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A novel fuzzy decision-making methodology for ranking energy storage investments in emerging economies

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ABSTRACT

This study aims to evaluate essential performance indicators of energy storage investments with a novel decision-making model. The first stage includes weighting the selected criteria with Spherical fuzzy TOPSIS-based DEMATEL, called TOP-DEMATEL. In the second stage, seven emerging countries are ranked based on the effectiveness of energy storage investments using ranking technique by geometric mean of similarity ratio to optimal solution (RATGOS). RATGOS is a new ranking method proposed in this study to address the shortcomings of the existing methods by using geometric mean. The findings indicate that energy storage capacity is the most significant factor in improving energy storage investments in developing economies. Technological improvements are also important in this regard. It is strongly recommended that energy storage technologies need to be developed by conducting new research and development activities. Owing to new technological developments, more efficient batteries can be produced. These new products allow energy to be stored at higher capacity.

1. Introduction

Energy storage investments are projects that enable the excess energy produced by renewable energy sources to be reused at any time. It is possible to talk about many important advantages of these investments. First, these projects contribute to increasing renewable energy integration. On the other hand, renewable energy types may be affected by climate differences [1]. This situation causes imbalances in the amount of energy production. Energy storage investments also contribute to solving these problems more effectively. Moreover, these investments also enable energy outages to be minimized. Thus, stored energy can be taken into account in emergency situations. Additionally, one of the most important advantages of energy storage investments is that it reduces greenhouse gas emissions. Since it contributes to increasing renewable energy investments, the solution to the carbon emission problem will become easier [2]. Similarly, by storing excess produced energy, the produced energy will not be wasted. This provides a significant opportunity to determine energy efficiency.

It is possible to mention a number of important factors that affect the effectiveness of energy storage investments. The legal regulations of the country in which the investment will be made should also be taken into consideration in this process [3]. As a result of activities that violate these regulations, businesses may be subject to high fines. Conditions in energy markets are another issue that should be taken into consideration in this context. Fluctuations in energy prices can significantly affect the profitability of energy storage investments. Similarly, exchange rate risks play also critical role in this framework. Any radical changes in the exchange rates may have negatively affect the performance of this process. For the effective management of these risks, financial derivatives should be considered.

Moreover, the project where energy storage will be carried out must be close to places where energy is demanded [4]. This situation contributes to reducing energy transmission costs. Because of this condition, appropriate location selection issue should be taken into consideration to improve the performance of this situation. Furthermore, technological competence is another issue that affects the performance of energy storage investments. It is important to use advanced technology for storage systems to operate at low cost. To achieve this goal, businesses need to make investments in the development of energy storage technologies. On the other hand, reducing costs may attract the attention of investors. The main issue is that the cost of these

Abbreviations: RATGOS, Ranking technique by geometric mean of similarity ratio to optimal solution; TOP-DEMATEL, TOPSIS-based DEMATEL

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technologies used is a critical factor that determines the success of the project.

Improvements need to be made for these variables to increase the performance of energy storage investments. In this way, it will be easier to ensure both financial and operational sustainability of these projects. However, the most important disadvantage of these improvements is that they increase costs. In other words, the costs of the actions taken should also be taken into account when making improvements [5]. Otherwise, the costs of energy storage projects will increase significantly, and this will cause investments to suffer losses. To avoid this problem, it would be appropriate to focus on the most important factors instead of making too many improvements. Therefore, it is necessary to determine the most important factors affecting energy storage investments. By identifying these factors, it is possible for businesses to have more reasonable costs while increasing the performance of these projects.

Accordingly, this study aims to identify key determinants of the performance of the energy storage investments with a new model. In this context, the main research question of the study is to determine the most important factors to increase the performance of energy storage investments. The first stage includes the weighting of the selected criteria with Spherical fuzzy TOPSIS-based DEMATEL (TOP-DEMATEL) methodology. At the second stage, emerging seven countries are ranked based on the effectiveness of energy storage investments. In this scope, ranking technique by geometric mean of similarity ratio to optimal solution (RATGOS) technique is taken into consideration.

The main contributions of this study are given as follows. (i) A new ranking approach, RATGOS, is proposed in this study to overcome the criticisms made for existing ranking techniques [6]. In this process, geometric mean is considered in the analysis process [7]. (ii) TOP-DEMATEL methodology is also newly proposed in this study to handle the disadvantages of classical DEMATEL technique, such as creating equal weights inappropriately in case of symmetrical evaluation [8,9]. Because of this issue, final steps of TOPSIS are integrated to the classical DEMATEL so that TOP-DEMATEL is generated [10]. (iii) It is possible to talk about some advantages of examining the effectiveness of energy storage investments for developing countries. Since these countries have fast-growing economies, energy demand can also increase radically. Energy storage projects need to be increased to meet this demand effectively and to avoid carbon emissions in this process.

The second part consists of literature review. The proposed methodology is explained in the third section. The fourth part focuses on the analysis results. The final section includes discussion and conclusion.

2. Literature review

Technological development is of great importance in increasing the effectiveness of energy storage investments. Gu et al. [11] defined that thanks to the application of advanced technologies, it is possible to reduce the costs of these processes. This contributes to the financial sustainability of the projects. On the other hand, Gacitúa et al. [12] mentioned that technological developments also help increase the efficiency of the process. Owing to these technologies, it is possible to store more energy. In this case, the capacity of energy storage projects can be increased. Moreover, Bian [13] identified that adapting to technological developments helps to use more durable materials. In this way, it is possible for energy storage facilities to have a longer lifespan. Gao et al. [14] denoted that this situation allows maintenance costs and possible disruptions to be reduced. Thus, the efficiency of energy storage projects can be increased. Zhang et al. [15] showed that technological advances also contribute to increasing the safety of energy storage processes. This situation makes these projects more preferred by the investors and customers.

