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Modified WASPAS Technique for Triangular Fuzzy Neutrosophic Number Multiple-Attribute Decision-Making to Safe Operation Risk Assessment of Batteries in Energy Storage Power Stations

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Abstract: With the proposal of China's "dual carbon" goals and the rapid development of the energy storage industry, in recent years, there have been more and more reports on safety accidents of energy storage power stations in the application of the energy storage industry. It can be seen that the pressure and safety hazards of the safe operation of energy storage power stations have significantly increased, and safety issues have become the main bottleneck restricting the good development of the energy storage industry. The safe operation risk assessment of batteries in energy storage power stations could be considered (MADM). Recently, the WASPAS technique has been used to rank the alternatives. The triangular fuzzy neutrosophic sets (TFNSs) express fuzzy information during the safe operation risk assessment of batteries in energy storage power stations. In this paper, the triangular fuzzy neutrosophic number WASPAS (TFNN-WASPAS) approach based on the triangular fuzzy neutrosophic number (TFNNWASPAS) is constructed to put forward MADM with TFNSs. The average method is employed to compute the weight values based on TFNN (TFNNWASPAS) under TFNSs. Finally, a numerical example of safe operation risk assessment of batteries in energy storage power stations and some comparisons are constructed to verify TFNN- WASPAS.

Keywords: Multiple-attribute decision-making (MADM); TFNSs; WASPAS technique; safe operation risk assessment

1. Introduction

Industry-related statistical data shows that as of the end of 2022, the cumulative installed capacity of power storage projects in China has reached 59.4 GW, with a year-on-year increase of 37% in new installed capacity in 2022. Among them, pumped storage accounts for the largest proportion, with a cumulative installed capacity of 46.1 GW [1, 2]. New energy storage continues to maintain high-speed growth compared to previous years, with a cumulative installed capacity exceeding 10GW and reaching 12.7GW[3, 4]. It is expected that by 2025, China's new energy storage installed capacity will exceed 30GW. In recent years, many provinces in China have required that a certain proportion of energy storage facilities must be installed in newly built new energy projects, with a configuration power ranging from 5% to 30% of the approved capacity of new energy projects, and a storage time of 1 to 4 hours[5, 6]. Compared with other electrochemical energy storage technologies such as flow batteries, lead-acid batteries, and sodium-ion batteries, lithium-ion batteries have the main advantages of high individual energy density, high charging, and discharging efficiency, low self-discharge rate, and fast dynamic response. They are widely used in the energy storage industry[7, 8]. With the continuous deepening of China's energy transformation, battery energy storage power stations have become an important component of ensuring the safe and stable operation of the power system. Battery energy storage is one of the most effective technical means to compensate for the real-time supply-demand deviation of the power system. Along with the rapid development of the energy storage industry, energy storage safety accidents are also common both domestically and internationally[9, 10]. The safety operating pressure and hidden dangers of energy storage power stations have significantly increased. Electrochemical energy storage is a chemical integrated equipment with high energy density, which poses significant safety risks during operation. Safety issues have become the main bottleneck restricting the healthy development of the energy storage industry[11]. In addition, as an emerging industry, energy storage currently has an incomplete and delayed regulatory standard system for energy storage safety. There are risk factors in battery quality and safety management, project planning, construction and operation, maintenance management, and retirement recycling for energy storage power stations. During daily operations, energy storage power stations cannot generally identify and warn of safety risks, and most of them fail to solve problems such as fire protection and emergency response[12, 13]. There are many safety hazards, and the corresponding safety supervision mechanisms are not perfect, leading to frequent safety accidents in energy storage power stations[14, 15]. In the past decade, there have been nearly a hundred energy storage safety accidents worldwide, especially in the past five years. With the explosive development of the global energy storage market, the scale application of energy storage projects continues to increase, and the scale of individual energy storage projects continues to expand, posing increasing risks to the safe operation of energy storage[16]. The safety accidents that have occurred in domestic and foreign energy storage power stations have had a profound impact and a heavy cost, and have also sounded the alarm for the healthy and good development of energy storage power stations in China in the future[17]. For the energy storage industry, safety issues must be taken seriously and solved before achieving large-scale development of energy storage[18]. In the current trend and environment, solving energy storage safety issues is the top priority for the healthy development of the industry[19]. At present, research on the safety management of battery electrochemical energy storage mainly focuses on battery body materials and technology, as well as risk warnings during the design and construction stages of battery energy storage power stations[20, 21]. At the same time, due to the short operation time of most energy storage power stations, there is not much research specifically focused on safety risk management during the operation period of battery energy storage power stations. In practice, there is a lack of targeted and systematic safety risk management system construction and simple and effective risk management methods. The safety of battery energy storage power stations is not only reflected in the progress of battery body materials and technology but also in the management of safety risks during their operation period[22].

