Table A.2 by considering the boundaries of $\mu_p^2 + n_p^2 = 1$. Next, the defuzzified relation matrix (DFR) is obtained as in Table A.3. Moreover, this matrix is normalized as in Table A.4. Later, the total relation matrix (TRM) is developed as in Table A.5. Additionally, the weights of the items are indicated in Table 2.

Table 2 explains that with respect to the wind energy alternative (A1), finance (C2) and internal process (C3) generate the highest costs. However, expenditures regarding the retention of the customers (C1) have the lowest costs. Similarly, as for hydroelectricity projects (A2), the highest costs are created by the finance (C2) and internal process (C3), as well. Also, the expenditures related to the learning (C4) are lower in comparison with others. Finally, regarding the solar energy alternative (A3), finance (C2) and growth (C5) generate the highest costs.

5.2. Measuring the cooperative cost management strategies

To define the cooperative cost management strategies for the low-carbon renewable energy alternatives, average and total costs in Table 3 are taken into consideration.

As seen in Table 3, these rates are obtained from the weights of the criteria for each low-carbon renewable energy alternative with Pythagorean fuzzy DEMATEL. According to the results, the averaged cost rates of the criteria are among the 16.4% and 23.6% while the total costs differ between 49.2% and 70.7%. The averaged costs could be defined the averaged individual cost rates of low-carbon renewable energy alternatives. However, the total costs could be employed as the limits of the cooperative cost rates. By considering these limitations, three cooperative cost management strategies could be defined as the weak cooperative cost strategy with 30%, the fair cooperative cost strategy with 40%, and the strong cooperative cost strategy with 60%. The Shapley values of the multidimensional criteria are created for the cooperative cost management strategies. Table A.6 gives information about the cooperative costs by the alternatives for the weak cooperative cost strategy. Table A.7 shows the cooperative costs for the second strategy. The cooperative costs regarding the strong cooperative cost strategy are indicated in Table A.8. Furthermore, the cooperative cost priorities of the criteria are ranked in increasing order by considering the Shapley values. The results of the weak cost management strategy are stated in Table 4.

Additionally, the results for the fair cost management strategy are demonstrated in Table 5.

On the other side, Table 6 explains the results for the strong cost management strategy.

After that, the cooperative cost rates of the low-carbon renewable energy alternatives are calculated by the cost management strategies. Table 7 summarizes the cooperative cost rates of the alternatives for different cost management strategies.

Table 7 represents the cooperative cost rates and the index results of several cooperative cost management strategies. The index results are obtained by computing the cost rate results are divided by the default cost rate of the selected strategy. For instance, internal process (C3) has always the lowest costs for the solar energy alternatives (A3). Hence, the investors can increase the effectiveness of the projects while improving the qualification of the employees because this situation creates lower costs. Similarly, customer (C1) is the lowest cost criterion for the wind energy alternative (A1). Therefore, the effectiveness of the wind energy projects can be increased with the help of giving significance to the customers. It can also be seen that the total cost index is 1.490 for weak cooperative cost management strategy. On the other side, this value is 1.455 and 1.373 for the fair and strong cooperative strategies. The results indicate that when the level of the cooperation increases, the efficiency of the investments can be higher.

5.3. Ranking the cooperative cost management strategies

In this phase, first, the decision matrix with the Shapley values is constructed for the cooperative cost management strategies as in Table A.9. Next, normalized matrix (NM) is created as in Table A.10. Later, Table A.11 gives information about the weighted matrix. Table 8 summarizes the ranking results.

Table 8 demonstrates that the hydroelectricity (A2) has the highest amount of cost priorities at all levels of cooperative cost management strategies. Another important point is that if the investors prefer to make weak or strong cooperative cost management strategy, they should primarily focus on solar energy projects since they have lower costs in comparison with other alternatives.

Additionally, the accuracy of the proposed model is measured for each cooperative cost management strategy by using the VIKOR method. Accordingly, sensitivity analysis is also applied with 5 cases for both the TOPSIS and VIKOR methods by changing the weighting results of the criteria consecutively. The comparative ranking results are given for the robustness check in Table 9.

Table 9 illustrates that the ranking results of the TOPSIS and VIKOR are same for the best alternative selection. It is clearly understood that the proposed model is coherent and appliable for the further studies. The ranking results of the sensitivity analysis are also consistent with the different cases by changing the weighting values consecutively.

6. Limitations and implications

The findings indicate that cooperative cost management strategies have a positive contribution to increase efficiency. With respect to the low-carbon renewable energy alternatives, investors should focus on different options cooperatively at the same time. In this process, many cost different energy alternatives are common. Therefore, by focusing on different alternatives at the same time, it is possible to benefit from these common costs. In this study, it is also understood that when the level of the cooperation increases, the efficiency of the investments can be higher. In this framework, investors must have the technical equipment to invest in different types of renewable energy at the same time. This will help the costs of projects to be managed more effectively. Zhao et al. (2020) and Weissbart (2020) also claimed that cooperative cost management strategies play a significant role in order to increase the performance of the renewable energy projects.