Effective legal regulations are also necessary to increase the performance of energy storage projects. According to Tang and Wang [16], for these projects to be developed, investors' sense of trust must increase. To achieve this goal, the legal infrastructure in the country must be sufficient. In other words, in an environment where legal uncertainties are reduced, investors focus much more on these projects [17]. On the other hand, Sun et al. [18] concluded that sufficient legal infrastructure also ensures that foreign investors are willing to come to the country. Since this situation will increase the liquid money in the market, it enables the capital needs in the country to be easily met. Moreover, Zhou et al. [19] demonstrated that when investors make energy storage investments in another country, they need to thoroughly understand the legal conditions of these countries. Otherwise, Hunt et al. [20] concluded that investors run the risk of being exposed to significant penalties. This situation may cause financial losses for energy storage investments.

Energy storage capacity is also vital to ensure the effectiveness of these projects. Moraski et al. [21] stated that energy storage capacity refers to how much energy can be stored. Energy storage investments play an important role, especially in providing uninterrupted energy to businesses. However, if the storage capacity cannot meet this need, energy outages may occur [22]. This situation causes disruptions in the production processes of businesses. In this context, it is important to have high capacity to meet energy demand effectively. On the other hand, Shirole et al. [23] defined that high energy storage capacity contributes to reducing the load on the main grid. Thus, it is possible for the energy provided by the main grid to be more stable. High energy storage capacity also helps to be less affected by market risks. In this context, Salehi and Rastegar [24] concluded that countries can obtain their own energy thanks to high-capacity energy storage processes. This eliminates the obligation of countries to import energy. Therefore, Cho et al. [25] indicated that in case of possible increases in energy prices, these countries will be less affected by these fluctuations.

Financial issues are of great importance in increasing the effectiveness of energy storage investments. Kosowski et al. [26] denoted that the high costs of energy storage projects significantly reduce the success of these investments. Therefore, low costs enable investors to focus on these projects. Avamolowo et al. [27] showed that finding low-cost financing sources is very important for the long-term sustainability of these projects. In this process, first, the financial markets in the country must be developed. Zhou et al. [28] identified that in this way, investors can easily access the financing source they need for energy storage projects. Moreover, Augadra et al. [29] concluded that some support should be provided by the state for these projects. In this context, low-interest loan opportunities and tax exemptions allow the costs of these projects to decrease. Furthermore, Vecchi and Sciacovelli [30] underlined that the high returns of energy storage projects may also attract the attention of investors. In this way, more investors can be found, and the financial support required to carry out these projects can be provided.

The findings obtained as a result of the literature review can be summarized as follows. Energy storage investments are very important in terms of clean energy use and energy independence in countries. Therefore, these projects should be increased effectively. To achieve this goal, the basic factors affecting performance need to be improved. On the other hand, every improvement made also leads to an increase in costs. Therefore, it is not financially possible to make improvements to too many variables. In this context, more important factors should be determined, and actions should be taken accordingly. Nevertheless, there are very limited studies in the literature focusing on this issue. This situation means a significant gap in the literature on energy storage investments. To fill this gap, a new decision-making model is created to make a priority analysis.

3. Proposed methodology

A new fuzzy decision-making model is constructed in this study to evaluate the main performance indicators of energy storage investments. The details of this model are provided in Fig. 1.

This section includes the methodological details of the approaches used in the proposed model.

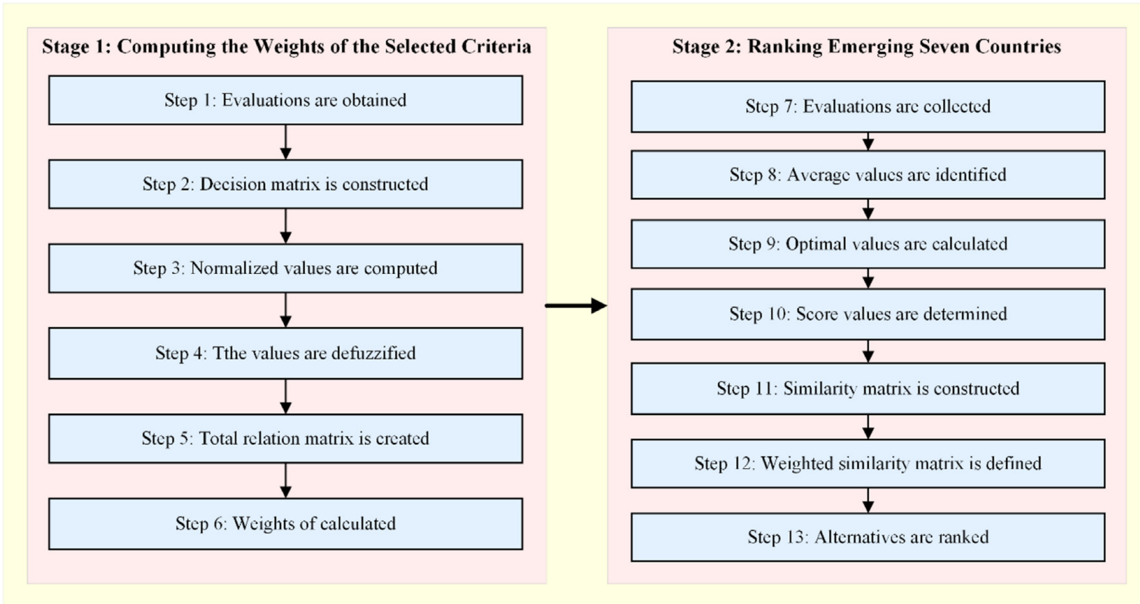

Fig. 1. Flowchart.