In the field of modern decision-making, MADM is a very important component[23]. MADM has been applied in many fields, such as social enterprises, military affairs, engineering technology, etc., and has been applied in all aspects of life[24, 25]. MADM is the evaluation of a limited number of alternative solutions under a certain number of evaluation attributes (indicators), using certain technical means to aggregate the evaluation information of alternative solutions under multiple evaluation attributes, to select the optimal or non-inferior solution from a limited number of alternative solutions[26-28]. With the development of multi-attribute decision-making and fuzzy uncertainty in real life, it is difficult for people to make accurate judgments in the decision-making process when facing complex decision-making problems, and the evaluation of solutions cannot be measured with accurate numbers[29, 30]. For this phenomenon, Zadeh [31] proposed a fuzzy set in 1965, which uses membership functions to express fuzzy uncertain information in the decision-making process. Once fuzzy set theory was proposed, it attracted many scholars in the industry to explore and study it. Later, with further research, it was found that although fuzzy set theory is a very useful tool for handling uncertain fuzzy information, it only considers membership and cannot handle more fuzzy and uncertain situations. Smarandache [32] implemented the neutrosophic sets (NSs). Biswas, Pramanik, and Giri [33] implemented the triangular fuzzy neutrosophic numbers (TFNNs). Aal, Abd Ellatif and Hassan [34] implemented two ranking techniques under TFNNs. Chakraborty et al. [35] implemented the triangular fuzzy neutrosophic sets (TFNSs). The safe operation risk assessment of batteries in energy storage power stations could be looked at as MADM. Recently, the WASPAS technique [36] and entropy technique [37] was put forward MADM. The TFNSs [33] are put forward expressing fuzzy information during the safe operation risk assessment of batteries in energy storage power stations. In this paper, the TFNN-WASPAS based on TFNN (TFNNWASPAS) is constructed to cope with the MADM under TFNSs. Finally, a numerical example of safe operation risk assessment of batteries in energy storage power stations is constructed and some decision comparisons are utilized to verify TFNN-WASPAS technique. This paper mainly supplies technique guidance and technical support for final realization of safe operation risk assessment of batteries in energy storage power stations. This technique has far-reaching significance for the MADM of safe operation risk assessment of batteries in energy storage power stations in the construction sector. The main research goal and motivation of this work is outlined: (1) the TFNN-WASPAS technique based on TFNN-WASPAS is constructed; (2) the average technique is employed to manage weight based on TFNN-WASPAS under TFNSs. (3) the TFNN-WASPAS technique is founded to manage the MADM based on TFNN-WASPAS under TFNSs; (4) a numerical example for safe operation risk assessment of batteries in energy storage power stations and some comparative analysis are utilized verify TFNN- WASPAS.

The research framework of such a study is outlined: Sect. 2 lists the TFNSs. Sect. 3 constructs MADM technique based on TFNN-WASPAS model. Sect. 4 verifies the TFNN-WASPAS model through a case study for safe operation risk assessment of batteries in energy storage power stations. Conclusions are constructed in Sect. 5.

2. Preliminaries

Biswas, Pramanik, and Giri [33] constructed the TFNSs.

Definition 1[33]. The TFNSs $s\eta$ is:

$$s\eta = \left\{ \left(\theta, s\phi_\eta(\theta), s\varphi_\eta(\theta), s\gamma_\eta(\theta) \right) \middle| \theta \in \Theta \right\} \quad (1)$$

where $s\phi_\eta(\theta), s\varphi_\eta(\theta), s\gamma_\eta(\theta)$ represent the truth-membership, the indeterminacy-membership and falsity-membership which is depicted by TFNs.

$$s\phi_\eta(\theta) = \left(s\phi_\eta^L(\theta), s\phi_\eta^M(\theta), s\phi_\eta^U(\theta) \right), 0 \le s\phi_\eta^L(\theta) \le s\phi_\eta^M(\theta) \le s\phi_\eta^U(\theta) \le 1 \quad (2)$$

$$s\varphi_\eta(\theta) = \left(s\varphi_\eta^L(\theta), s\varphi_\eta^M(\theta), s\varphi_\eta^U(\theta) \right), 0 \le s\varphi_\eta^L(\theta) \le s\varphi_\eta^M(\theta) \le s\varphi_\eta^U(\theta) \le 1 \quad (3)$$

$$s\gamma_\eta(\theta) = \left(s\gamma_\eta^L(\theta), s\gamma_\eta^M(\theta), s\gamma_\eta^U(\theta) \right), 0 \le s\gamma_\eta^L(\theta) \le s\gamma_\eta^M(\theta) \le s\gamma_\eta^U(\theta) \le 1 \quad (4)$$

For convenience, $s\eta = \left\{ \begin{array}{l} \left(s\phi^L, s\phi^M, s\phi^U \right), \\ \left(s\varphi^L, s\varphi^M, s\varphi^U \right), \left(s\gamma^L, s\gamma^M, s\gamma^U \right) \end{array} \right\}$ is a TFNN that meets the condition $0 \le s\phi^U + s\varphi^U + s\gamma^U \le 3$.

To cope with TFNNs, Biswas, Pramanik, and Giri [33] constructed some novel operations on the TFNNs $s\eta$, $s\eta_1$ and $s\eta_2$.

Definition 2[33]. Let $s\eta_1 = \left\{ \begin{array}{l} \left(s\phi_1^L, s\phi_1^M, s\phi_1^U \right), \\ \left(s\varphi_1^L, s\varphi_1^M, s\varphi_1^U \right), \left(s\gamma_1^L, s\gamma_1^M, s\gamma_1^U \right) \end{array} \right\}$, $s\eta_2 = \left\{ \begin{array}{l} \left(s\phi_2^L, s\phi_2^M, s\phi_2^U \right), \\ \left(s\varphi_2^L, s\varphi_2^M, s\varphi_2^U \right), \left(s\gamma_2^L, s\gamma_2^M, s\gamma_2^U \right) \end{array} \right\}$ and $s\eta = \left\{ \begin{array}{l} \left(s\phi^L, s\phi^M, s\phi^U \right), \\ \left(s\varphi^L, s\varphi^M, s\varphi^U \right), \left(s\gamma^L, s\gamma^M, s\gamma^U \right) \end{array} \right\}$, the constructed operation laws of TFNNs are designed:

