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Research paper

Analysis of inventive problem-solving capacities for renewable energy storage investments

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A B S T R A C T

The energy storage process becomes very important due to the imbalances in energy supply and demand. Therefore some factors need to be considered to increase the efficiency of the energy storage system, such as cost–benefit analysis and technological improvements. This study aims to examine the inventive problem-solving capacities for renewable energy storage investments. A new model is suggested for this objective by considering fuzzy decision-making methodology. It is concluded that prior action and dynamicity are the most essential capacities of renewable energy storage investments. Additionally, dynamicity plays the most critical role when all factors are considered in renewable energy investment projects in a collaborative manner. Hence, it is recommended that the companies should mainly consider the initial developments of the storage facilities. Moreover, location selection for effective energy storage should also be considered to increase the performance of these investments.

1. Introduction

The demand for energy in the world is increasing day by day. Countries develop many different energy policies to meet this increasing demand. The main reason is that the energy supply must meet the energy demand (Guo and Sepanta, 2021). Otherwise, both basic human needs will not be met, and the raw materials required for the production of companies cannot be satisfied. As a result, the industrial volume in the country decreases significantly (Al-Ghussain et al., 2020). On the other hand, there may be decreases in energy supply from time to time due to situations such as malfunctions in the electricity generation or distribution process. Additionally, the amount of energy produced in renewable energy sources can be much more or less than expected due to factors such as climate conditions (Hassan et al., 2020). These issues can cause imbalances in energy supply and demand (Alkhalidi et al., 2018). These issues increase the significance of the energy storage. However, some factors need to be considered to increase the efficiency of the energy storage system (Doretti et al., 2020).

Some of the studies have considered the cost aspects of energy storage. The energy storage process causes the costs of companies to increase (Schmidt et al., 2017; Al Wahedi and Bicer, 2020). In this framework, a comprehensive cost analysis should be made for this process. In this context, it is very important that the cost of energy storage is not higher than the revenue that can be obtained from excess energy (Smallbone et al., 2017). Otherwise, energy storage investments will not be efficient (Wang et al., 2018; Lu et al., 2020). In this context, companies are required to make a very detailed cost–benefit analysis (Yan et al., 2018). Mostafa et al. (2020) aimed to make techno-economic assessment of energy storage systems. In this regard, annualized life cycle cost of storage and levelized cost of energy metrics are considered. They defined that when investing in energy storage, first of all, cost analysis should be made. Al-Ghussain et al. (2020) highlighted the significance of this situation for the renewable energy investments.

The importance of technological competence in the energy storage process has been discussed. The amount of energy obtained from renewable energy projects varies by periods. This difference problem reveals the importance of the energy storage system (Damak et al., 2020). Otherwise, it becomes difficult to achieve full efficiency from renewable energy projects. One of the most important problems in this process is the high costs in the energy storage process (Ortega-Fernández et al., 2017). In order to minimize this problem, technological developments must be adapted to these investments quickly. For this purpose, companies should also follow the technological innovations related to this process instantly (Wang et al., 2017). This situation will play

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a very important role in increasing the efficiency of renewable energy investments. Lehtola and Zahedi (2019) examined solar energy and wind power supply supported by storage technology. They concluded that technological development plays a crucial role for the effectiveness of the energy storage investments. Similarly, Hahn et al. (2017), Wicki and Hansen (2017) and Liu and Du (2020) supported this situation in their analyses.

Moreover, some researchers have also addressed security issues in the energy storage process. Storing excess energy from renewable energy is very important in terms of energy efficiency (Nguyen et al., 2018). However, it is equally essential to take the necessary security measures in these investment processes (Mohamad et al., 2018). If these products are not installed safely, there is a possibility that many damages may occur (Mohamad and Teh, 2018). This situation will cause serious problems regarding the efficiency of energy investments (Prajapati and Mahajan, 2021). In this framework, the necessary control tests must be carried out completely. Razmi and Janbaz (2020) focused on the significant issues of the energy storage. In this study, green energy investments are taken into consideration. They concluded that the energy storage system should be reliable so that the effectiveness of the green energy projects can be increased. This situation was also supported by different studies, such as Shi and Luo (2017) and Vatanpour and Yazdankhah (2018).

It is possible to reach essential points in the literature review. Firstly, energy storage subject attracted the attention of many different researchers in the literature. Because of this issue, the researchers aim to find appropriate strategies to increase the performance of the energy storage. Secondly, some important factors of energy storage effectiveness were examined, such as cost–benefit analysis, technological improvement, and reliability. Therefore, the missing part of the literature is that there are limited studies that include many different factors at the same time regarding the effectiveness of the energy storage investments. This study aims to identify the inventive problem-solving capacities for renewable energy storage investments. For this purpose, six different characteristics and four different inventive problem-solving capacities taken into consideration.

This study tries to identify the inventive problem-solving capacities for renewable energy storage investments. A model is created by considering a fuzzy multi-criteria decision-making (MCDM) approach. At first, the literature is reviewed in a detailed manner and six different characteristics are defined. Next, the expert team evaluated these factors, and four different inventive problem-solving capacities are determined. After that, the group fuzzy preferences are determined with group decision making and consensus reaching approach. Finally, the inventive problem-solving capacities for renewable energy storage investments are weighted. In this context, Spherical fuzzy DEMATEL and Shapley values are used.

This suggested model has some novelties. By determining the criteria using the TRIZ technique, it will be possible to produce quick solutions to problems (Asyraf et al., 2020; Sharaf et al., 2020). This will contribute to the increase in the efficiency of the investments (Li et al., 2021; Yuan et al., 2021). In addition, a more effective analysis will be made for different expert opinions by using consensus-based group decision-making approach (Liu and Pedrycz, 2020; Carneiro et al., 2020). Furthermore, by using the Spherical fuzzy numbers, uncertainty in the process will be better managed (Gündoğdu and Kahraman, 2020; Mathew et al., 2020). The main reason for this is that different parameters are taken into account in the analysis process of these numbers (Liu et al., 2020; Shishavan et al., 2020). Thanks to the preference of the DEMATEL method, the causality relationship between the criteria can be revealed (Mao et al., 2020; Zhang et al., 2020; Garg, 2021). The impacts of each alternatives can be identified by considering Shapley values (Sundararajan and Najmi, 2020; Chen et al., 2021).

This manuscript is designed as following. Section 2 identifies methodological background. Section 3 presents the analysis results. The final section includes discussion and conclusion.

2. Methodology

This section defines the details of the methods considered in this study.

2.1. Cooperative games and Shapley value

There are more than two players in the cooperative games. $N = \{1, 2, \ldots, n\}$ defines the set of the players. On the other side, S refers to the subset of N and υ shows the characteristic function. Additionally, the competitive condition is defined as $v(S)$. In this process, $x = (x_1, x_2, \ldots, x_n)$ demonstrates the reward vector. Eqs. (1) and (2) gives information about the group and individual rationality ($v(N)$ and $v(i)$) (Aas et al., 2021).

