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A study of entrepreneur and innovative university index by entropy-based grey relational analysis and PROMETHEE

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Abstract

In recent years, the concept of entrepreneurial and innovative universities has gained widespread prominence. Many universities have been paying more attention to being entrepreneurial and innovative by improving their organizational systems, advancing their infrastructure, and increasing financial support. Since numerous criteria with different weights exist, ranking universities based on entrepreneurial and innovative performance can be considered a multi-criteria decision-making (MCDM) problem. This article aims to investigate how different multi-criteria decision-making methods with different criterion weights can affect university rankings and to highlight the reasons that contribute to these differences. In this scope, Grey Relational Analysis (GRA) and Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) methods were used to rank and compare the universities in Türkiye according to the 2022 Entrepreneur and Innovative University Index (EIUI). In addition to the current weights of each EIUI dimension, entropy-based weights and equal weights were used in MCDM methods. Three ranking approaches with varying weights provided different rankings for universities. The effect of criterion weights was found to be more important in the ranking difference than the method used. The ranks for universities coded U1 and U2 as the most entrepreneurial and innovative universities remained the same. In addition, the performance of each university according to each dimension was evaluated graphically using the GAIA plane to enable them to identify areas for improvement in their rankings.

Keywords Entrepreneur · Entropy · Grey relational analysis · Innovative · PROMETHEE

Introduction

Increased social and economic requirements forced universities to broaden their traditional functions. Innovative research and the transfering these findings to society became necessary since providing high-quality education is no longer a sufficient factor. From first to third-generation universities, innovation, transfer, and implementation have been added to traditional university functions (Skribans et al., 2013). Today, the entrepreneurial and

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value-creating structures of 3rd generation universities make them stand out from the competition.

According to the 11th Development Plan of Türkiye for 2019–2023, the need to transform R&D results into economic and social benefits and to develop entrepreneurship and commercialization activities are still important. In this scope, there is a mandatory transition period for 3rd generation universities in which universities take an active role in transforming the knowledge produced into value and in close cooperation with industry and the public. Entrepreneur and Innovative University Index (EIUI) is used to objectively measure and rank the transformation journeys of universities into 3rd generation universities. In addition, it gives valuable information to all stakeholders of the entrepreneurship ecosystem, such as governments/policy makers and current/potential entrepreneurs.

The Entrepreneur and Innovative University Index (EIUI) ranks the first 50 universities among 208 universities in Türkiye based on their "scientific and technological research capabilities", "intellectual property pool", "cooperation and interaction" and "economic and social contribution" since 2012. Prepared by the Scientific and Technological Research Council of Türkiye (TUBITAK), it aims to increase the entrepreneurship and innovation-oriented competition between universities and to contribute to the development of the entrepreneurial and innovation ecosystem. The index, initially evaluated under five dimensions before 2018, was reduced to 4 with the revision. The composite indicator of weighted four dimensions and 23 indicators is calculated from data gathered from public records, universities, and technoparks. Thus, the scientific activities of universities and industry collaborations are simultaneously considered.

There are various studies in the literature about EIUI to disseminate entrepreneurship and innovation among universities. İskender and Batı (2015) compared the EIUI results with the ranking obtained by sentiment analysis on 13,007 tweets containing the "entrepreneur" keyword and 14,579 tweets that contained the "innovation" keyword. Karagöz et al. (2020) calculated the efficiency scores of the top 50 universities for 2011–2016 EIUI data by Data Envelopment Analysis, identifying 35 universities that do not use resources efficiently and provide periodic systematic improvement. Selamzade and Özdemir (2021) analyzed the efficiencies of the entrepreneurial and innovative universities using constant return to scale (CRS) and variable return to scale methods (VRS) of Data Envelopment Analysis based on 2020 EIUI data. Regarding the Entrepreneurship and Innovation Dimensions of EIUI, they found that only 18% of universities are efficient in CRS analysis and 26% in VRS analysis.

The evaluation of entrepreneurship and innovation performance involves multiple criteria with different priorities (weights), which can be modeled as a multiple-criteria decision-making (MCDM) problem. Table 1 summarizes some studies on ranking universities in Türkiye according to their entrepreneurship and innovation performance using different multi-criteria decision-making methods (MCDM). According to Table 1, 50 universities were ranked using different MCDM methods in three studies. Oğuz (2022) used four dimensions according to the revision made in 2018. Ömürbek and Karataş (2018) and Oğuz (2022) used two MCDM methods for comparison purposes. In addition, criterion weighting methods (Entropy and CRITIC) were only used in two of the studies.

In the literature, a limited number of studies focus on ranking universities, countries, or organizations based on entrepreneurship and innovation performance using MCDM. Rostamzadeh et al. (2014) prioritized the entrepreneurial intensity among small and medium-sized enterprises using the Fuzzy Analytic Hierarchy Process (F-AHP) based VIKOR and TOPSIS techniques. Quan and Zhou (2018) employed Entropy TOPSIS to rank the innovation and entrepreneurship education capacity of

Table 1 Literature summary

Author (Year)	Index (Year)	# of University	# of criteria	Weighting method	MCDM
Ömürbek and Karataş (2018)	EIUI* (2016)	50	5	ENTROPY	MAUT-SAW
Er and Yıldız (2018)	EIUI (2016–2017)	50	5	–	ORESTE
Ertuğrul et al. (2016)	URAP** (2016)	10	5	–	GREY RELATIONAL ANALYSIS
Oğuz (2022)	EIUI (2018)	10	4	ENTROPY	EDAS-TOPSIS
Karahan and Peşmen (2021)	EIUI (2018)	11	4	–	PROMETHEE GAIA
Çınaroğlu (2021)	EIUI (2020)	50	4	CRITIC	MARCOS
Karahan and Kizkapan (2022)	EIUI (2021)	11	4	–	PROMETHEE GAIA

*Entrepreneur and innovative university index

**University ranking by academic performance

9 colleges and universities in Jiangsu Province in 2016. Karimi et al. (2019) utilized the Analytical Network Process (ANP) and the Decision Making Trial and Assessment Laboratory (DEMATEL) to rank the innovation and entrepreneurship indices of international companies. Özkan et al. (2019) ranked 81 cities in Türkiye according to the R&D performance using a hybrid MCDM model including DEMATEL and ANP for assigning importance to the indicators and VIKOR for ranking performance. Altıntaş (2020) conducted a comparative analysis of the Global Innovation Index of G7 countries using Entropy-based Grey Relational Analysis. Ishizaka et al. (2020) applied PROMETHEE to rank 162 UK universities based on their portfolio of knowledge transfer activity from the 2015–2016 Higher Education Business and Community Interaction Survey dataset. Zhu et al. (2022) evaluated the entrepreneurial environment of 48 countries according to World Development Indicators by using Grey Relational Analysis.