Table 1
Linguistic variable.

	μ	η	υ
4	,85	,15	,45
3	,6	,2	,35
2	,35	,25	,25
1	0	,3	,15
0	0	0	0

3.1. Spherical fuzzy top-dematel

DEMATEL is used to calculate weight of the criteria. The main advantage of this method is that it considers causality between criteria. If the decision matrix is symmetrical, a problem is occurred while calculating of weights in the classical DEMATEL. Therefore, TOP-DEMATEL is proposed to overcome these disadvantages [8]. This newly generated method with spherical fuzzy numbers is developed below. Firstly, evaluations are received from experts and converted into spherical fuzzy numbers detailed in Table 1 where μ, η and υ are membership value, non-membership value and hesitancy value, respectively [9].

The matrix form of the evaluation is shown in Eq. (1).

$$D^i = \begin{bmatrix} (0,0,0) & \cdots & \left(\mu^i_{1n}, \eta^i_{1n}, v^i_{1n}\right) \\ \vdots & \ddots & \vdots \\ \left(\mu^i_{n1}, \eta^i_{n1}, v^i_{n1}\right) & \cdots & (0,0,0) \end{bmatrix} \tag{1}$$

Decision matrix (D) is created by using Eqs. (2) and (3).

$$SFWAM_W\left(\tilde{D}_1, \tilde{D}_2, \ldots \tilde{D}_k\right) = \left\{ \left[1 - \prod_{i=1}^{k}(1-\mu^2_{D_i})^{\frac{1}{k}}\right]^{\frac{1}{2}}, \prod_{i=1}^{k}\eta_{D_i}^{\frac{1}{k}}, \left[\prod_{i=1}^{k}\left(1-\mu^2_{D_i}\right)^{\frac{1}{k}} - \prod_{i=1}^{k}\left(1-\mu^2_{D_i}-v^2_{D_i}\right)^{\frac{1}{k}}\right]^{\frac{1}{2}} \right\} \tag{2}$$

$$D = \begin{bmatrix} 0 & \cdots & \left(\mu^d_{1n}, \eta^d_{1n}, v^d_{1n}\right) \\ \vdots & \ddots & \vdots \\ \left(\mu^d_{n1}, \eta^d_{n1}, v^d_{n1}\right) & \cdots & 0 \end{bmatrix} \tag{3}$$

Then, three separate submatrices are generated for each component in spherical fuzzy numbers. For normalize, the largest row and column summation is taken into account. The decision matrix is divided by the value. After that, each submatrix is normalized by the help of Eqs. (4) and (5).

$$X = sD(4) \tag{4}$$

$$s = \min\left[\frac{1}{\max_i \sum_{j=1}^{n}\left|d_{ij}\right|}, \frac{1}{\max_j \sum_{i=1}^{n}\left|d_{ij}\right|}\right] \tag{5}$$

Normalized submatrices are constructed with Eq. (6).

$$X^{\mu} = \begin{bmatrix} 0 & \cdots & \mu_{1n} \\ \vdots & \ddots & \vdots \\ \mu_{n1} & \cdots & 0 \end{bmatrix} X^{\eta} = \begin{bmatrix} 0 & \cdots & \eta_{1n} \\ \vdots & \ddots & \vdots \\ \eta_{n1} & \cdots & 0 \end{bmatrix} X^{v} = \begin{bmatrix} 0 & \cdots & v_{1n} \\ \vdots & \ddots & \vdots \\ v_{n1} & \cdots & 0 \end{bmatrix} \tag{6}$$

With the help of Eq. (7), total relationship matrices (T) are calculated for each submatrix.

$$T = X * (1-X)^{-1} \tag{7}$$

Calculated sub-total relationship matrices are combined and total relationship matrix ($\tilde{T}$) is generated as in Eq. (8).

$$\tilde{T} = \begin{bmatrix} \left(\mu^T_{11}, \eta^T_{11}, v^T_{11}\right) & \cdots & \left(\mu^T_{1n}, \eta^T_{1n}, v^T_{1n}\right) \\ \vdots & \ddots & \vdots \\ \left(\mu^T_{n1}, \eta^T_{n1}, v^T_{n1}\right) & \cdots & \left(\mu^T_{nn}, \eta^T_{nn}, v^T_{nn}\right) \end{bmatrix} \tag{8}$$

Score function is calculated by Eq. (9) to generate defuzzified values.

$$Score = \mu^2 - \eta^2 - v^2 \tag{9}$$

Finally, the Euclidean distance of the values to the maximum and minimum values for the row and column in the total impact matrix is taken into account. The weights are calculated with the sum of these distances. Weights (W) are obtained by Eqs. (10)–(16).

$$C^*_j = \sqrt{\sum_{i=1}^{n}\left(t_i - \max_j t_i\right)^2} \quad j = 1, 2, ..n \tag{10}$$

Table 2
Linguistic variables for ranking.

Scales	μ	η	υ
1	.1	.9	0
2	.2	.8	.1
3	.3	.7	.2
4	.4	.6	.3
5	.5	.5	.4
6	.6	.4	.3
7	.7	.3	.2
8	.8	.2	.1
9	.9	.1	.0

$$C_j^- = \sqrt{\sum_{i=1}^{n}\left(t_i - \min_j t_i\right)^2} \quad j = 1,2,..n \tag{11}$$

$$R_i^* = \sqrt{\sum_{j=1}^{n}\left(t_j - \max_i t_j\right)^2} \quad i = 1,2,..n \tag{12}$$

$$R_i^- = \sqrt{\sum_{j=1}^{n}\left(t_j - \max_i t_j\right)^2} \quad i = 1,2,..n \tag{13}$$

$$S_i^* = C_i^* + R_i^* \tag{14}$$

$$S_i^- = C_i^- + R_i^- \tag{15}$$

$$W_i = \frac{S_i^-}{S_i^- + S_i^*} \tag{16}$$

3.2. Spherical fuzzy RATGOS

Existing ranking models in the literature are criticized by the scholars. In the analysis process of TOPSIS technique, Euclidean distance is taken into consideration to compute the distance to the optimal value. This situation is criticized for the calculation of the distance to the negative optimal value [6]. Due to these disadvantages, it is understood that a new approach should be created to find the solution of these issues. RATGOS is a newly generated ranking method that considers similarity ratios [7]. Geometric mean is taken into consideration in this method in the calculation process. First, evaluations of the experts are converted to the spherical fuzzy numbers defined in Table 2.