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

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

Moreover, Eq. (3) indicates the imputation $y = (y_1, y_2, \ldots, y_n)$ (Rodríguez-Pérez and Bajorath, 2020).

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

Shapley value states the reward vector. The reward of the ith player x_i is presented as in Eq. (4). In this equation, $|S|$ represents the number of players (Sundararajan and Najmi, 2020).

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

2.2. Group decision making approach

This approach aims to reach the consensus with the help of the feedback mechanism. In this process, P shows the fuzzy preference relations whereas $\mu_p : X \times X \rightarrow [0, 1]$ represents the membership function. They are detailed in Eq. (5) (Akkuzu et al., 2020).

$$P = (P_{ik}) \text{ and } P_{ik} = \mu_p\left(x_i, x_k\right), \left(\forall i, k \in \{1, \ldots, n\}\right) \tag{5}$$

Eq. (6) indicates the computation of the corresponding fuzzy preferences (CP) (Taghavi et al., 2020).

$$CP_{ik} = \frac{\sum_{j=1; i\neq k\neq j}^{n} (CP_{ik})^{j1} + \cdots + (CP_{ik})^{j(n-1)}}{(n-1) * (n-2)} \tag{6}$$

Eqs. (7) and (8) demonstrate the consistency level (CL) of the criteria (Xiao et al., 2020).

$$CL_{ik} = 1 - \left(\frac{2 * |CP_{ik} - P_{ik}|}{(n-1)}\right) \tag{7}$$

$$CL_i = \frac{\sum_{k=1; i\neq k}^{n} (CL_{ik} + CL_{ki})}{2\,(n-1)} \tag{8}$$

Eq. (9) indicates the calculation of the global consistency level (GCL) (Xie et al., 2021; Tian et al., 2020).

$$GCL = \frac{\sum_{i=1}^{n} CL_i}{n} \tag{9}$$

With the help of Eqs. (10) and (11), similarity matrixes (SM) can be generated. In this process, ϕ represents the aggregation function. On the other side, the pair of the experts are shown as e_h and e_l (Tang et al., 2020).

$$SM_{ik}^{hl} = 1 - \left|P_{ik}^{h} - P_{ik}^{l}\right| \tag{10}$$

$$SM_{ik} = \phi\left(SM_{ik}^{hl}\right) \tag{11}$$

Eq. (12) shows the generation of the global consensus degrees (CR) (Liu and Pedrycz, 2020). The consensus degree on the relation, denoted CR, is defined to measure the global consensus degree amongst all the experts' opinion.

$$CR = \frac{\sum_{i=1}^{n}\frac{\sum_{k=1;k\neq i}^{n}(SM_{ik}+SM_{ki})}{2(n-1)}}{n} \tag{12}$$

The consensual degrees can be computed by Eq. (13). In this equation, δ represents the control parameter regarding the consistency. In this study, it is defined as 0.75 (Carneiro et al., 2020).

$$Z_{ik}^{h} = (1-\delta) * CL_{ik}^{h} + \delta * \left(\frac{\sum_{l=h+1}^{n} SM_{ik}^{hl} + \sum_{l=1}^{h-1} SM_{ik}^{lh}}{n-1}\right) \tag{13}$$

Also, P_{ik}^{c} demonstrates the collective fuzzy preference relations. The details of the calculations are given in Eqs. (14)–(16). In this context, σ demonstrates a permutation of $\{1,\ldots,m\}$, $Z_{ik}^{\sigma(h)} \geq Z_{ik}^{\sigma(h+1)}$, $\forall h = 1,\ldots,m-1$. Additionally, $\left\langle Z_{ik}^{\sigma(h)}, P_{\sigma(i)}\right\rangle$ is two-tuple with $Z_{ik}^{\sigma(h)}$ the hth largest value in $\left\{Z_{ik}^{1},\ldots,Z_{ik}^{m}\right\}$ (Akkuzu et al., 2020).

$$P_{ik}^{c} = \Phi w\left(\left\langle Z_{ik}^{1}, P_{ik}^{1}\right\rangle,\ldots,\left\langle Z_{ik}^{m}, P_{ik}^{m}\right\rangle\right) = \sum_{h=1}^{m} w_h * P_{ik}^{\sigma(h)} \tag{14}$$

$$w_h = Q(h/n) - Q(h-1/n) \tag{15}$$

$$(r) = \begin{cases} 0 & if\ r < a \\ \frac{r-a}{b-a} & if\ a \leq r \leq b \\ 1 & if\ r > a \end{cases} \tag{16}$$

Eqs. (17) and (18) include the generation of the proximity levels (PP_{ik}^{h}) and the relation between criteria (Pr^{h}) (Yuan et al., 2021; Taghavi et al., 2020).

$$PP_{ik}^{h} = 1 - \left|P_{ik}^{h} - P_{ik}^{c}\right| \tag{17}$$

$$Pr^{h} = \frac{\sum_{i=1}^{n}\frac{\sum_{k=1;k\neq i}^{n}(PP_{ik}^{h}+PP_{ki}^{h})}{2(n-1)}}{n} \tag{18}$$

Eq. (19) shows the calculation of the consensus control level (CCL) (Xiao et al., 2020).

$$CCL = (1-\delta) * GCL + \delta * CR \tag{19}$$

Eqs. (20)–(22) identify the values of EXPCH, ALT, and APS (Tian et al., 2020).

$$EXPCH = \left\{h \left| (1-\delta) * CL^{h} + \delta * Pr^{h} < \gamma \right.\right\} \tag{20}$$

$$ALT = \left\{(h,i) \left| e_h \in EXPCH \wedge (1-\delta) * CL_{i}^{h} + \delta * \frac{\sum_{k=1;k\neq i}^{n}(PP_{ik}^{h} + PP_{ki}^{h})}{2(n-1)} < \gamma \right.\right\} \tag{21}$$

$$APS = \left\{(h,i,k) \left| (h,i) \in ALT \wedge (1-\delta) * CL_{ik}^{h} + \delta * PP_{ik}^{h} < \gamma \right.\right\} \tag{22}$$

The value of CCL should be greater than the threshold to achieve effective consensus level. If it is necessary, the feedback system is implemented.