EIUI ranking involving the weight of the j^{th} criterion ($j = 1,2,\ldots,n$) and the performance of i^{th} university ($i = 1,2,\ldots,m$) with respect to j^{th} criterion is a multi-criteria decision-making problem in nature. This paper aims to emphasize that using different multi-criteria decision-making methods with varying criteria weights may lead to different university rankings and to highlight the causes contributing to different results. To the best of the authors' knowledge, comparative analysis of Grey Relational Analysis and PROMETHEE for different criteria weights (Equal, TUBITAK, and Data Based-Entropy Weights) has not been conducted for university ranking before. The reasons for choosing these methods are listed below.

1. EIUI is based on the subjective weight of each dimension. Given that judgments specific to a particular time period are based on the experience or knowledge of decision-makers, it is necessary to review and evaluate the weighting system for reliable and robust decision-making. This study employed the Entropy Method, an objective weighting method using currently available data, to determine the criterion weights instead of relying on a past cross-sectional perspective based on expert judgments.
2. IEUI includes 23 size-dependent criteria, such as the number of Ph.D. graduates favoring large and/or old-founded universities. The absence of size-independent criteria results in rankings against small but productive universities. GRA was employed to rank universities in this study, as grey system theory deals with uncertain systems with partially known information, mirroring the uncertainty in the EIUI calculation.
3. As another MCDM method for comparison, PROMETHEE was used because of its visual support in exploring the structure of the decision problem and better interpreting the results.

In summary, this study proposes an approach for ranking universities in terms of the Entrepreneur and Innovative University Index by leveraging the strengths of each MCDM method used. Using GRA and PROMETHEE with varying criteria weights provides comprehensive evaluation. To the best of the authors' knowledge, there is no study in which 50 universities are ranked on the basis of 4 dimensions of EIUI using GRA and MCDM methods with different criterion weights. In this scope, the rest of this paper is organized as follows: "Method" Section briefly explains the weighting and MCDM methods used in this study. "Data" Section presents the data used, and "Analysis" Section displays the results of ranking studies. The last section is a discussion and conclusions.

Method

Multi-Criteria Decision Making (MCDM) is a scientific discipline that addresses various decision-making problems. Considering multiple conflicting criteria, these methods evaluate alternatives to rank or select the optimal solution. Numerous MCDM methods are available in the literature, including AHP, ELECTRE, TOPSIS, PROMETHEE, and Grey Theory, as highlighted by Aruldoss et al. (2013). Due to their different aggregation procedures, normalization methods, and treatment for the cost/benefit criteria, there is no clear guideline on selecting which method to solve a specific decision problem. The choice depends only on the nature of the problem to be solved. Aruldoss et al. (2013) provide a detailed discussion of the advantages and disadvantages of some MCDMs. Selmi et al. (2013) proposed a comparative study to identify similarities and divergences between six MCDM methods: ELECTRE III, PROMETHEE I and II, TOPSIS, AHP, and PEG-MCDM. They used the Gini Index to measure dispersion of ranks obtained from the mentioned methods. A case study noted a good similarity between PROMETHEE-AHP and TOPSIS-PEG and a larger dispersion between ELECTRE III-TOPSIS and ELECTRE III-PEG.

Since the final decision in MCDM is influenced by the criteria weights, several methods, objective and subjective in nature, are utilized (Paramanik et al., 2022). Objective methods calculate the criteria weights based on available data by mathematical algorithms neglecting the experience of the decision-makers. Conversely, subjective methods rely on decision-makers judgments based on expertise, experience, and cognitive efforts in calculating criteria weights. However, it is essential to note that the lack of experience or knowledge of the decision-maker can potentially lead to incorrect decisions when using subjective methods.

The following sections summarize the Entropy Method as an objective criteria weighting method and MCDM methods (GRA and PROMETHEE) used in ranking universities.

Entropy method

Entropy, introduced by Shannon (1948) into information theory, is a measure of how disordered a system is. A higher entropy value indicates a higher degree of disorder and a lower utility value of information. As an uncertainty measurement of a system, entropy is considered a reliable method for objectively calculating the criteria weightings of multi-criteria decision-making problems by avoiding the effect of human judgment in calculating criteria weighting (Guoliang & Qiang, 2007). The original procedure of Shannon's entropy involves the following steps (Guoliang & Qiang, 2007; Quan & Zhou, 2018; Safari et al., 2012):

Step 1 A decision matrix is created. The performance of alternative-i for criteria-j is denoted by X_{ij} in Eq. (1).

$$X_{ij} = \begin{bmatrix} x_{11}x_{12} \cdots .x_{1n} \\ x_{11}x_{12} \cdots .x_{2n} \\ \cdots \cdots \cdots \cdots \cdots .. \\ x_{m1}x_{12} \cdots .x_{mn} \end{bmatrix} \tag{1}$$

$$i = 1, 2, \ldots, m \text{ (Alternatives)}$$

$$j = 1, 2, \ldots, n \text{ (Criteria)}$$

Step 2 The decision matrix is normalized to transform different scales and units into common measurable units.

$$P_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \tag{2}$$

where P_{ij} is the normalized value.

Step 3 Entropy value (e_j) is calculated.

$$e_j = -\frac{\sum_{i=1}^{m} P_{ij} \ln\left(P_{ij}\right)}{\ln(m)} \tag{3}$$

$$d_j = 1 - e_j \tag{4}$$

where d_j is the redundancy index as diversification degree.

