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An Integrated Dynamic Generalized Trapezoidal Fuzzy AHP-TOPSIS Approach for Evaluating Sustainable Performance of Bank

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Abstract

Purpose: The assessment of sustainable performance is critical in enhancing the bank's competitive advantages. To evaluate sustainable banking performance, it is necessary to consider various economic, environmental, and social criteria. Therefore, sustainable banking performance assessment can be regarded as a multiple-criteria decision-making (MCDM) problem in a vague environment. This paper proposes a new MCDM approach to assess the sustainable performance of banks in Vietnam.

Design/methodology/approach: This study proposes a new integrated approach that combines the dynamic fuzzy Analytic Hierarchy Process (AHP) and Technique for Order Performance by Similarity to Ideal Solution (TOPSIS) methods to evaluate the sustainable performance of banks in Vietnam. The proposed approach is demonstrated using an application to show its applicability and efficiency.

Findings: The findings reveal that the proposed integrated dynamic GTrF-AHP-TOPSIS approach is more efficient and effective than previous relevant studies.

Originality/value: The proposed approach utilizes generalized trapezoidal fuzzy numbers (GTrFNs) to represent the banks' ratings and criteria weights. The dynamic GTrF-AHP approach is developed to determine the criteria weights over time. The banks' ranking order is determined using a closeness coefficient that calculates the distance between the banks and the ideal/negative-ideal solutions.

Keywords: Dynamic Fuzzy AHP, Dynamic Fuzzy TOPSIS, Generalized Trapezoidal Fuzzy Numbers, MCDM

JEL classification: D81, Q01

1. Introduction

Nowadays, sustainable development is a global trend, particularly in light of the climate change and resource depletion crisis (Bogers et al., 2022). In addition, the environmental and climate change agreements and commitments of countries are also driving economies and businesses toward sustainable economic development (Azam et al., 2022). The banking sector plays a crucial role in driving the economy, and promoting sustainable development is vital to its mission (Nosratabadi et al., 2020). While there has been a significant amount of research on sustainability in manufacturing and business organizations, less attention has been paid to sustainability in the service sector (Raut et al., 2017). According to Rebai (2014), sustainable banking refers to a banking system that takes into account the needs and concerns of all its stakeholders, including financial and non-financial factors. It prioritizes social and environmental considerations in its intermediation activities and aims to achieve a balance among the interests of different stakeholders. By adhering to ethical values and managing risks effectively, sustainable banking contributes to the overall stability and health of the financial system. Banks have introduced many strategies to promote sustainable development, including waste management, energy and water consumption management, and strong staff (Schleich, 2009, Li and Chen, 2014; Zaitseva et al., 2019; Ramasubramanian et al., 2019; Marzouqi et al., 2019; Nosratabadi et al., 2020). However, to enhance competitiveness and profitability, banks must focus on creating innovative services, improving service provision and delivery, and developing new business forms (Nosratabadi, 2020).

Performance evaluation and measurement are crucial for banks as they can significantly impact the banking system's overall performance, productivity, and profitability. To evaluate sustainable banking performance, many economic, environmental, and social criteria need to be considered, such as liquidity ratio, net operating profit margin, net operating profit growth rates, customer health and safety, social responsibility, environment-friendly management system, energy consumption, etc. (Nosratabadi, 2020; Raut et al., 2017). Evaluating sustainable performance in the banking sector is a multifaceted task that requires making decisions based on multiple criteria in an environment of uncertainty. Although sustainability has become an increasingly popular topic, there are relatively few studies that have used fuzzy MCDM techniques to evaluate sustainability in the banking sector. Raut et al. (2017) developed an integrated MCDM model to evaluate the sustainability practices of six of India's largest commercial banks. Lin and Chang (2019) employed a hybrid MCDM approach to evaluate twenty-five banks in Taiwan. Kumar and Prakash (2019) proposed a framework that emphasizes the environmental and social practices of banks in India. Additionally, Nosratabadi et al. (2020) employed the integrated method to assess the sustainability of sixteen banks across Europe.

The fuzzy TOPSIS approach has become popular due to its effectiveness and simplicity in computations. Several recent studies have applied this method in various fields (Alibeigi et al., 2021; Sadat et al., 2021; Raufirad, 2022; Liang et al., 2022; Zhang and Dai, 2022; Yang et al., 2022; Aksoy et al., 2022). Sadat et al. (2021) assessed the barriers to photovoltaic development and proposed solutions using fuzzy AHP. Liang et al. (2022) presented an integrated risk assessment methodology for urban polyethylene gas pipelines using fuzzy TOPSIS and cloud inference. Raufirad (2022) utilized fuzzy TOPSIS and GIS methodologies to assess the correlation between land cover indices and socioeconomic vulnerability in Iran. Zhang and Dai (2022) applied decision-theoretic rough fuzzy sets to sort and classify alternatives. Yang et al. (2022) developed a decision-making framework for evaluating green low-carbon ports.

Although the fuzzy TOPSIS method has several advantages, it also has some limitations, such as not taking into account the hierarchical structure between main criteria and sub-criteria and separating qualitative and quantitative variables. To overcome these limitations, many researchers have combined the fuzzy TOPSIS method with Chang’s (1996) fuzzy AHP method (Kien et al., 2018; Solangi et al., 2020; Sadat et al., 2021; Ekmekcioğlu et al., 2021; Alghassab, 2022; Nazim et al., 2022). However, the approach proposed by Chang has some limitations. It may assign an unjustified zero weight to relevant decision criteria and/or sub-criteria, leading to incorrect decisions that favor the worst alternative. Furthermore, Chang's method is constrained by its applicability only to normalized and triangular fuzzy numbers, as well as static time. However, real-world data may include non-normal fuzzy numbers from various time intervals or multiple periods. To address these challenges, several studies have proposed dynamic TOPSIS methods in the literature. Jiang et al. (2019) developed a dynamic TOPSIS method to evaluate the low-carbon competitiveness of Chinese steelworks. Chen and Yang (2021) proposed a novel dynamic TOPSIS method and applied it to the context of COVID-19 vaccination. Long et al. (2021) employed a dynamic TOPSIS approach to evaluate the level of green development in cities in China. However, no study has yet explored the dynamic AHP-TOPSIS approach based on Hue et al.’s fuzzy AHP method to evaluate the sustainable performance of banks in Vietnam.

Therefore, this study proposes an innovative integrated dynamic approach, named GTrF-AHP-TOPSIS, to evaluate the sustainable performance of banks in Vietnam. The proposed approach represents the evaluations of each bank and the criteria weights given by decision-makers using generalized trapezoidal fuzzy numbers (GTrFNs). GTrFNs were selected for their simplicity and widespread use in solving decision-making problems in economics and management. To establish the criteria weights over time, we developed the GTrF-AHP approach. Our proposed method calculates a closeness coefficient to rank the banks based on their distances from the positive/negative-ideal solutions. To demonstrate the feasibility and efficacy of our approach, an application is presented.