2.3. Spherical Fuzzy sets

Spherical fuzzy sets ($\tilde{A}_S$) include membership (m), non-membership (n), and hesitancy (h) parameters. Their squared sum will be between 0 and 1. Eqs. (23) and (24) define this process (Cheng et al., 2020).

$$\tilde{A}_S = \left\{\left\langle u, \left(m_{\tilde{A}_S}(u), n_{\tilde{A}_S}(u), h_{\tilde{A}_S}(u)\right)\right| u \in U\right\} \tag{23}$$

$$0 \leq m_{\tilde{A}_S}^2(u) + n_{\tilde{A}_S}^2(u) + h_{\tilde{A}_S}^2(u) \leq 1,\ \forall_u \in U \tag{24}$$

X_1 and X_2 define two different universes. Also, $\tilde{A}_S = (m_{\tilde{A}_S}, n_{\tilde{A}_S}, h_{\tilde{A}_S})$ and $\tilde{B}_S = (m_{\tilde{B}_S}, n_{\tilde{B}_S}, h_{\tilde{B}_S})$ represent two spherical fuzzy sets. Eqs. (25)–(28) detail this situation (Xie et al., 2020; Özgül et al., 2021).

$$\tilde{A}_S \oplus \tilde{B}_S = \left\{\left(m_{\tilde{A}_S}^2 + m_{\tilde{B}_S}^2 - m_{\tilde{A}_S}^2 m_{\tilde{B}_S}^2\right)^{\frac{1}{2}}, n_{\tilde{A}_S} n_{\tilde{B}_S}, \left(\left(1 - m_{\tilde{B}_S}^2\right) h_{\tilde{A}_S}^2 + \left(1 - m_{\tilde{A}_S}^2\right) h_{\tilde{B}_S}^2 - h_{\tilde{A}_S}^2 h_{\tilde{B}_S}^2\right)^{\frac{1}{2}}\right\} \tag{25}$$

$$\tilde{A}_S \otimes \tilde{B}_S = \left\{\left(m_{\tilde{A}_S} m_{\tilde{B}_S}, \left(n_{\tilde{A}_S}^2 + n_{\tilde{B}_S}^2 - n_{\tilde{A}_S}^2 n_{\tilde{B}_S}^2\right)^{\frac{1}{2}}\right), \left(\left(1 - n_{\tilde{B}_S}^2\right) h_{\tilde{A}_S}^2 + \left(1 - n_{\tilde{A}_S}^2\right) h_{\tilde{B}_S}^2 - h_{\tilde{A}_S}^2 h_{\tilde{B}_S}^2\right)^{\frac{1}{2}}\right\} \tilde{A}_S \otimes \tilde{B}_S = \left\{\left(m_{\tilde{A}_S} m_{\tilde{B}_S}, \left(n_{\tilde{A}_S}^2 + n_{\tilde{B}_S}^2 - n_{\tilde{A}_S}^2 n_{\tilde{B}_S}^2\right)^{\frac{1}{2}}\right), \left(\left(1 - n_{\tilde{B}_S}^2\right) h_{\tilde{A}_S}^2 + \left(1 - n_{\tilde{A}_S}^2\right) h_{\tilde{B}_S}^2 - h_{\tilde{A}_S}^2 h_{\tilde{B}_S}^2\right)^{\frac{1}{2}}\right\} \tag{26}$$

$$\lambda * \tilde{A}_S = \left\{\left(1 - \left(1 - m_{\tilde{A}_S}^2\right)^{\lambda}\right)^{\frac{1}{2}}, n_{\tilde{A}_S}^{\lambda}, \left(\left(1 - m_{\tilde{A}_S}^2\right)^{\lambda} - \left(1 - m_{\tilde{A}_S}^2 - h_{\tilde{A}_S}^2\right)^{\lambda}\right)^{\frac{1}{2}}\right\}, \lambda > 0 \tag{27}$$

$$\tilde{A}_S^{\lambda} = \left\{m_{\tilde{A}_S}^{\lambda}, \left(1 - \left(1 - n_{\tilde{A}_S}^2\right)^{\lambda}\right)^{\frac{1}{2}}, \left(\left(1 - n_{\tilde{A}_S}^2\right)^{\lambda} - \left(1 - n_{\tilde{A}_S}^2 - h_{\tilde{A}_S}^2\right)^{\lambda}\right)^{\frac{1}{2}}\right\}, \lambda > 0 \tag{28}$$

Spherical weighted arithmetic mean (SWAM) operator is also considered in this process as in Eq. (29) (Gündoğdu and Kahraman, 2020; Cheng et al., 2020).

$$SWAM_w\left(\tilde{A}_{S1},\ldots,\tilde{A}_{Sn}\right) = w_1\tilde{A}_{S1} + \cdots + w_n\tilde{A}_{Sn} = \left\{\left[1 - \prod_{i=1}^{n}\left(1 - m_{\tilde{A}_{Si}}^2\right)^{w_i}\right]^{\frac{1}{2}}, \prod_{i=1}^{n} n_{\tilde{A}_{Si}}^{w_i}, \left[\prod_{i=1}^{n}\left(1 - m_{\tilde{A}_{Si}}^2\right)^{w_i} - \prod_{i=1}^{n}\left(1 - m_{\tilde{A}_{Si}}^2 - h_{\tilde{A}_{Si}}^2\right)^{w_i}\right]^{\frac{1}{2}}\right\} \tag{29}$$

2.4. DEMATEL

DEMATEL aims to identify the significance of different items. An expert team firstly evaluates the factors based on a scale. The average values are calculated so that the direct relation matrix (A) is generated as in Eq. (30). In this matrix, a_{ij} gives information about the impact of factor i on factor j (Fang et al., 2021; Zhong et al., 2020).

$$A = \begin{bmatrix} 0 & a_{12} & a_{13} & & \cdots & a_{1n} \\ a_{21} & 0 & a_{23} & & \cdots & a_{2n} \\ a_{31} & a_{32} & 0 & & \cdots & a_{3n} \\ \vdots & \vdots & \vdots & \ddots & & \vdots \\ a_{n1} & a_{n2} & a_{n3} & & \cdots & 0 \end{bmatrix} \tag{30}$$

By considering equation (31), normalized matrix (B) can be created (Jun et al., 2021; Yazdi et al., 2020).

$$B = \frac{A}{max_{1 \le i \le n} \sum_{j=1}^{n} a_{ij}} \tag{31}$$

Eq. (32) shows the calculation of the total relation matrix (C) (Meng et al., 2021; Korsakiene et al., 2020).

$$C = B(I - B)^{-1} \tag{32}$$

Eqs. (33) and (34) defines the sums of rows (D) and columns (E) (Mao et al., 2020).

$$D = \left[\sum_{j=1}^{n} e_{ij} \right]_{nx1} \tag{33}$$

$$E = \left[\sum_{i=1}^{n} e_{ij} \right]_{1xn} \tag{34}$$

The importance of the factors can be defined with "$D+E$". Also, "$D-E$" is used for the causal relationship. Threshold value (α) is defined as in Eq. (35) (Dinçer et al., 2020; Zhang et al., 2020; Garg, 2021).

$$\alpha = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} \left[e_{ij} \right]}{N} \tag{35}$$

2.5. Proposed model

In this study, a new model is created with respect to the renewable energy storage investments. The details are stated in Fig. 1.

This proposed model is organized as following.

Stage 1: Determining the group fuzzy preferences with consensus for the inventive problem-solving capacities of the renewable energy storage investments.

Step 1: Define the inventive problem-solving characteristics of the renewable energy storage investments.

Step 2: Assign the decision makers for collecting the evaluations.