Step 4 Entropy weight (W_j) for each criterion is calculated.

$$W_j = \frac{d_j}{\sum_{j=1}^{d} d_j} \tag{5}$$

$$\sum_{i=1}^{n} w_j = 1 \tag{6}$$

Grey relational analysis

Developed by Deng (1982), the grey theory provides relational analysis, prediction, decision-making, programming, and control in a grey system consisting of imprecise and incomplete information. The distinctions between grey systems and the other uncertain systems (stochastics, fuzzy, and rough) are discussed in Liu et al. (2012). GRA solves multi-criteria decision-making problems by aggregating all performance attribute values for each alternative into a single value (Zhu et al., 2022). In order to analyze the similarity between the reference series and alternative series in a grey system, GRA involves the following steps (Hu, 2009; Lin et al., 2004; Wu, 2017).

Step 1 The data set is prepared, and the decision matrix (X) is created.

$$X = \begin{bmatrix} X_1(1)X_1(2)\ldots X_1(n) \\ x_2(1)x_2(2)\ldots x_2(n) \\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \\ x_m(1)x_m(2)\ldots x_m(n) \end{bmatrix} \tag{7}$$

$$X_i = \left(X_i(j), \ldots\ldots, X_i(n)\right)$$

$$i = 1, 2, \ldots, m \text{ (Alternatives)}$$

$$j = 1, 2, \dots, n \,(\text{Criteria})$$

where $X_i(j)$ is the value of ith alternative for jth criteria.

Step 2 Data values that have different measurement units are transformed into 0–1 intervals for comparison using one of the following formulas to normalize the data.

If the expectancy is "the larger- the better", then the data is normalized using the following formula.

$$X_i^* = \frac{X_i(j) - minX_i(j)}{maxX_i(j) - minX_i(j)} \tag{8}$$

If the expectancy is "the smaller- the better", then the data is normalized using the following formula.

$$X_i^* = \frac{maxX_i(j) - X_i(j)}{maxX_i(j) - minX_i(j)} \tag{9}$$

where X_i is the original sequence, X_i^* is the sequence after the data preprocessing, $maxX_i(j)$ is the largest value of $X_i(j)$, and $minX_i(j)$ is the smallest value of $X_i(j)$. The standardized decision matrix is as follows.

$$X^* = \begin{bmatrix} X_1^*(1)X_1^*(2)\dots X_1^*(n) \\ X_2^*(1)X_2^*(2)\dots X_2^*(n) \\ \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.. \\ X_m^*(1)X_m^*(2)\dots X_m^*(n) \end{bmatrix} \tag{10}$$

Step 3 Reference series is determined.

$$X_0 = \left(X_0(1), \dots\dots, X_0(n)\right)$$

where $X_0(j)$ is the standardized and largest value in the jth factor.

Step 4 Absolute Differences (Distances) between the reference series and compared series are calculated.

$$\Delta_{0i}(j) = \left|X_0^*(j) - X_i^*(j)\right| \tag{11}$$

$$\Delta_{0i} = \begin{vmatrix} \Delta_{01}(1)\Delta_{01}(2)\dots\Delta_{01}(n) \\ \Delta_{02}(1)\Delta_{02}(2)\dots\Delta_{02}(n) \\ \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots. \\ \Delta_{0m}(1)\Delta_{0m}(2)\dots\Delta_{0m}(n) \end{vmatrix} \tag{12}$$

where $\Delta_{0i}(j)$ is the deviation sequence.

Step 5 Grey relational coefficient is calculated.

$$\gamma_{0i}(j) = \frac{\min_i \min_j \Delta_{0i}(j) + \xi \max_i \max_j \Delta_{0i}(j)}{\Delta_{0i}(j) + \delta \max_i \max_j \Delta_{0i}(j)} \tag{13}$$

where ξ is an identification (distinguished) coefficient between 0–1, generally, it is set to 0.5 for good stability(Wu, 2017).

Table 2 Dimensions used in IEUI

Dimension		Weight (%)	Sub-dimension (criteria)		Weight (%)
D1	Scientific and technological research capabilities (STRC)	15	1.1	Number of scientific article	2.50
			1.2	Number of citation	3.50
			1.3	Number of projects	2.00
			1.4	Amount of project funds	3.00
			1.5	Number of national and international scientific prize	1.50
			1.6	Number of Ph.D. graduates	2.50
D2	Intellectual property pool (IPP)	20	2.1	Number of national patent grants	5.20
			2.2	Number of utility model grants	3.00
			2.3	Number of international patent applications	5.00
			2.4	Number of international patent grants	6.80
D3	Cooperation and interaction (CI)	25	3.1	Number of industry collaboration projects	5.00
			3.2	Amount of industry collaboration project funds	6.00
			3.3	Number of international collaboration Projects	5.00
			3.4	Amount of international collaboration project funds	6.00
			3.5	Number of academicians/students who are in circulation	1.44
			3.6	Number of registered students in Industry Ph.D. program	1.56
D4	Economic and social contribution (ESC)	40	4.1	Number of firms founded by academicians	5.68
			4.2	Number of firms founded by students/graduates	7.57
			4.3	Net sales revenue of firms founded by academicians	7.57
			4.4	Net sales revenue of firms founded by students/graduates	10.41
			4.5	Number of licensed patent/utility model/industrial design	3.78
			4.6	Number of BİGG* firms	3.00
			4.7	Number of 4004–4005** projects	2.00