$$(1)\ s\eta_1 \oplus s\eta_2 = \begin{Bmatrix} \left(s\phi_1^L + s\phi_2^L - s\phi_1^L s\phi_2^L, s\phi_1^M + s\phi_2^M - s\phi_1^M s\phi_2^M, s\phi_1^U + s\phi_2^U - s\phi_1^U s\phi_2^U\right), \\ \left(s\varphi_1^L s\varphi_2^L, s\varphi_1^M s\varphi_2^M, s\varphi_1^U s\varphi_2^U\right), \\ \left(s\gamma_1^L s\gamma_2^L, s\gamma_1^M s\gamma_2^M, s\gamma_1^U s\gamma_2^U\right) \end{Bmatrix};$$

$$(2) s\eta_1 \otimes s\eta_2 = \begin{Bmatrix} \left(s\phi_1^L s\phi_2^L, s\phi_1^M s\phi_2^M, s\phi_1^U s\phi_2^U\right), \\ \left(s\varphi_1^L + s\varphi_2^L - s\varphi_1^L s\varphi_2^L, s\varphi_1^M + s\varphi_2^M - s\varphi_1^M s\varphi_2^M, s\varphi_1^U + s\varphi_2^U - s\varphi_1^U s\varphi_2^U\right), \\ \left(s\gamma_1^L + s\gamma_2^L - s\gamma_1^L s\gamma_2^L, s\gamma_1^M + s\gamma_2^M - s\gamma_1^M s\gamma_2^M, s\gamma_1^U + s\gamma_2^U - s\gamma_1^U s\gamma_2^U\right) \end{Bmatrix};$$

$$(3)\ \lambda \times s\eta = \begin{Bmatrix} \left(1-\left(1-s\phi^L\right)^\lambda, 1-\left(1-s\phi^M\right)^\lambda, 1-\left(1-z\phi^U\right)^\lambda\right), \\ \left(\left(s\varphi^L\right)^\lambda, \left(s\varphi^M\right)^\lambda, \left(s\varphi^U\right)^\lambda\right), \\ \left(\left(s\gamma^L\right)^\lambda, \left(s\gamma^M\right)^\lambda, \left(s\gamma^U\right)^\lambda\right) \end{Bmatrix}, \lambda > 0;$$

$$(4)\ s\eta^\lambda = \begin{Bmatrix} \left(\left(s\phi^L\right)^\lambda, \left(s\phi^M\right)^\lambda, \left(s\phi^U\right)^\lambda\right), \\ \left(1-\left(1-s\varphi^L\right)^\lambda, 1-\left(1-s\varphi^M\right)^\lambda, 1-\left(1-s\varphi^U\right)^\lambda\right), \\ \left(1-\left(1-s\gamma^L\right)^\lambda, 1-\left(1-s\gamma^M\right)^\lambda, 1-\left(1-s\gamma^U\right)^\lambda\right) \end{Bmatrix}, \lambda > 0.$$

Then, the constructed operation laws have some properties.

$$(1) s\eta_1 \oplus s\eta_2 = s\eta_2 \oplus s\eta_1, s\eta_1 \otimes s\eta_2 = s\eta_2 \otimes s\eta_1, \left(\left(s\eta_1\right)^{\lambda_1}\right)^{\lambda_2} = \left(s\eta_1\right)^{\lambda_1\lambda_2}; \tag{5}$$

$$(2)\ \lambda\left(s\eta_1 \oplus s\eta_2\right) = \lambda s\eta_1 \oplus \lambda s\eta_2, \left(s\eta_1 \otimes s\eta_2\right)^\lambda = \left(s\eta_1\right)^\lambda \otimes \left(s\eta_2\right)^\lambda; \tag{6}$$

$$(3)\ \lambda_1 s\eta_1 \oplus \lambda_2 s\eta_1 = \left(\lambda_1 + \lambda_2\right) s\eta_1, \left(s\eta_1\right)^{\lambda_1} \otimes \left(s\eta_1\right)^{\lambda_2} = \left(s\eta_1\right)^{\left(\lambda_1+\lambda_2\right)}. \tag{7}$$

Irvanizam et al.[38] put forward the TFNN Hamming distance (TFNNHD) and TFNN Euclid distance (TFNNED).

Definition 3[38]. Let $s\eta_1 = \begin{Bmatrix} \left(s\phi_1^L, s\phi_1^M, s\phi_1^U\right), \\ \left(s\varphi_1^L, s\varphi_1^M, s\varphi_1^U\right), \left(s\gamma_1^L, s\gamma_1^M, s\gamma_1^U\right) \end{Bmatrix}$, $s\eta_2 = \begin{Bmatrix} \left(s\phi_2^L, s\phi_2^M, s\phi_2^U\right), \\ \left(s\varphi_2^L, s\varphi_2^M, s\varphi_2^U\right), \left(s\gamma_2^L, s\gamma_2^M, s\gamma_2^U\right) \end{Bmatrix}$, the TFNN Hamming distance is constructed:

$$TFNNHD\left(s\eta_1, s\eta_2\right) = \frac{1}{9}\begin{pmatrix} \left|s\phi_1^L - s\phi_2^L\right| + \left|s\phi_1^M - s\phi_2^M\right| + \left|s\phi_1^U - s\phi_2^U\right| \\ + \left|s\varphi_1^L - s\varphi_2^L\right| + \left|s\varphi_1^M - s\varphi_2^M\right| + \left|s\varphi_1^U - s\varphi_2^U\right| \\ + \left|s\gamma_1^L - s\gamma_2^L\right| + \left|s\gamma_1^M - s\gamma_2^M\right| + \left|s\gamma_1^U - s\gamma_2^U\right| \end{pmatrix} \tag{8}$$