Step 3: Provide the evaluations for the capacities of renewable energy storage investments.

Step 4: Define the fuzzy preferences for the capacity criteria.

Step 5: Construct the consistency levels of the criteria.

Step 6: Compute the similarity matrices of the criteria.

Step 7: Determine the consensual degrees.

Step 8: Calculate the proximity levels for the capacity criteria.

Step 9: Apply the feedback mechanism for providing the satisfied consensus control level.

Stage 2: Measuring the inventive problem-solving capacities with multiplayer coalition for renewable energy storage investments using Spherical fuzzy sets and Shapley value.

Step 1: Construct the consensus-based Spherical fuzzy relation matrix.

Step 2: Compute the defuzzified relation matrix.

Step 3: Calculate the normalized relation matrix.

Step 4: Define the impact and relation degrees of the criteria.

Step 5: Order the inventive problem-solving capacities with multiplayer cooperative game rules.

This proposed model has some benefits in comparison with the previous models in the literature. Firstly, in this study, the inventive problem-solving capacities of the energy storage are defined by considering TRIZ technique. Thanks to this method, it will be possible to produce solutions suitable for customer needs (Delgado-Maciel et al., 2020). On the other hand, many patents have been examined in this technique and generally accepted solution proposals have been determined (Asyraf et al., 2020). In this way, it will be possible to produce quick solutions to existing problems thanks to the TRIZ approach (Li et al., 2021). This will help increase the efficiency of the investments as it will save time in the process (Sharaf et al., 2020). Therefore, this study brings innovation compared to other studies that do not use the TRIZ approach (Yuan et al., 2021). On the other hand, using the consensus methodology is another specificity of the study (Tang et al., 2020). Experts express different opinions about a criterion that reduces the effectiveness (Liu and Pedrycz, 2020). In this framework, it will be possible to solve this problem thanks to the consensus approach (Carneiro et al., 2020). Therefore, this model can reach more accurate results compared to other methods that do not take the consensus approach into account (Akkuzu et al., 2020).

Additionally, the use of Spherical fuzzy numbers is another positive aspect of this model. In some studies in the literature of MCDM models, it is aimed to manage the uncertainty in the process in a better way by considering fuzzy numbers (Liu et al., 2020). On the other hand, fuzzy numbers are also criticized in the decision-making process that gets more complicated (Mathew et al., 2020). In this context, different parameters are considered using spherical fuzzy numbers (Shishavan et al., 2020). More appropriate results can be defined compared to models using other fuzzy sets (Cheng et al., 2020; Xie et al., 2020). On the other hand, considering the DEMATEL method during the weighting of the criteria is another factor that strengthens the model. Thanks to this model, both the importance weights of the items can be determined and the causality relationship between these factors can be revealed (Zhong et al., 2020; Yazdi et al., 2020; Korsakiene et al., 2020). Therefore, this model has some advantages compared to other models in which analytic hierarchy process (AHP) and analytic network process (ANP) approaches are preferred (Lokhande et al., 2020; Mistarihi et al., 2020; Ocampo et al., 2020; Nimawat and Gidwani, 2020). Furthermore, it is possible to evaluate the impacts of each alternatives with the help of considering Shapley values (Chen et al., 2021; Aas et al., 2021). On the other hand, this proposed model is also very suitable for the employee subject. In this study, inventive problem-solving capacities of renewable energy storage investments are evaluated, such as prior action, dynamicity, periodic action, and transformation of the priorities. These factors include elements that will affect each other. Therefore, the causality relationship should not be ignored while analyzing these factors. For this reason, the DEMATEL method is taken into account in the proposed model. In this way, it will be possible to determine which factors are influencing/influenced (Mao et al., 2020; Zhang et al., 2020). The biggest limitation of this study is the determination of the criteria by taking the TRIZ method into consideration.

3. Analysis results

In this study, a two-stage model is suggested to evaluate inventive problem-solving capacities for renewable energy storage investments. The details of the analysis results are demonstrated below.

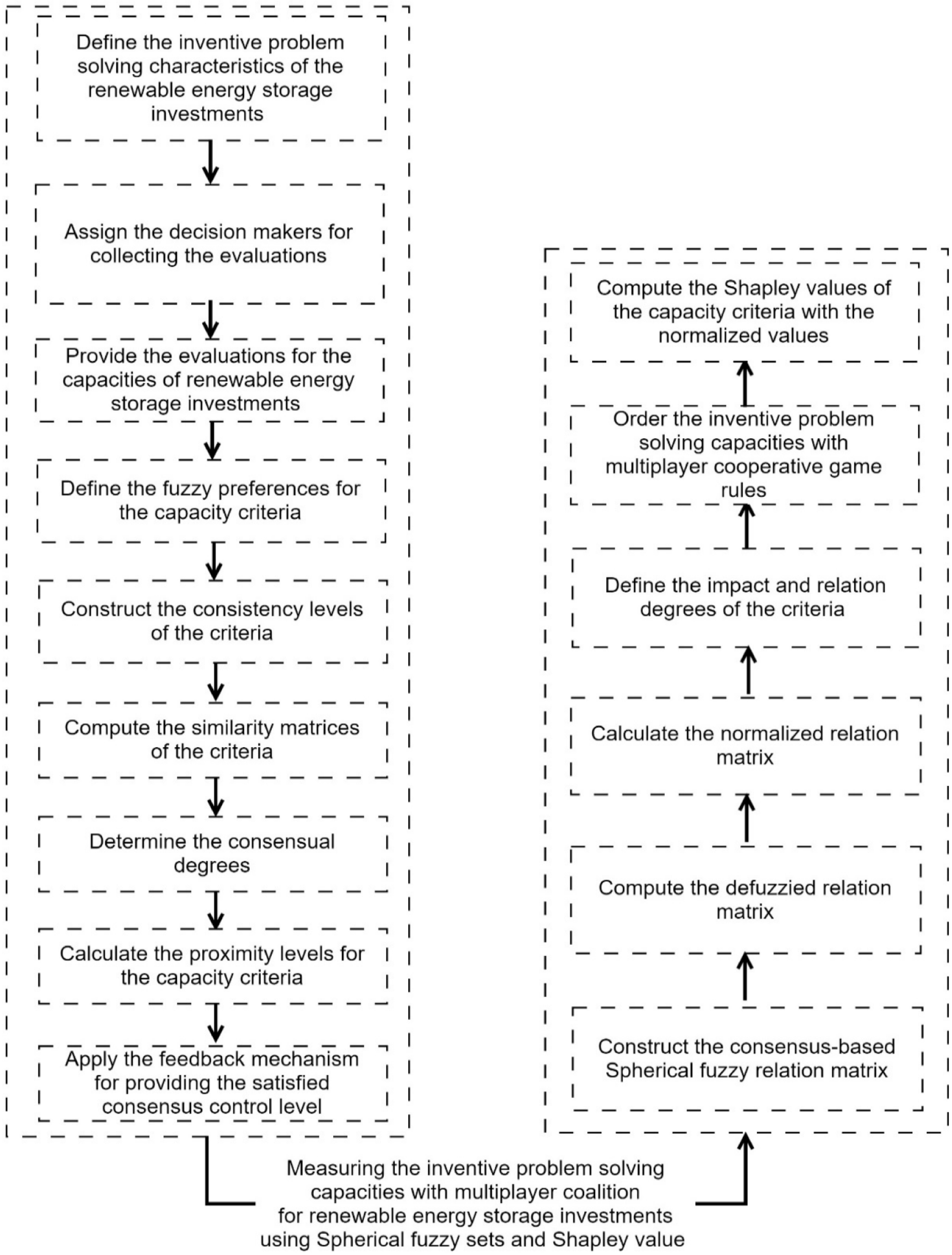

Fig. 1. Flowchart.