*TUBITAK 1512 Entrepreneurship Support Program

**TUBITAK Nature Education and Science Schools- Innovative Educational Practices

Table 3 Codes of the top 50 universities in 2022 EIUI

Code	University name	Code	University name	Code	University name
U1	ORTA DOĞU TEKNİK UNIV	U18	İSTANBUL MEDİPOL UNIV	U35	ONDOKUZ MAYIS UNIV
U2	SABANCI UNIV	U19	TOBB EKON. VE TEK. UNIV	U36	ACIBADEM M. ALİ AYD. UNIV
U3	İSTANBUL TEKNİK UNIV	U20	BURSA ULUDAĞ UNIV	U37	ATATÜRK UNIV
U4	YILDIZ TEKNİK UNIV	U21	MARMARA UNIV	U38	KADİR HAS UNIV
U5	İHSAN DOĞ. BİLKENT UNIV	U22	ESKİŞEHİR TEKNİK UNIV	U39	SÜLEYMAN DEMİREL UNIV
U6	KOÇ UNIV	U23	DOKUZ EYLÜL UNIV	U40	ABDULLAH GÜL UNIV
U7	BOĞAZİÇİ UNIV	U24	BAHÇEŞEHİR UNIV	U41	SELÇUK UNIV
U8	GEBZE TEKNİK UNIV	U25	YEDİTEPE UNIV	U42	İZMİR EKONOMİ UNIV
U9	ÖZYEĞİN UNIV	U26	YAŞAR UNIV	U43	KONYA TEKNİK UNIV
U10	İZMİR YÜKSEK TEK. ENS	U27	KARADENİZ TEKNİK UNIV	U44	BURSA TEKNİK UNIV
U11	HACETTEPE UNIV	U28	ATILIM UNIV	U45	ANKARA YIL. BEYAZIT UNIV
U12	EGE UNIV	U29	ÇUKUROVA UNIV	U46	ÇANKAYA UNIV
U13	ERCİYES UNIV	U30	AKDENİZ UNIV	U47	PAMUKKALE UNIV
U14	ANKARA UNIV	U31	KOCAELİ UNIV	U48	İSTANBUL OKAN UNIV
U15	İSTANBUL UNIV	U32	ESK. OSMANGAZİ UNIV	U49	ÇAN. ONSEKİZ MART UNIV
U16	GAZİ UNIV	U33	FIRAT UNIV	U50	HASAN KALYONCU UNIV
U17	İSTANBUL UNIV. CERRAHPAŞA	U34	SAKARYA UNIV		

Table 4 Dimension weights

Dimension	ej	dj	Entropy weight (W_{Ent})	TUBITAK weight (W_{TUB})	Equal weight (WEq)
D1	0.9916	0.0084	0.1540	0.15	0.25
D2	0.97316	0.0269	0.4924	0.20	0.25
D3	0.98786	0.0122	0.2226	0.25	0.25
D4	0.9929	0.0071	0.1309	0.40	0.25

Table 5 Preference parameters for PROMETHEE

		Dimensions			
		D1	D2	D3	D4
Min/max		Max	Max	Max	Max
	Equal (W_{Eq})	0.25	0.25	0.25	0.25
Weight	Entropy (W_{Ent})	0.16	0.49	0.22	0.13
	TUBITAK (W_{TUB})	0.15	0.20	0.25	0.40
Preference function		Linear	Linear	Linear	Linear

Step 6 Grey relational degree (grade) indicating the degree of similarity between the reference and comparable sequences is calculated. If the two series are identical, grey relational grade equals to 1.

$$\Gamma_{0i} = \sum_{j=1}^{n} w_j \cdot \gamma_{0i}(j) \tag{14}$$

where w_j is the criteria weight and $\sum_{i=1}^{n} w_j = 1$.

Step 7 Alternatives are ranked according to Γ_{0i}.

PROMETHEE

PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation) was developed as a reliable multi-criteria decision-making method in the early 1980s by Brans et al. (1986). PROMETHEE methods are based on mutual comparisons of each alternative pair with respect to each of the selected criteria. Two notable variants include PROMETHEE I for partial ranking and PROMETHEE II for complete ranking. The application of the PROMETHEE method to decision-making problems involves the following steps (Ishizaka et al., 2020; Karahan & Peşmen, 2021; Safari et al., 2012):

Step 1 Create a decision matrix. The basis of the PROMETHEE method is to compare alternatives $A = \{a_1, a_2, \ldots, a_n\}$ in pairs for defined criteria $C = \{c_1, c_2, \ldots, c_m\}$. The PROMETHEE method, therefore, starts by creating a Decision Matrix (DM) containing the values of the alternatives for each criterion. This matrix is given below:

Table 6 Comparative rankings based on GRA and PROMETHEE for different weights

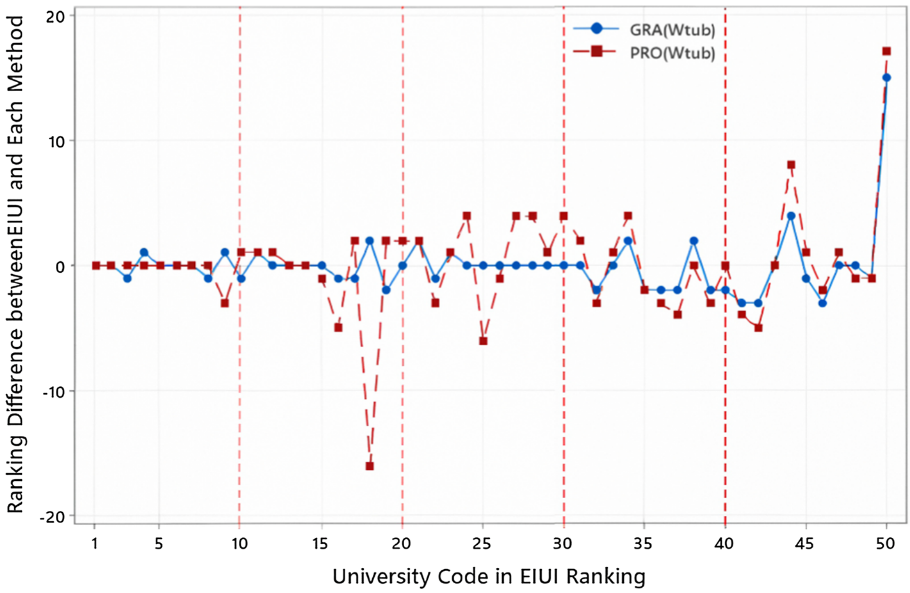
Univ. code	Grey relational grade						PROMETHEE preference level					
	W_{Eq}	Rank	W_{Ent}	Rank	W_{TUB}	Rank	W_{Eq}	Rank	W_{Ent}	Rank	W_{TUB}	Rank
U1	0.9130	1	0.8570	1	0.9252	1	0.9643	1	0.9477	1	0.9704	1
U2	0.8111	2	0.7844	2	0.7971	2	0.9107	2	0.9060	2	0.9099	2
U3	0.7412	3	0.6979	4	0.7402	4	0.8579	3	0.8233	3	0.8733	3
U4	0.7111	5	0.6829	5	0.7564	3	0.7695	5	0.7808	5	0.8114	4
U5	0.6989	6	0.6780	6	0.6785	5	0.7969	4	0.8021	4	0.7788	5
U6	0.7125	4	0.6696	7	0.6732	6	0.7662	6	0.7364	6	0.7355	6
U7	0.6196	8	0.5830	11	0.6350	7	0.6524	7	0.5653	10	0.7018	7
U8	0.6077	10	0.5889	10	0.6161	9	0.6336	8	0.5828	9	0.6706	8
U9	0.6400	7	0.7633	3	0.6277	8	0.4204	12	0.6164	7	0.4679	12
U10	0.5994	11	0.5988	9	0.5882	11	0.5649	9	0.5968	8	0.5195	9
U11	0.6128	9	0.5565	12	0.5925	10	0.4917	11	0.3141	12	0.4978	10
U12	0.5659	12	0.5494	13	0.5596	12	0.5052	10	0.4813	11	0.4853	11
U13	0.5348	15	0.5017	20	0.5498	13	0.2818	15	0.1453	19	0.3490	13
U14	0.5563	13	0.5037	18	0.5491	14	0.3104	13	0.0309	23	0.3404	14
U15	0.5332	16	0.5144	17	0.5225	15	0.2862	14	0.2643	13	0.2314	16
U16	0.5254	17	0.5017	19	0.5206	17	0.0621	18	0.2106	15	−0.0258	21
U17	0.5169	18	0.5339	14	0.5030	18	0.2655	16	0.2008	16	0.2585	15
U18	0.5447	14	0.6510	8	0.5221	16	−0.1209	26	0.2549	14	−0.2484	34
U19	0.4786	25	0.4811	22	0.4920	21	−0.0040	22	0.0784	20	0.0811	17
U20	0.4831	23	0.4696	27	0.4928	20	0.0141	20	−0.0595	27	0.0642	18
U21	0.4953	19	0.4716	26	0.4963	19	0.0630	17	−0.0650	28	0.0448	19
U22	0.4888	21	0.5206	16	0.4865	23	−0.0712	23	0.1660	18	−0.1252	25
U23	0.4912	20	0.4811	23	0.4874	22	0.0369	19	0.0379	22	−0.0399	22
U24	0.4662	28	0.4608	30	0.4839	24	−0.1411	27	−0.1172	30	−0.0129	20
U25	0.4873	22	0.5260	15	0.4819	25	−0.1161	25	0.1766	17	−0.1900	31

