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A Comparative Analysis of Incremental and Disruptive Innovation Policies in the European Banking Sector with Hybrid Interval Type-2 Fuzzy Decision-Making Models

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Abstract Nowadays innovation is a key issue in all business sectors, maintaining a positive correlation with the countries' economic development. The banking sector stands out among the different economic sectors, as globalization has pushed banks into tough competition. Hence, banks within this competitive framework must innovate by developing new products to be competitive and survive. The innovation in banking products is usually sorted as *incremental or disruptive*. Therefore, this paper aims to evaluate the innovation policies for the European Banking Sector by analyzing incremental and disruptive innovation policies. The novelty of the paper is to propose a set of dimensions and criteria for the innovation policies of European banking industry and to construct a hybrid decision-making model based on interval type-2 fuzzy sets. Accordingly, a comparative analysis of the top five GDP European countries has been carried out using a multiple criteria decision model (MCDM). The MCDM defines different criteria for incremental and disruptive innovations according to the specialized literature. Interval type-2 fuzzy DEMATEL (IT2 FDEMATEL) is used for weighting factors, and interval type-2 fuzzy VIKOR (IT2 FVIKOR) and interval type-2 fuzzy TOPSIS (IT2 FTOPSIS) are considered for ranking alternatives in the integrated modeling. Eventually, the findings highlight the most important criteria in this analysis and the results demonstrate that the comparative analysis of IT2 FVIKOR and IT2 FTOPSIS provides comprehensive and coherent results to select the best country in the innovation policies. In addition, the need to redesign the European banking system with necessary regulations to contribute to the development of the innovations is pointed out.

Keywords Innovation · Europe · Banking sector · Interval type-2 fuzzy DEMATEL · Interval type-2 fuzzy TOPSIS · Interval type-2 fuzzy VIKOR

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1 Introduction

Innovation has become one of the fastest growing concepts in business, especially in recent years. It can be defined as using new methods in social, cultural and managerial environments. It is believed that there is a positive correlation between innovation and a country's economic development. Due to this situation, governments encourage innovation in many ways. As such, innovation also has a positive influence on company improvement. By presenting innovative products, companies can attract the attention of customers. Thus, this process increases the profitability of these companies [1].

Innovation has an important role for the banking industry within the competitive market environment. Notably, the global strategies and competition in the banking industry require innovative policies to increase their local and international market potential. As a result, global competitors are gradually developing international banking operations based on sustainable changes. And also, large-scale banks are dominant at the innovation policies and drive the competencies of competitive market more effectively. So, local banks should be able to survive against the global competitors of the banking industry by generating new ideas and innovative products.

Innovative products in the banking sector can be classified into two different categories. First of all, incremental innovation refers to improving or innovating existing products. In other words, it means making small improvements to the banks' current products to increase efficiency and get competitive power. On the other hand, disruptive innovation can be explained as developing a new product or service that has not been used before [2]. It can be said that incremental innovation is used more in the banking sector in comparison with disruptive innovation, whereas disruptive innovation has much more of an impact on the market if it is successful [2, 3].

The European banking sector is also experiencing very serious competition. Hence, European banks try to develop many different strategies to increase their competitiveness [3]. For this purpose, these banks have made different innovations over the last few years. For example, according to the Innovation and Retail Banking Report prepared by the companies Efma and Infosys, UniCredit developed a biometric security system. In addition to this issue, ActivoBank developed a system that allows peer-to-peer payment using social media channels. It can be observed that European banks give a lot of importance to making sure innovations become permanent in the market.

The main contributions of this study are to propose the incremental and disruptive innovation policies for the European banking industry and provide several policy recommendations to develop the most appropriate innovations of the banking industry in the Europe. In addition, it is aimed to construct a hybrid extended multi-criteria decision-making approach based on interval type-2 fuzzy sets. Thus, a comparative analysis regarding incremental and disruptive innovation policies is performed. Within this scope, five different European Union member countries (Germany, United Kingdom, France Italy, Spain) are evaluated. The main selection criterion of these countries is having more than 1000 billion USD nominal GDP in 2017 according to IMF statistics. Two dimensions and eight criteria that show the innovation performance of these banks are also determined. IT2 FDEMATEL is used to weigh the dimensions and criteria. Moreover, IT2 FTOPSIS and IT2 FVIKOR approaches are considered to rank the selected European countries.

This study is structured as follows: in Sect. 2, significant studies in the literature are assessed. In Sect. 3, IT2 fuzzy sets, IT2 FDEMATEL, IT2 FTOPSIS and IT2 FVIKOR approaches are discussed. In addition, Sect. 4 focuses on the application of integrated analysis with the previous IT2 Fuzzy Models on European banking industry. Eventually, in Sect. 5 several recommendations are identified to improve the performance of this industry.

2 Literature Review

Innovation concept was evaluated with various concepts. Most of the studies are related to the effects of innovation on financial performance. Kostopoulos et al. [4] analyzed the relationship between these variables. For this scope, a survey analysis was conducted with a sample of 461 Greek companies. It has been concluded that effective innovation positively affects the financial performance of these companies. Faems et al. [5], Zahra and Das [6], Aspara et al. [7] and Merton [8] also reached a similar conclusion with the help of different methodologies. In addition, Liao and Rice [9] also examined the innovation performance of Australian SMEs. While using a sample of 449 manufacturing companies, they identified that effective innovation policies lead to efficiency in investment that in turn contributes to financial profitability. Also, Ramanathan et al. [10] and Ho et al. [11] underlined the importance of innovation on the effectiveness of the investments.

In addition, some studies also considered the positive influence of the innovation on the competitive powers of the companies. For instance, Salunke et al. [12] aimed to understand the relationship between innovation and competitive power. They conducted a survey analysis with Australian and US project-oriented firms. As a result, we can see that innovation positively affects the competitive power of these companies. Furthermore, Wu and Chiu [13], Hinterhuber and Liozu [14], Herrera [15] and Anning-Dorson [16] also evaluated the relationship between these variables and concluded that effective innovation increases the competitive powers of the companies. Moreover, Chen et al. [17] also made an analysis for Chinese companies. Using results from questionnaires that were sent out to 138 CEOs, they determined that effective innovation increases the information technology performance of the companies. Similarly, this situation increases the competitive power of these companies.

Furthermore, the relationship between innovation and customer satisfaction has also been taken into consideration in many different studies. As an example, Rubera and Kirca [18] have tried to find the effects of innovation on customer satisfaction. A hierarchical linear modeling was considered with 85 companies between 1999 and 2011. They defined that effective innovation positively affects customer satisfaction. In line with this study, Lun et al. [19], Bellingkrodt and Wallenburg [20], Oyner and Korelina [21] and Subramanian et al. [22] focused on this subject using other analysis techniques. They demonstrated that when companies give importance to the innovation, these new products increase customer satisfaction. On the other hand, Gassmann et al. [23] and Zhang et al. [24] underlined the necessity of understanding customer expectation in the implementation process to increase customer satisfaction.

Moreover, some researchers have also aimed to evaluate the relationship between the innovation and risk management. Xu and Tang [25] focused on this relationship in their study. They highlighted that risk management should be considered when making innovation. Otherwise, innovative products or service may affect the financial performance of the companies in a negative manner. In addition, Bowers and Khorakian [26], Nikolova et al. [27] and Gurd and Helliar [28] also highlighted the significance of this issue. Some studies have also analyzed the influence of the innovation on effective risk management of the companies. Kwak et al. [29], Ali et al. [30] and Penning-Rowsell et al. [31] identified that innovation positively affects risk management.

Some researchers have also evaluated the effects of innovation on economic growth. As an example, Sohag et al. [32] focused on the relationship between technological innovation and economic improvement in Malaysia. Within this scope, the data between the years of 1985 and 2012 were examined using the ARDL methodology. It was concluded that GDP per capita can be increased with the help of innovation. Malecki [33], Pradhan et al. [34], Pece et al. [35] and Capello and Lenzi [36] all reached similar conclusions. In addition, some other studies also considered the effect of economic development on the innovation performance. Galindo and Méndez [37] tried to analyze this relationship in 13 developed countries. It is concluded that countries that have high economic development have a tendency to make more innovative changes. This condition was also emphasized in other studies [38–40].

In the literature, there are several extensions of DEMATEL, VIKOR, and TOPSIS. Pishdar [41] evaluated environmental factors with the IT2 FDEMATEL method. Baykasoğlu and Gölcük [42] and Hosseini and Tarokh [43] also carried out a study regarding this approach. However, DEMATEL are also used in the topics of innovation and banking industry. Patent analysis [44], quality and [45] supply chain management [46] and information system [47] are the main research topics of innovation applied with DEMATEL. However, the use of the DEMATEL method is extremely limited in the banking industry [48–50].

In addition, IT2 FVIKOR was also considered in some subjects, such as the risk evaluation of project investments [51], selection of the best projects [52] and supplier selection [53]. Furthermore, Cevik Onar et al. [54], Dymova et al. [55], Liao [56] and Sang and Liu [57] are also the studies that have used the IT2 FTOPSIS method for different purposes like supplier selection, public transportation, material selection and risk assessment. The studies on innovation using TOPSIS generally deal with green practices [58–60], energy [61] and manufacturing technologies [62]. However, the use of the VIKOR method for innovation is quite infrequent in the literature [63–65]. Similarly, the banking application of the VIKOR method is not well-known [66, 67] while TOPSIS has been relatively extensive applied to, including the banking industry [68–70]. Dincer and Yuksel [71] and Wu et al. [72] each apply the comparative analysis using VIKOR and TOPSIS to the banking industry.