2. *Hue et al.’s fuzzy AHP approach*

Hue et al. (2022) presented a modified version of the fuzzy AHP approach as a solution to the shortcomings of Chang's (1996) approach. In the initial stage, the generalized triangular fuzzy comparison matrix is defined and expressed as follows:

$$\hat{\mathrm{T}} = (\hat{\partial}_{pq})_{l \mathrm{x} l} = \begin{bmatrix} (1,1,1;\hat{\varpi}_{11}) & (\hat{\alpha}_{12},\hat{\beta}_{12},\lambda_{12};\varpi_{12}) & \cdots & (\alpha_{1n},\hat{\beta}_{1n},\lambda_{1n};\hat{\varpi}_{1n}) \\ (\hat{\alpha}_{21},\hat{\beta}_{21},\lambda_{21};\hat{\varpi}_{21}) & (1,1,1;\varpi_{22}) & \cdots & (\alpha_{2l},\hat{\beta}_{2l},\lambda_{2l};\hat{\varpi}_{2l}) \\ \vdots & \vdots & \vdots & \vdots \\ (\hat{\alpha}_{l1},\hat{\beta}_{l1},\lambda_{l1};\hat{\varpi}_{l1}) & (\alpha_{l2},\hat{\beta}_{l2},\lambda_{l2};\varpi_{l2}) & \cdots & (1,1,1;\hat{\varpi}_{ll}) \end{bmatrix},$$

where $\tilde{\partial}_{pq} = (\hat{\alpha}_{pq}, \beta_{pq}, \tilde{\lambda}_{pq}; \hat{\varpi}_{pq})$, $\tilde{\partial}_{pq}^{-1} = (1/\lambda_{pq}, 1/\tilde{\beta}_{pq}, 1/\hat{\alpha}_{pq}; \hat{\varpi}_{pq})$ for $p,q = 1,\ldots,1$ and $p \neq q$.

Then, we define the fuzzy synthetic extents:

$$\hat{E}_p = \left(\hat{\theta}_p, \tilde{\sigma}_p, \hat{\rho}_p; \min(\varpi_{pq})\right) = \sum_{q=1}^{1} \tilde{\mathrm{N}}_{\tilde{\partial}_p}^{q} \otimes \left[\sum_{p=1}^{1}\sum_{q=1}^{1} \mathrm{N}_{\partial_p}^{q}\right]^{-1}$$

$$= \left(\frac{\sum_{q=1}^{1} \hat{\alpha}_{pq}}{\sum_{q=1}^{1} \tilde{\partial}_{pq} + \sum_{k=1,k\neq p}^{1} \sum_{q=1}^{1} \tilde{\delta}_{kq}}, \frac{\sum_{q=1}^{1} \tilde{\beta}_{pq}}{\sum_{p=1}^{1} \sum_{q=1}^{1} \hat{\beta}_{pq}}, \frac{\sum_{q=1}^{1} \delta_{pq}}{\sum_{q=1}^{1} \delta_{pq} + \sum_{k=1,k\neq p}^{1} \sum_{q=1}^{1} \alpha_{kq}}; \min(\hat{\varpi}_{pq}) \right), \quad (1)$$

where $\sum_{q=1}^{1} \hat{\mathrm{N}}_{\hat{\partial}_p}^{q} = \left(\sum_{q=1}^{1} \hat{\alpha}_{pq}, \sum_{q=1}^{1} \tilde{\beta}_{pq}, \sum_{q=1}^{1} \delta_{pq}; \min(\hat{\varpi}_{pq}) \right), \; p,q = 1,2,\ldots,1$

In the third step, we determine the centroid points, $\hat{\Phi}_p = (\bar{x}_{\hat{E}_p}, \bar{y}_{\hat{E}_p}), p = 1,2,\ldots,1$, and minimum points, $\hat{\mathrm{M}} = (x_{\min}, y_{\min})$, of the fuzzy synthetic extent ($\hat{E}_p$) while also computing the distance between them, $\hat{D}(\tilde{\Phi}_p, \mathrm{M})$:

$$\bar{x}_{\hat{E}_p} = (\hat{\theta}_p + \hat{\sigma}_p + \hat{\rho}_p)/3 \quad , \quad (2)$$

$$\bar{y}_{\hat{E}_p} = \min(\hat{\varpi}_{pq})/3 \quad , \quad (3)$$

$$\hat{D}(\tilde{\Phi}_p, \mathrm{M}) = \sqrt{(\bar{x}_{\hat{E}_p} - x_{\min})^2 + (\bar{y}_{\hat{E}_p} - \frac{\hat{\varpi}}{3} y_{\min})^2} \quad , \quad (4)$$

where $x_{\min} = \min(\hat{\theta}_p), y_{\min} = \min(\tilde{\varpi}_{pq})$

The final step determines the criteria weights by using the following equation:

$$\hat{w}_p = \frac{\hat{D}(\tilde{\Phi}_i, \mathrm{M})}{\sum_{q=1}^{n} \hat{D}(\tilde{\Phi}_i, \mathrm{M})} = \frac{\sqrt{(\bar{x}_{\hat{E}_p} - x_{\min})^2 + (\bar{y}_{\hat{E}_p} - \frac{\hat{\varpi}}{3} y_{\min})^2}}{\sum_{q=1}^{n} \sqrt{(\bar{x}_{\hat{E}_p} - x_{\min})^2 + (\bar{y}_{\hat{E}_p} - \frac{\hat{\varpi}}{3} y_{\min})^2}}, \quad p = 1,\ldots,1 \quad . \quad (5)$$

4. Developing a new integrated dynamic generalized trapezoidal fuzzy AHP-TOPSIS approach

This section presented a new approach, called dynamic GTrF-AHP-TOPSIS, for assessing the performance of sustainable banking. The evaluation is carried out by a committee of h decision-makers $(\tilde{D}_e, e = 1,\ldots,h)$ who are responsible for assessing m sustainable banks $(\tilde{B}_i, i = 1,\ldots,m)$ based on n selection criteria $(\tilde{C}_j, j = 1,\ldots,n)$ in time sequence $\tilde{t}_u, u = 1,\ldots,s$. The banks' ratings and criteria weights are expressed using GTrFNs.

4.1. Aggregating the ratings of sustainable banks

Let $\tilde{A}_{ije}(t_u) = \left\langle \tilde{a}_{ije}(\tilde{t}_u), \tilde{b}_{ije}(\tilde{t}_u), \tilde{c}_{ije}(\tilde{t}_u), \tilde{d}_{ije}(\tilde{t}_u); \tilde{\varpi}_{ije}(\tilde{t}_u) \right\rangle$, $i = 1, \ldots, m$, $j = 1, \ldots, n$, $e = 1, \ldots, h$, $u = 1, \ldots, s$, are the ratings assigned to bank $\tilde{B}_i$, by decision-maker $\tilde{D}_e$, for criteria $\tilde{C}_j$ in $\tilde{t}_u$. Then, the averaged ratings, $\tilde{r}_{ij} = (\tilde{a}_{ij}, \tilde{b}_{ij}, \tilde{c}_{ij}, \tilde{d}_{ij}; \tilde{\varpi}_{ij})$, are obtained as:

$$\tilde{A}_{ij} = \frac{1}{s*h} \otimes (\tilde{A}_{ij1}(\tilde{t}_1) \oplus \tilde{A}_{ij2}(\tilde{t}_2) \oplus \ldots \oplus \tilde{A}_{ijv}(\tilde{t}_u) \oplus \ldots \oplus \tilde{A}_{ijh}(\tilde{t}_s)), \tag{6}$$

where $\tilde{a}_{ij} = \frac{1}{s*h} \sum_{e=1}^{h} \tilde{a}_{ije}(\tilde{t}_u)$, $\tilde{b}_{ij} = \frac{1}{s*h} \sum_{e=1}^{h} \tilde{b}_{ije}(\tilde{t}_u)$, $\tilde{c}_{ij} = \frac{1}{s*h} \sum_{e=1}^{h} \tilde{c}_{ije}(\tilde{t}_u)$, $\tilde{d}_{ij} = \frac{1}{s*h} \sum_{e=1}^{h} \tilde{d}_{ije}(\tilde{t}_u)$ and $\tilde{\varpi}_{ij} = \min\{\tilde{\varpi}_{ij1}(\tilde{t}_1), \tilde{\varpi}_{ij2}(\tilde{t}_2), \ldots, \tilde{\varpi}_{ijh}(\tilde{t}_s)\}$.