Definition 4[38]. Let $s\eta_1=\left\{\begin{matrix}\left(s\phi_1^L,s\phi_1^M,s\phi_1^U\right),\\ \left(s\varphi_1^L,s\varphi_1^M,s\varphi_1^U\right),\left(s\gamma_1^L,s\gamma_1^M,s\gamma_1^U\right)\end{matrix}\right\}$, $s\eta_2=\left\{\begin{matrix}\left(s\phi_2^L,s\phi_2^M,s\phi_2^U\right),\\ \left(s\varphi_2^L,s\varphi_2^M,s\varphi_2^U\right),\left(s\gamma_2^L,s\gamma_2^M,s\gamma_2^U\right)\end{matrix}\right\}$, the Euclid distance is constructed:

$$ED\left(s\eta_1,s\eta_2\right)=\sqrt{\frac{1}{9}\left(\begin{matrix}\left|s\phi_1^L-s\phi_2^L\right|^2+\left|s\phi_1^M-s\phi_2^M\right|^2+\left|s\phi_1^U-s\phi_2^U\right|^2\\ +\left|s\varphi_1^L-s\varphi_2^L\right|^2+\left|s\varphi_1^M-s\varphi_2^M\right|^2+\left|s\varphi_1^U-s\varphi_2^U\right|^2\\ +\left|s\gamma_1^L-s\gamma_2^L\right|^2+\left|s\gamma_1^M-s\gamma_2^M\right|^2+\left|s\gamma_1^U-s\gamma_2^U\right|^2\end{matrix}\right)} \tag{9}$$

Biswas, Pramanik and Giri [33] combined the concepts of the TFNNs about the score decision values (SDV) and defined THE accuracy decision values (ADV), the SV, and AV of TFNNs to compare two TFNNs.

Definition 5[33]. Let $s\eta_1=\left\{\begin{matrix}\left(s\phi_1^L,s\phi_1^M,s\phi_1^U\right),\\ \left(s\varphi_1^L,s\varphi_1^M,s\varphi_1^U\right),\left(s\gamma_1^L,s\gamma_1^M,s\gamma_1^U\right)\end{matrix}\right\}$, $s\eta_2=\left\{\begin{matrix}\left(s\phi_2^L,s\phi_2^M,s\phi_2^U\right),\\ \left(s\varphi_2^L,s\varphi_2^M,s\varphi_2^U\right),\left(s\gamma_2^L,s\gamma_2^M,s\gamma_2^U\right)\end{matrix}\right\}$, the SV and AV are defined:

$$SDV\left(s\eta_1\right)=\frac{1}{12}\begin{bmatrix}8+\left(s\phi_1^L+2s\phi_1^M+s\phi_1^U\right)\\ -\left(s\varphi_1^L+2s\varphi_1^M+s\varphi_1^U\right)\\ -\left(s\gamma_1^L+2s\gamma_1^M+s\gamma_1^U\right)\end{bmatrix},SDV\left(s\eta_1\right)\in\left[0,1\right] \tag{10}$$

$$SDV\left(s\eta_2\right)=\frac{1}{12}\begin{bmatrix}8+\left(s\phi_2^L+2s\phi_2^M+s\phi_2^U\right)\\ -\left(s\varphi_2^L+2s\varphi_2^M+s\varphi_2^U\right)\\ -\left(s\gamma_2^L+2s\gamma_2^M+s\gamma_2^U\right)\end{bmatrix},SDV\left(s\eta_2\right)\in\left[0,1\right] \tag{11}$$

$$ADV\left(s\eta_1\right)=\frac{1}{4}\left(\begin{matrix}\left(s\phi_1^L+2s\phi_1^M+s\phi_1^U\right)\\ -\left(s\gamma_1^L+2s\gamma_1^M+s\gamma_1^U\right)\end{matrix}\right),ADV\left(s\eta_1\right)\in\left[-1,1\right] \tag{12}$$

$$ADV\left(s\eta_2\right)=\frac{1}{4}\left(\begin{matrix}\left(s\phi_2^L+2s\phi_2^M+s\phi_2^U\right)\\ -\left(s\gamma_2^L+2s\gamma_2^M+s\gamma_2^U\right)\end{matrix}\right),ADV\left(s\eta_2\right)\in\left[-1,1\right] \tag{13}$$

For two TFNNs $s\eta_1=\left\{\begin{matrix}\left(s\phi_1^L,s\phi_1^M,s\phi_1^U\right),\\ \left(s\varphi_1^L,s\varphi_1^M,s\varphi_1^U\right),\left(s\gamma_1^L,s\gamma_1^M,s\gamma_1^U\right)\end{matrix}\right\}$, $s\eta_2=\left\{\begin{matrix}\left(s\phi_2^L,s\phi_2^M,s\phi_2^U\right),\\ \left(s\varphi_2^L,s\varphi_2^M,s\varphi_2^U\right),\left(s\gamma_2^L,s\gamma_2^M,s\gamma_2^U\right)\end{matrix}\right\}$, then

$$(1)\ if\ \ SDV(s\eta_1) \prec SDV(s\eta_2),\ then\ s\eta_1 \prec s\eta_2;$$
$$(2)\ if\ \ SDV(s\eta_1) = SDV(s\eta_2),\ ADV(s\eta_1) \prec ADV(s\eta_2),\ then\ s\eta_1 \prec s\eta_2;$$
$$(3)\ if\ \ SDV(s\eta_1) = SDV(s\eta_2),\ ADV(s\eta_1) = ADV(s\eta_2),\ then\ s\eta_1 = s\eta_2.$$

3. TFNN-WASPAS technique for MADM with TFNSs

The TFNN-WASPAS technique is put forward MADM. Let $\{SX_1, SX_2, \ldots, SX_m\}$ be alternatives, $\{SG_1, SG_2, \ldots, SG_n\}$ be attributes. The TFNN-WASPAS technique is put forward MADM (See Figure 1).