As a result, it is understood that innovation has been evaluated using various concepts. The relationship between innovation with economic growth and risk management, the influences of innovation on financial performance, competitive power and customer satisfaction are all examples of topics that have been studied. While similar methods are generally considered in these studies such as regression, ARDL, survey analysis, the extensions of DEMATEL; VIKOR and TOPSIS based on interval type 2 fuzzy sets are novel for banking industry. Thus, this study could provide several contributions to the literature by analyzing the incremental and disruptive innovation strategies in the European banking industry and proposing an extended hybrid multi-criteria decision-,making model with trapezoidal fuzzy numbers.

3 Methodology

In this section, we further explained the different concepts and approaches that are used in our proposal starting with Interval Type 2 Fuzzy Sets (IT2FS) and the three decision-making approaches utilized in our analysis, namely IT2 Fuzzy DEMATEL, IT2 Fuzzy VIKOR and IT2 Fuzzy TOPSIS.

3.1 IT2 Fuzzy Sets (IT2FS)

IT2FS are generated from type-1 fuzzy sets. $\widetilde{P}$ represents type-2 fuzzy sets. $\mu_{\widetilde{P}(x,u)}$ defines the membership function based on IT2 with values from 0 to 1. The fuzzy set is defined as [73, 74]

$$\widetilde{P} = \left\{ \left((x,u), \mu_{\widetilde{P}(x,u)} \right) | \forall_x \in X, \forall_u \in J_x \subseteq [0,1] \right\}, \text{ or } \tilde{P} = \int_{x \in X} \int_{u \in J_x} \mu_{\widetilde{P}}(x,u)/(x,u) J_x \subseteq [0,1]. \quad (1)$$

In Eq. (1), $\int\int$ explains the union of all x and u. If the membership function is equal to 1, IT2FS are demonstrated as Eq. (2).

$$\widetilde{P} = \int_{x \in X} \int_{u \in J_x} 1/(x, u) J_x \subseteq [0, 1] \tag{2}$$

On the other hand, the upper trapezoidal membership function is represented by $\widetilde{P}_\iota^\lambda$ whereas $\widetilde{P}_\iota^\nu$ explains the lower trapezoidal membership function. This situation is demonstrated in Eq. (3).

$$\begin{aligned}\widetilde{P}_\iota &= (\widetilde{P}_\iota^\lambda, \widetilde{P}_\iota^\nu) \\ &= ((\rho_{\iota1}^\lambda, \rho_{\iota2}^\lambda, \rho_{\iota3}^\lambda, \rho_{\iota4}^\lambda; \Gamma_1(\widetilde{P}_\iota^\lambda), \Gamma_2(\widetilde{P}_\iota^\lambda)), (\rho_{\iota1}^\nu, \rho_{\iota2}^\nu, \rho_{\iota3}^\nu, \rho_{\iota4}^\nu; \Gamma_1(\widetilde{P}_\iota^\nu), \Gamma_2(\widetilde{P}_\iota^\nu)))\end{aligned} \tag{3}$$

In Eq. (3), $\rho_{\iota1}^\lambda, \ldots, \rho_{\iota4}^\nu$ represent the reference values. Furthermore, the type-1 fuzzy sets are given by $\tilde{P}_\iota^\lambda$ and $\tilde{P}_\iota^\nu$. Moreover, $\Gamma_\kappa(\tilde{P}_\iota^\lambda)$ and $\Gamma_\kappa(\tilde{P}_\iota^\nu)$ refer to the membership values. The essential operations of IT2FS are defined in Eqs. (4)–(8).

$$\begin{aligned}\tilde{P}_1 \oplus \tilde{P}_2 &= (\tilde{P}_1^\lambda, \tilde{P}_1^\nu) \oplus (\tilde{P}_2^\lambda, \tilde{P}_2^\nu) \\ &= \begin{pmatrix} (\rho_{11}^\lambda + \rho_{21}^\lambda, \rho_{12}^\lambda + \rho_{22}^\lambda, \rho_{13}^\lambda + \rho_{23}^\lambda, \rho_{14}^\lambda + \rho_{24}^\lambda; \min(\Gamma_1(\tilde{P}_1^\lambda), \Gamma_1(\tilde{P}_2^\lambda)), \min(\Gamma_2(\tilde{P}_1^\lambda), \Gamma_2(\tilde{P}_2^\lambda))), \\ (\rho_{11}^\nu + \rho_{21}^\nu, \rho_{12}^\nu + \rho_{22}^\nu, \rho_{13}^\nu + \rho_{23}^\nu, \rho_{14}^\nu + \rho_{24}^\nu; \min(\Gamma_1(\tilde{P}_1^\nu), \Gamma_1(\tilde{P}_2^\nu)), \min(\Gamma_2(\tilde{P}_1^\nu), \Gamma_2(\tilde{P}_2^\nu))) \end{pmatrix}\end{aligned} \tag{4}$$

$$\begin{aligned}\tilde{P}_1 \ominus \tilde{P}_2 &= (\tilde{P}_1^\lambda, \tilde{P}_1^\nu) \ominus (\tilde{P}_2^\lambda, \tilde{P}_2^\nu) \\ &= \begin{pmatrix} (\rho_{11}^\lambda - \rho_{24}^\lambda, \rho_{12}^\lambda - \rho_{23}^\lambda, \rho_{13}^\lambda - \rho_{23}^\lambda, \rho_{14}^\lambda - \rho_{21}^\lambda; \min(\Gamma_1(\tilde{P}_1^\lambda), \Gamma_1(\tilde{P}_2^\lambda)), \min(\Gamma_2(\tilde{P}_1^\lambda), \Gamma_2(\tilde{P}_2^\lambda))), \\ (\rho_{11}^\nu - \rho_{24}^\nu, \rho_{12}^\nu - \rho_{23}^\nu, \rho_{13}^\nu - \rho_{23}^\nu, \rho_{14}^\nu - \rho_{21}^\nu; \min(\Gamma_1(\tilde{P}_1^\nu), \Gamma_1(\tilde{P}_2^\nu)), \min(\Gamma_2(\tilde{P}_1^\nu), \Gamma_2(\tilde{P}_2^\nu))) \end{pmatrix}\end{aligned} \tag{5}$$

$$\begin{aligned}\tilde{P}_1 \otimes \tilde{P}_2 &= (\tilde{P}_1^\lambda, \tilde{P}_1^\nu) \otimes (\tilde{P}_2^\lambda, \tilde{P}_2^\nu) \\ &= \begin{pmatrix} (\rho_{11}^\lambda \times \rho_{21}^\lambda, \rho_{12}^\lambda \times \rho_{22}^\lambda, \rho_{13}^\lambda \times \rho_{23}^\lambda, \rho_{14}^\lambda \times \rho_{24}^\lambda; \min(\Gamma_1(\tilde{P}_1^\lambda), \Gamma_1(\tilde{P}_2^\lambda)), \min(\Gamma_2(\tilde{P}_1^\lambda), \Gamma_2(\tilde{P}_2^\lambda))), \\ (\rho_{11}^\nu \times \rho_{21}^\nu, \rho_{12}^\nu \times \rho_{22}^\nu, \rho_{13}^\nu \times \rho_{23}^\nu, \rho_{14}^\nu \times \rho_{24}^\nu; \min(\Gamma_1(\tilde{P}_1^\nu), \Gamma_1(\tilde{P}_2^\nu)), \min(\Gamma_2(\tilde{P}_1^\nu), \Gamma_2(\tilde{P}_2^\nu))) \end{pmatrix}\end{aligned} \tag{6}$$

$$\begin{aligned}m\widetilde{P}_1 = {} & (m \times \rho_{11}^\lambda, m \times \rho_{12}^\lambda, m \times \rho_{13}^\lambda, m \times \rho_{14}^\lambda; \Gamma_1(\tilde{P}_1^\lambda), \\ & \Gamma_2(\tilde{P}_1^\lambda)), (m \times \rho_{11}^\nu, m \times \rho_{12}^\nu, m \times \rho_{13}^\nu, m \times \rho_{14}^\nu; \Gamma_1(\tilde{P}_1^\nu), \Gamma_2(\tilde{P}_1^\nu))\end{aligned} \tag{7}$$

$$\begin{aligned}\frac{\widetilde{P}_1}{m} = {} & \left(\frac{1}{m} \times \rho_{11}^\lambda, \frac{1}{m} \times \rho_{12}^\lambda, \frac{1}{m} \times \rho_{13}^\lambda, \frac{1}{m} \times \rho_{14}^\lambda; \Gamma_1(\tilde{P}_1^\lambda), \Gamma_2(\tilde{P}_1^\lambda)\right), \\ & \left(\frac{1}{m} \times \rho_{11}^\nu, \frac{1}{m} \times \rho_{12}^\nu, \frac{1}{m} \times \rho_{13}^\nu, \frac{1}{m} \times \rho_{14}^\nu; \Gamma_1(\tilde{P}_1^\nu), \Gamma_2(\tilde{P}_1^\nu)\right)\end{aligned} \tag{8}$$

3.2 IT2 FDEMATEL

The term of DEMATEL deals with the decision-making trial and the evaluation laboratory in the multi-criteria process. It aims to evaluate the interdependence among the items. In addition, the importance levels of these items can be defined using this methodology. IT2 FDEMATEL is an approach for complex decision-making problems. This process can be identified in five different steps [75, 76]:

(1) Collect decision-makers' priorities. Obtained evaluations are defined as the interval fuzzy sets.