Table 6 (continued)

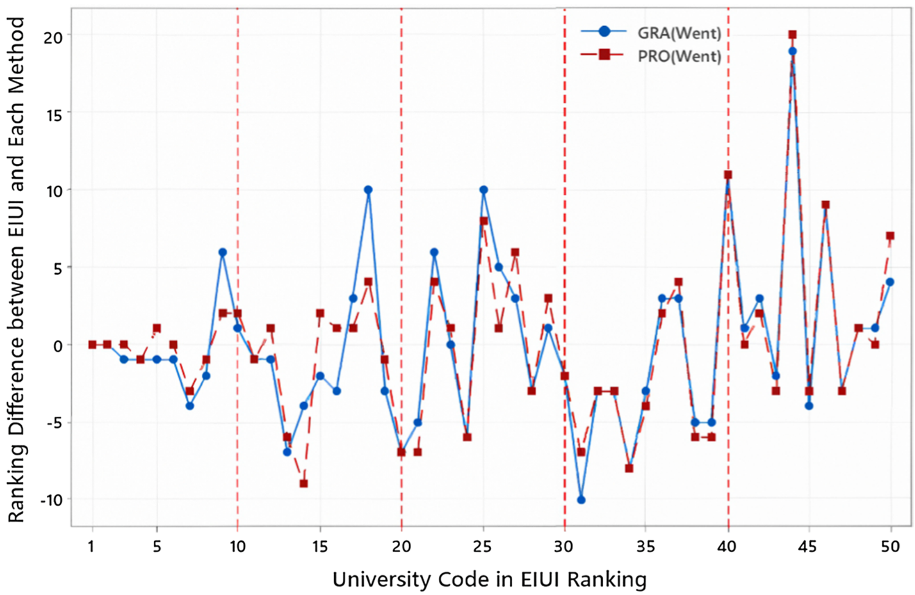
Univ. code	Grey relational grade						PROMETHEE preference level					
	W_{Eq}	Rank	W_{Ent}	Rank	W_{TUB}	Rank	W_{Eq}	Rank	W_{Ent}	Rank	W_{TUB}	Rank
U26	0.4718	27	0.4981	21	0.4797	26	−0.2180	31	−0.0021	25	−0.1571	27
U27	0.4799	24	0.4772	24	0.4785	27	0.0025	21	0.0672	21	−0.0644	23
U28	0.4588	31	0.4577	31	0.4719	28	−0.2012	29	−0.1415	31	−0.1105	24
U29	0.4725	26	0.4690	28	0.4711	29	−0.0886	24	−0.0377	26	−0.1632	28
U30	0.4651	29	0.4565	32	0.4690	30	−0.1517	28	−0.1703	32	−0.1569	26
U31	0.4494	36	0.4259	41	0.4648	31	−0.2701	35	−0.4241	38	−0.1702	29
U32	0.4566	32	0.4407	35	0.4589	34	−0.2292	32	−0.3043	35	−0.2719	35
U33	0.4589	30	0.4372	36	0.4617	33	−0.2122	30	−0.3238	36	−0.2024	32
U34	0.4468	38	0.4175	42	0.4622	32	−0.2866	36	−0.4986	42	−0.1839	30
U35	0.4445	39	0.4281	38	0.4492	37	−0.3432	38	−0.4309	39	−0.3422	37
U36	0.4484	37	0.4472	33	0.4475	38	−0.3658	39	−0.2977	34	−0.4223	39
U37	0.4501	34	0.4461	34	0.4423	39	−0.3327	37	−0.2821	33	−0.4529	41
U38	0.4403	40	0.4153	43	0.4496	36	−0.4216	40	−0.5635	44	−0.3953	38
U39	0.4306	42	0.4114	44	0.4383	41	−0.4715	43	−0.5797	45	−0.4577	42
U40	0.4525	33	0.4624	29	0.4367	42	−0.2517	34	−0.0817	29	−0.4269	40
U41	0.4380	41	0.4268	40	0.4328	44	−0.4376	41	−0.4610	41	−0.5425	45
U42	0.4251	44	0.4271	39	0.4296	45	−0.5650	46	−0.4607	40	−0.5766	47
U43	0.4283	43	0.4090	45	0.4345	43	−0.5077	45	−0.6062	46	−0.5168	43
U44	0.4500	35	0.4750	25	0.4384	40	−0.2505	33	0.0140	24	−0.3420	36
U45	0.4166	47	0.3929	49	0.4275	46	−0.5814	47	−0.7309	48	−0.5299	44
U46	0.4246	45	0.4294	37	0.4203	49	−0.5008	44	−0.3834	37	−0.6032	48
U47	0.4113	48	0.3927	50	0.4260	47	−0.6479	48	−0.7569	50	−0.5455	46
U48	0.4067	49	0.3954	47	0.4221	48	−0.6949	49	−0.7293	47	−0.6156	49
U49	0.4046	50	0.3945	48	0.4154	50	−0.7279	50	−0.7326	49	−0.6768	50