Then, with Eq. (2), the average of the expert opinions (Z) is created. In the Z matrix, the optimal value is calculated for each criterion. Eqs. (17) and (18) are used for this situation.

$$optimal = \left\{(\mu,\eta,\upsilon)\,|\,\max(Score(Z_i))\right\}\ for\ benefit\ criteria \tag{17}$$

$$optimal = \left\{(\mu,\eta,\upsilon)|\,\min(Score(Z_i))\right\}\ for\ cost\ criteria \tag{18}$$

In this context, Score (Z_i) is the score function of the spherical fuzzy Z_i number and is calculated by Eq. (9). Then, using Z matrix in Eq. (9), the defuzzified matrix (F) is obtained. By dividing values of the F matrix to the optimal value, the similarity matrix to the optimal value (B) is obtained. Eqs. (19) and (20) are used for this condition.

$$b_{ij} = \frac{f_{ij}}{Score(optimal_j)} \quad i = 1,2,\ldots,n, j = 1,2,\ldots,m\ for\ benefit\ criteria \tag{19}$$

$$b_{ij} = \frac{Score(optimal_j)}{f_{ij}} \quad i = 1,2,\ldots,n, j = 1,2,\ldots,m\ for\ cost\ criteria \tag{20}$$

With the help of Eq. (21), the weighted similarity matrix (N) is obtained by multiplying the B matrix with the weights (W) of the criteria.

$$N = B * W \tag{21}$$

Since the values of the N matrix have negative values due to the score function, the geometric mean (G) is calculated on a row basis by Eq. (22). Thus, the average similarity ratios are calculated.

$$G_i = \sqrt[n]{\prod_{i=1}^{n}(1 + n_{ij})} - 1 \tag{22}$$

In the following step, G values are ranked. The highest value is considered similar to the most optimal and determined as the most suitable alternative.

Table 3
Selected Criteria.

Criteria	Literature
Technological Developments	[11]
Effective Legal Regulations	[18]
Energy Storage Capacity	[23]
Financial Effectiveness	[27]
Energy Market Risk	[29]

4. Analysis results

A new model is constructed to identify key determinants of the performance of the energy storage investments. The first stage consists of the weighting of the selected criteria with Spherical fuzzy TOP-DEMATEL methodology. Secondly, emerging seven countries are examined according to the effectiveness of energy storage investments. For this purpose, RATGOS technique is taken into consideration. The results of this model are shown in the following subsections.

4.1. Computing the weights of the selected criteria

Based on the literature review results, five different criteria are selected that have an impact on the effectiveness of the energy storage investments. The details of these items are demonstrated in Table 3.

Advanced energy storage technologies contribute to more effective operation of energy storage systems. With the help of these technological improvements, the cost of the energy storage systems can be decreased. Hence, effectiveness of the energy storage systems can be provided. Thanks to a well-designed legal system, investors can be encouraged to focus on energy storage projects. This situation attracts the attention of the investors so that investments of these projects can be increased. Energy storage projects with sufficient capacity help to achieve energy supply and demand balance. To ensure long-term sustainability of energy storage projects, the projects must also be financially successful. Price fluctuations in energy markets also cause the performance of these projects to decrease. The details of the expert evaluations are given in Table A.1. Expert opinions are converted into spherical fuzzy numbers. It is converted into a 3-component number corresponding to the scale score given by the experts. In other words, if the expert says "1" in the criterion comparison, fuzzy numbers are taken into account, including the corresponding values of 0, 0.3 and 0.15. In the equations, 0 is used for membership value, 0.3 is used for non-membership value and 0.15 is used for hesitancy value. Then, the average of the expert opinions obtained is taken by Eq. (2). Thus, the decision matrix is obtained as in Table A.2. Three submatrices are created from the resulting decision matrix. Afterwards, they are normalized with the help of Eqs. (4) and (5) as in Table A.3. The values in the decision matrix are normalized to remove the unit size and obtain the standardize values. With Eq> (7), the component of the total relationship matrix is calculated over each sub-matrix. Then, Euclidean normalization is applied to be suitable for spherical fuzzy sets. Defuzzified total relationship matrix is given in Table A.4. Criterion weights are calculated based on the total relationship matrix. Eqs. (10)–(16) are used to calculate the weights as detailed in Table 4.

It is concluded that energy storage capacity is the most significant factor to improve energy storage investments in developing economies. Technological improvements are also important in this

Table 4
S*, S⁻ and weights.

Criteria	S*	S⁻	Weights	Rank
Technology	0,8983	4,6849	0,2157	2
Legal	0,6224	1,6547	0,1868	4
Capacity	0,9175	5,0866	0,2178	1
Finance	0,9436	4,8948	0,2156	3
Market	1,0394	1,8323	0,1640	5

Table 5
G values and ranking.

Alternatives	G	Ranking
Brazil	−.2475	4
China	.0804	1
India	−.2497	5
Indonesia	−.2212	3
Mexico	−.2583	6
Russia	.0366	2
Turkey	−.2813	7

regard. Nonetheless, effective legal regulations, financial effectiveness and energy market risk have lower importance for this situation.