Table 1
Selected characteristics of renewable energy storage investments.

Characteristics	Supported literature
Loss of energy (F1)	Schmidt et al. (2017); Smallbone et al. (2017)
Reliability (F2)	Mostafa et al. (2020); Al-Ghussain et al. (2020)
Convenience of use (F3)	Wang et al. (2018); Yan et al. (2018)
Repairability (F4)	Damak et al. (2020); Wicki and Hansen (2017)
Adaptability (F5)	Liu and Du (2020); Ortega-Fernández et al. (2017)
Capacity (F6)	Hahn et al. (2017); Wang et al. (2017)

3.1. Determining the group Fuzzy preferences with consensus

The inventive problem-solving characteristics of the renewable energy storage investments are defined as in Table 1.

Table 1 defines 6 different TRIZ-based factors that affect the performance of the renewable energy storage investments. Firstly, the loss of the energy should be minimized to improve the performance of the energy storage. Additionally, the mechanism should be reliable for the effectiveness of this issue. Also, the use of these items should be very easy to achieve this objective. Moreover, the problems in these projects should be repairable.

Table 2
Details of decision makers.

Decision makers	Industry	Experience	Position	Education
DM 1	Manufacturing	10 years	Senior manager	Business and Economics
DM 2	Manufacturing	16 years	Board member	Industrial engineering
DM 3	Energy	22 years	Chief of Executive Officer	Electronic and Mechanical engineering
DM 4	Energy	18 years	Board member	Business management and Industrial engineering

Table 3
Contradiction matrix.

	Worsening characteristics						
	Characteristics	F1	F2	F3	F4	F5	F6
Improving characteristics	F1	–	10	15, 19	15, 19	10, 35	10, 15, 19
	F2	15, 19	–	10, 15, 19, 35	10, 15, 19	10, 19	10
	F3	10, 15, 19	15	–	19	10, 15, 19, 35	10, 15, 35
	F4	10, 15, 19	10, 15, 19, 35	10, 15, 35	–	19	15, 19, 35
	F5	10, 15	10	19	15, 19	–	10, 15
	F6	19, 35	10, 15, 19	19, 35	35	15, 19	–

Table 4
Inventive problem-solving capacities of renewable energy storage investments.

TRIZ numbers	Capacity (CAP)
10	Prior action (CAP1)
15	Dynamicity (CAP2)
19	Periodic action (CAP3)
35	Transformation of properties (CAP4)

Moreover, there are rapid technologic improvements in the renewable energy storage systems. Because of this situation, these projects should be adoptable for any changes. Finally, the capacity also plays a crucial role in this regard to increase the efficiency of the investments. After that, 4 decision makers are assigned for collecting the evaluations. The qualifications of these people are explained in Table 2.

Table 2 clarifies that the decision makers have sufficient qualifications for evaluating the characteristics. These people made a comparative evaluation of 6 different characteristics and identified the appropriate TRIZ-based principles out of 38 different items. Table 3 gives information about the contradiction matrix.

Table 4 summarizes the details of selected TRIZ principles.

Table 4 highlights four different inventive problem-solving capacities. With respect to the prior action, the pre-planning of the project is very important. In this framework, for renewable energy storage investments, this capacity identifies that initial developments of the storage facilities are taken into consideration. Additionally, the dynamicity capacity indicates that the product should be designed in accordance with the external environment for the best solution. In this context, factors such as meeting the

Table 5
Consistency levels.

DM1 (CL^1:.90)					DM2 (CL^2:.88)				
CL^1	CAP1	CAP2	CAP3	CAP4	CL2	CAP1	CAP2	CAP3	CAP4
CAP1	–	.96	.98	.96	CAP1	–	.87	.91	.96
CAP2	.78	–	.96	.89	CAP2	.87	–	.91	.96
CAP3	.96	.76	–	.98	CAP3	.84	.71	–	.93
CAP4	.84	.96	.84	–	CAP4	.98	.84	.80	–
DM3 (CL^3:.82)					DM4 (CL^4:.90)				
CL^3	CAP1	CAP2	CAP3	CAP4	CL^4	CAP1	CAP2	CAP3	CAP4
CAP1	–	.98	.80	.80	CAP1	–	.84	.87	.80
CAP2	.82	–	.60	.87	CAP2	.71	–	.93	1.00
CAP3	.93	.80	–	.84	CAP3	1.00	.93	–	.89
CAP4	.87	.73	.82	–	CAP4	.93	.87	.98	–

Table 6
Similarity matrixes.

DM1-DM3					DM1-DM4				
SM^{13}	CAP1	CAP2	CAP3	CAP4	SM^{14}	CAP1	CAP2	CAP3	CAP4
CAP1		.80	.60	.80	CAP1		.80	.80	.60
CAP2	.80		.8	.80	CAP2	.80		.80	.60
CAP3	.80	.60		.80	CAP3	1.00	.60		1.00
CAP4	.60	.80	.60		CAP4	1.00	1.00	.60	
DM2-DM3					DM2-DM4				
SM^{23}	CAP1	CAP2	CAP3	CAP4	SM^{24}	CAP1	CAP2	CAP3	CAP4
CAP1		.80	.80	.80	CAP1		.80	1.00	.60
CAP2	.60		1.00	.80	CAP2	1.00		.60	1.00
CAP3	.80	.60		1.00	CAP3	1.00	.60		.80
CAP4	.80	.60	.60		CAP4	.80	.80	.60	