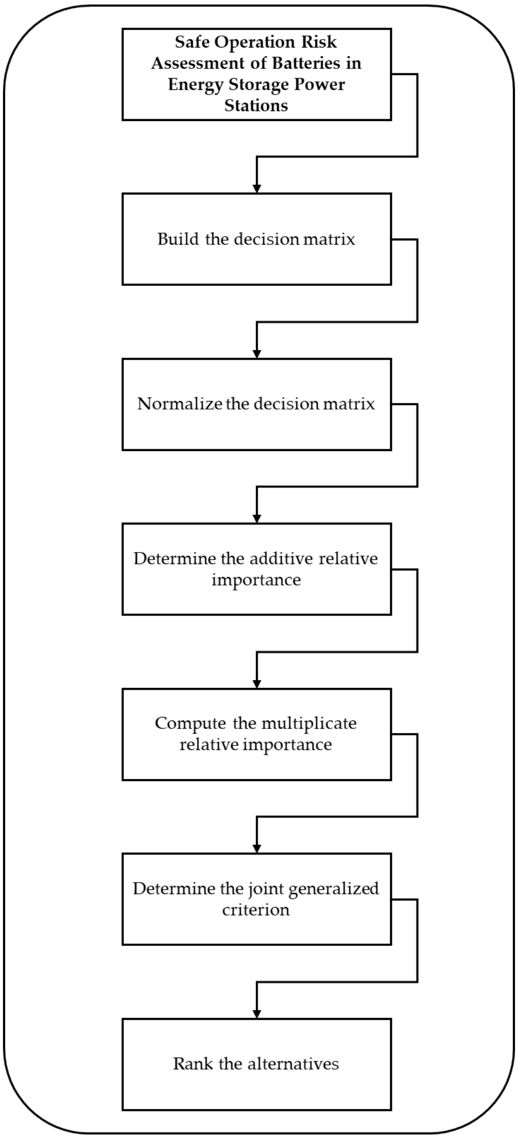

Figure 1. TFNN-WASPAS technique for MADM

Step 1. Build the decision matrix.

$$Y = \begin{bmatrix} y_{11} & \cdots & y_{1n} \\ \vdots & \ddots & \vdots \\ y_{m1} & \cdots & y_{mn} \end{bmatrix} \tag{14}$$

Where $i = 1, \ldots, m; j = 1, \ldots, n$

Step 2. Normalize the decision matrix

$$P_{ij} = \frac{SDV(y_{ij})}{\max_i SDV(y_{ij})} \tag{15}$$

$$P_{ij} = \frac{\min_i SDV(y_{ij})}{SDV(y_{ij})} \tag{16}$$

Step 3. Determine the additive relative importance

$$U_i^{(1)} = \sum_{j=1}^{n} w_j P_{ij} \tag{17}$$

Step 4. Compute the multiplicate relative importance

$$U_i^{(2)} = \prod_{j=1}^{n} \left(P_{ij}\right)^{w_j} \tag{18}$$

Step 5. Determine the joint generalized criterion.

$$U_i = 0.5\left(U_i^{(1)} + U_i^{(2)}\right) \tag{19}$$

Step 6. Rank the alternatives.

4. Numerical example and comparative analysis

With the proposal of the dual-stage goal of carbon reduction in China, "peaking carbon" and "carbon neutrality" have become current research hotspots, and new energy-related industries are experiencing faster development. Building a new power system with new energy as the main body can be foreseen as a key task for development in the next thirty years. However, as a large number of new energy generation equipment such as wind power and photovoltaics occupy an increasing proportion of the overall power grid, the randomness, volatility, and intermittency of new energy generation also pose significant risks to the smooth operation of the power system. Energy storage, as a key technology that can improve the consumption level of new energy generation, enhance the flexibility of power systems, and support the smooth and safe operation of new power systems, will undoubtedly be the next trillion-level emerging market. The energy storage industry is facing significant opportunities and challenges. Building a new type of energy storage in the large power grid can effectively improve the regulation capacity of the power system and enhance the system's ability to absorb and store renewable energy. It is an important guarantee for establishing a new type of power system mainly based on new energy and has important practical significance for building a clean, low-carbon, safe, and efficient energy system. With the advancement of energy storage technology and the urgent increase in demand, new energy storage power stations have the characteristics of flexible site selection and layout, short construction period, and fast regulation response speed, which have led to the rapid development of new energy storage power station construction and increasing large-scale applications. The safe operation risk assessment of batteries in energy storage power stations could be put forward by the MADM. Then, a numerical example is done for safe operation risk assessment of batteries in energy storage power stations through the TFNN-WASPAS technique. Five energy storage power stations are assessed in line with 27 attributes as shown in Table 1.

Table 1. The weights of criteria.

	Criteria	Weights
C_1	Temperature Sensitivity	0.039035
C_2	Maintenance Complexity	0.038284
C_3	Human Error Probability	0.033374
C_4	Cybersecurity Risks	0.035291
C_5	Load Demand Fluctuation	0.038474
C_6	State of Health	0.039258
C_7	Natural Disasters	0.035884
C_8	Power Outages or Fluctuations	0.035291
C_9	Vibration and Shock Resistance	0.039035
C_{10}	Humidity and Corrosion Resistance	0.038619
C_{11}	Emergency Response Preparedness	0.033262
C_{12}	Chemical Stability	0.037084
C_{13}	Fault Tolerance	0.039976
C_{14}	Energy Management System Reliability	0.038507
C_{15}	Compliance with Standards	0.033485
C_{16}	System Redundancy	0.036412
C_{17}	Thermal Stability	0.040536
C_{18}	Toxicity of Materials	0.037723
C_{19}	Regulatory Penalties	0.033485
C_{20}	Monitoring and Diagnostics	0.036412
C_{21}	Electrical Safety	0.040536
C_{22}	End-of-Life Disposal Risks	0.038284
C_{23}	Training and Competency	0.033485
C_{24}	Grid Compatibility	0.036412
C_{25}	Fire and Explosion Risk	0.039976
C_{26}	Recycling and Reusability	0.037084
C_{27}	Cost of Safety Measures	0.034796

Step 1: We begin by constructing the decision matrix using Equation (14), which is displayed in Table 2. Then, we calculate the criteria weights, as shown in Table 1.