4.2. Ranking emerging seven countries

In the second part of the proposed model, emerging seven countries are evaluated with respect to the performance of the energy storage projects. In other words, in this process, it is aimed to understand which of these countries are more successful for the effectiveness of the energy storage investments. There are significant advantages of examining the effectiveness of energy storage investments for developing countries. Because these countries have fast-growing economies, energy demand can also increase radically. Energy storage projects need to be increased to meet this demand effectively and to avoid carbon emissions in this process. Evaluations are denoted in Table A.5. Expert opinions are converted to spherical fuzzy numbers. The average of expert opinions (Z) is obtained with Eq. (2). Z matrix is demonstrated in Table A.6. Optimal values are determined with help of Eq. (17) because all criteria are benefit. Score values of $\boldsymbol{Z}$ and optimal values are calculated by Eq. (9). Next, $\boldsymbol{B}$ matrix is found with Eq. (19). After that, $\boldsymbol{B}$ matrix is given in Table A.7. Then, $\boldsymbol{B}$ matrix is multiplied by the weights with Eq. (21). In this process, the values in the first subsection are used as weights. The weighted similarity matrix is denoted in Table A.8. Finally, G values and rankings of the alternatives are given in Table 5.

The ranking results demonstrate that China has the greatest performance for the energy storage investment performance. Russia is also another important emerging economy in this respect. However, Brazil, India, Indonesia, Mexico, and Turkey have lower performance for these investments.

5. Discussion

It has been determined that energy storage capacity is of great importance in increasing the effectiveness of energy storage investments. High capacity allows more renewable energy to be stored. Therefore, designing the energy storage system with high capacity allows the performance of these projects to be increased. Xiao et al. [31] discussed that energy storage systems with sufficient capacity play a very important role in cases where the amount of energy produced is not sufficient. According to Ezika et al. [32], this condition contributes significantly to minimizing energy outages. The amount of electricity produced from renewable energy projects may vary according to different seasons. Singh et al. [33] defined that to manage this imbalance more accurately, energy storage capacity needs to be increased. This allows these outages to be managed more effectively. Thus, it is possible to supply the energy needed by businesses in a more stable manner. Yi et al. [34] showed that this situation gives an opportunity to minimize the disruptions that may occur in the production process. Thus, the development of country economies can be both more sustainable and more stable.

It is possible to take various actions to increase the storage capacity in energy storage systems. First, energy storage technologies need to be developed. Yu et al. [35] identified that research studies in this field enable us to achieve this goal. Thanks to new technological developments, more efficient batteries can be produced. These new products allow energy to be stored with higher capacity. Higher-scale investments are needed to design a larger capacity energy storage system [36]. Higher amounts of financial resources are needed to realize these projects. Wei et al. [37] concluded that both government support and the development of financial markets in the country are of vital importance in this process. Lu et al. [38] also underlined that handling two different renewable energy projects in a hybrid way is also very effective in increasing energy storage capacity. In this way, it is possible to produce and store more energy.

In the literature, many different scholars also underlined the significance of the effective risk management to increase the effectiveness of the energy storage investments [39,40]. In this scope, Saqib et al. [41] evaluated the performance of energy imports in Pakistan. In this framework, the importance of exchange rate volatility is highlighted. Candila et al. [42] made similar evaluation for oil-exporting and oil-importing countries. They reached a conclusion that exchange rate volatility has a significant influence on the performance of this industry. An et al. [43] examined the global oil market in South Korea and concluded the same issues. Tabar et al. [44], Zishan et al. [45] and Cao et al. [46] also demonstrated the importance of effective exchange rate risk management to improve the performance of energy storage systems. On the other side, Dong et al. [47], Arellano-Prieto et al. [48] and Lotfi et al. [49] denoted that technological risks should be managed effectively to reach this objective.

6. Conclusion

This study tries to examine important performance indicators of the energy storage investments with a novel decision-making model. The first stage includes the weighting of the selected criteria with Spherical fuzzy TOP-DEMATEL methodology. At the second stage, emerging seven countries are ranked based on the effectiveness of energy storage investments. In this scope, RATGOS technique is taken into consideration. It is concluded that energy storage capacity is the most significant factor to improve energy storage investments in developing economies. Technological improvements are also important in this regard. Nonetheless, effective legal regulations, financial effectiveness and energy market risk have lower importance for this situation.

The main contribution of this study is that a new ranking approach (RATGOS) is generated in this study to handle the criticisms made for existing ranking techniques. For this purpose, geometric mean is considered in the analysis process. Additionally, TOP-DEMATEL methodology is also newly proposed in this study to manage the disadvantages of classical DEMATEL technique, such as creating equal weights inappropriately in case of symmetrical evaluation. Because of this issue, final steps of TOPSIS are integrated to the classical DEMATEL so that TOP-DEMATEL is generated. The main limitation of this study is that only emerging economies are evaluated. These countries have fast-growing economies. Because of this issue, energy demand can be increased significantly in these countries. Therefore, energy storage investments should be improved for these countries. However, these projects are also significant for developed economies.

Table A.1
Expert opinions for weighting.

Expert 1					
	Technology	Legal	Capacity	Finance	Market
Technology	0	4	2	4	4
Legal	1	0	2	1	1
Capacity	3	4	0	4	4
Finance	1	1	1	0	1
Market	1	2	2	1	0
Expert 2					
	Technology	Legal	Capacity	Finance	Market
Technology	0	4	3	2	2
Legal	2	0	1	1	2
Capacity	4	3	0	4	4
Finance	1	1	1	0	2
Market	1	2	2	1	0
Expert 3					
	Technology	Legal	Capacity	Finance	Market
Technology	0	4	2	2	2
Legal	1	0	2	1	1
Capacity	3	4	0	4	4
Finance	1	2	1	0	2
Market	1	1	2	2	0

Table A.2
Decision matrix.