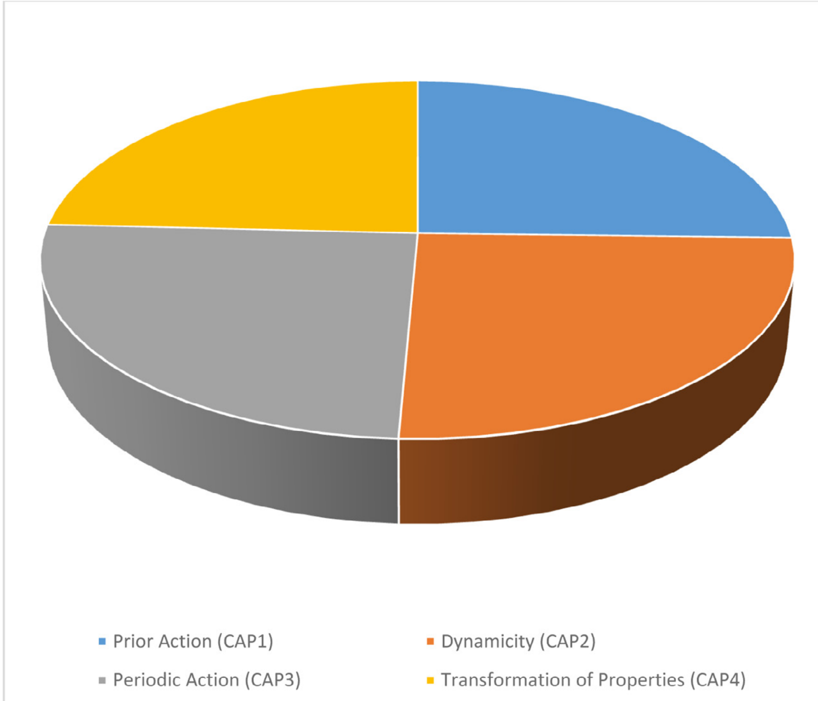

Fig. 2. Weighting Results.

Table 7
CSM.

SM	CAP1	CAP2	CAP3	CAP4
CAP1		.80	.80	.70
CAP2	.80		.80	.80
CAP3	.90	.60		.90
CAP4	.80	.80	.60	

Table 9
Collective fuzzy preferences.

P^c	CAP1	CAP2	CAP3	CAP4
CAP1		.85	.82	.81
CAP2	.78		.81	.78
CAP3	.92	.75		.88
CAP4	.81	.84	.76	

expectations of customers and continuous system development play a very important role. Therefore, regarding the dynamicity of the renewable energy storage investments, location selection for effective energy storage plays a key role. The main reason is that with the help of effective location selection, it can be more possible to meet customer expectations and design the project in accordance with the external environment. Moreover, as for periodic action, gradual updates for avoiding energy losses are considered. Finally, transformation and properties include upgrades of storage properties for increasing capacity. Evaluations of the experts, fuzzy preferences and corresponding fuzzy preferences are stated on the appendix part (Tables A.1–A.3). Consistency levels are presented in Table 5.

In this framework, the global consistency level (GCL) is found as 0.88 by using Eq. (9). Table 6 defines the details of the similarity matrixes.

Collective similarity matrix (CSM) is proposed in Table 7 by using Eqs. (10) and (11).

Global consensus (CR) is defined as 0.78 by considering equation (12). Also, the consensual degrees (CDs) are demonstrated in Table 8 with the help of Eq. (13).

Furthermore, the collective fuzzy preferences are summarized in Table 9. In this context, Eqs. (14)–(16) are taken into consideration.

The proximity levels are computed by using Eqs. (17) and (18) as in Table 10.

Table 8
CDs.

DM1					DM2				
Z^1	CAP1	CAP2	CAP3	CAP4	Z^2	CAP1	CAP2	CAP3	CAP4
CAP1		.89	.79	.84	CAP1		.87	.88	.84
CAP2	.79		.84	.72	CAP2	.82		.83	.84
CAP3	.94	.74		.89	CAP3	.91	.73		.88
CAP4	.81	.89	.76		CAP4	.84	.76	.75	
DM3					DM4				
Z^3	CAP1	CAP2	CAP3	CAP4	Z^4	CAP1	CAP2	CAP3	CAP4
CAP1		.79	.75	.80	CAP1		.76	.87	.70
CAP2	.71		.75	.82	CAP2	.78		.73	.85
CAP3	.83	.75		.86	CAP3	.95	.78		.87
CAP4	.72	.73	.76		CAP4	.83	.87	.79	

Table 10
Proximity levels for the capacity criteria.

DM1 (Pr^1: .77)					DM2 (Pr^2: .80)				
PP^1	CAP1	CAP2	CAP3	CAP4	PP^2	CAP1	CAP2	CAP3	CAP4
CAP1		.85	.88	.69	CAP1		.85	.68	.69
CAP2	.92		.89	.52	CAP2	.88		.91	.92
CAP3	.58	.85		.62	CAP3	.58	.85		.82
CAP4	.69	.86	.86		CAP4	.89	.66	.86	
DM3 (Pr^3: .77)					DM4 (Pr^4: .77)				
PP^3	CAP1	CAP2	CAP3	CAP4	PP^4	CAP1	CAP2	CAP3	CAP4
CAP1		.65	.48	.89	CAP1		.95	.68	.91
CAP2	.72		.91	.72	CAP2	.88		.69	.92
CAP3	.78	.75		.82	CAP3	.58	.75		.62
CAP4	.91	.94	.74		CAP4	.69	.86	.74	

Table 11
The results of the second round.

DM1					DM2				
P^1	CAP1	CAP2	CAP3	CAP4	P^2	CAP1	CAP2	CAP3	CAP4
CAP1	–	.70	.70	.50	CAP1	–	.70	.77	.50
CAP2	.70	–	.70	.30	CAP2	.90	–	.90	.70
CAP3	.50	.90	–	.50	CAP3	.87	.90	–	.70
CAP4	.79	.70	.90	–	CAP4	.70	.50	.90	–
DM3					DM4				
P^3	CAP1	CAP2	CAP3	CAP4	P^4	CAP1	CAP2	CAP3	CAP4
CAP1	–	.76	.76	.70	CAP1	–	.90	.79	.90
CAP2	.78	–	.90	.50	CAP2	.90	–	.50	.70
CAP3	.70	.50	–	.70	CAP3	.82	.50	–	.83
CAP4	.90	.90	.50	–	CAP4	.50	.70	.50	–

CCL value tests consistency of results in group decision making. In this framework, the threshold value is accepted as 0.85 like many different studies in the literature (Herrera-Viedma et al., 2007). The consensus control level (CCL) is computed as 0.80 by using Eq. (19). It is obvious that this value is lower than 0.85. Hence, the necessary condition is not satisfied. Because the consistency/consensus level does not satisfy the minimum consensus threshold value, CCL value is not meet the necessary conditions. The results of the second round are indicated in Table 11.

New CCL is 0.81 that is lower than the threshold. The next round results are given in Table 12.

Third CCL is 0.88 and this result is appropriate for the fuzzy preferences.

3.2. Measuring the inventive problem-solving capacities for renewable energy storage investments

The normalized values of fuzzy preference relations are obtained with the boundaries of $0 \leq \mu_p^2(u) + v_p^2(u) + \pi_p^2(u) \leq 1$ for the member, non-membership, and hesitant degrees of Spherical fuzzy sets. The fuzzy relation matrix is stated in Table A.4. Later, the defuzzified relation matrix and normalized relation matrix are created as in Tables A.5 and A.6. The weight results are indicated in Table 13.