4.2. Aggregating the importance weights of criteria

This section introduces a novel dynamic GTrF-AHP approach for determining the weights of sustainable banking performance criteria and sub-criteria, as the following:

Firstly: Defining a dynamic GTrF comparison matrix

The GTrF comparison matrix is expressed as:

$$\tilde{V} = \left\langle \tilde{v}_{xye}(\tilde{t}_u) \right\rangle_{\mathrm{nxn}} = \begin{bmatrix} (1,1,1,1;1) & \left\langle \tilde{k}_{12e}(\tilde{t}_u), \tilde{o}_{12e}(\tilde{t}_u), \tilde{p}_{12e}(\tilde{t}_u), \tilde{q}_{12e}(\tilde{t}_u); \tilde{\varpi}_{12e}(\tilde{t}_u) \right\rangle & \cdots & \left\langle \tilde{k}_{1ne}(\tilde{t}_u), \tilde{o}_{1ne}(\tilde{t}_u), \tilde{p}_{1ne}(\tilde{t}_u), \tilde{q}_{1ne}(\tilde{t}_u); \tilde{\varpi}_{1ne}(\tilde{t}_u) \right\rangle \\ \left\langle \tilde{k}_{21e}(\tilde{t}_u), \tilde{o}_{21e}(\tilde{t}_u), \tilde{p}_{21e}(\tilde{t}_u), \tilde{q}_{21e}(\tilde{t}_u); \tilde{\varpi}_{21e}(\tilde{t}_u) \right\rangle & (1,1,1,1;1) & \cdots & \left\langle \tilde{k}_{2ne}(\tilde{t}_u), \tilde{o}_{2ne}(\tilde{t}_u), \tilde{p}_{2ne}(\tilde{t}_u), \tilde{q}_{2ne}(\tilde{t}_u); \tilde{\varpi}_{2ne}(\tilde{t}_u) \right\rangle \\ \left\langle \tilde{k}_{x1e}(\tilde{t}_u), \tilde{o}_{x1e}(\tilde{t}_u), \tilde{p}_{x1e}(\tilde{t}_u), \tilde{q}_{x1e}(\tilde{t}_u); \tilde{\varpi}_{x1e}(\tilde{t}_u) \right\rangle & \left\langle \tilde{k}_{x2e}(\tilde{t}_u), \tilde{o}_{x2e}(\tilde{t}_u), \tilde{p}_{x2e}(\tilde{t}_u), \tilde{q}_{x2e}(\tilde{t}_u); \tilde{\varpi}_{x2e}(\tilde{t}_u) \right\rangle & \cdots & (1,1,1,1;1) \end{bmatrix}, \tag{7}$$

where $\tilde{v}_{xye}(\tilde{t}_u) = \left\langle \tilde{k}_{xye}(\tilde{t}_u), \tilde{o}_{xye}(\tilde{t}_u), \tilde{p}_{xye}(\tilde{t}_u), \tilde{q}_{xye}(\tilde{t}_u); \tilde{\varpi}_{xye}(\tilde{t}_u) \right\rangle$ and $\tilde{v}_{xye}^{-1}(\tilde{t}_u) = \left\langle 1/\tilde{q}_{xye}(\tilde{t}_u), 1/\tilde{p}_{xye}(\tilde{t}_u), 1/\tilde{o}_{xye}(\tilde{t}_u), 1/\tilde{k}_{xye}(\tilde{t}_u); \tilde{\varpi}_{xye}(\tilde{t}_u) \right\rangle$ for $x, y = 1, \ldots, n$.

Secondly: Calculating the average values of the fuzzy synthetic extents

The average value of each row of the fuzzy comparison matrix $\tilde{V}$ assessed by the committee in $\tilde{t}_u, u = 1, \ldots, s$ can be evaluated as:

$$\widetilde{AV}_j = \frac{1}{s*h} \sum_{e=1}^{h} \tilde{v}_{xye}(\tilde{t}_u) = \left\langle \frac{1}{s*h} \sum_{e=1}^{h} \tilde{k}_{xye}(\tilde{t}_u), \frac{1}{s*h} \sum_{e=1}^{h} \tilde{o}_{xye}(\tilde{t}_u), \frac{1}{s*h} \sum_{e=1}^{h} \tilde{p}_{xye}(\tilde{t}_u), \frac{1}{s*h} \sum_{e=1}^{h} \tilde{q}_{xye}(\tilde{t}_u); \min\left(\tilde{\varpi}_{xye}(\tilde{t}_u)\right) \right\rangle. \tag{8}$$

Then, the average values of fuzzy synthetic extents $\tilde{T}_j$ are calculated as follows:

$$\tilde{T}_j = \left\{ f_j, g_j, l_j, r_j; \min\left(\tilde{\varpi}_{xye}(\tilde{t}_u)\right)\right\}$$

$$= \left\{ \begin{array}{l} \dfrac{\frac{1}{s*h}\sum_{e=1}^{h}\tilde{k}_{xye}(\tilde{t}_u)}{\frac{1}{s*h}\sum_{e=1}^{h}\tilde{k}_{xye}(\tilde{t}_u) + \sum_{r=1,r\neq y}^{n}\left(\frac{1}{s*h}\sum_{e=1}^{h}\tilde{q}_{xye}(\tilde{t}_u)\right)}, \dfrac{\frac{1}{s*h}\sum_{e=1}^{h}\tilde{o}_{xye}(\tilde{t}_u)}{\frac{1}{s*h}\sum_{e=1}^{h}\tilde{o}_{xye}(\tilde{t}_u) + \sum_{r=1,r\neq y}^{n}\left(\frac{1}{s*h}\sum_{e=1}^{h}\tilde{p}_{xye}(\tilde{t}_u)\right)}, \\ \dfrac{\frac{1}{s*h}\sum_{e=1}^{h}\tilde{p}_{xye}(\tilde{t}_u)}{\frac{1}{s*h}\sum_{e=1}^{h}\tilde{p}_{xye}(\tilde{t}_u) + \sum_{r=1,r\neq y}^{n}\left(\frac{1}{s*h}\sum_{e=1}^{h}\tilde{o}_{xye}(\tilde{t}_u)\right)}, \dfrac{\frac{1}{s*h}\sum_{e=1}^{h}\tilde{q}_{xye}(\tilde{t}_u)}{\frac{1}{s*h}\sum_{e=1}^{h}\tilde{q}_{xye}(\tilde{t}_u) + \sum_{r=1,r\neq y}^{n}\left(\frac{1}{s*h}\sum_{e=1}^{h}\tilde{k}_{xye}(\tilde{t}_u)\right)}; \\ \min\left(\tilde{\varpi}_{xye}(\tilde{t}_u)\right) \end{array} \right\}, \quad (9)$$

where: $x, y = 1,\ldots,n; u = 1,\ldots,s; e = 1,\ldots,h$.