Solar energy investments are the most optimal low-carbon investment type for two different cooperative cost strategies. Especially, with the technological improvements, there has been

Table A.7
Fair cooperative costs and Shapley values (SV).

C1			
Orders	Cooperative costs		
	A1	A2	A3
1,2,3	0.124	0.185	0.091
1,3,2	0.124	0.093	0.183
2,1,3	0.124	0.185	0.091
2,3,1	0.032	0.185	0.183
3,1,2	0.124	0.093	0.183
3,2,1	0.032	0.185	0.183
SV	0.093	0.155	0.152
C2			
Orders	Cooperative costs		
	A1	A2	A3
1,2,3	0.247	0.153	0.000
1,3,2	0.247	0.000	0.153
2,1,3	0.167	0.233	0.000
2,3,1	0.000	0.233	0.167
3,1,2	0.173	0.000	0.227
3,2,1	0.000	0.173	0.227
SV	0.139	0.132	0.129
C3			
Orders	Cooperative costs		
	A1	A2	A3
1,2,3	0.256	0.144	0.000
1,3,2	0.256	0.000	0.144
2,1,3	0.157	0.243	0.000
2,3,1	0.000	0.243	0.157
3,1,2	0.195	0.000	0.205
3,2,1	0.000	0.195	0.205
SV	0.144	0.138	0.118
C4			
Orders	Cooperative costs		
	A1	A2	A3
1,2,3	0.174	0.156	0.070
1,3,2	0.174	0.048	0.178
2,1,3	0.174	0.156	0.070
2,3,1	0.065	0.156	0.178
3,1,2	0.174	0.048	0.178
3,2,1	0.065	0.156	0.178
SV	0.138	0.120	0.142
C5			
Orders	Cooperative costs		
	A1	A2	A3
1,2,3	0.200	0.182	0.018
1,3,2	0.200	0.000	0.200
2,1,3	0.200	0.182	0.018
2,3,1	0.010	0.182	0.208
3,1,2	0.192	0.000	0.208
3,2,1	0.010	0.182	0.208
SV	0.135	0.121	0.143

Table A.8
Strong cooperative costs and Shapley values (SV).

C1			
Orders	Cooperative costs		
	A1	A2	A3
1,2,3	0.124	0.185	0.183
1,3,2	0.124	0.185	0.183
2,1,3	0.124	0.185	0.183
2,3,1	0.124	0.185	0.183
3,1,2	0.124	0.185	0.183
3,2,1	0.124	0.185	0.183
SV	0.124	0.185	0.183
C2			
Orders	Cooperative costs		
	A1	A2	A3
1,2,3	0.247	0.233	0.120
1,3,2	0.247	0.126	0.227
2,1,3	0.247	0.233	0.120
2,3,1	0.141	0.233	0.227
3,1,2	0.247	0.126	0.227
3,2,1	0.141	0.233	0.227
SV	0.212	0.197	0.191
C3			
Orders	Cooperative costs		
	A1	A2	A3
1,2,3	0.256	0.243	0.101
1,3,2	0.256	0.140	0.205
2,1,3	0.256	0.243	0.101
2,3,1	0.152	0.243	0.205
3,1,2	0.256	0.140	0.205
3,2,1	0.152	0.243	0.205
SV	0.221	0.209	0.170
C4			
Orders	Cooperative costs		
	A1	A2	A3
1,2,3	0.174	0.156	0.178
1,3,2	0.174	0.156	0.178
2,1,3	0.174	0.156	0.178
2,3,1	0.174	0.156	0.178
3,1,2	0.174	0.156	0.178
3,2,1	0.174	0.156	0.178
SV	0.174	0.156	0.178
C5			
Orders	Cooperative costs		
	A1	A2	A3
1,2,3	0.200	0.182	0.208
1,3,2	0.200	0.182	0.208
2,1,3	0.200	0.182	0.208
2,3,1	0.200	0.182	0.208
3,1,2	0.200	0.182	0.208
3,2,1	0.200	0.182	0.208
SV	0.200	0.182	0.208

a significant decrease in the costs of solar energy projects. Therefore, solar energy is predicted to be much more active in the future. In addition, the results of this study show that solar investments are well suited for cooperative cost strategies. In case of investing in another type of renewable energy with low carbon emissions, the investors will also have to cover some of the expenses of these projects. Investing in different renewable energy types, including solar energy projects, will contribute to increasing efficiency. Kabir et al. (2018), Li et al. (2017) and Shahsavari and Akbari (2018) also reached a conclusion that solar energy projects will be preferred more by comparing with other alternatives. The main reason is that these projects have cost advantage because of the technological improvements.