The value of (D+E) gives information about the impact degrees in the criterion set whereas the value of (D−E) shows the relation directions among the criteria. Thus, the impacts of inventive problem-solving capacities could be illustrated by using the weights of the criteria. However, CAP1 and CAP3 have negative (D−E) values as −1.802 and −1.165 respectively. Fig. 2 illustrates the weighting results of the capacities.

On the other side, impact relation map is also created by considering (D−E) values. This map is depicted in Fig. 3.

The cooperative rules with multiplayer games could be defined by considering the value of (D−E) as following.

Rule 1: CAP1 is not ordered before other criteria except CAP3.

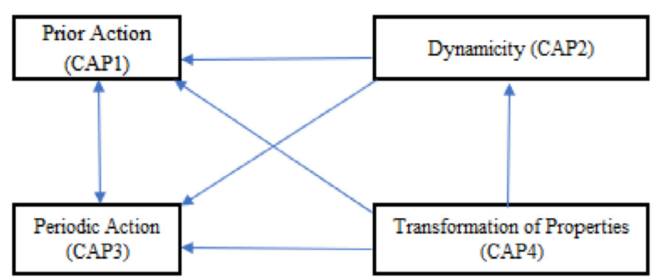

Fig. 3. Impact Relation Map.

Rule 2: CAP3 is not ordered before other criteria except CAP1.

Furthermore, the order the inventive problem-solving capacities with multiplayer cooperative game rules are depicted in Table 14.

In the final step, Shapley values of the capacity criteria are identified as in Table 15.

Table 15 indicates that dynamicity (CAP2) is the most significant factor when all items are considered at the same time. Similarly, transformation of properties (CAP4) plays the second most important role in this framework.

4. Discussion and conclusion

This study aims to identify appropriate inventive problem-solving capacities for renewable energy storage investments with group decision making and consensus reaching approach, Spherical fuzzy DEMATEL and Shapley values. The findings indicate that prior action and dynamicity are the most crucial capacities of renewable energy storage investments. Also, dynamicity is found as the most critical factor when all items are considered in renewable energy investment projects in a collaborative manner. It is recommended that the companies should mainly consider location selection for effective energy storage to increase the

Table 12
The results of the third round.

DM1					DM2				
P^1	CAP1	CAP2	CAP3	CAP4	P^2	CAP1	CAP2	CAP3	CAP4
CAP1	–	.70	.70	.50	CAP1	–	.70	.77	.76
CAP2	.70	–	.70	.69	CAP2	.90	–	.90	.70
CAP3	.76	.90	–	.73	CAP3	.87	.90	–	.70
CAP4	.79	.70	.90	–	CAP4	.70	.81	.90	–
DM3					DM4				
P^3	CAP1	CAP2	CAP3	CAP4	P^4	CAP1	CAP2	CAP3	CAP4
CAP1	–	.76	.76	.70	CAP1	–	.90	.79	.90
CAP2	.78	–	.90	.77	CAP2	.90	–	.76	.70
CAP3	.70	.50	–	.70	CAP3	.82	.50	–	.83
CAP4	.90	.90	.81	–	CAP4	.78	.70	.50	–

Table 13
Analysis results.

Criteria	CAP1	CAP2	CAP3	CAP4	D	E	D+E	D−E	Weights
CAP1	2.951	2.889	3.073	2.582	11.495	13.297	24.792	−1.802	.254
CAP2	3.527	2.927	3.413	2.809	12.676	11.965	24.641	.710	.253
CAP3	3.246	2.919	2.898	2.623	11.686	12.850	24.536	−1.165	.251
CAP4	3.572	3.231	3.466	2.668	12.938	10.682	23.619	2.256	.242

Table 14
Order of inventive problem-solving capacities.

Order of capacities	Cooperative capacity			
	CAP1	CAP2	CAP3	CAP4
1,2,3,4	.000	.253	.000	.242
1,3,2,4	.000	.253	.000	.242
1,4,2,3	.000	.253	.251	.242
1,2,4,3	.000	.253	.251	.242
1,3,4,2	.000	.253	.000	.242
1,4,3,2	.000	.253	.000	.242
2,1,3,4	.000	.253	.000	.242
2,3,1,4	.000	.253	.000	.242
2,4,1,3	.254	.253	.251	.242
2,1,4,3	.000	.253	.251	.242
2,3,4,1	.254	.253	.000	.242
2,4,3,1	.254	.253	.251	.242
3,2,1,4	.000	.253	.000	.242
3,1,2,4	.000	.253	.000	.242
3,4,2,1	.254	.253	.000	.242
3,2,4,1	.254	.253	.000	.242
3,1,4,2	.000	.253	.000	.242
3,4,1,2	.000	.253	.000	.242
4,2,3,1	.254	.253	.251	.242
4,3,2,1	.254	.253	.000	.242
4,1,2,3	.000	.253	.251	.242
4,2,1,3	.254	.253	.251	.242
4,3,1,2	.000	.253	.000	.242
4,1,3,2	.000	.253	.000	.242

Table 15
Shapley values of the capacity criteria.

Order of capacities	Normalized values of cooperative capacity			
	CAP1	CAP2	CAP3	CAP4
1,2,3,4	.000	.511	.000	.489
1,3,2,4	.000	.511	.000	.489
1,4,2,3	.000	.338	.337	.324
1,2,4,3	.000	.338	.337	.324
1,3,4,2	.000	.511	.000	.489
1,4,3,2	.000	.511	.000	.489
2,1,3,4	.000	.511	.000	.489
2,3,1,4	.000	.511	.000	.489
2,4,1,3	.254	.253	.251	.242
2,1,4,3	.000	.338	.337	.324
2,3,4,1	.339	.337	.000	.323
2,4,3,1	.254	.253	.251	.242
3,2,1,4	.000	.511	.000	.489
3,1,2,4	.000	.511	.000	.489
3,4,2,1	.339	.337	.000	.323
3,2,4,1	.339	.337	.000	.323
3,1,4,2	.000	.511	.000	.489
3,4,1,2	.000	.511	.000	.489
4,2,3,1	.254	.253	.251	.242
4,3,2,1	.339	.337	.000	.323
4,1,2,3	.000	.338	.337	.324
4,2,1,3	.254	.253	.251	.242
4,3,1,2	.000	.511	.000	.489
4,1,3,2	.000	.511	.000	.489
Shapley values	**.099**	**.410**	**.098**	**.393**

effectiveness of these investments. The storage cost of renewable energies should not be too high. This problem will negatively affect the efficiency of all investments. Therefore, an effective location selection is vital. Within this framework, a very comprehensive analysis should be made for the selection of the location where the excess renewable energy will be stored. Many different researchers reached the similar conclusions regarding this issue. Li et al. (2018), Roch-Dupré et al. (2021) and Yücenur and Ipekçi (2021) aimed to identify significant issues with respect to the energy storage systems. They identified that the feasibility of the location should be evaluated in a detailed manner. Zhang et al. (2018) focused on the energy storage systems for solar energy projects in the United States. They also highlighted the importance of the location selection in this regard. Alkhalidi et al. (2018), Khosravi et al. (2021), Razmi et al. (2021) and Ramírez et al. (2018) also stated that location selection for effective energy storage should also considered to increase the effectiveness of these investments.