	Technology			Legal			Capacity			Finance			Market		
Technology	.00	.00	.00	.85	.15	.45	.46	.23	.25	.63	.21	.52	.63	.21	.52
Legal	.21	.28	.15	.00	.00	.00	.29	.27	.25	.00	.30	.15	.21	.28	.15
Capacity	.72	.18	.37	.80	.17	.48	.00	.00	.00	.85	.15	.45	.85	.15	.45
Finance	.00	.30	.15	.21	.28	.15	.00	.30	.15	.00	.00	.00	.29	.27	.15
Market	.00	.30	.15	.29	.27	.25	.35	.25	.25	.21	.28	.15	.00	.00	.00

Table A.3
Normalized matrices..

X^{μ}	Technology	Legal	Capacity	Finance	Market
Technology	.0000	.2645	.1426	.1973	.1973
Legal	.0642	.0000	.0899	.0000	.0642
Capacity	.2234	.2476	.0000	.2645	.2645
Finance	.0000	.0642	.0000	.0000	.0899
Market	.0000	.0899	.1089	.0642	.0000
X^{η}	Technology	Legal	Capacity	Finance	Market
Technology	.0000	.1307	.2022	.1837	.1837
Legal	.2459	.0000	.2314	.2613	.2459
Capacity	.1583	.1438	.0000	.1307	.1307
Finance	.2613	.2459	.2613	.0000	.2314
Market	.2613	.2314	.2178	.2459	.0000
X^{ν}	Technology	Legal	Capacity	Finance	Market
Technology	.0000	.2365	.1315	.2747	.2747
Legal	.0789	.0000	.0000	.0788	.0789
Capacity	.1953	.2529	.0788	.2365	.2365
Finance	.0788	.0789	.1314	.0000	.0789
Market	.0788	.1315	.0000	.0789	.0000

Thus, in the future studies, a new evaluation can be conducted for developed countries.

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.

Data availability

No data was used for the research described in the article.

Appendix

See Tables A.1–A.8.

Table A.4
Total relationship matrix.

	Technology	Legal	Capacity	Finance	Market
Technology	−.1561	−.0854	−.0509	−.2336	−.2357
Legal	−.2313	−.1852	−.1146	−.3083	−.2679
Capacity	.0943	−.1038	−.2363	.0217	.0013
Finance	−.3932	−.3448	−.5260	−.2205	−.3195
Market	−.3137	−.2808	−.0722	−.2593	−.1783

Table A.5
Experts opinions for ranking.

	Expert 1				
	Technology	Legal	Capacity	Finance	Market
Brazil	2	1	2	3	2
China	7	7	7	7	7
India	3	2	1	4	2
Indonesia	1	4	5	3	2
Mexico	4	1	2	3	2
Russia	6	6	7	5	6
Turkey	3	2	2	3	1
	Expert 2				
	Technology	Legal	Capacity	Finance	Market
Brazil	3	2	2	1	2
China	7	6	7	6	7
India	3	3	1	2	1
Indonesia	1	3	2	3	1
Mexico	2	1	2	1	2
Russia	6	5	6	6	6
Turkey	2	1	2	1	1
	Expert 3				
	Technology	Legal	Capacity	Finance	Market
Brazil	1	1	1	2	3
China	6	7	7	6	6
India	2	1	1	3	2
Indonesia	1	5	2	2	1
Mexico	2	1	3	1	2
Russia	6	5	7	6	6
Turkey	2	1	1	2	1

Table A.6
Z Matrix.

	Technology			Legal			Capacity			Finance			Market		
Brazil	.22	.80	.10	.14	.87	.00	.17	.83	.10	.22	.80	.20	.24	.77	.10
China	.67	.33	.20	.67	.33	.20	.70	.30	.20	.64	.36	.20	.67	.33	.20
India	.27	.73	.20	.22	.80	.10	.10	.90	.00	.31	.70	.30	.17	.83	.10
Indonesia	.10	.90	.00	.41	.59	.30	.34	.68	.40	.27	.73	.20	.14	.87	.10
Mexico	.29	.73	.30	.10	.90	.00	.24	.77	.10	.19	.83	.20	.20	.80	.10
Russia	.60	.40	.30	.54	.46	.30	.67	.33	.20	.57	.43	.40	.60	.40	.30
Turkey	.24	.77	.20	.14	.87	.10	.17	.83	.10	.22	.80	.20	.10	.90	.00

Table A.7
B Matrix.

Alternatives	Technology	Legal	Capacity	Finance	Market
Brazil	.7451	.9109	−1.8672	−2.6720	−1.7913
China	−.3758	−.3758	1.0000	1.0000	1.0000
India	.6275	.7451	−2.2222	−2.0290	−2.2359
Indonesia	1.0000	.3429	−1.4261	−2.1424	−2.4572
Mexico	.6709	1.0000	−1.4959	−2.9347	−2.0290
Russia	−.1375	.0214	.8351	−.0895	.3659
Turkey	.7107	.9234	−1.8672	−2.6720	−2.6610

Table A.8
The weighted similarity matrix.

Alternatives	Technology	Legal	Capacity	Finance	Market
Brazil	.1608	.1702	−.4067	−.5760	−.2939
China	−.0811	−.0702	.2178	.2156	.1640
India	.1354	.1392	−.4840	−.4374	−.3668
Indonesia	.2157	.0641	−.3106	−.4618	−.4031
Mexico	.1447	.1868	−.3258	−.6326	−.3329
Russia	−.0297	.0040	.1819	−.0193	.0600
Turkey	.1533	.1725	−.4067	−.5760	−.4365

References

[1] J. Hjalmarsson, K. Thomas, C. Boström, Service stacking using energy storage systems for grid applications–A review, J. Energy Storage 60 (2023) 106639.