(2) Employ the initial direct-relation matrix. In this process, the evaluations of each expert are considered collectively. In the following process, the matrix $\tilde{P}$ is generated with the average scores. This condition is further detailed in Eqs. (9) and (10).

$$\widetilde{P} = \begin{bmatrix} 0 & \tilde{p}_{12} & \cdots & \cdots & \tilde{p}_{1n} \\ \tilde{p}_{21} & 0 & \cdots & \cdots & \tilde{p}_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \tilde{p}_{n1} & \tilde{p}_{n2} & \cdots & \cdots & 0 \end{bmatrix} \tag{9}$$

$$\widetilde{P} = \frac{\widetilde{P}^1 + \widetilde{P}^2 + \widetilde{P}^3 + \cdots + \widetilde{P}^n}{n} \tag{10}$$

(3) The pairwise matrix is normalized by considering Eqs. (11)–(13).

$$\tilde{X} = \begin{bmatrix} \tilde{p}_{11} & \tilde{p}_{12} & \cdots & \cdots & \tilde{p}_{1n} \\ \tilde{p}_{21} & \tilde{p}_{22} & \cdots & \cdots & \tilde{p}_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \tilde{p}_{n1} & \tilde{p}_{n2} & \cdots & \cdots & \tilde{p}_{nn} \end{bmatrix} \tag{11}$$

$$\begin{aligned}\tilde{x}_{\iota\kappa} = \frac{\tilde{P}_{\iota\kappa}}{r} = {} & \left(\frac{\rho_{\alpha_{\iota\kappa}}}{r}, \frac{\rho_{\beta_{\iota\kappa}}}{r}, \frac{\rho_{\gamma_{\iota\kappa}}}{r}, \frac{\rho_{\delta_{\iota\kappa}}}{r}; \Gamma_1(P_{\iota\kappa}^\lambda), \Gamma_2(P_{\iota\kappa}^\lambda)\right), \\ & \left(\frac{\rho_{\varepsilon_{\iota\kappa}}}{r}, \frac{\rho_{\in_{\iota\kappa}}}{r}, \frac{\rho_{\zeta_{\iota\kappa}}}{r}, \frac{\rho_{\eta_{\iota\kappa}}}{r}; \Gamma_1(P_{\iota\kappa}^\nu), \Gamma_2(P_{\iota\kappa}^\nu)\right)\end{aligned} \tag{12}$$

$$r = \max\left(\max_{1 \le \iota \le n} \sum_{\kappa=1}^{n} \rho_{d_{\iota\kappa}}, \max_{1 \le \iota \le n} \sum_{\kappa=1}^{n} \rho_{d_{\iota\kappa}}\right) \tag{13}$$

(4) This step generates the total degrees of influence as

$$X_\alpha = \begin{bmatrix} 0 & \alpha'_{12} & \cdots & \cdots & \alpha'_{1n} \\ \alpha'_{21} & 0 & \cdots & \cdots & \alpha'_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \alpha'_{n1} & \alpha'_{n2} & \cdots & \cdots & 0 \end{bmatrix}, \ldots, X_\eta = \begin{bmatrix} 0 & \eta'_{12} & \cdots & \cdots & \eta'_{1n} \\ \eta'_{21} & 0 & \cdots & \cdots & \eta'_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \eta'_{n1} & \eta'_{n2} & \cdots & \cdots & 0 \end{bmatrix} \tag{14}$$

$$\tilde{A} = \lim_{t \to \infty} \tilde{X} + \tilde{X}^2 + \cdots + \tilde{X}^t \tag{15}$$

$$\tilde{A} = \begin{bmatrix} \tilde{a}_{11} & \tilde{a}_{12} & \cdots & \cdots & \tilde{a}_{1n} \\ \tilde{a}_{21} & \tilde{a}_{22} & \cdots & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \cdots & \cdots & \tilde{a}_{nn} \end{bmatrix} \tag{16}$$

$$\tilde{a}_{\iota\kappa} = \left(\alpha''_{\iota\kappa}, \beta''_{\iota\kappa}, \gamma''_{\iota\kappa}, \delta''_{\iota\kappa}; \Gamma_1\left(\tilde{a}^{\lambda}_{\iota\kappa}\right), \Gamma_2\left(\tilde{a}^{\lambda}_{\iota\kappa}\right)\right), \left(\varepsilon''_{\iota\kappa}, \in''_{\iota\kappa}, \zeta''_{\iota\kappa}, \eta''_{\iota\kappa}; \Gamma_1\left(\tilde{a}^{v}_{\iota\kappa}\right), \Gamma_2 \tilde{a}^{v}_{\iota\kappa}\right) \tag{17}$$

$$\left[\alpha''_{\iota\kappa}\right] = X_{\alpha} \times (1 - X_{\alpha})^{-1}, \ldots, \left[\eta''_{\iota\kappa}\right] = X_{\eta} \times \left(1 - X_{\eta}\right)^{-1} \tag{18}$$

5) The defuzzified total influence matrix is calculated in the last step. For this issue, formulas (19)–(22) are considered.

$$\mathrm{Def}_A = \frac{\frac{(\lambda_A - v_N) + (\beta_A \times m_{1A} - v_A) + (\alpha_U \times m_{2U} - l_U)}{4} + l_U + \left[\frac{(\lambda_A - v_N) + (\beta_N \times m_{1N} - v_N) + (\alpha_N \times m_{2N} - l_N)}{4} + v_N\right]}{2} \tag{19}$$

$$Def_A = [a_{\iota\kappa}]_{n \times n}, \quad \kappa = 1, 2, \ldots, n \tag{20}$$

$$\tilde{R}_i^{\mathrm{def}} = R = \left[\sum_{\kappa=1}^{n} a_{\iota\kappa}\right]_{n \times 1} = (R_\iota)_{n \times 1} = (R_1, \ldots, R_\iota, \ldots, R_n) \tag{21}$$

$$\tilde{Y}_i^{\mathrm{def}} = Y = \left[\sum_{\iota=1}^{n} a_{\iota\kappa}\right]'_{1 \times n} = (Y_\kappa)'_{1 \times n} = ((Y_1, \ldots, Y_\iota, \ldots, Y_n)) \tag{22}$$

After that, using the values of $\left(\tilde{R}_i + \tilde{Y}_i\right)^{\mathrm{def}}$ and $\left(\tilde{R}_i - \tilde{Y}_i\right)^{\mathrm{def}}$, the defuzzification is employed. Furthermore, the sum of all vector rows is shown as $\tilde{R}_i^{\mathrm{def}}$ and $\tilde{Y}_i^{\mathrm{def}}$ explains the sum of all vector columns. Hence, in case of a high $\left(\tilde{R}_i + \tilde{Y}_i\right)^{\mathrm{def}}$ value, it means that it becomes closer to the central point. The degree of the causality is also shown as $\left(\tilde{R}_i - \tilde{Y}_i\right)^{\mathrm{def}}$. In this circumstance, the positive value means that this criterion affects others.

3.3 IT2 Fuzzy VIKOR

The name VIKOR stands for "VlseKriterijumska Optimizacija I Kompromisno Resenje" and was introduced by [77]. Multi-criteria optimization is made with the help of this approach. In this process, the choice that is closest to the ideal result is calculated. The IT2 FVIKOR method can be explained in five different steps [76]:

Step 1: The decision matrix is generated by converting the values to the IT2 fuzzy numbers. As a result, a fuzzy decision matrix can be provided and averaged values of the decision-makers' evaluations are calculated. In this matrix, $P_{\iota\kappa}$ states the aggregated fuzzy ratings. The matrix is defined as

$$\mathrm{P}_{\iota\kappa} = \begin{array}{c} \\ H_1 \\ H_2 \\ H_3 \\ \vdots \\ H_m \end{array} \begin{array}{c} \begin{array}{ccccc} G_1 & G_2 & G_3 & \ldots & G_n \end{array} \\ \begin{bmatrix} p_{11} & p_{12} & p_{13} & \cdots & p_{1n} \\ p_{21} & p_{22} & p_{23} & \cdots & p_{2n} \\ p_{31} & p_{32} & p_{33} & \cdots & p_{3n} \\ \vdots & \vdots & \ddots & \cdots & \vdots \\ p_{m1} & p_{m2} & p_{m3} & \cdots & p_{mn} \end{bmatrix} \end{array} \tag{23}$$

$$\mathrm{P}_{\iota\kappa} = \frac{1}{D}\left[\sum_{e=1}^{n} p^{e}_{\iota\kappa}\right], \quad \iota = 1, 2, 3, \ldots, m \tag{24}$$

where H defines the alternative, G is the criterion set for the decision matrix. D is the number of decision makers. $1 \le o \le 3$,

Step 2: A defuzzified fuzzy decision matrix for IT2 fuzzy sets is calculated. In this circumstance, the ranking method is considered. The details are given in Eqs. (25)–(28).