The main limitation of this study is the determination of the criteria by considering the TRIZ technique. In the future studies, the factors can be defined by using some other approaches, such as balance scorecard. Additionally, in this study, any countries or companies are not ranked based on the performance of the renewable energy storage investments. Hence, fuzzy TOPSIS or VIKOR methodologies can be used in this manner so that more successful countries and companies can be identified for this situation. On the other side, in this study, renewable energy projects are evaluated in a general manner. Therefore, in the following studies, more specific analysis can be conducted. For instance, energy storage investments for solar energy systems can be examined. Hence, more specific recommendations can be

Table A.1
Evaluations.

DM1					DM2				
DM1	CAP1	CAP2	CAP3	CAP4	DM2	CAP1	CAP2	CAP3	CAP4
CAP1	–	H	H	M	CAP1	–	H	M	M
CAP2	H	–	H	S	CAP2	VH	–	VH	H
CAP3	M	VH	–	M	CAP3	M	VH	–	H
CAP4	M	H	VH	–	CAP4	H	M	VH	–
DM3					DM4				
DM3	CAP1	CAP2	CAP3	CAP4	DM4	CAP1	CAP2	CAP3	CAP4
CAP1	–	M	S	H	CAP1	–	VH	M	VH
CAP2	M	–	VH	M	CAP2	VH	–	M	H
CAP3	H	M	–	H	CAP3	M	M	–	M
CAP4	VH	VH	M	–	CAP4	M	H	M	–

Table A.2
Fuzzy preferences.

DM1					DM2				
P^1	CAP1	CAP2	CAP3	CAP4	P^2	CAP1	CAP2	CAP3	CAP4
CAP1	–	.70	.70	.50	CAP1	–	.70	.50	.50
CAP2	.70	–	.70	.30	CAP2	.90	–	.90	.70
CAP3	.50	.90	–	.50	CAP3	.50	.90	–	.70
CAP4	.50	.70	.90	–	CAP4	.70	.50	.90	–
DM3					DM4				
P^3	CAP1	CAP2	CAP3	CAP4	P^4	CAP1	CAP2	CAP3	CAP4
CAP1	–	.50	.30	.70	CAP1	–	.90	.50	.90
CAP2	.50	–	.90	.50	CAP2	.90	–	.50	.70
CAP3	.70	.50	–	.70	CAP3	.50	.50	–	.50
CAP4	.90	.90	.50	–	CAP4	.50	.70	.50	–

Table A.3
Corresponding fuzzy preferences.

DM1					DM2				
CP^1	CAP1	CAP2	CAP3	CAP4	CP^2	CAP1	CAP2	CAP3	CAP4
CAP1	–	.77	.67	.43	CAP1	–	.50	.63	.57
CAP2	.37	–	.63	.47	CAP2	.70	–	.77	.63
CAP3	.57	.53	–	.47	CAP3	.73	.47	–	.60
CAP4	.73	.77	.67	–	CAP4	.67	.73	.60	–
DM3					DM4				
CP^3	CAP1	CAP2	CAP3	CAP4	CP^4	CAP1	CAP2	CAP3	CAP4
CAP1	–	.47	.60	.40	CAP1	–	.67	.70	.60
CAP2	.77	–	.30	.70	CAP2	.47	–	.60	.70
CAP3	.60	.80	–	.47	CAP3	.50	.60	–	.67
CAP4	.70	.50	.77	–	CAP4	.60	.50	.47	–

presented in order to improve the effectiveness of these investments. In this study, expert opinions are taken into consideration. However, econometric methods can be used in the future studies, such as regression and cointegration. In addition, in this study, only important factors of renewable energy storage investments are explained. Nonetheless, there is no industrial application to test the consistency of these analysis results. Thus, for the next studies, a case evaluation can be conducted.

CRediT authorship contribution statement

Yue Meng: Conceptualization, Methodology, Software, Data curation, Writing - original draft. **Ronghua Zhou:** Conceptualization, Methodology, Software, Data curation, Writing - original draft. **Hasan Dinçer:** Supervision, Software, Validation, Methodology, Conceptualization. **Serhat Yüksel:** Visualization, Investigation, Methodology, Conceptualization. **Chong Wang:** Methodology, Writing - review & editing.

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–A.6.

Table A.4
Parameters.

	DM1											
	CAP1			CAP2			CAP3			CAP4		
	m	n	h	m	n	h	m	n	h	m	n	h
CAP1				.63	.11	.11	.63	.11	.11	.45	.17	.17
CAP2	.63	.11	.11				.63	.11	.11	.62	.11	.11
CAP3	.69	.09	.09	.81	.06	.06				.66	.10	.10
CAP4	.71	.09	.09	.63	.11	.11	.81	.06	.06			
	DM2											
	CAP1			CAP2			CAP3			CAP4		
	m	n	h	m	n	h	m	n	h	m	n	h
CAP1				.63	.11	.11	.69	.09	.09	.69	.09	.09
CAP2	.81	.06	.06				.81	.06	.06	.63	.11	.11
CAP3	.79	.06	.06	.81	.06	.06				.63	.11	.11
CAP4	.63	.11	.11	.72	.08	.08	.81	.06	.06			
	DM3											
	CAP1			CAP2			CAP3			CAP4		
	m	n	h	m	n	h	m	n	h	m	n	h
CAP1				.68	.10	.10	.69	.09	.09	.63	.11	.11
CAP2	.70	.09	.09				.81	.06	.06	.69	.09	.09
CAP3	.63	.11	.11	.45	.17	.17				.63	.11	.11
CAP4	.81	.06	.06	.81	.06	.06	.73	.08	.08			
	DM4											
	CAP1			CAP2			CAP3			CAP4		
	m	n	h	m	n	h	m	n	h	m	n	h
CAP1				.81	.06	.06	.71	.09	.09	.81	.06	.06
CAP2	.81	.06	.06				.68	.10	.10	.63	.11	.11
CAP3	.73	.08	.08	.45	.17	.17				.75	.08	.08
CAP4	.70	.09	.09	.63	.11	.11	.45	.17	.17			

Table A.5
Defuzzified relation matrix.

Criteria	CAP1	CAP2	CAP3	CAP4
CAP1	.000	.369	.343	.326
CAP2	.453	.000	.446	.290
CAP3	.397	.340	.000	.328
CAP4	.407	.387	.419	.000

Table A.6
Normalized relation matrix.

Criteria	CAP1	CAP2	CAP3	CAP4
CAP1	.000	.305	.283	.268
CAP2	.374	.000	.368	.239
CAP3	.327	.280	.000	.270
CAP4	.335	.319	.345	.000

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