[2] L. Wang, Merchant energy storage investment analysis considering multi-energy integration, Energies 16 (12) (2023) 4695.

[3] R. Haghighi, S.H. Jalalzad, M.R. Salehizadeh, H.H. Alhelou, P. Siano, Cloud energy storage investment by collaboration of microgrids for profit and reliability

enhancement considering a TSO-DSO yearly reward, IEEE Access 11 (2023) 23808–23826.
[4] M. Liebensteiner, A. Haxhimusa, F. Naumann, Subsidized renewables' adverse effect on energy storage and carbon pricing as a potential remedy, Renew. Sustain. Energy Rev. 171 (2023) 112990.
[5] X. Xu, S. Yüksel, H. Dinçer, An integrated decision-making approach with golden cut and bipolar q-ROFSs to renewable energy storage investments, Int. J. Fuzzy Syst. 25 (1) (2023) 168–181.
[6] H. Dinçer, S. Eti, S. Yüksel, S. Özdemir, A.E. Yílmaz, E. Ergün, Integrating data mining and fuzzy decision-making techniques for analyzing the key minimizing factors of carbon emissions, J. Intell. Fuzzy Systems (2023) 1–17, Preprint.
[7] H. Dinçer, S. Yüksel, S. Eti, Identifying the right policies for increasing the efficiency of the renewable energy transition with a novel fuzzy decision-making model, J. Soft Comput. Decis. Anal. 1 (1) (2023) 50–62.
[8] F. Özdemirci, S. Yüksel, H. Dinçer, S. Eti, An assessment of alternative social banking systems using T-spherical fuzzy TOP-DEMATEL approach, Decis. Anal. J. (2023) 100184.
[9] S. Eti, H. Dinçer, S. Yüksel, Y. Gökalp, Analysis of the suitability of the solar panels for hospitals: A new fuzzy decision-making model proposal with the T-spherical TOP-DEMATEL method, J. Intell. Fuzzy Systems (2022) 1–13, Preprint.
[10] H. Dınçer, S. Etı, T. Aksoy, S. Yüksel, U. Hacioglu, A. Mikhaylov, S.M. Muyeen, Analysis of environmental impact for material production investments using a novel soft computing methodology, IEEE Access (2023).
[11] C. Gu, J. Wang, L. Wu, Distributed energy resource and energy storage investment for enhancing flexibility under a TSO-dso coordination framework, IEEE Trans. Autom. Sci. Eng. (2023).
[12] L. Gacitúa, D. Olivares, M. Negrete-Pincetic, Á. Lorca, The role of fast-acting energy storage for contingency grid support in the transmission planning, Energy 283 (2023) 128465.
[13] L. Bian, China's role in scaling up energy storage investments, Energy Storage Saving 2 (2) (2023) 415–420.
[14] M. Gao, Z. Han, C. Zhang, P. Li, D. Wu, Optimal configuration for regional integrated energy systems with multi-element hybrid energy storage, Energy 277 (2023) 127672.
[15] S. Zhang, Y. Li, E. Du, C. Fan, Z. Wu, Y. Yao, A review and outlook on cloud energy storage: An aggregated and shared utilizing method of energy storage system, Renew. Sustain. Energy Rev. (2023) 113606.
[16] H. Tang, S. Wang, Life-cycle economic analysis of thermal energy storage, new and second-life batteries in buildings for providing multiple flexibility services in electricity markets, Energy 264 (2023) 126270.
[17] B. Wang, X. Wang, Z. Zhu, X. Wu, Siting and sizing of energy storage for renewable generation utilization with multi-stage dispatch under uncertainty: A tri-level model and decomposition approach, Appl. Energy 344 (2023) 121286.
[18] Q. Sun, J. Zhou, Z. Lan, X. Ma, The economic influence of energy storage construction in the context of new power systems, Sustainability 15 (4) (2023) 3070.
[19] Y. Zhou, J. Wang, Y. Li, C. Wei, A collaborative management strategy for multi-objective optimization of sustainable distributed energy system considering cloud energy storage, Energy (2023) 128183.
[20] J.D. Hunt, B. Zakeri, J. Jurasz, W. Tong, P.B. Dąbek, R. Brandão, Underground gravity energy storage: A solution for long-term energy storage, Energies 16 (2) (2023) 825.
[21] J.W. Moraski, N.D. Popovich, A.A. Phadke, Leveraging rail-based mobile energy storage to increase grid reliability in the face of climate uncertainty, Nature Energy (2023) 1–11.
[22] Y. Wu, J. Fang, X. Ai, X. Xue, S. Cui, X. Chen, J. Wen, Robust co-planning of AC/DC transmission network and energy storage considering uncertainty of renewable energy, Appl. Energy 339 (2023) 120933.
[23] A. Shirole, M. Wagh, V. Kulkarni, P. Patil, Short-term energy scenario of district energy system using optimised renewable energy mix with and without energy storage, Results Eng. 18 (2023) 101017.
[24] M.K. Salehi, M. Rastegar, Distributed peer-to-peer transactive residential energy management with cloud energy storage, J. Energy Storage 58 (2023) 106401.
[25] N.R. Cho, Y. Kim, K. Murali, M. Yavuz, Drivers and implications of combined investment in renewables and energy storage in the residential sector, Decis. Sci. (2023).
[26] K. Kosowski, M. Piwowarski, W. Włodarski, P. Ziemiański, G. Pawlak, Technical and economic analysis of energy storage in the compressed air technology with low capacity for the production plant, Energy Convers. Manage. 282 (2023) 116872.