Table 6 (continued)

Univ. code	Grey relational grade						PROMETHEE preference level					
	W_{Eq}	Rank	W_{Ent}	Rank	W_{TUB}	Rank	W_{Eq}	Rank	W_{Ent}	Rank	W_{TUB}	Rank
U50	0.4205	46	0.3975	46	0.4553	35	−0.4452	42	−0.5591	43	−0.2227	33

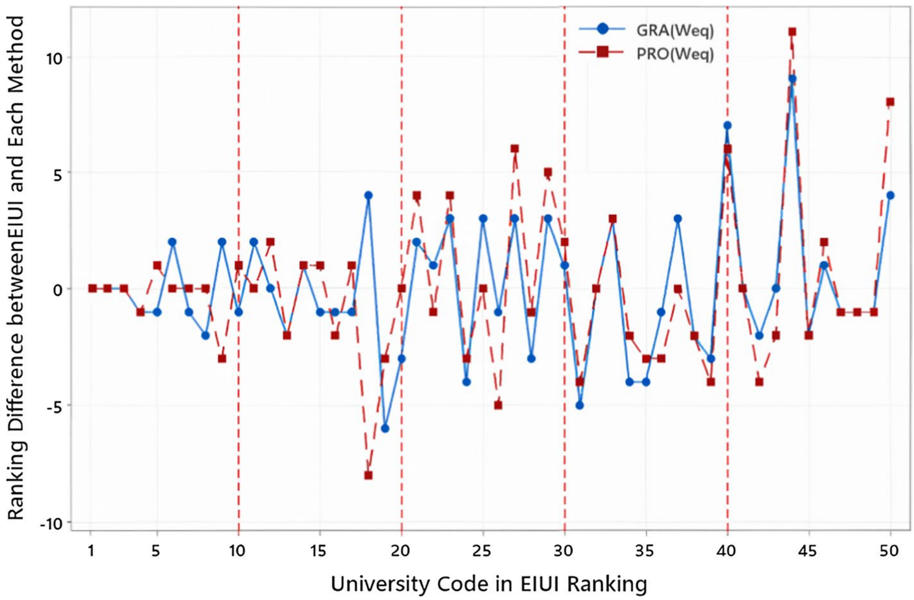


a) TUBITAK Weight



b) Entropy Weight

Fig. 1 Ranking differences between EIUI and Each method according to different weights of dimensions



c) Equal Weight

Fig. 1 (continued)