4.3. Normalize the sustainable performance of the banks versus criteria

This study categorizes the criteria and/or sub-criteria into two groups: benefit ($\tilde{B}$) and cost ($\tilde{C}$). To ensure consistency between the ratings and weights, the bank ratings are normalized to a common scale. Suppose $\tilde{N}_{ij}$ is the performance of the bank *i* on criteria/sub-criteria *j*. The normalized value $\tilde{N}_{ij}$ can then be denoted in the following equations:

$$\tilde{N}_{ij}(t_u) = \left\langle \frac{\tilde{a}_{ije}(\tilde{t}_u)}{\tilde{d}^*_{je}(\tilde{t}_u)}, \frac{\tilde{b}_{ije}(\tilde{t}_u)}{\tilde{d}^*_{je}(\tilde{t}_u)}, \frac{\tilde{c}_{ije}(\tilde{t}_u)}{\tilde{d}^*_{je}(\tilde{t}_u)}, \frac{\tilde{d}_{ije}(\tilde{t}_u)}{\tilde{d}^*_{je}(\tilde{t}_u)}; \min(\tilde{\varpi}_{ije}(\tilde{t}_u)) \right\rangle, j \in \tilde{B} \quad , \quad (10)$$

$$\tilde{N}_{ij}(t_u) = \left\langle \frac{\tilde{a}^-_{je}(\tilde{t}_u)}{\tilde{d}_{ije}(\tilde{t}_u)}, \frac{\tilde{a}^-_{je}(\tilde{t}_u)}{\tilde{c}_{ije}(\tilde{t}_u)}, \frac{\tilde{a}^-_{je}(\tilde{t}_u)}{\tilde{b}_{ije}(\tilde{t}_u)}, \frac{\tilde{a}^-_{je}(\tilde{t}_u)}{\tilde{a}_{ije}(\tilde{t}_u)}; \min(\tilde{\varpi}_{ije}(\tilde{t}_u)) \right\rangle, j \in \tilde{C} \quad , \quad (11)$$

where $\tilde{a}^-_{je}(\tilde{t}_u) = \min\left(\tilde{a}_{ije}(\tilde{t}_u)\right), \tilde{d}^*_{je}(\tilde{t}_u) = \max\left(\tilde{d}_{ije}(\tilde{t}_u)\right)$.

4.4. Constructing the weighted GTrF decision matrix

The weighted GTRF decision matrixes $\tilde{W}_i = (\tilde{w}_1, \tilde{w}_2, \tilde{w}_3, \tilde{w}_4; \tilde{\varpi}_{\tilde{W}_i})$ are defined in the following equation::

$$\tilde{W}_i = \frac{1}{n}\sum_{j=1}^{n}\tilde{W}_{ij} = \frac{1}{n}\sum_{j=1}^{n}\tilde{A}_{ij} \otimes \tilde{T}_j , \quad (12)$$

where $\tilde{\varpi}_{\tilde{W}_i} = \min\left\{\tilde{\varpi}_{ije}(\tilde{t}_u), \tilde{\varpi}_{xye}(\tilde{t}_u)\right\}$.

4.5. Calculation of $\tilde{d}_i^+$ and $\tilde{d}_i^-$

The distance of each bank $\tilde{B}_i, i = 1,\ldots,m$ from fuzzy positive-ideal solution $(\tilde{B}^+)$ and fuzzy negative ideal solution $(\tilde{B}^-)$ is defined in the following equations:

$$\tilde{d}_i^+ = \sqrt{\tilde{\varpi}_{\tilde{W}_i} * \sum_{j=1}^{n} (\tilde{S}_i - \tilde{B}^+)^2}\ , \tag{13}$$

$$\tilde{d}_i^- = \sqrt{\tilde{\varpi}_{\tilde{W}_i} * \sum_{j=1}^{n} (\tilde{S}_i - \tilde{B}^-)^2}\ , \tag{14}$$

where: $\tilde{B}^+ = [1,1,1,1;1]$ and $\tilde{B}^- = [0,0,0,0;1]$.

4.6. Obtain the closeness coefficient

The closeness coefficient $(\tilde{CC}_i)$ as defined in the following equation is used to rank the banks.

$$\tilde{CC}_i = \frac{\sqrt{\tilde{\varpi}_{\tilde{W}_i} * \sum_{j=1}^{n} (\tilde{S}_i - \tilde{B}^-)^2}}{\sqrt{\tilde{\varpi}_{\tilde{W}_i} * \sum_{j=1}^{n} (\tilde{S}_i - \tilde{B}^+)^2} + \sqrt{\tilde{\varpi}_{\tilde{W}_i} * \sum_{j=1}^{n} (\tilde{S}_i - \tilde{B}^-)^2}}\ . \tag{15}$$

5. Application

This section applies the proposed dynamic GTrF-AHP-TOPSIS approach to assess the sustainable performance of banks in Vietnam. Following a preliminary screening process, four state-owned banks in Vietnam were selected for further evaluation. A committee composed of three senior executives from banks in Vietnam was tasked with evaluating the sustainable performance of four banks. These decision-makers possess extensive expertise and experience in bank management. The study collected data on the banks' ratings and the importance weights of various criteria through three rounds of questionnaires administered to the decision-makers at three different time periods (t_1, t_2, and t_3). This study uses four criteria and nineteen sub-criteria, which are adapted from Raut et al. (2017), to evaluate the performance of the selected banks. The definitions of these criteria and sub-criteria can be found in Table 1.

Table 1. Criteria definitions

Criteria	**Sub-criteria**
Financial Stability (F_S)	Liquidity ratio (F_S_1)
	Net asset value per share (F_S_2)
	Net operating margin (F_S_3)
	Net profit growth rates (F_S_4)
	Equity ratio (F_S_5)
Customer Relationship Management (CRM)	Customer satisfaction (CRM_1)
	Customer health and safety (CRM_2)
	Reputation and position in the market (CRM_3)
	Ability to maintain product/service (CRM_4)
	Customer retention rate (CRM_5)
Internal Business Process (IBP)	Knowledge of the market (IBP_1)
	Information systems (IBP_2)
	Networking resources available (IBP_3)
	Social responsibility (IBP_4)
Environment Friendly Management System ($EFMS$)	Environmental certifications ($EFMS_1$)
	Waste management ($EFMS_2$)
	Green packaging ($EFMS_3$)
	Green house management ($EFMS_4$)

Source: Adapted from Raut et al. (2017)

5.1. Aggregation of the ratings of banks

The evaluation of four banks $(\tilde{B}_1,...,\tilde{B}_4)$ against the criteria is done by decision-makers using linguistic variables. Table 2 presents the linguistic variables used for rating the banks.