Step 2: Next, we normalize the decision matrix using Equation (15), and the results are shown in Table 3.

Step 3: After that, we calculate the additive relative importance based on Equation (19).

Step 4: Then, we determine the multiplicative relative importance using Equation (20).

Step 5: We proceed by calculating the joint generalized criterion with Equation (21).

Step 6: Finally, we rank the alternatives, as illustrated in Figure 2.

Table 2. The decision matrix.

	A_1	A_2	A_3	A_4	A_5
C_1	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)
C_2	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)
C_3	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)
C_4	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)
C_5	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)
C_6	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)
C_7	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)
C_8	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)
C_9	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)
C_{10}	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)
C_{11}	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)
C_{12}	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)
C_{13}	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)
C_{14}	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)
C_{15}	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)
C_{16}	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)
C_{17}	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)
C_{18}	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)
C_{19}	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)
C_{20}	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)
C_{21}	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)
C_{22}	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)
C_{23}	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)

C_{24}	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)
C_{25}	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)
C_{26}	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)
C_{27}	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)
	A_1	A_2	A_3	A_4	A_5
C_1	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)
C_2	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)
C_3	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)
C_4	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)
C_5	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)
C_6	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)
C_7	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)
C_8	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)
C_9	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)
C_{10}	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)
C_{11}	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)
C_{12}	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)
C_{13}	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)
C_{14}	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)
C_{15}	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)
C_{16}	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)
C_{17}	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)
C_{18}	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)
C_{19}	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)
C_{20}	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)
C_{21}	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)
C_{22}	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)
C_{23}	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)
C_{24}	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)
C_{25}	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)
C_{26}	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)
C_{27}	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)
	A_1	A_2	A_3	A_4	A_5
C_1	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)
C_2	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)
C_3	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)
C_4	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)
C_5	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)
C_6	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)
C_7	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)
C_8	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)
C_9	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)
C_{10}	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)
C_{11}	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)
C_{12}	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)
C_{13}	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)
C_{14}	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)
C_{15}	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)
C_{16}	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)
C_{17}	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)
C_{18}	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)
C_{19}	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)
C_{20}	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)
C_{21}	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)
C_{22}	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)
C_{23}	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)
C_{24}	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)
C_{25}	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)
C_{26}	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(1,3,5;0.5,1.5,2.5;1.2,2.7,4.5)
C_{27}	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(1,2,3;0.5,1.5,2.5;1.2,2.7,3.5)	(0.5,1.5,2.5;0.3,1.3,2.2;0.7,1.7,2.2)	(0.3,1.2,2.8;0.5,1.5,2.5;0.8,1.7,2.7)

Table 3. The normalized decision matrix.

	A_1	A_2	A_3	A_4	A_5
C_1	0.918595	1	0.658472	0.776431	0.878483
C_2	0.597938	0.686089	0.942722	0.686089	1
C_3	0.781704	0.739381	0.848384	1	0.848384
C_4	1	0.749556	0.976498	0.907335	0.722004
C_5	0.703651	1	0.880889	1	0.956333
C_6	0.670574	0.857836	0.939242	0.788534	1
C_7	1	0.79227	0.933857	0.779095	0.73
C_8	1	0.974485	0.985044	0.985044	0.78384
C_9	0.597938	0.942722	0.620756	1	0.828165
C_{10}	0.632165	0.686089	0.942722	0.686089	1
C_{11}	0.753489	1	0.929172	0.739381	0.781704
C_{12}	1	0.620756	0.686089	0.808701	0.67468
C_{13}	0.935311	0.990903	0.839543	1	0.84864
C_{14}	0.609347	0.885443	0.808701	0.632165	1
C_{15}	0.828708	0.78384	1	0.959529	0.914354
C_{16}	1	0.805444	0.845238	0.956333	0.690476
C_{17}	0.686089	0.942722	0.686089	1	0.828165
C_{18}	0.634268	0.797078	0.869939	0.788534	1
C_{19}	0.767596	0.848384	1	0.834277	0.781704
C_{20}	1	0.847251	0.856431	0.856431	0.681498
C_{21}	0.751423	0.942722	0.620756	1	0.828165
C_{22}	0.597938	0.686089	0.942722	0.686089	1
C_{23}	0.763332	0.883832	1	0.722004	0.763332
C_{24}	1	0.805444	0.845238	0.956333	0.690476
C_{25}	0.956333	1	0.805444	1	0.956333
C_{26}	0.597938	0.762832	0.731959	0.697498	1