$$\begin{aligned} \mathrm{Def}(p_{\iota\kappa}) &= \mathrm{Rank}(\tilde{p}_{\iota\kappa})_{m \times n} \\ &= \Pi_1\left(\tilde{\mathrm{P}}^{\lambda}_{\iota}\right) + \Pi_1\left(\tilde{\mathrm{P}}^{v}_{\iota}\right) + \Pi_2\left(\tilde{\mathrm{P}}^{\lambda}_{\iota}\right) + \Pi_2\left(\tilde{\mathrm{P}}^{v}_{\iota}\right) + \Pi_3\left(\tilde{\mathrm{P}}^{\lambda}_{\iota}\right) \\ &+ \Pi_3\left(\tilde{\mathrm{P}}^{v}_{\iota}\right) \Upsilon_q\left(\tilde{P}^{\kappa}_{\iota}\right) = \sqrt{\frac{1}{2}\sum\nolimits_{i=q}^{q+1}\left(p^{\kappa}_{\iota i} - \frac{1}{2}\sum\nolimits_{i=q}^{q+1} p^{\kappa}_{\iota i}\right)^2} \\ &- \frac{1}{4}\left(\Upsilon_1\left(\tilde{P}^{\lambda}_{\iota}\right) + \Upsilon_1\left(\tilde{P}^{v}_{\iota}\right) + \Upsilon_2\left(\tilde{P}^{\lambda}_{\iota}\right) + \Upsilon_2\left(\tilde{P}^{v}_{\iota}\right)\right. \\ &+ \left.\Upsilon_3\left(\tilde{P}^{\lambda}_{\iota}\right) + \Upsilon_3\left(\tilde{P}^{v}_{\iota}\right) + \Upsilon_4\left(\tilde{P}^{\lambda}_{\iota}\right) + \Upsilon_4\left(\tilde{P}^{v}_{\iota}\right)\right) + \Pi_1\left(\tilde{P}^{\lambda}_{\iota}\right) \\ &+ \Pi_1\left(\tilde{P}^{v}_{\iota}\right) + \Pi_2\left(\tilde{P}^{\lambda}_{\iota}\right) + \Pi_2\left(\tilde{P}^{v}_{\iota}\right) \end{aligned} \tag{25}$$

$$\Pi_p\left(\tilde{P}^{\kappa}_{\iota}\right) = \left(p^{\kappa}_{\iota o} + p^{\kappa}_{\iota(o+1)}\right)/2 \tag{26}$$

where $\Pi_o\left(\tilde{P}^{\kappa}_{\iota}\right)$ is the average of the elements $p^{\kappa}_{\iota o}$ and $\left(p^{\kappa}_{\iota(o+1)}\right)$, $1 \le o \le 3$,

$$\Upsilon_q\left(\tilde{P}^{\kappa}_{\iota}\right) = \sqrt{\frac{1}{2}\sum_{i=q}^{q+1}\left(p^{\kappa}_{\iota i} - \frac{1}{2}\sum_{i=q}^{q+1} p^{\kappa}_{\iota i}\right)^2} \tag{27}$$

where is the standard deviation of $p^{\kappa}_{\iota q}$ and $p^{\kappa}_{\iota(q+1)}$, $1 \le q \le 3$,

$$\Upsilon_4(\tilde{P}_\iota^\kappa) = \sqrt{\frac{1}{4}\sum\nolimits_{i=1}^{4}\left(p_{\iota i}^\kappa - \frac{1}{4}\sum\nolimits_{i=1}^{4} p_{\iota i}^\kappa\right)^2} \tag{28}$$

$\Pi_o(\tilde{P}_\iota^\kappa)$ is the membership value of $\Pi_o\left(p_{\iota(o+1)}^\kappa\right)$, and $\tilde{P}_\iota^\kappa, \quad 1 \le o \le 2, \quad \kappa \in \{\lambda, v\} 1 \le \iota \le n.$
Step 3: The fuzzy best value (f_j^*) and worst value (f_j^-) are computed with the help of Eq. (29).

$$f_j^* = \max_i p_{ij} \text{ and } f_j^- = \min_i p_{ij} \tag{29}$$

Step 4: S_i and R_i are calculated with Eqs. (30) and (31).

$$S_i = \sum_{i=1}^{n} w_j \frac{\left(\left|f_j^* - p_{ij}\right|\right)}{\left(\left|f_j^* - f_j^-\right|\right)} \tag{30}$$

$$R_i = \max j\left[w_j \frac{\left(\left|f_j^* - p_{ij}\right|\right)}{\left(\left|f_j^* - f_j^-\right|\right)}\right] \tag{31}$$

In Eq. (31), w_j show the weights of the criteria identified with the IT2 FDEMATEL method.
Step 5: The value of Q_i is computed by considering Eq. (32).

$$\tilde{Q}_i = \frac{v(S_i - S^*)}{(S^- - S^*)} + (1 - v)\frac{(R_i - R^*)}{(R^- - R^*)} \tag{32}$$

In Eq. (32), S^* and R^* represent minimum values whereas S^- and R^- demonstrate maximum values. Nevertheless, maximum group utility is shown as v. This value is assumed to be 0.5 in this study. In addition, the value of $(1 - v)$ indicates the degree of individual regret. For this situation, there are two different conditions. The condition (1), which is also referred to as acceptable advantage, is given in Eq. (33).

$$Q\left(A^{(2)}\right) - Q\left(A^{(1)}\right) \ge 1/(j-1) \tag{33}$$

where $A^{(2)}$ represents the second highest alternative. Moreover, condition 2 is also referred to as acceptable stability. It means that the best score of either S or R should be included in the best alternative. If condition 2 is not confirmed, the solution becomes the composition of $A^{(1)}$ and $A^{(2)}$. On the other hand, the alternatives of $Q(A1)$, $Q(A2)$, …, $Q(AM)$ are taken into the consideration. In this process, Eq. (34) is used.

$$Q\left(A^{(M)}\right) - Q\left(A^{(1)}\right) < \frac{1}{(j-1)} \tag{34}$$

3.4 IT2 Fuzzy TOPSIS

The TOPSIS is a method introduced by Yoon and Hwang and is used to rank the priorities by their similarity to the ideal solution [78]. This approach aims to order the alternatives and the ideal solutions negatively and positively are defined. After that, the best alternative is determined according to the distance from this ideal solution. The first three steps of the IT2 FTOPSIS approach are the same as in IT2 FVIKOR. The remaining steps of this extended method are detailed below [76]:

Step 4: The positive (A^+) and negative (A^-) ideal solutions are calculated. In this process, the weighted values of the defuzzified matrix are used, as given in Eq. (35).

$$A^+ = \max(v_1, v_2, v_3, \ldots, v_n); A^- = \min(v_1, v_2, v_3, \ldots, v_n) \tag{35}$$

In this equation, v_{ij} refers to the weighted values of the defuzzified matrix.
Step 5: D^+ and D^- values are computed. In this process, Eqs. (36) and (37) are taken into consideration.

$$D_i^+ = \sqrt{\sum_{i=1}^{m} (v_i - A_i^+)^2} \tag{36}$$

$$D_i^- = \sqrt{\sum_{i=1}^{m} (v_i - A_i^-)^2} \tag{37}$$

Step 6: The closeness coefficient (CC_i) is calculated using Eq. (38).

$$\text{CC}_i = \frac{D_i^-}{D_i^+ + D_i^-} \tag{38}$$

4 An Analysis of the European Banking Sector

To achieve our aim of analyzing the European Banking sector, an integrated analysis of the IT2 Fuzzy Models is developed. As such, the model is measured comparatively using IT2 FDEMATEL-TOPSIS and IT2 FDEMATEL-VIKOR and the results are discussed to determine policy recommendations and the applicability of models. Figure 1 explains the flowchart of the comparative analysis.

Stage 1: Constructing the factors and linguistic evaluations

Step 1: Define the problem of innovation policies in the European banking sector. Incremental and disruptive innovations are defined as a set of dimensions. Four criteria are also appointed to each dimension with the supported literature. However, five countries are selected for ranking the innovation policies in their banking sectors. Selected countries have the first 5 seats at the GDP among the European region, and these are Germany (A1), France (A2), Italy (A3), England (A4), and Spain (A5). Table 1 represents the dimensions and criteria of the innovation policies for the European banking sector.

Table 1 states that innovation policies are mainly classified into two different dimensions: incremental (D1) and disruptive (D2). With respect to the incremental innovation, the diversification policies of the companies (C1) are selected to be the first criterion. Moreover, it is believed that providing affordable technological services and products with the economies of scale (C2) can have an effect on the performance of innovation policies. Also, when the capacity of technology followers (C3) is higher, there is an increase in innovation. Finally, having competing projects in sector (C4) means that incremental innovation increases.

In addition to the incremental innovation, four different criteria are also identified with respect to the disruptive innovation. The concentration level, alongside the unique service and products (C5) give information regarding the increase in disruptive innovation. On the other hand, disruptive innovation performance goes up when there is growth in high-tech companies (C6). In addition, it is also believed that there is a positive relationship between disruptive innovation and the potential of the first entrants (C7). Furthermore, providing scope economies with the inventions (C8) is the last criterion of the disruptive innovation. It explains that with the help of radical innovation, banks will have the advantage of providing different services easily.

Step 2: Collect the linguistic evaluations for the dimensions, criteria and alternatives. In the analysis process, three decision makers are appointed to evaluate the factors and alternatives. They give their scores by considering the linguistic scales given in Tables 2 and 3, respectively.