Table 2. Linguistic term set

Linguistic variables	**GTrFNs**
Very Low (Ve_Lo)	(0.1, 0.2, 0.3; 0.6)
Low (Lo)	(0.2, 0.3, 0.4; 0.7)
Medium (Me)	(0.3, 0.5, 0.7; 0.8)
High (Hi)	(0.5, 0.7, 0.9; 0.9)
Very High (Ve_Hi)	(0.8, 0.9, 1.0; 1.0)

Table 3 presents the aggregated ratings of the banks versus the nineteen sub-criteria from the three decision-makers at three periods t_1, t_2 and t_3 by using Eq. (6) and Table 2.

Table 3. Averaged ratings of banks versus the sub-criteria

Sub-criteria	**Banks**	**Decision-makers**									**Aggregated ratings**
		t_1			t_2			t_3			
		D_1	D_2	D_3	D_1	D_2	D_3	D_1	D_2	D_3	
***F_S*₁**	$\tilde{B}_1$	Hi	Hi	Hi	Me	Me	Me	Me	Me	Me	(0.50, 0.70, 0.90, 1.00; 0.9)
	$\tilde{B}_2$	Me	Hi	Me	Me	Me	Me	Me	Me	Me	(0.37, 0.57, 0.77, 0.87; 0.8)
	$\tilde{B}_3$	Ve_Hi	Hi	Hi	Ve_Hi	Hi	Hi	Hi	Ve_Hi	Hi	(0.56, 0.74, 0.92, 1.00; 0.9)
	$\tilde{B}_4$	Hi	Hi	Ve_Hi	Me	Me	Lo	Me	Me	Me	(0.64, 0.79, 0.95, 1.00; 0.9)
***F_S*₂**	$\tilde{B}_1$	Hi	Hi	Hi	Hi	Hi	Me	Ve_Hi	Hi	Hi	(0.50, 0.70, 0.90, 1.00; 0.9)
	$\tilde{B}_2$	Hi	Me	Me	Hi	Hi	Hi	Me	Me	Me	(0.34, 0.54, 0.74, 0.84; 0.8)
	$\tilde{B}_3$	Ve_Hi	Ve_Hi	Ve_Hi	Hi	Ve_Hi	Ve_Hi	Ve_Hi	Hi	Ve_Hi	(0.80, 0.90, 1.00, 1.00; 1.0)
	$\tilde{B}_4$	Ve_Hi	Hi	Hi	Me	Lo	Me	Me	Me	Me	(0.56, 0.74, 0.92, 1.00; 0.9)
***F_S*₃**	$\tilde{B}_1$	Hi	Me	Hi	Hi	Hi	Hi	Hi	Hi	Hi	(0.43, 0.63, 0.83, 0.93; 0.8)
	$\tilde{B}_2$	Ve_Hi	Hi	Hi	Ve_Hi	Hi	Ve_Hi	Hi	Ve_Hi	Hi	(0.56, 0.74, 0.92, 1.00; 0.9)
	$\tilde{B}_3$	Me	Hi	Me	Me	Hi	Me	Me	Me	Me	(0.37, 0.57, 0.77, 0.87; 0.8)
	$\tilde{B}_4$	Hi	Hi	Me	Me	Me	Me	Me	Me	Me	(0.41, 0.61, 0.81, 0.91; 0.8)

F_S_4	$\tilde{B}_1$	Hi	Me	Hi	Hi	Hi	Hi	Me	Me	Hi	(0.43, 0.63, 0.83, 0.93; 0.8)
	$\tilde{B}_2$	Hi	Hi	Ve_Hi	Me	Me	Me	Me	Me	Me	(0.64, 0.79, 0.95, 1.00; 0.9)
	$\tilde{B}_3$	Hi	Hi	Ve_Hi	Ve_Hi	Hi	Ve_Hi	Ve_Hi	Hi	Hi	(0.64, 0.79, 0.95, 1.00; 0.9)
	$\tilde{B}_4$	Me	Hi	Me	Me	Me	Me	Me	Me	Me	(0.37, 0.57, 0.77, 0.87; 0.8)
F_S_5	$\tilde{B}_1$	Me	Me	Hi	Me	Me	Me	Me	Me	Hi	(0.39, 0.59, 0.79, 0.89; 0.8)
	$\tilde{B}_2$	Hi	Hi	Hi	Ve_Hi	Hi	Hi	Ve_Hi	Hi	Ve_Hi	(0.50, 0.70, 0.90, 1.00; 0.9)
	$\tilde{B}_3$	Ve_Hi	Hi	Ve_Hi	Hi	Hi	Ve_Hi	Hi	Hi	Ve_Hi	(0.70, 0.83, 0.97, 1.00; 0.9)
	$\tilde{B}_4$	Hi	Me	Hi	Me	Me	Me	Me	Hi	Hi	(0.43, 0.63, 0.83, 0.93; 0.8)
CRM_1	$\tilde{B}_1$	Me	Me	Me	Me	Me	Me	Me	Me	Me	(0.30, 0.50, 0.70, 0.80; 0.8)
	$\tilde{B}_2$	Hi	Ve_Hi	Hi	Me	Me	Me	Me	Me	Me	(0.60, 0.77, 0.93, 1.00; 0.9)
	$\tilde{B}_3$	Hi	Ve_Hi	Hi	Hi	Ve_Hi	Hi	Hi	Hi	Ve_Hi	(0.60, 0.77, 0.93, 1.00; 0.9)
	$\tilde{B}_4$	Hi	Hi	Me	Me	Lo	Me	Me	Me	Me	(0.41, 0.61, 0.81, 0.91; 0.8)
CRM_2	$\tilde{B}_1$	Me	Me	Hi	Hi	Me	Hi	Me	Me	Hi	(0.39, 0.59, 0.79, 0.89; 0.8)
	$\tilde{B}_2$	Hi	Hi	Ve_Hi	Me	Me	Me	Me	Lo	Me	(0.64, 0.79, 0.95, 1.00; 0.9)
	$\tilde{B}_3$	Hi	Ve_Hi	Ve_Hi	Hi	Hi	Hi	Ve_Hi	Hi	Hi	(0.74, 0.86, 0.98, 1.00; 0.9)
	$\tilde{B}_4$	Me	Me	Me	Me	Me	Me	Me	Me	Me	(0.30, 0.50, 0.70, 0.80; 0.8)
CRM_3	$\tilde{B}_1$	Me	Me	Hi	Ve_Hi	Ve_Hi	Hi	Ve_Hi	Hi	Hi	(0.39, 0.59, 0.79, 0.89; 0.8)
	$\tilde{B}_2$	Hi	Me	Hi	Hi	Hi	Hi	Hi	Me	Hi	(0.43, 0.63, 0.83, 0.93; 0.8)
	$\tilde{B}_3$	Me	Me	Hi	Me	Ve_Hi	Ve_Hi	Hi	Me	Hi	(0.39, 0.59, 0.79, 0.89; 0.8)
	$\tilde{B}_4$	Me	Me	Me	Me	Me	Hi	Me	Hi	Me	(0.30, 0.50, 0.70, 0.80; 0.8)