C_{27}	0.73	1	0.956333	0.690476	0.73

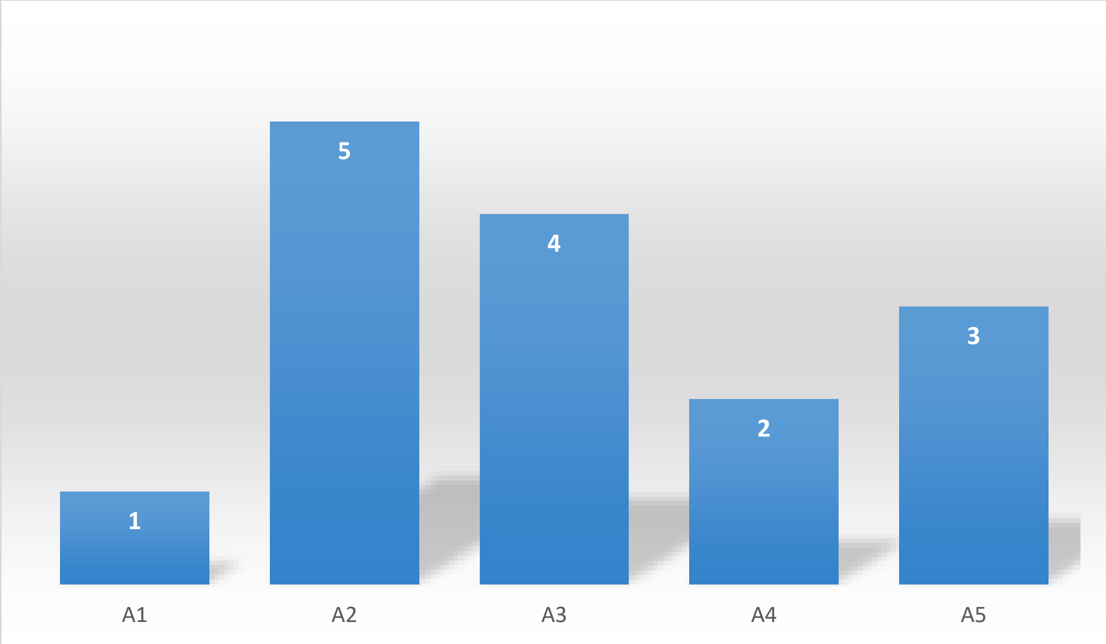

Figure 2. The rank of alternatives.

4.1 Sensitivity analysis

We adjusted the criteria weights across 28 different cases, as shown in Figure 3. In the first case, we assigned equal weights to all criteria. In the other cases, we set the weight of the first criterion to 0.05, while the remaining criteria had equal weights. Next, we applied the TFNN-WASPAS method for each set of criteria weights, as illustrated in Figure 4. Our results show that Alternative 3 is the best option, while Alternative 1 is the worst.

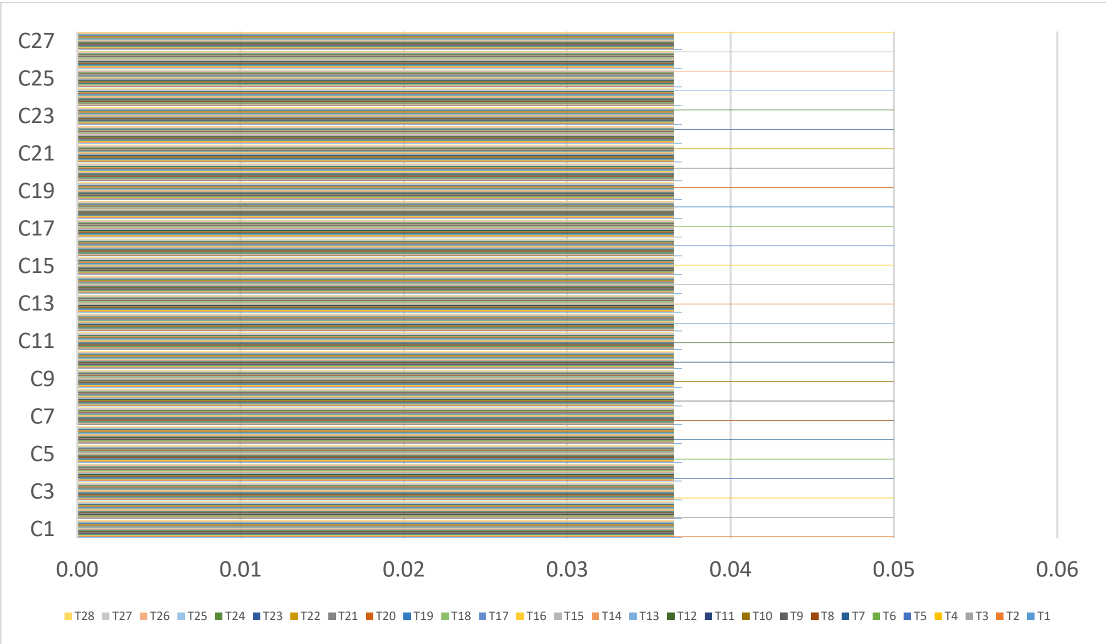

Figure 3. The criteria weights.