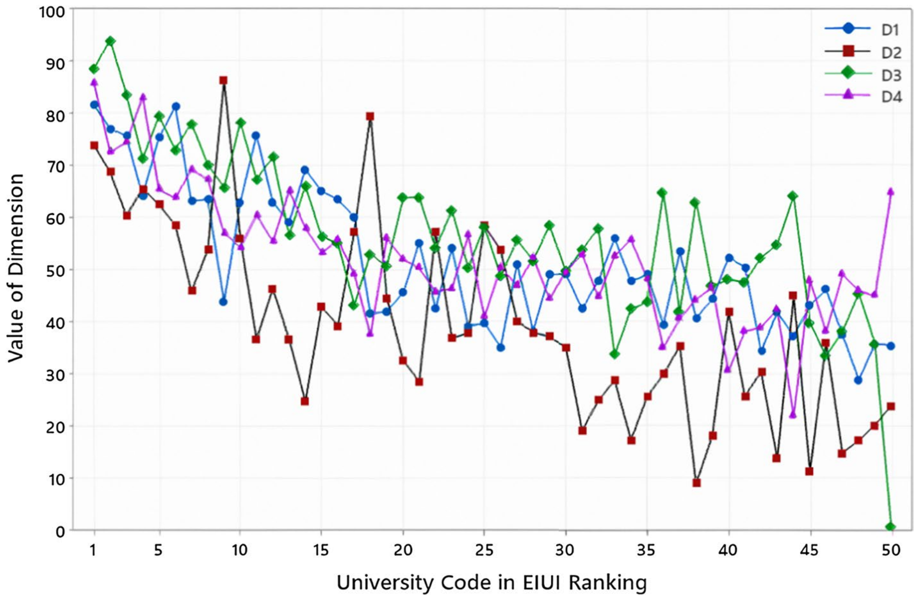


Fig. 2 Dimension values for each university

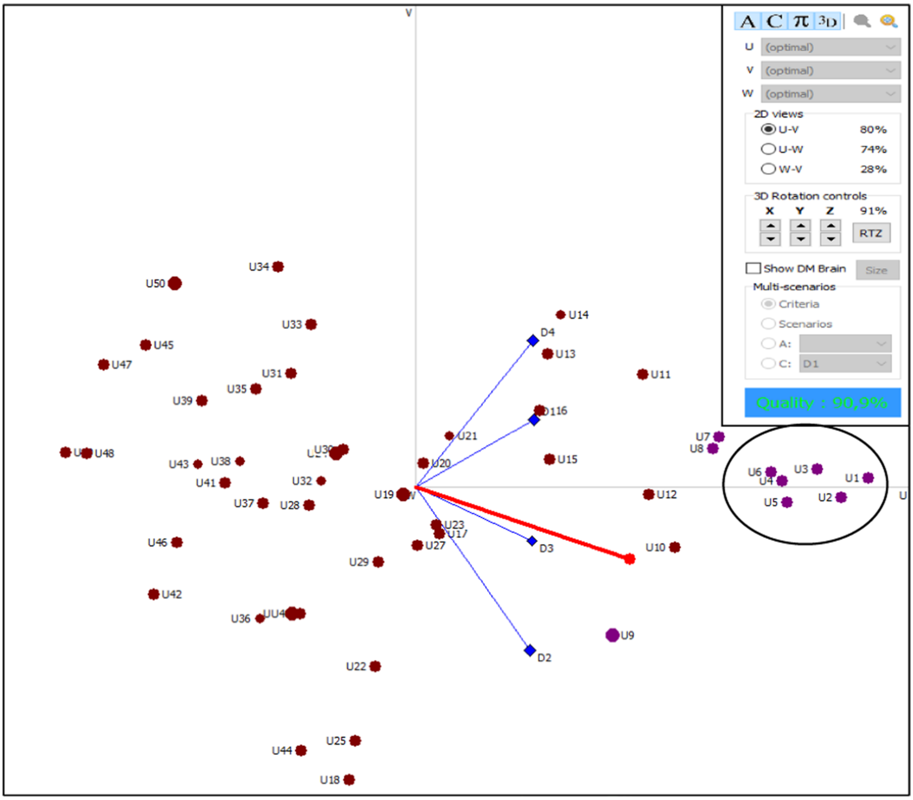


Fig. 3 GAIA plane for entropy weight

$$DM = \begin{bmatrix} c_1(a_1) & \cdots & c_1(a_n) \\ \vdots & \ddots & \vdots \\ c_m(a_1) & \cdots & c_m(a_n) \end{bmatrix} \tag{15}$$

where.

c_j (a_i) = value of i alternative according to criteria j,

$$i = 1, 2, \ldots, m \,(m \text{ denotes the number of alternatives})$$

$$j = 1, 2, \ldots, n \,(n \text{ denotes the number of criteria})$$

Step 2 Define preference functions. The preference level for an alternative a_i over alternative a_j is defined by the preference function as given below:

$$P_k(d_k) = c_k(a_i) - c_k(a_j) \tag{16}$$

$$0 \le P_k(d_k) \le 1$$

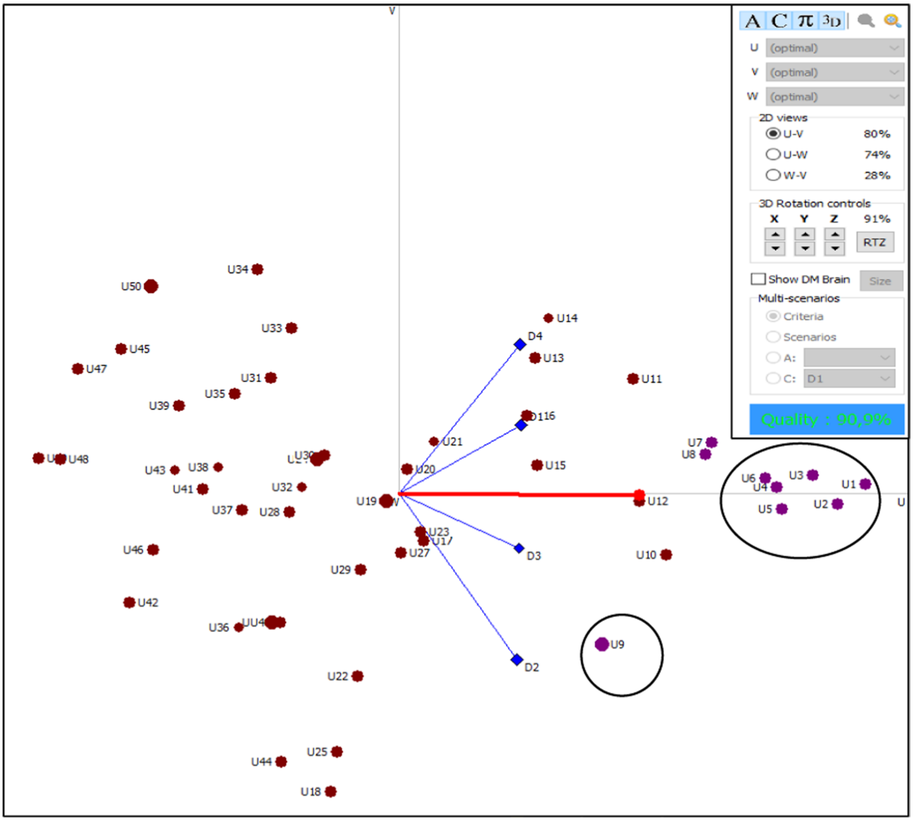


Fig. 4 GAIA plane for equal weight

$$P_k\left(d_k\right) = 0 - \text{ no preference between } a \text{ and } b;$$

$$P_k\left(d_k\right)0 \sim a \text{ is preferable weakly over } b$$

$$P_k\left(d_k\right)1 - a \text{ is preferable strongly over } b$$

$$P_k\left(d_k\right) = 1 - a \text{ is definitely preferable over } b$$

Step 3 Calculate the preference index.

$$\Pi\left(a_i, a_j\right) = \sum_{j=1}^{n} P_j\left(a_i, a_j\right) w_j \quad (17)$$

where $\prod (a_i,a_j)$ represents the strength of alternative a_i over alternative a_j.

Step 4 Calculate negative and positive outranking flows (PROMETHEE I).