[27] O.J. Ayamolowo, P.T. Manditereza, K. Kusakana, Assessing the role of hybrid energy storage in generation expansion planning for enhanced frequency stability, Energy Rep. 9 (2023) 1–10.
[28] S. Zhou, Y. Han, S. Chen, P. Yang, K. Mahmoud, M.M. Darwish, A multiple uncertainty-based bi-level expansion planning paradigm for distribution networks complying with energy storage system functionalities, Energy 275 (2023) 127511.
[29] M. Auguadra, D. Ribó-Pérez, T. Gómez-Navarro, Planning the deployment of energy storage systems to integrate high shares of renewables: The Spain case study, Energy 264 (2023) 126275.
[30] A. Vecchi, A. Sciacovelli, Long-duration thermo-mechanical energy storage–present and future techno-economic competitiveness, Appl. Energy 334 (2023) 120628.
[31] J.W. Xiao, Y.B. Yang, S. Cui, X.K. Liu, A new energy storage sharing framework with regard to both storage capacity and power capacity, Appl. Energy 307 (2022) 118171.
[32] A.C. Ezika, E.R. Sadiku, C.I. Idumah, S.S. Ray, Y. Hamam, On energy storage capacity of conductive mxene hybrid nanoarchitectures, J. Energy Storage 45 (2022) 103686.
[33] M. Singh, I.E. Apata, S. Samant, W. Wu, B.V. Tawade, N. Pradhan, Nanoscale strategies to enhance the energy storage capacity of polymeric dielectric capacitors: Review of recent advances, Polym. Rev. 62 (2) (2022) 211–260.
[34] T. Yi, H. Ye, Q. Li, C. Zhang, W. Ren, Z. Tao, Energy storage capacity optimization of wind-energy storage hybrid power plant based on dynamic control strategy, J. Energy Storage 55 (2022) 105372.
[35] H. Yu, X. Yang, H. Chen, S. Lou, Y. Lin, Energy storage capacity planning method for improving offshore wind power consumption, Sustainability 14 (21) (2022) 14589.
[36] K. Vijayalakshmi, K. Vijayakumar, K. Nandhakumar, Prediction of virtual energy storage capacity of the air-conditioner using a stochastic gradient descent based artificial neural network, Electr. Power Syst. Res. 208 (2022) 107879.
[37] D. Wei, M. Weng, M.H.H. Mahmoud, A.Y. Elnaggar, I.H.E. Azab, X. Sheng, Development of novel biomass hybrid aerogel supported composite phase change materials with improved light-thermal conversion and thermal energy storage capacity, Adv. Compos. Hybrid Mater. 5 (3) (2022) 1910–1921.
[38] Y. Lu, J. Guo, Z. He, Z. Gao, Y.Y. Song, Direct access to NiCo-LDH nanosheets by electrochemical-scanning-mediated hydrolysis for photothermally enhanced energy storage capacity, Energy Storage Mater. 48 (2022) 487–496.
[39] R. Stokes, Overview of li-ion battery energy storage system failures and risk management considerations, Process Saf. Prog. 41 (3) (2022) 437–439.
[40] Y. Yin, J. Liu, Risk assessment of photovoltaic-energy storage utilization project based on improved cloud-TODIM in China, Energy 253 (2022) 124177.
[41] A. Saqib, T.H. Chan, A. Mikhaylov, H.H. Lean, Are the responses of sectoral energy imports asymmetric to exchange rate volatilities in Pakistan? Evidence from recent foreign exchange regime, Front. Energy Res. 9 (2021) 614463.
[42] V. Candila, D. Maximov, A. Mikhaylov, N. Moiseev, T. Senjyu, N. Tryndina, On the relationship between oil and exchange rates of oil-exporting and oil-importing countries: From the great recession period to the Covid-19 era, Energies 14 (23) (2021) 8046.
[43] J. An, A. Mikhaylov, S.U. Jung, The strategy of South Korea in the global oil market, Energies 13 (10) (2020) 2491.
[44] V.S. Tabar, H. Banazadeh, M. Tostado-Véliz, A.R. Jordehi, M. Nasir, F. Jurado, Stochastic multi-stage multi-objective expansion of renewable resources and electrical energy storage units in distribution systems considering crypto-currency miners and responsive loads, Renew. Energy 198 (2022) 1131–1147.
[45] F. Zishan, E. Akbari, O.D. Montoya, D.A. Giral-Ramírez, A.M. Nivia-Vargas, Electricity retail market and accountability-based strategic bidding model with short-term energy storage considering the uncertainty of consumer demand response, Results Eng. 16 (2022) 100679.
[46] Y. Cao, Y. Wu, P. Tian, X. Xiao, L. Yu, Risk assessment of retired power battery energy storage system, in: International Conference on Energy Storage and Intelligent Vehicles, Springer Nature Singapore, Singapore, 2022, pp. 720–729.
[47] H. Dong, Y. Wu, J. Zhou, W. Chen, Optimal selection for wind power coupled hydrogen energy storage from a risk perspective, considering the participation of multi-stakeholder, J. Clean. Prod. 356 (2022) 131853.
[48] Y. Arellano-Prieto, E. Chavez-Panduro, P. Salvo Rossi, F. Finotti, Energy storage solutions for offshore applications, Energies 15 (17) (2022) 6153.
[49] R. Lotfi, B. Kargar, A. Gharehbaghi, H. Hazrati, S. Nazari, M. Amra, Resource-constrained time–cost-quality-energy-environment tradeoff problem by considering blockchain technology, risk and robustness: A case study of healthcare project, Environ. Sci. Pollut. Res. 29 (42) (2022) 63560–63576.