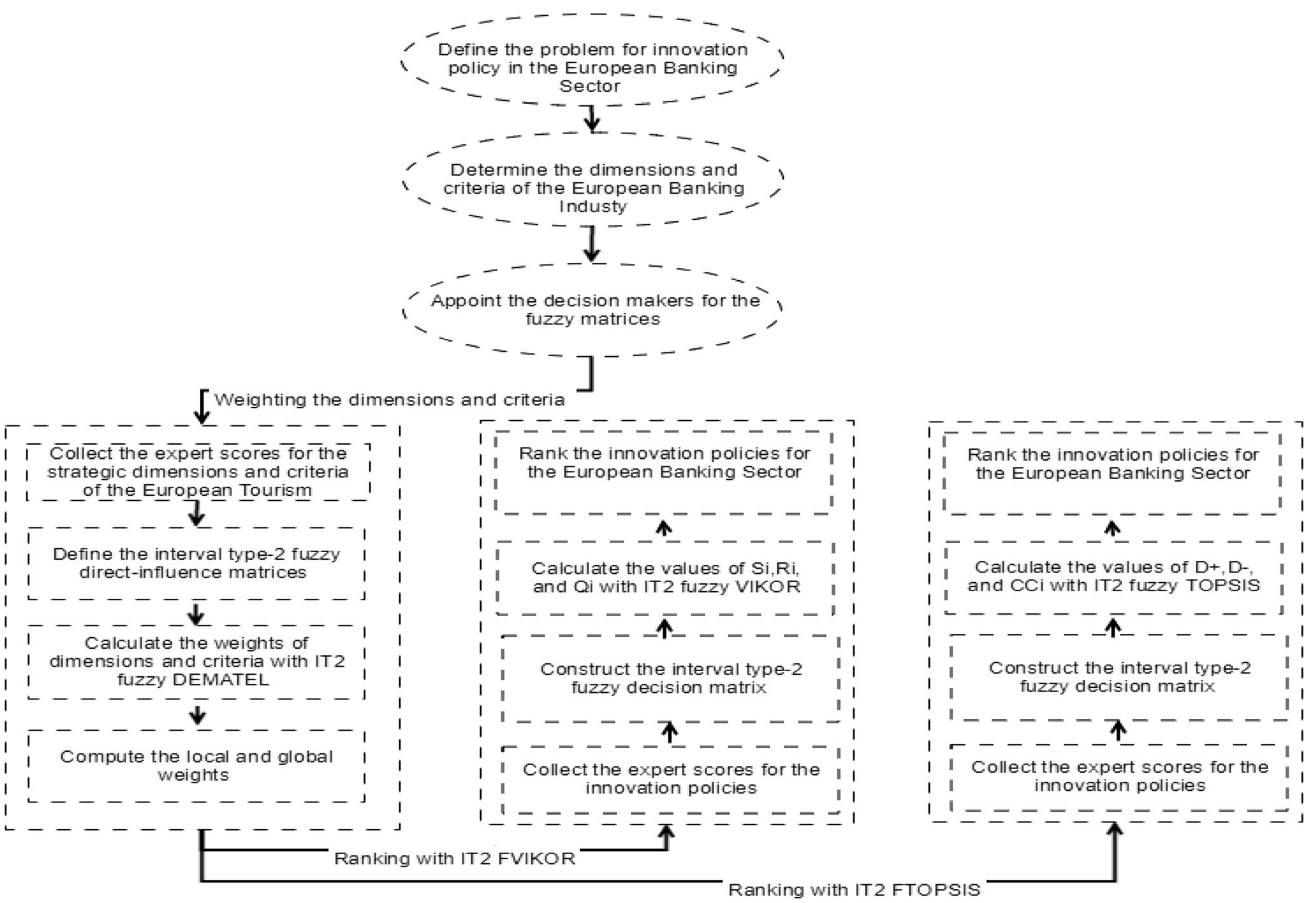

Fig. 1 The flowchart of the proposed model

Table 1 Dimensions and criteria of the innovation policies for the European Banking Sector

Dimensions	Criteria	Supported literature
Incremental (D1)	Diversification policies of the companies (C1)	Hartmann [79], Fan et al. [80]
	Providing affordable technological service and products with the scale economies (C2)	Kim et al. [81], Banoun et al. [82]
	The capacity of technology followers (C3)	Tsai et al. [83], Ernst et al. [84]
	Competing projects in the sector (C4)	Cassanelli et al. [85], Neimark [86]
Disruptive (D2)	Concentration level with the unique service and products (C5)	Witell et al. [87], Tang et al. [88]
	Growth in high-tech companies (C6)	Grilli and Murtinu [89], Hsia et al. [90]
	Potentials of the first entrants (C7)	Gomez et al. [91], Wilkie and Johnson [92]
	Providing scope economies with the inventions (C8)	Romano et al. [93], Carneiro et al. [94]

Table 2 Scales for the factors

Linguistic scales	Trapezoidal fuzzy numbers
Extremely weak (EW)	((0.00, 0.10, 0.10, 0.20; 1.00, 1.00), (0.05, 0.10, 0.10, 0.15; 0.90, 0.90))
Very weak (VW)	((0.10, 0.20, 0.20, 0.35;1.00, 1.00), (0.15, 0.20, 0.20, 0.30;0.90, 0.90))
Weak (WK)	((0.20, 0.35, 0.35, 0.50;1.00, 1.00), (0.25, 0.35, 0.35, 0.45;0.90, 0.90))
Moderate (MD)	((0.35, 0.50, 0.50, 0.65;1.00, 1.00), (0.40, 0.50, 0.50, 0.60;0.90, 0.90))
Moderate high (MH)	((0.50, 0.65, 0.65, 0.80;1.00, 1.00), (0.55, 0.65, 0.65, 0.75;0.90, 0.90))
Very high (VH)	((0.65, 0.80, 0.80, 0.90;1.00, 1.00), (0.70, 0.80, 0.80, 0.85;0.90, 0.90))
Extremely high (EH)	((0.80, 0.90, 0.90, 1.00;1.00, 1.00), (0.85, 0.90, 0.90, 0.95;0.90, 0.90))

Source: Adapted from Baykasoglu and Golcuk [42]

Table 3 Scales for the alternatives

Linguistic scales	IT2 fuzzy numbers
Extremely poor (VP)	((0.00, 0.00, 0.00, 0.10;1.00, 1.00), (0.00, 0.00, 0.00, 0.05;0.90, 0.90))
Very poor (VP)	((0.00, 0.10, 0.10, 0.30;1.00, 1.00), (0.05, 0.10, 0.10, 0.20;0.90, 0.90))
Moderately poor (MP)	((0.10, 0.30, 0.30, 0.50;1.00, 1.00), (0.20, 0.30, 0.30, 0.40;0.90, 0.90))
Moderate (MD)	((0.30, 0.50, 0.50, 0.70;1.00, 1.00), (0.40, 0.50, 0.50, 0.60;0.90, 0.90))
Moderately good (MG)	((0.50, 0.70, 0.70, 0.90;1.00, 1.00), (0.60, 0.70, 0.70, 0.80;0.90, 0.90))
Very good (VG)	((0.70, 0.90, 0.90, 1.00;1.00, 1.00), (0.80, 0.90, 0.90, 0.95;0.90, 0.90))
Extremely good (EG)	((0.90, 1.00, 1.00, 1.00;1.00, 1.00), (0.95, 1.00, 1.00, 1.00;0.90, 0.90))

Source: Adapted from Baykasoglu and Golcuk [42]

Table 4 Linguistic evaluations of the decision makers for incremental and disruptive innovation

	Dimension 1			Dimension 2		
	Expert 1	Expert 2	Expert 3	Expert 1	Expert 2	Expert 3
Dimension 1	–	–	–	MH	VH	VH
Dimension 2	MH	VH	EH	–	–	–

Also, linguistic evaluations provided from the decision makers are represented in Tables 4, 5, 6 and 7.

Stage 2: Weighting the dimensions and criteria

Step 1: Compute the weights of dimensions. Linguistic scores are converted to the IT2 fuzzy numbers and the computing processes of IT2 FDEMATEL are applied the

Table 5 Linguistic evaluations of the decision makers for the criteria of incremental innovation

	Criterion 1			Criterion 2			Criterion 3			Criterion 4		
	Expert 1	Expert 2	Expert 3	Expert 1	Expert 2	Expert 3	Expert 1	Expert 2	Expert 3	Expert 1	Expert 2	Expert 3
Criterion 1	–	–	–	MH	VH	MH	MH	MH	VH	VH	MH	MH
Criterion 2	MD	MH	MD	–	–	–	MH	MH	MD	MD	MD	MH
Criterion 3	VH	MH	MH	MH	MH	MH	–	–	–	MH	MH	VH
Criterion 4	VH	MH	MH	MH	MH	VH	VH	MH	VH	–	–	–

Table 6 Linguistic evaluations of the decision makers for the criteria of disruptive innovation

	Criterion 5			Criterion 6			Criterion 7			Criterion 8		
	Expert 1	Expert 2	Expert 3	Expert 1	Expert 1	Expert 2	Expert 3	Expert 1	Expert 1	Expert 2	Expert 3	Expert 1
Criterion 5	–	–	–	MD	MD	MH	MH	MH	MD	EH	VH	VH
Criterion 6	EH	MH	VH	–	–	–	MH	MH	MH	EH	EH	VH
Criterion 7	MD	MH	MH	MD	MD	MH	–	–	–	MH	MH	VH
Criterion 8	MD	MD	MH	MD	MD	MD	MD	MH	MH	–	–	–

weights of dimensions. Tables 8, 9, 10 and 11 show the initial, normalized, total, and defuzzified relation matrix, respectively.

Step 2: Calculate the weights of the criteria. Similar procedures of dimensions are also computed for the criteria of each dimension in Tables 12, 13, 14, 15, 16, 17, 18 and 19.

Step 3: Define the local and global weights. Global and local weights for the innovation policies are calculated using the weights of dimensions and criteria provided from IT2 FDEMATEL. The details are shown in Table 20.

Table 20 indicates that both dimensions have equal weights of (0.50). In addition, while considering global weights it can be understood that providing scope economies with the inventions (C8) is the most important criterion. Moreover, the capacity of technology followers (C3) and the competing projects in sector (C4) are other criteria that are highly significant. These results show that banks should mainly consider scope economies. The logic of providing different products and services that are much easier to use has a positive influence on innovation performance. This issue has also been emphasized in many different studies [93–95]. Tsai et al. [83], Ernst et al. [84], Cassanelli et al. [85] and Neimark [86] also reached similar conclusions in the literature.

Stage 3: Ranking the alternatives

Step 1: Developing the fuzzy decision matrix. Linguistic evaluations of each expert are converted to the IT2 fuzzy numbers. In addition, the average values are considered for the alternatives to construct the fuzzy decision matrix as seen in Table 21. After that, the fuzzy decision matrix is defuzzified to rank the alternatives.