CRM_4	$\breve{B}_1$	Hi	Me	Hi	Hi	Me	Me	Hi	Ve_Hi	Hi	(0.43, 0.63, 0.83, 0.93; 0.8)
	$\breve{B}_2$	Me	Me	Me	Me	Me	Me	Hi	Hi	Ve_Hi	(0.30, 0.50, 0.70, 0.80; 0.8)
	$\breve{B}_3$	Hi	Hi	Me	Hi	Hi	Ve_Hi	Hi	Me	Me	(0.41, 0.61, 0.81, 0.91; 0.8)
	$\breve{B}_4$	Me	Me	Hi	Me	Me	Me	Me	Me	Me	(0.39, 0.59, 0.79, 0.89; 0.8)
CRM_5	$\breve{B}_1$	Hi	Me	Hi	Hi	Ve_Hi	Hi	Ve_Hi	Hi	Hi	(0.43, 0.63, 0.83, 0.93; 0.8)
	$\breve{B}_2$	Me	Hi	Me	Me	Me	Me	Me	Me	Me	(0.37, 0.57, 0.77, 0.87; 0.8)
	$\breve{B}_3$	Hi	Ve_Hi	Hi	Ve_Hi	Ve_Hi	Hi	Hi	Hi	Hi	(0.60, 0.77, 0.93, 1.00; 0.9)
	$\breve{B}_4$	Hi	Me	Hi	Me	Lo	Me	Me	Me	Me	(0.43, 0.63, 0.83, 0.93; 0.8)
IBP_1	$\breve{B}_1$	Me	Hi	Hi	Me	Me	Hi	Hi	Hi	Hi	(0.46, 0.66, 0.86, 0.96; 0.8)
	$\breve{B}_2$	Me	Hi	Me	Me	Hi	Me	Me	Hi	Me	(0.37, 0.57, 0.77, 0.87; 0.8)
	$\breve{B}_3$	Ve_Hi	Ve_Hi	Hi	Hi	Ve_Hi	Ve_Hi	Ve_Hi	Hi	Hi	(0.66, 0.81, 0.95, 1.00; 0.9)
	$\breve{B}_4$	Hi	Me	Hi	Me	Me	Me	Me	Hi	Me	(0.43, 0.63, 0.83, 0.93; 0.8)
IBP_2	$\breve{B}_1$	Me	Me	Me	Hi	Me	Me	Hi	Ve_Hi	Hi	(0.30, 0.50, 0.70, 0.80; 0.8)
	$\breve{B}_2$	Hi	Hi	Ve_Hi	Hi	Me	Hi	Ve_Hi	Hi	Hi	(0.64, 0.79, 0.95, 1.00; 0.9)
	$\breve{B}_3$	Hi	Me	Me	Hi	Me	Me	Hi	Hi	Ve_Hi	(0.34, 0.54, 0.74, 0.84; 0.8)
	$\breve{B}_4$	Hi	Ve_Hi	Hi	Me	Me	Me	Me	Me	Me	(0.60, 0.77, 0.93, 1.00; 0.9)
IBP_3	$\breve{B}_1$	Hi	Hi	Me	Hi	Ve_Hi	Hi	Me	Hi	Hi	(0.41, 0.61, 0.81, 0.91; 0.8)
	$\breve{B}_2$	Me	Hi	Me	Me	Me	Me	Me	Lo	Me	(0.37, 0.57, 0.77, 0.87; 0.8)
	$\breve{B}_3$	Hi	Ve_Hi	Hi	Ve_Hi	Hi	Hi	Me	Me	Hi	(0.60, 0.77, 0.93, 1.00; 0.9)
	$\breve{B}_4$	Hi	Hi	Hi	Lo	Me	Me	Me	Me	Me	(0.50, 0.70, 0.90, 1.00; 0.9)

IBP$_4$	$\tilde{B}_1$	Hi	Me	Me	Me	Me	Me	Hi	Me	Hi	(0.34, 0.54, 0.74, 0.84; 0.8)
	$\tilde{B}_2$	Hi	Hi	Me	Me	Hi	Me	Hi	Hi	Ve_Hi	(0.41, 0.61, 0.81, 0.91; 0.8)
	$\tilde{B}_3$	Ve_Hi	Ve_Hi	Ve_Hi	Hi	Ve_Hi	Hi	Hi	Hi	Ve_Hi	(0.80, 0.90, 1.00, 1.00; 1.0)
	$\tilde{B}_4$	Hi	Hi	Hi	Me	Me	Me	Me	Me	Me	(0.50, 0.70, 0.90, 1.00; 0.9)
EFMS$_1$	$\tilde{B}_1$	Hi	Me	Hi	Ve_Hi	Hi	Hi	Ve_Hi	Hi	Hi	(0.43, 0.63, 0.83, 0.93; 0.8)
	$\tilde{B}_2$	Hi	Me	Hi	Hi	Ve_Hi	Hi	Hi	Hi	Hi	(0.43, 0.63, 0.83, 0.93; 0.8)
	$\tilde{B}_3$	Hi	Hi	Hi	Hi	Hi	Hi	Hi	Me	Hi	(0.50, 0.70, 0.90, 1.00; 0.9)
	$\tilde{B}_4$	Me	Hi	Hi	Me	Me	Me	Me	Me	Me	(0.46, 0.66, 0.86, 0.96; 0.8)
EFMS$_2$	$\tilde{B}_1$	Me	Me	Hi	Hi	Me	Hi	Hi	Hi	Hi	(0.39, 0.59, 0.79, 0.89; 0.8)
	$\tilde{B}_2$	Me	Hi	Hi	Me	Me	Me	Me	Me	Me	(0.46, 0.66, 0.86, 0.96; 0.8)
	$\tilde{B}_3$	Hi	Hi	Ve_Hi	Me	Hi	Hi	Ve_Hi	Hi	Ve_Hi	(0.64, 0.79, 0.95, 1.00; 0.9)
	$\tilde{B}_4$	Hi	Me	Me	Me	Me	Me	Me	Me	Me	(0.34, 0.54, 0.74, 0.84; 0.8)
EFMS$_3$	$\tilde{B}_1$	Hi	Me	Hi	Me	Me	Hi	Hi	Ve_Hi	Hi	(0.43, 0.63, 0.83, 0.93; 0.8)
	$\tilde{B}_2$	Ve_Hi	Hi	Hi	Hi	Me	Hi	Hi	Me	Hi	(0.56, 0.74, 0.92, 1.00; 0.9)
	$\tilde{B}_3$	Hi	Hi	Hi	Me	Me	Me	Hi	Hi	Me	(0.50, 0.70, 0.90, 1.00; 0.9)
	$\tilde{B}_4$	Me	Me	Me	Me	Me	Me	Me	Me	Me	(0.30, 0.50, 0.70, 0.80; 0.8)
EFMS$_4$	$\tilde{B}_1$	Hi	Hi	Ve_Hi	Hi	Me	Hi	Hi	Me	Me	(0.64, 0.79, 0.95, 1.00; 0.9)
	$\tilde{B}_2$	Hi	Ve_Hi	Hi	Hi	Ve_Hi	Hi	Ve_Hi	Ve_Hi	Hi	(0.60, 0.77, 0.93, 1.00; 0.9)
	$\tilde{B}_3$	Hi	Me	Hi	Ve_Hi	Hi	Hi	Hi	Hi	Hi	(0.43, 0.63, 0.83, 0.93; 0.8)
	$\tilde{B}_4$	Ve_Hi	Hi	Ve_Hi	Me	Me	Me	Me	Me	Me	(0.70, 0.83, 0.97, 1.00; 0.9)