This study mainly contributes to the literature by evaluating different cost-management strategies regarding low-carbon renewable energy alternatives with a novel methodology. However, focusing on only general criteria is the main limitation. In addition, in this evaluation process, there is no industrial implications. Instead of this situation, it is aimed to identify critical issues which can lead investors. Therefore, in the future studies, a case study can be implemented to see the impact of investing different renewable energy alternatives at the same time on the cost effectiveness.

7. Conclusion

The optimal cost management strategies regarding the low-carbon renewable energy investments are identified in this manuscript. A three-stage novel model is created by using DEMATEL and TOPSIS methods based on Pythagorean fuzzy sets and the

Table A.9
Decision matrix.

Weak cooperative cost management strategy			
	A1	A2	A3
C1	0.080	0.111	0.109
C2	0.106	0.099	0.096
C3	0.111	0.104	0.085
C4	0.102	0.093	0.104
C5	0.102	0.093	0.106
Fair cooperative cost management strategy			
	A1	A2	A3
C1	0.093	0.155	0.152
C2	0.139	0.132	0.129
C3	0.144	0.138	0.118
C4	0.138	0.120	0.142
C5	0.135	0.121	0.143
Strong cooperative cost management strategy			
	A1	A2	A3
C1	0.124	0.185	0.183
C2	0.212	0.197	0.191
C3	0.221	0.209	0.170
C4	0.174	0.156	0.178
C5	0.200	0.182	0.208

Table A.10
NM.

Weak cooperative cost management strategy			
	A1	A2	A3
C1	0.457	0.633	0.625
C2	0.610	0.568	0.552
C3	0.635	0.599	0.488
C4	0.589	0.539	0.602
C5	0.586	0.535	0.609
Fair cooperative cost management strategy			
	A1	A2	A3
C1	0.395	0.655	0.644
C2	0.602	0.571	0.558
C3	0.621	0.595	0.511
C4	0.594	0.519	0.615
C5	0.584	0.525	0.619
Strong cooperative cost management strategy			
	A1	A2	A3
C1	0.430	0.643	0.634
C2	0.610	0.568	0.552
C3	0.635	0.599	0.488
C4	0.591	0.532	0.607
C5	0.586	0.535	0.609

Shapley values. Additionally, the accuracy of the proposed model is measured for each cooperative cost management strategy by using the VIKOR method. Accordingly, sensitivity analysis is also applied with 5 cases for both the TOPSIS and VIKOR methods by changing the weighting results of the criteria consecutively. This manuscript has important contributions by evaluating different cost-management to increase renewable energy investment projects. Owing to the analysis results of this study, the ways to minimize carbon emission problem can be presented. It is determined that internal process has always the lowest costs for the solar energy alternatives while customer is the lowest cost criterion for the wind energy alternative. Moreover, the total cost index is 1.490 for weak cooperative cost management strategy. Furthermore, this value is 1.455 and 1.373 for the fair and strong cooperative strategies. It is obvious that when the level of the cooperation increases, the efficiency of the investments can be higher. Another significant conclusion is that the hydroelectricity has the highest amount of cost priorities at all levels of cooperative cost management strategies. Furthermore, investors should

Table A.11
Weighted matrix.

Weak cooperative cost management strategy			
	A1	A2	A3
C1	0.075	0.104	0.102
C2	0.144	0.134	0.130
C3	0.149	0.141	0.114
C4	0.100	0.091	0.102
C5	0.115	0.105	0.120
Fair cooperative cost management strategy			
	A1	A2	A3
C1	0.065	0.107	0.106
C2	0.142	0.134	0.131
C3	0.146	0.139	0.120
C4	0.101	0.088	0.104
C5	0.115	0.103	0.122
Strong cooperative cost management strategy			
	A1	A2	A3
C1	0.070	0.105	0.104
C2	0.144	0.134	0.130
C3	0.149	0.141	0.114
C4	0.100	0.090	0.103
C5	0.115	0.105	0.120

primarily focus on solar energy projects if they prefer to make weak or strong cooperative cost management strategy because they have lower costs in comparison with other alternatives. It is identified that cooperative cost management strategies have a positive contribution to increase efficiency. With respect to the low-carbon renewable energy alternatives, investors should focus on different options cooperatively at the same time.

CRediT authorship contribution statement

Hasan Dinçer: Validation, Formal analysis, Writing – original draft, Writing – review & editing. **Serhat Yüksel:** Conceptualization, Methodology, Validation, Formal analysis, Writing – original draft, Writing – review & editing. **Luis Martínez:** Conceptualization, Methodology, Validation, Formal analysis, Writing – original draft, Writing – review & editing, Supervision, Project administration, Funding acquisition.

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.

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Appendix

See Tables A.1 and A.11.

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