In addition to this issue, Table 22 defines the defuzzified values of the decision matrix.

Step 2: Rank the alternatives with IT2 FVIKOR. Defuzzified vales are used to calculate the values of S_i, R_i and Q_i. The results and ranking scores are presented in Table 23.

Table 23 shows that England (A4) is the best country with respect to innovation performance. In addition, Germany (A1) is ranked second-best. We can also see that Spain (A5) is ranked last.

Step 3: Rank the alternatives with IT2 FTOPSIS. The values of defuzzified decision matrix are multiplied with the weights of the criteria obtained from the IT2 FDEMATEL and the weighted decision matrix is constructed in Table 24.

Table 7 Linguistic evaluations of the decision makers for the innovation policies

	Alternative 1			Alternative 2			Alternative 3			Alternative 4			Alternative 5		
	Expert 1	Expert 2	Expert 3	Expert 1	Expert 2	Expert 3	Expert 1	Expert 2	Expert 3	Expert 1	Expert 2	Expert 3	Expert 1	Expert 2	Expert 3
C1	MG	VG	VG	VG	MG	MD	MG	MD	MD	EG	VG	MG	MG	MG	MG
C2	MD	MG	MG	MG	MD	MG	MD	MG	MG	MD	MD	MG	MD	MG	MD
C3	EG	EG	VG	VG	MG	MD	MD	MD	MG	EG	VG	VG	MD	MG	MG
C4	EG	EG	VG	VG	MG	VG	VG	MG	MG	VG	VG	EG	MG	MD	MG
C5	MD	MG	MD	MD	MG	MD	MD	MG	MG	VG	MG	MG	MD	MG	MD
C6	EG	EG	VG	MG	VG	MG	MG	MG	MG	EG	VG	VG	MG	MD	MG
C7	EG	EG	VG	VG	VG	VG	MD	MG	MG	VG	EG	VG	MD	MG	MG
C8	EG	VG	VG	VG	MG	MG	MG	MD	MG	VG	VG	VG	MG	MD	MG

The values of D^{+}, D^{-}, C_i, and the ranking results are computed as seen in Table 25.

IT2 FVIKOR and IT2 FTOPSIS give same ranking results. England (A4) is selected as the best country for innovation policies of the European banking sector while Spain (A5) has the worst performance in the innovative banking policies. The results demonstrate that the comparative analysis of IT2 FVIKOR and IT2 FTOPSIS provides comprehensive and coherent results for the IT2-based hybrid decision-making models.

5 Conclusion

Innovation in the banking sector has increased dramatically with the effect of globalization. Due to this fact, banks have been forced to develop new products and/or services to be competitive regarding their rivals. For this purpose, innovation plays a crucial role for the banking sector. Innovative products can be provided for the banking sector in two different ways. Incremental innovation means innovating current products or bank services. On the other hand, developing a new product or service which has not been used before can be defined as disruptive innovation.

This study has carried out a comparative analysis of incremental and disruptive innovation policies in the European banking sector. For this purpose, eight different criteria for two dimensions were selected. In this context, five European Union member countries that have the highest nominal GDP (Germany, United Kingdom, France Italy, and Spain) are taken into the consideration. In addition, IT2 FDEMATEL is employed with the aim of weighting the dimensions and criteria, and IT2 FTOPSIS and VIKOR approaches are used to rank these countries.

It is concluded that both dimensions have equal weights (0.50). Furthermore, it is also identified that providing scope economies with the inventions (C8) is the most important out of all criteria. In addition, the criteria of the capacity of technology followers (C3) and the competing projects in the sector (C4) are amongst the first rankings. It is recommended that scope economies should be the first concern of these banks. Moreover, the European banking system should be redesigned with the implication of the necessary regulations. These actions contribute to the development of the innovations.

This study focuses on a very significant subject for the European banking sector. Nevertheless, in future studies, different regions could be analyzed. For example, a new analysis could be conducted for developing economies. In addition, different methodologies could be considered in other studies. For instance, as a new method, IT2 FQUALIFLEX could be used to enhance the originality of any new studies.

Table 8 Initial direct relation matrix for the incremental and disruptive innovation policies

	Incremental (D1)	Disruptive (D2)
Incremental (D1)	((0, 0, 0, 0;1, 1), (0, 0,0, 0; 0.90, 0.90))	((0.60, 0.75, 0.75, 0.87;1, 1), (0.65, 0.75, 0.75, 0.82; 0.90, 0.90))
Disruptive (D2)	((0.65, 0.78, 0.78, 0.90;1, 1), (0.70, 0.78, 0.78, 0.85; 0.90, 0.90))	((0, 0, 0, 0;1, 1), (0, 0, 0, 0; 0.90, 0.90))

Table 9 The normalized direct-relation matrix for the dimensions

	D1	D2
D1	((0, 0, 0, 0; 1, 1), (0, 0, 0, 0;0.90, 0.90))	((0.67, 0.83, 0.83, 0.96; 1, 1), (0.72, 0.83, 0.83, 0.91;0.90, 0.90))
D2	((0.72, 0.87, 0.87, 1;1, 1), (0.78, 0.87, 0.87, 0.94; 0.90, 0.90))	((0, 0, 0, 0; 1, 1), (0, 0, 0, 0;0.90, 0.90))

Table 10 The total relation matrix for the dimensions

	D1	D2
D1	((0.93, 2.64, 2.64, 26; 1, 1), (1.28, 2.64, 2.64, 5.99; 0.90, 0.90))	((1.29, 3.03, 3.03, 26; 1, 1), (1.65, 3.03, 3.03, 6.35; 0.90, 0.90))
D2	((1.39, 3.17, 3.17, 27; 1, 1), (1.77, 3.17, 3.17, 6.60; 0.90, 0.90))	((0.93, 2.64, 2.64, 26; 1, 1), (1.28, 2.64, 2.64, 5.99; 0.90, 0.90))

Table 11 Defuzzified total relation matrix and the weights for the dimensions

	D1	D2	r	y	$r + y$	$r - y$	Weights
D1	5.53	5.85	11.38	11.63	23.01	− 0.25	0.50
D2	6.10	5.53	11.63	11.38	23.01	0.25	0.50

Table 12 Initial direct relation matrix for the criteria of dimension 1

	C1	C2	C3	C4
C1	((0, 0, 0, 0;1, 1), (0, 0, 0, 0; 0.90, 0.90))	((0.55, 0.70, 0.70, 0.83;1, 1), (0.60, 0.70, 0.70, 0.78; 0.90, 0.90))	((0.55, 0.70, 0.70, 0.83;1, 1), (0.60, 0.70, 0.70, 0.78; 0.90, 0.90))	((0.55, 0.70, 0.70, 0.83;1, 1), (0.60, 0.70, 0.70, 0.78; 0.90, 0.90))
C2	((0.40, 0.55, 0.55, 0.70;1, 1), (0.45, 0.55, 0.55, 0.65; 0.90, 0.90))	((0, 0, 0, 0;1, 1), (0, 0, 0, 0; 0.90, 0.90))	((0.45, 0.60, 0.60, 0.75;1, 1), (0.50, 0.60, 0.60, 0.70; 0.90, 0.90))	((0.40, 0.55, 0.55, 0.70;1, 1), (0.45, 0.55, 0.55, 0.65; 0.90, 0.90))
C3	((0.55, 0.70, 0.70, 0.83; 1, 1), (0.60, 0.70, 0.70, 0.78; 0.90, 0.90))	((0.50, 0.65, 0.65, 0.80;1, 1), (0.55, 0.65, 0.65, 0.75; 0.90, 0.90))	((0, 0, 0, 0;1, 1), (0, 0, 0, 0; 0.90, 0.90))	((0.55, 0.70, 0.70, 0.83;1, 1), (0.60, 0.70, 0.70, 0.78; 0.90, 0.90))
C4	((0.55, 0.70, 0.70, 0.83;1, 1), (0.60, 0.70, 0.70, 0.78; 0.90, 0.90))	((0.55, 0.70, 0.70, 0.83;1, 1), (0.60, 0.70, 0.70, 0.78; 0.90, 0.90))	((0.60, 0.75, 0.75, 0.87;1, 1), (0.65, 0.75, 0.75, 0.82; 0.90, 0.90))	((0, 0, 0, 0;1, 1), (0, 0, 0, 0; 0.90, 0.90))

Table 13 The normalized direct-relation matrix for the criteria of dimension 1

	C1	C2	C3	C4
C1	((0, 0, 0, 0;1, 1), (0, 0, 0, 0; 0.90, 0.90))	((0.22, 0.28, 0.28, 0.33;1, 1), (0.24, 0.28, 0.28, 0.31; 0.90, 0.90))	((0.22, 0.28, 0.28, 0.33;1, 1), (0.24, 0.28, 0.28, 0.31; 0.90, 0.90))	((0.22, 0.28, 0.28, 0.33; 1, 1), (0.24, 0.28, 0.28, 0.31; 0.90, 0.90))
C2	((0.16, 0.22, 0.22, 0.28;1, 1), (0.18, 0.22, 0.22, 0.26; 0.90, 0.90))	((0, 0, 0, 0;1, 1), (0, 0, 0, 0; 0.90, 0.90))	((0.18, 0.24, 0.24, 0.30;1, 1), (0.20, 0.24, 0.24, 0.28; 0.90, 0.90))	((0.16, 0.22, 0.22, 0.28;1, 1), (0.18, 0.22, 0.22, 0.26; 0.90, 0.90))
C3	((0.22, 0.28, 0.28, 0.33; 1, 1), (0.24, 0.28, 0.28, 0.31; 0.90, 0.90))	((0.20, 0.26, 0.26, 0.32;1, 1), (0.22, 0.26, 0.26, 0.30; 0.90, 0.90))	((0, 0, 0,0; 1, 1), (0, 0, 0, 0; 0.90, 0.90))	((0.22, 0.28, 0.28, 0.33; 1, 1), (0.24, 0.28, 0.28, 0.31; 0.90, 0.90))
C4	((0.22, 0.28, 0.28, 0.33;1, 1), (0.24, 0.28, 0.28, 0.31; 0.90, 0.90))	((0.22, 0.28, 0.28, 0.33;1, 1), (0.24, 0.28, 0.28, 0.31; 0.90, 0.90))	((0.24, 0.30, 0.30, 0.34;1, 1), (0.26, 0.30, 0.30, 0.32; 0.90, 0.90))	((0, 0, 0, 0; 1, 1), (0, 0, 0, 0; 0.90, 0.90))