5.2. Aggregating the criteria weights

Three decision-makers determine the weights of four criteria and nineteen sub-criteria using the intensity scale for generalized TrFNs: Equal_importance (Eq_Im) = (1, 1, 1, 1; 1.0), Between Eq_Im and We_Im = (1, 2, 3, 4; 0.6), Weak_importance of one over another (We_Im) = (2, 3, 4, 5; 0.7), Between We_Im and St_Im = (3, 4, 5, 6; 0.8), Strong_importance (St_Im) = (4, 5, 6, 7; 0.8), Between SI and VSI = (5, 6, 7, 8; 0.9), Very_strong_importance (Ve_St_Im) = (6, 7, 8, 9; 0.9), Between VSI and AI = (7, 8, 9, 9; 1.0), and Absolute_importance (Ab_Im) = (8, 9, 9, 10; 1.0). Using the intensity scale for generalized TrFNs, each decision-maker conducted a priority assessment of criteria/sub-criteria based on pairwise comparisons at three periods t_1, t_2 and t_3. Then, the aggregated weights of criteria/sub-criteria by three decision-makers and three periods t_1, t_2 and t_3 are obtained using Eq. (08) (as shown in Tables 4-8).

Table 4. The averaged GTrF comparison matrix of four criteria

Criteria	***F_S***	***CRM***	***IBP***	***EFMS***
F_S	(1.00, 1.00, 1.00, 1.00; 1.0)	(1.80, 2.40, 3.01, 3.65; 0.6)	(2.25, 3.00, 3.75, 4.50; 0.6)	(1.03, 1.30, 1.58, 1.88; 0.6)
CRM	(0.27, 0.33, 0.42, 0.56; 0.6)	(1.00, 1.00, 1.00, 1.00; 1.0)	(1.85, 2.43, 3.02, 3.60; 0.6)	(0.35, 0.46, 0.57, 0.72; 0.6)
IBP	(0.22, 0.27, 0.33, 0.44; 0.6)	(0.28, 0.33, 0.41, 0.54; 0.6)	(1.00, 1.00, 1.00, 1.00; 1.0)	(0.63, 0.73, 0.85, 1.00; 0.6)
EFMS	(0.53, 0.63, 0.77, 0.97; 0.6)	(1.39, 1.75, 2.82, 1.67; 0.6)	(1.00, 1.18, 1.37, 1.60; 0.6)	(1.00, 1.00, 1.00, 1.00; 1.0)

Table 5. The averaged GTrF comparison matrix of five sub-criteria with respect to F_S

F_S	F_S_1	F_S_2	F_S_3	F_S_4	F_S_5
F_S_1	(1.00, 1.00, 1.00, 1.00; 1.0)	(1.19, 1.64, 2.10, 2.64; 0.6)	(1.77, 2.44, 3.11, 3.78; 0.6)	(0.70, 1.06, 1.44, 1.90; 0.6)	(0.49, 0.70, 0.94, 1.31; 0.6)
F_S_2	(0.38, 0.48, 0.61, 0.84; 0.6)	(1.00, 1.00, 1.00, 1.00; 1.0)	(2.52, 3.03, 3.54, 4.00; 0.6)	(1.62, 1.96, 2.30, 2.64; 0.8)	(1.32, 1.75, 2.19, 2.59; 0.6)
F_S_3	(0.26, 0.32, 0.41, 0.56; 0.6)	(0.25, 0.28, 0.33, 0.40; 0.6)	(1.00, 1.00, 1.00, 1.00; 1.0)	(0.51, 0.70, 0.90, 1.17; 0.6)	(0.42, 0.44, 0.46, 0.49; 0.7)
F_S_4	(0.53, 0.69, 0.94, 1.43; 0.6)	(0.38, 0.44, 0.51, 0.62; 0.8)	(0.86, 1.11, 1.43, 1.96; 0.6)	(1.00, 1.00, 1.00, 1.00; 1.0)	(1.04, 1.38, 1.74, 2.12; 0.6)
F_S_5	(0.76, 1.06, 1.43, 2.03; 0.6)	(0.39, 0.46, 0.57, 0.76; 0.6)	(2.03, 2.18, 2.29, 2.36; 0.7)	(0.47, 0.58, 0.72, 0.96; 0.6)	(1.00, 1.00, 1.00, 1.00; 1.0)

Table 6. The averaged GTrF comparison matrix of five sub-criteria with respect to CRM

CRM	CRM_1	CRM_2	CRM_3	CRM_4	CRM_5
CRM_1	(1.00, 1.00, 1.00, 1.00; 1.0)	(2.39, 3.07, 3.77, 4.44; 0.6)	(1.28, 1.88, 2.48, 3.11; 0.6)	(3.34, 4.26, 5.18, 6.02; 0.7)	(1.98, 2.58, 2.92, 3.87; 0.6)
CRM_2	(0.23, 0.27, 0.33, 0.42; 0.6)	(1.00, 1.00, 1.00, 1.00; 1.0)	(0.83, 1.27, 1.71, 2.20; 0.6)	(2.17, 2.92, 3.67, 4.42; 0.6)	(0.71, 0.99, 1.31, 1.75; 0.6)
CRM_3	(0.32, 0.40, 0.53, 0.78; 0.6)	(0.45, 0.58, 0.79, 1.20; 0.6)	(1.00, 1.00, 1.00, 1.00; 1.0)	(3.18, 4.01, 4.74, 5.60; 0.6)	(2.09, 2.61, 2.95, 3.64; 0.6)
CRM_4	(0.17, 0.19, 0.23, 0.30; 0.7)	(0.23, 0.27, 0.34, 0.46; 0.6)	(0.18, 0.21, 0.25, 0.31; 0.6)	(1.00, 1.00, 1.00, 1.00; 1.0)	(0.37, 0.48, 0.61, 0.81; 0.6)
CRM_5	(0.26, 0.34, 0.39, 0.50; 0.6)	(0.57, 0.76, 1.01, 1.41; 0.6)	(0.27, 0.34, 0.38, 0.48; 0.6)	(1.23, 1.63, 2.07, 2.68; 0.6)	(1.00, 1.00, 1.00, 1.00; 1.0)

Table 7. The averaged GTrF comparison matrix of four sub-criteria with respect to IBP