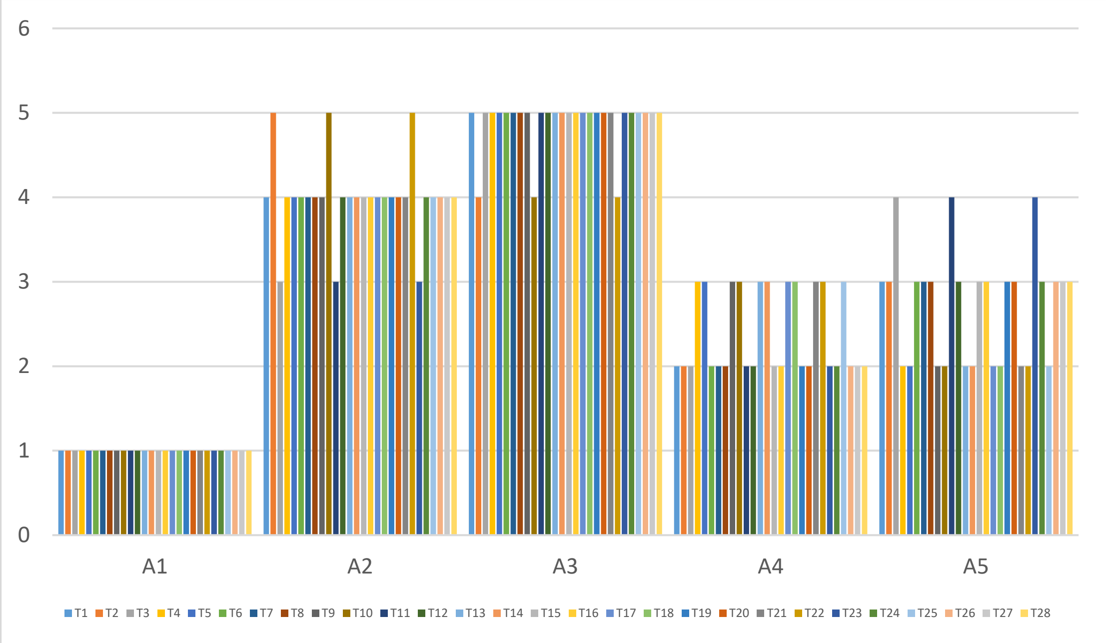

Figure 4. The rank of alternatives under different weights.

4.2 Comparative Study

This study compares the proposed methodology by various MADM methods such as TFNN-TOPSIS, TFNN-VIKOR, TFNN-COPRAS, and TFNN-EDAS methods. These methods are compared under the weights of criteria by the proposed method. Figure 5 shows comparative study. We show the proposed method is robust compared with other MADM methods.

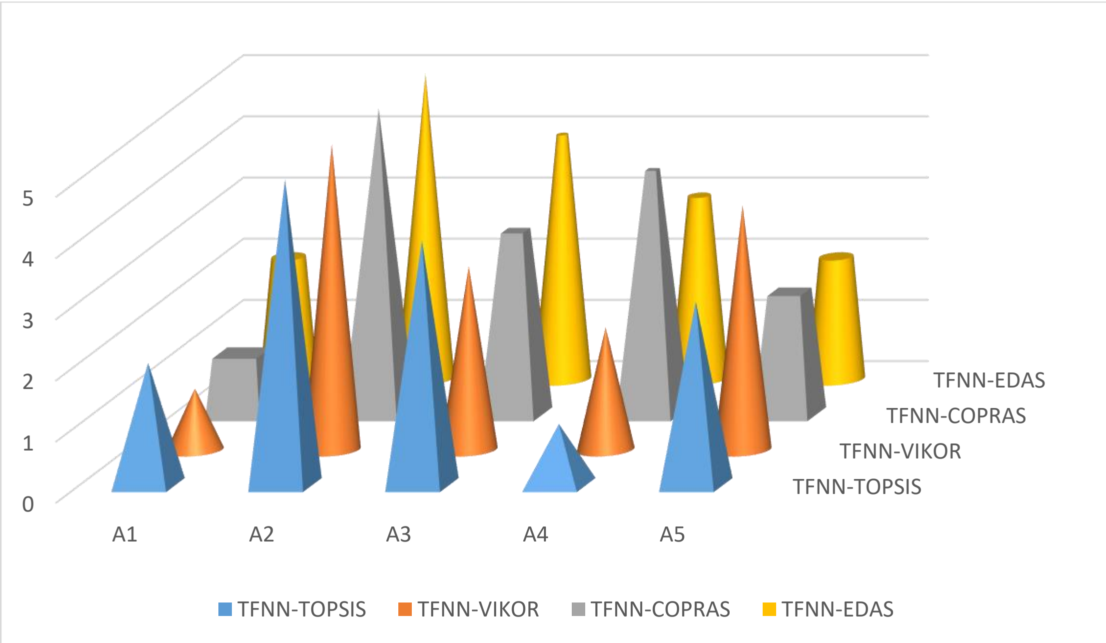

Figure 5 The comparative study.

5. Conclusion

With the rapid development of related technologies, the scale of batteries in energy storage power stations continues to increase, but they face huge challenges in terms of safety. The more than 30 incidents of energy storage power plant accidents in South Korea and the fire and explosion accidents at energy storage power plants in Fengtai District, Beijing have had a profound impact and sounded the alarm for the subsequent development of energy storage power plants in China. The safety of batteries is not only reflected in breakthroughs in materials and technology but also in the management of operational risks. Risk assessment, as an important step in the safe operation risk management of energy storage power station batteries, is currently less studied, and the results of the assessment directly affect subsequent risk control. Proper and accurate evaluation can effectively prevent and reduce the occurrence of accidents. The safe operation risk assessment of batteries in energy storage power stations is considered a MADM problem. Recently, the WASPAS technique and the average method have been applied to address MADM challenges. To better express uncertainty during the risk assessment process, TFNSs have been utilized. In this paper, a TFNN-WASPAS approach based on TFNN-WASPAS is proposed to handle MADM with TFNSs. The average method is used to calculate weight values through TFNNWASPAS under TFNSs. A numerical example is provided to evaluate the safe operation risks of batteries in energy storage power stations, and comparative analyses are conducted to validate the effectiveness of the TFNN-WASPAS method. The key contributions of this work are summarized as follows: (1) the construction of the TFNN- WASPAS technique based on TFNN-WASPAS; (2) the use of the average method to manage weights within the TFNN-WASPAS framework under TFNSs; (3) the application of the TFNN-WASPAS technique to address MADM problems using TFNN-WASPAS under TFNSs; and (4) the provision of a numerical example and comparative analysis for the safe operation risk assessment of batteries in energy storage power stations to verify the proposed method.

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