Table 14 The total relation matrix for the criteria of dimension 1

	C1	C2	C3	C4
C1	((0.27, 0.79, 0.79, 4.80;1, 1), (0.38, 0.79, 0.79, 1.93; 0.90, 0.90))	((0.47, 1.04, 1.04, 5.20;1, 1), (0.59, 1.04, 1.04, 2.23; 0.90, 0.90))	((0.47, 1.04, 1.04, 5.18;1, 1), (0.59, 1.04, 1.04, 2.22; 0.90, 0.90))	((0.45, 1.01, 1.01, 5.15;1, 1), (0.57, 1.01, 1.01, 2.20; 0.90, 0.90))
C2	((0.35, 0.85, 0.85, 4.49;1, 1), (0.46, 0.85, 0.85, 1.91; 0.90, 0.90))	((0.23, 0.70, 0.70, 4.41;1, 1), (0.32, 0.70, 0.70, 1.76; 0.90, 0.90))	((0.38, 0.89, 0.89, 4.62;1, 1), (0.49, 0.89, 0.89, 1.97; 0.90, 0.90))	((0.35, 0.85, 0.85, 4.49;1, 1), (0.46, 0.85, 0.85, 1.91; 0.90, 0.90))
C3	((0.45, 1, 1, 5; 1, 1), (0.56, 1, 1, 2.15; 0.90, 0.90))	((0.45, 1.01, 1.01, 5.15; 1, 1), (0.57, 1.01, 1.01, 2.20; 0.90, 0.90))	((0.28, 0.81, 0.81, 4.88; 1, 1), (0.39, 0.81, 0.81, 1.96; 0.90, 0.90))	((0.45, 1, 1, 5; 1, 1), (0.56, 1, 1, 2.15; 0.90, 0.90))
C4	((0.46, 1.02, 1.02, 5.10; 1, 1), (0.58, 1.02, 1.02, 2.19; 0.90, 0.90))	((0.47, 1.06, 1.06, 5.25; 1, 1), (0.60, 1.06, 1.06, 2.25; 0.90, 0.90))	((0.49, 1.07, 1.07, 5.23; 1, 1), (0.61, 1.07, 1.07, 2.25; 0.90, 0.90))	((0.28, 0.81, 0.81, 4.85; 1, 1), (0.39, 0.81, 0.81, 1.95; 0.90, 0.90))

Table 15 Defuzzified total relation matrix and the weights for the criteria of dimension 1

	C1	C2	C3	C4	r	y	$r+y$	$r-y$	Weights
C1	1.30	1.56	1.55	1.51	5.91	5.62	11.54	0.29	0.252
C2	1.30	1.17	1.35	1.30	5.13	5.83	10.96	− .70	0.240
C3	1.49	1.53	1.32	1.49	5.84	5.81	11.65	0.03	0.254
C4	1.53	1.57	1.58	1.32	6.00	5.62	11.62	0.38	0.254

Table 16 Initial direct relation matrix for the criteria of dimension 2

	C1	C2	C3	C4
C1	((0, 0, 0, 0, 1, 1), (0, 0, 0, 0; 0.90, 0.90))	((0.40, 0.55, 0.55, 0.70;1, 1), (0.45, 0.55, 0.55, 0.65; 0.90, 0.90))	((0.45, 0.60, 0.60, 0.75;1, 1), (0.50, 0.60, 0.60, 0.70; 0.90, 0.90))	((0.70, 0.83, 0.83, 0.93;1, 1), (0.75, 0.83, 0.83, 0.88; 0.90, 0.90))
C2	((0.65, 0.78, 0.78, 0.90;1, 1), (0.70, 0.78, 0.78, 0.85; 0.90, 0.90))	((0, 0, 0, 0, 1, 1), (0, 0, 0, 0; 0.90, 0.90))	((0.50, 0.65, 0.65, 0.80, 1, 1), (0.55, 0.65, 0.65, 0.75; 0.90, 0.90))	((0.75, 0.87, 0.87, 0.97, 1, 1), (0.80, 0.87, 0.87, 0.92; 0.90, 0.90))
C3	((0.45, 0.60, 0.60, 0.75, 1, 1), (0.50, 0.60, 0.60, 0.70; 0.90, 0.90))	((0.40, 0.55, 0.55, 0.70, 1, 1), (0.45, 0.55, 0.55, 0.65; 0.90, 0.90))	((0, 0, 0, 0, 1, 1), (0, 0, 0, 0; 0.90, 0.90))	((0.55, 0.70, 0.70, 0.83, 1, 1), (0.60, 0.70, 0.70, 0.78; 0.90, 0.90))
C4	((0.40, 0.55, 0.55, 0.70, 1, 1), (0.45, 0.55, 0.55, 0.65; 0.90, 0.90))	((0.35, 0.50, 0.50, 0.65, 1, 1), (0.40, 0.50, 0.50, 0.60, 0.90, 0.90))	((0.45, 0.60, 0.60, 0.75, 1, 1), (0.50, 0.60, 0.60; 0.70, 0.90, 0.90))	((0, 0, 0, 0, 1, 1), (0, 0, 0, 0; 0.90, 0.90))

Table 17 The normalized direct-relation matrix for the criteria of dimension 2

	C1	C2	C3	C4
C1	((0, 0, 0, 0; 1, 1), (0, 0, 0, 0; 0.90, 0.90))	((0.15, 0.21, 0.21, 0.26; 1,1), (0.17, 0.21, 0.21, 0.24; 0.90, 0.90))	((0.17, 0.23, 0.23, 0.28; 1, 1), (0.19, 0.23, 0.23, 0.26; 0.90, 0.90))	((0.26, 0.31, 0.31, 0.35; 1, 1), (0.28, 0.31, 0.31, 0.33; 0.90, 0.90))
C2	((0.24, 0.29, 0.29, 0.34; 1, 1), (0.26, 0.29, 0.29, 0.32; 0.90, 0.90))	((0, 0, 0, 0; 1, 1), (0, 0,0, 0; 0.90, 0.90))	((0.19, 0.24, 0.24, 0.30; 1, 1), (0.21, 0.24, 0.24, 0.28; 0.90, 0.90))	((0.28, 0.33, 0.33, 0.36; 1, 1), (0.30, 0.33, 0.33, 0.34; 0.90, 0.90))
C3	((0.17, 0.23, 0.23, 0.28; 1, 1), (0.19, 0.23, 0.23, 0.28; 0.90, 0.90))	((0.15, 0.21, 0.21, 0.26; 1, 1), (0.17, 0.21, 0.21, 0.24; 0.90, 0.90))	((0, 0, 0, 0; 1, 1), (0, 0, 0, 0; 0.90, 0.90))	((0.21, 0.26, 0.26, 0.31; 1, 1), (0.23, 0.26, 0.26, 0.29; 0.90, 0.90))
C4	((0.15, 0.21, 0.21, 0.26; 1, 1), (0.17, 0.21, 0.21, 0.24; 0.90, 0.90))	((0.13, 0.19, 0.19, 0.24; 1, 1), (0.15, 0.19, 0.19, 0.23; 0.90, 0.90))	((0.17, 0.23, 0.23, 0.28; 1, 1), (0.19, 0.23, 0.23, 0.28; 0.90, 0.90))	((0, 0, 0, 0; 1, 1), (0, 0,0, 0; 0.90, 0.90))

Table 18 The total relation matrix for the criteria of dimension 2

	C1	C2	C3	C4
C1	((0.20, 0.51, 0.51, 1.65; 1, 1), (0.27, 0.51, 0.51, 1; 0.90, 0.90))	((0.29, 0.61, 0.61, 1.70; 1, 1), (0.37, 0.61, 0.61, 1.09; 0.90, 0.90))	((0.34, 0.68, 0.68, 1.85; 1, 1), (0.42, 0.68, 0.68, 1.20; 0.90, 0.90))	((0.47, 0.85, 0.85, 2.12; 1, 1), (0.56, 0.85, 0.85, 1.39; 0.90, 0.90))
C2	((0.44, 0.80, 0.80, 2.06; 1, 1), (0.53, 0.80, 0.80, 1.35; 0.90, 0.90))	((0.19, 0.50, 0.50, 1.63; 1, 1), (0.27, 0.50, 0.50, 0.99; 0.90, 0.90))	((0.39, 0.76, 0.76, 2.02; 1, 1), (0.48, 0.76, 0.76, 1.31; 0.90, 0.90))	((0.53, 0.94, 0.94, 2.31; 1, 1), (0.64, 0.94, 0.94, 1.51; 0.90, 0.90))
C3	((0.33, 0.66, 0,66, 1.82; 1, 1), (0.41, 0.66, 0,66, 1.18; 0.90, 0.90))	((0.28, 0.59, 0.59, 1.66; 1, 1), (0.35, 0.59, 0.59, 1.06; 0.90, 0.90))	((0.18, 0.47, 0.47, 1.58; 1, 1), (0.24, 0.47, 0.47, 0.96; 0.90, 0.90))	((0.41, 0.78, 0.78, 2.05; 1, 1), (0.50, 0.78, 0.78, 1.33; 0.90, 0.90))
C4	((0.29, 0.61, 0.61, 1.71; 1, 1), (0.37, 0.61, 0.61, 1.10; 0.90, 0.90))	((0.25, 0.54, 0.54, 1.55; 1, 1), (0.32, 0.54, 0.54, 0.99; 0.90, 0.90))	((0.30, 0.61, 0.61, 1.71; 1,1), (0.38, 0.61, 0.61, 1.10; 0.90 ,0.90))	((0.21, 0.53, 0.53, 1.70; 1, 1), (0.28, 0.53, 0.53, 1.03; 0.90, 0.90))