IBP	IBP_1	IBP_2	IBP_3	IBP_4

IBP_1	(1.00, 1.00, 1.00, 1.00; 1.0)	(2.08, 2.92, 3.53, 4.58; 0.6)	(0.97, 1.26, 1.04, 2.03; 0.6)	(0.39, 0.49, 0.61, 0.75; 0.8)
IBP_2	(0.22, 0.28, 0.34, 0.48; 0.6)	(1.00, 1.00, 1.00, 1.00; 1.0)	(0.45, 0.55, 0.68, 0.88; 0.6)	(0.15, 0.17, 0.21, 0.30; 0.6)
IBP_3	(0.49, 0.96, 0.79, 1.03; 0.6)	(1.14, 1.46, 1.80, 2.25; 0.6)	(1.00, 1.00, 1.00, 1.00; 1.0)	(0.40, 0.53, 0.68, 0.97; 0.6)
IBP_4	(1.33, 1.63, 2.02, 2.58; 0.8)	(3.31, 4.71, 5.86, 6.85; 0.6)	(1.04, 1.46, 1.90, 2.47; 0.6)	(1.00, 1.00, 1.00, 1.00; 1.0)

Table 8. The averaged GTrF comparison matrix of four sub-criteria with respect to EFMS

EFMS	**$EFMS_1$**	**$EFMS_2$**	**$EFMS_3$**	**$EFMS_4$**
$EFMS_1$	(1.00, 1.00, 1.00, 1.00; 1.0)	(2.08, 2.92, 3.75, 4.50; 0.6)	(0.19, 0.24, 0.32, 0.55; 0.6)	(1.03, 1.39, 1.78, 2.28; 0.6)
$EFMS_2$	(0.22, 0.27, 0.34, 0.48; 0.6)	(1.00, 1.00, 1.00, 1.00; 1.0)	(0.13, 0.15, 0.18, 0.23; 0.8)	(0.62, 0.73, 0.86, 1.05; 0.6)
$EFMS_3$	(1.83, 3.10, 4.24, 5.31; 0.6)	(4.36, 5.45, 6.51, 7.45; 0.8)	(1.00, 1.00, 1.00, 1.00; 1.0)	(3.00, 3.83, 4.64, 5.33; 0.6)
$EFMS_4$	(0.44, 0.56, 0.72, 0.97; 0.6)	(0.95, 1.17, 1.38, 1.62; 0.6)	(0.19, 0.22, 0.26, 0.33; 0.6)	(1.00, 1.00, 1.00, 1.00; 1.0)

Table 9 shows the averaged GTrF synthetic extent values of criteria and sub-criteria using Eq. (09) and the data in Tables 4-8. Table 9 shows that F_S is the most importance criteria, following by EFMS, CRM and IBP.

Table 9. The averaged GTrF synthetic extent values

Criteria	**Averaged GTrF synthetic extent**	**Sub-criteria**	**Averaged GTrF synthetic extent**
F_S	(0.30, 0.36, 0.46, 0.54; 0.6)	**F_S_1**	(0.15, 0.22, 0.29, 0.37; 0.6)
		F_S_2	(0.19, 0.26, 0.33, 0.41; 0.6)
		F_S_3	(0.06, 0.08, 0.11, 0.15; 0.6)
		F_S_4	(0.11, 0.14, 0.20, 0.27; 0.6)
		F_S_5	(0.13, 0.16, 0.21, 0.28; 0.6)
CRM	(0.15, 0.19, 0.26, 0.33; 0.6)	**CRM_1**	(0.24, 0.34, 0.42, 0.52; 0.6)
		CRM_2	(0.11, 0.16, 0.22, 0.30; 0.6)
		CRM_3	(0.16, 0.22, 0.28, 0.38; 0.6)
		CRM_4	(0.04, 0.05, 0.07, 0.10; 0.6)
		CRM_5	(0.07, 0.10, 0.14, 0.20; 0.6)
IBP	(0.09, 0.10, 0.14, 0.18; 0.6)	**IBP_1**	(0.18, 0.25, 0.30, 0.42; 0.6)
		IBP_2	(0.06, 0.09, 0.11, 0.16; 0.6)
		IBP_3	(0.11, 0.17, 0.21, 0.29; 0.6)
		IBP_4	(0.29, 0.41, 0.48, 0.58; 0.6)
EFMS	(0.16, 0.21, 0.30, 0.31; 0.6)	**$EFMS_1$**	(0.14, 0.20, 0.27, 0.36; 0.6)
		$EFMS_2$	(0.06, 0.07, 0.10, 0.14; 0.6)
		$EFMS_3$	(0.40, 0.52, 0.61, 0.68; 0.6)
		$EFMS_4$	(0.08, 0.10, 0.14, 0.19; 0.6)

5.3. Determining the weighted GTrF decision matrix

This study determined the final fuzzy evaluation values of the banks by averaging the ratings of banks against the sub-criteria (as presented in Table 3) and the synthetic extent values of GTrF (as presented in Table 9). The final GTrF evaluation values of each bank, calculated using Eq. (12), are shown in Table 10.

Table 10. Final fuzzy evaluation values of each bank

Banks	**Final GTrF evaluation values**

$\tilde{B}_1$	(0.060, 0.121, 0.202, 0.294; 0.600)
$\tilde{B}_2$	(0.069, 0.131, 0.212, 0.303; 0.600)
$\tilde{B}_3$	(0.086, 0.150, 0.229, 0.317; 0.600)
$\tilde{B}_4$	(0.063, 0.124, 0.205, 0.296; 0.600)

5.4. Calculate the distance of each bank from $\tilde{B}^{+}$ and $\tilde{B}^{-}$ and the closeness coefficient

By Eqs. (13)-(15), the distance of each bank from $\tilde{B}^{+}$ and $\tilde{B}^{-}$ and the closeness coefficients of banks are obtained (in Table 11). Therefore, the ranking order of four banks is $\tilde{B}_3$ f $\tilde{B}_2$ f $\tilde{B}_4$ f $\tilde{B}_1$. So, the best bank is $\tilde{B}_3$. The results of the study showcase the efficiency and practicality of the proposed approach in addressing multi-criteria decision-making problems in real-world scenarios. Regulatory agencies and banks can leverage this method to assess the sustainable performance of banks.

Table 11. The distance of each bank from $\tilde{B}^{+}$ and $\tilde{B}^{-}$ and the closeness coefficient

Banks	$\tilde{d}_i^{+}$	$\tilde{d}_i^{-}$	**Closeness coefficient**	**Ranking**
$\tilde{B}_1$	1.002	0.229	0.186	4
$\tilde{B}_2$	0.991	0.239	0.194	2
$\tilde{B}_3$	0.971	0.257	0.209	1
$\tilde{B}_4$	0.999	0.232	0.188	3

6. Conclusion

The GTrF-AHP-TOPSIS approach was proposed in this study to evaluate the sustainable performance of banks in Vietnam. The approach utilized GTrFNs to express both the ratings of banks and the criteria weights assigned by decision-makers. The GTrF-AHP method was developed to determine the criteria weights over time. The ranking of banks was determined by utilizing the closeness coefficient, which calculated the distances of each bank to both the positive/negative-ideal solutions. The proposed method's effectiveness was demonstrated through its application, which evaluated four criteria and nineteen sub-criteria at three distinct time periods. The results show that the proposed integrated dynamic GTrF-AHP-TOPSIS approach outperforms previous relevant studies in terms of efficiency and versatility. This approach can be used to address other business or management issues, but it is constrained by the use of fuzzy sets that solely consider membership and cannot account for non-membership. Future studies could broaden the proposed approach by incorporating intuitionistic fuzzy sets or neutrosophic sets.

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