Table 19 Defuzzified total relation matrix and the weights for the criteria of dimension 2

	C1	C2	C3	C4	r	y	r + y	r-y	Weights
C1	0.63	0.72	0.80	0.97	3.12	3.07	6.19	0.05	0.250
C2	0.93	0.62	0.88	1.07	3.50	2.69	6.19	0.82	0.250
C3	0.78	0.70	0.59	0.91	2.98	3.00	5.98	− 0.02	0.242
C4	0.72	0.64	0.73	0.65	2.75	3.60	6.35	− .85	0.257

Table 20 Local and global weights of the innovation dimensions and criteria for the European Banking Sector

Dimensions	Local weights	Criteria	Local weights	Global weights
D1	0.50	C1	0.252	0.126
		C2	0.240	0.120
		C3	0.254	0.127
		C4	0.254	0.127
D2	0.50	C5	0.250	0.125
		C6	0.250	0.125
		C7	0.242	0.121
		C8	0.257	0.128

Table 21 IT2 fuzzy decision matrix for the European Banking Sector

	A1	A2	A3	A4	A5
C1	((0.63, 0.83, 0.83, 0.97; 1, 1), 0.73, 0.83, 0.83,0.9; 0.90, 0.90)	((0.5, 0.7, 0.7, 0.9;1, 1), (0.6, 0.7, 0.7, 0.8; 0.90, 0.90))	((0.37, 0.57, 0.57, 0.77; 1.00, 1.00), (0.47, 0.57, 0.57, 0.67; 0.90, 0.90))	((0.70, 0.87, 0.87, 0.97; 1,1), (0.78, 0.87, 0.87, 0.92; 0.90, 0.90))	((0.5, 0.7, 0.7, 0.9; 1,1), (0.6, 0.7, 0.7, 0.8; 0.90, 0.90))
C2	((0.43, 0.63, 0.63, 0.83; 1, 1), (0.53, 0.63, 0.63, 0.73; 0.90, 0.90))	((0.43, 0.63, 0.63, 0.83; 1, 1), (0.53, 0.63, 0.63, 0.73; 0.90, 0.90))	((0.43, 0.63, 0.63, 0.83; 1, 1), (0.53, 0.63, 0.63,0.73; 0.90, 0.90))	((0.37, 0.57, 0.57, 0.77; 1.00, 1.00), (0.47, 0.57, 0.57, 0.67; 0.90, 0.90))	((0.37, 0.57, 0.57, 0.77; 1.00, 1.00), (0.47, 0.57, 0.57, 0.67; 0.90, 0.90))
C3	((0.83, 0.97, 0.97, 1; 1, 1), (0.9, 0.97, 0.97, 0.98; 0.90, 0.90)	((0.5, 0.7, 0.7, 0.9; 1, 1), (0.6, 0.7, 0.7, 0.8; 0.90, 0.90))	((0.37, 0.57, 0.57, 0.77; 1.00, 1.00), (0.47, 0.57, 0.57, 0.67; 0.90, 0.90))	((0.77, 0.93, 0.93, 1; 1, 1), (0.85, 0.93, 0.93, 0.97; 0.90, 0.90))	((0.43, 0.63, 0.63, 0.83; 1, 1), (0.53, 0.63, 0.63, 0.73; 0.90, 0.90))
C4	((0.83,0.97,0.97,1;1,1), (0.9,0.97,0.97,0.98;0.90,0.90)	((0.63,0.83,0.83,0.97;1,1), 0.73,0.83,0.83,0.9;0.90,0.90)	((0.57,0.77,0.77,0.93;1,1), (0.67,0.77,0.77,0.85;0.90,0.90))	((0.77,0.93,0.93,1;1,1), (0.85,0.93,0.93,0.97;0.90,0.90))	((0.43,0.63,0.63,0.83;1,1), (0.53,0.63,0.63,0.73;0.90,0.90))
C5	((0.37, 0.57, 0.57, 0.77; 1.00, 1.00), (0.47, 0.57, 0.57, 0.67; 0.90, 0.90))	((0.37, 0.57, 0.57, 0.77; 1.00, 1.00), (0.47, 0.57, 0.57, 0.67; 0.90, 0.90))	((0.43, 0.63, 0.63, 0.83; 1, 1), (0.53, 0.63, 0.63, 0.73; 0.90, 0.90))	((0.57, 0.77, 0.77, 0.93; 1, 1), (0.67, 0.77, 0.77, 0.85; 0.90, 0.90))	((0.37, 0.57, 0.57, 0.77; 1.00, 1.00), (0.47, 0.57, 0.57, 0.67; 0.90, 0.90))
C6	((0.83, 0.97, 0.97, 1; 1, 1), (0.9, 0.97, 0.97, 0.98; 0.90, 0.90)	((0.57, 0.77, 0.77, 0.93; 1, 1), (0.67, 0.77, 0.77, 0.85; 0.90, 0.90))	((0.5, 0.7, 0.7,0.9; 1, 1), (0.6, 0.7, 0.7,0.8; 0.90, 0.90))	((0.77, 0.93, 0.93, 1; 1, 1), (0.85, 0.93, 0.93, 0.97; 0.90, 0.90))	((0.43, 0.63, 0.63, 0.83; 1, 1), (0.53, 0.63, 0.63, 0.73; 0.90, 0.90))
C7	((0.83, 0.97, 0.97, 1; 1, 1), (0.9, 0.97, 0.97, 0.98; 0.90, 0.90)	((0.7, 0.9, 0.9, 1; 1, 1), (0.8, 0.9, 0.9, 0.95; 0.90, 0.90))	((0.43, 0.63, 0.63, 0.83; 1, 1), (0.53, 0.63, 0.63, 0.73; 0.90, 0.90))	((0.77, 0.93, 0.93, 1; 1, 1), (0.85, 0.93, 0.93, 0.97; 0.90, 0.90))	((0.43, 0.63, 0.63, 0.83; 1, 1), (0.53, 0.63, 0.63, 0.73; 0.90, 0.90))
C8	((0.77, 0.93, 0.93, 1; 1, 1), (0.85, 0.93, 0.93, 0.97; 0.90, 0.90))	((0.57, 0.77, 0.77, 0.93; 1, 1), (0.67, 0.77, 0.77, 0.85; 0.90, 0.90))	((0.43, 0.63, 0.63, 0.83; 1, 1), (0.53, 0.63, 0.63, 0.73; 0.90, 0.90))	((0.7, 0.9, 0.9, 1; 1, 1), (0.8, 0.9, 0.9, 0.95; 0.90, 0.90))	((0.43, 0.63, 0.63, 0.83; 1, 1), (0.53, 0.63, 0.63, 0.73; 0.90, 0.90))

Table 22 Defuzzified decision matrix

	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
Criterion 1	8.64	7.86	7.07	8.86	7.87
Criterion 2	7.47	7.47	7.47	7.07	7.07
Criterion 3	9.47	7.86	7.07	9.25	7.47
Criterion 4	9.47	8.64	8.26	9.25	7.47
Criterion 5	7.07	7.07	7.47	8.26	7.07
Criterion 6	9.47	8.26	7.87	9.25	7.47
Criterion 7	9.47	9.03	7.47	9.25	7.47
Criterion 8	9.25	8.26	7.47	9.03	7.47

Table 23 Ranking results with IT2 FVIKOR

	S_i	R_i	Q_i	Ranks
Alternative 1	0.141	0.125	0.314	2
Alternative 2	0.509	0.125	0.549	3
Alternative 3	0.763	0.128	0.898	4
Alternative 4	0.189	0.120	0.031	1
Alternative 5	0.923	0.128	1.000	5

Table 25 Ranking results with IT2 FTOPSIS

	D^+	D^-	C_i	Ranks
Alternative 1	0.151	0.610	0.802	2
Alternative 2	0.365	0.316	0.464	3
Alternative 3	0.573	0.131	0.187	4
Alternative 4	0.078	0.580	0.881	1
Alternative 5	0.585	0.113	0.162	5

Table 24 Weighted defuzzified decision matrix

	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
Criterion 1	1.09	0.99	0.89	1.12	0.99
Criterion 2	0.89	0.89	0.89	0.85	0.85
Criterion 3	1.20	1.00	0.90	1.18	0.95
Criterion 4	1.20	1.10	1.05	1.17	0.95
Criterion 5	0.89	0.89	0.94	1.03	0.89
Criterion 6	1.19	1.03	0.99	1.16	0.94
Criterion 7	1.15	1.09	0.90	1.12	0.90
Criterion 8	1.19	1.06	0.96	1.16	0.96

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Compliance with Ethical Standards

Conflict of Interest The authors of this paper declare that they have no conflict of interest and certify that they have NO affiliations with or involvement in any organization or entity with any financial interest, or non-financial interest in the subject matter or materials discussed in this manuscript.

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