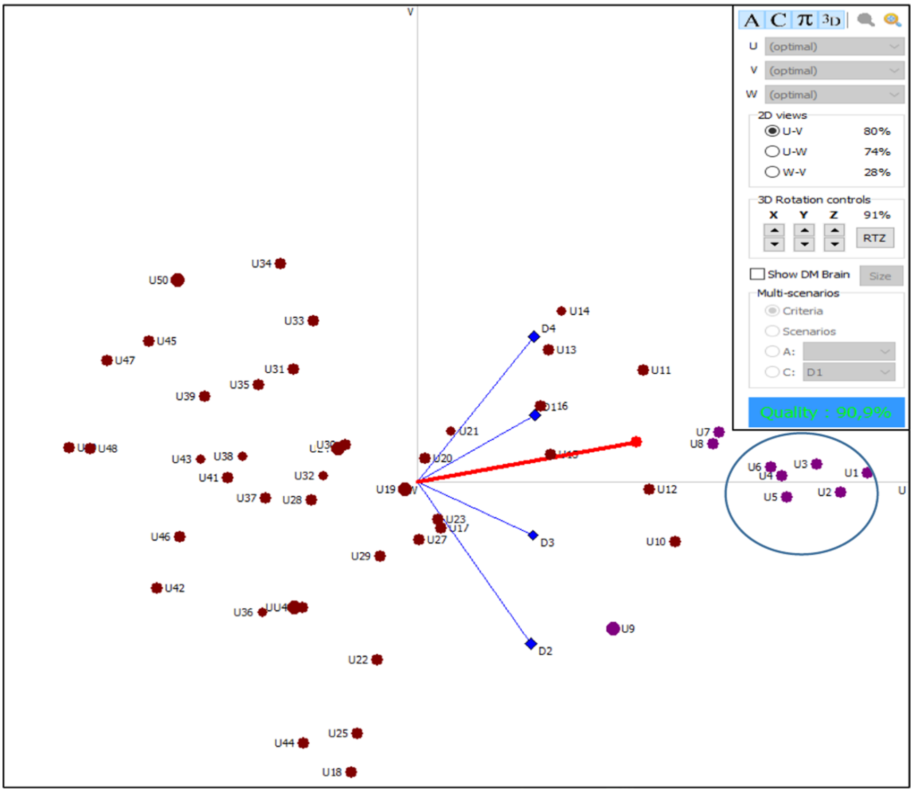


Fig. 5 GAIA plane for TUBITAK weight

$$\phi^{-}\left(a_i\right) = \frac{1}{n-1}\sum\nolimits_{j=1, j\neq i}^{n} \Pi\left(a_j, a_i\right) \tag{18}$$

$$\phi^{+}\left(a_i\right) = \frac{1}{n-1}\sum\nolimits_{j=1, j\neq i}^{n} \Pi\left(a_i, a_j\right) \tag{19}$$

where $\phi^{+}(a_i)$ positive outflow of alternative a_i and, $\phi^{-}(a_i)$ negative outflow of alternative a_i.

Step 5 Calculate the complete ranking (PROMETHEE II). The net outranking flow of each alternative is calculated using the following equation.

$$\phi^{net}\left(a_i\right) = \phi^{+}\left(a_i\right) - \phi^{-}\left(a_i\right) \tag{20}$$

Alternatives are ranked according to $\phi^{net}\left(a_i\right)$.

The results provided by PROMETHEE II can be better understood by using a geometrical tool known as the "Geometrical Analysis for Interactive Aid (GAIA) Plane", which was developed by Marechal and Brans (1988). The fundamental approach for GAIA involves performing a principal component analysis (PCA) on the uni-criterion net flows of each alternative. The GAIA plane is defined by the corresponding unit Eigenvectors *u* and *v*, resulting from a covariance matrix of the uni-criterion net flows obtained using PCA. In the GAIA plane, each point represents an alternative, and the axes indicate criteria. The net flow of an alternative is the vector of its single criterion net flows for weight w. The orientation of the axes indicates compatible criteria and conflicting criteria. The length of the axis will indicate the parsing of the criteria. The decision axis ($\prod$) is the projection of the weight vector. The best alternative and the decision axis are in the same direction. The length of the decision axis is a strong indicator of selecting alternatives in the same direction. Criteria expressing similar preferences over alternatives are located on the same side of the GAIA plane while conflicting criteria for alternatives are located on the opposite side of the GAIA plane.

Data

In the calculation of IEUI, 23 criteria are evaluated under four dimensions (Table 2). As per TUBITAK scoring, the highest achievable value for a dimension is limited to its weight. The dimensions' scores are obtained by the weighted average of the criteria evaluated in the range of 0–100. Subsequently, universities are ranked according to the sum of the scores of the four dimensions.

The codes of 50 universities among 208 universities ranked from highest to lowest EIUI in 2022 are shown in Table 3.

In this study, four dimensions of EIUI were used to rank universities. Since the original data's largest dimension value is limited to that dimension's weight value, TUBITAK weights were used to transform the data so that the score of the relevant dimension falls within the 0–100 scale. Table 7 in the Appendix presents only the scores for dimensions, as it is impractical to display values for 50 universities across 23 criteria.

Analysis

TUBITAK provides the subjective weights for all dimensions based on the decision maker's expertise and judgment (Table 2). In this study, Shannon's entropy method as an objective method without considering the decision maker's preferences was employed to determine reasonable dimension weights for proper ranking of universities. Table 4 shows entropy weights by using the scores given in Table 7. The closer the entropy of a dimension to 1, the less important the dimension is deemed to be. "Intellectual property pool" was identified to be the most important dimension. In addition to Entropy weights, equal weights for dimensions were also used for comparison purposes.

For GRA, data in Table 7 was normalized using Eq. (8) since high values of dimensions provide better performance. Difference/Distance values and Grey Relational Coefficients were then calculated based on normalized data (Table 8 in the Appendix).

The decision matrix given in Table 7 was also used for PROMETHEE analysis. The preference parameters, including three different weight sets, are given in Table 5.

PROMETHEE analysis was carried out using Visual PROMETHEE Academic Edition software. Obtained outranking values for each university are given in Table 9 (see Appendix). The positive flow expresses how much a university dominates the others, and the negative flow how much the others dominate it.

Results

Table 6 illustrates the overall evaluation of universities using GRA and PROMETHEE methods with different dimension weights from Table 4. Notably, the ranks of U1 (Orta Dogu Teknik Univ) and U2 (Sabanci Univ) remained the same across all calculations, including the EIUI rank in the first column. The main reason is that all the dimension values of U1 and U2 surpass those of other universities. Clearly, the combined effects of dimensions, some high and some low, affect the ranking. Estimating this combined effect of dimensions for each university is based on the mathematical framework of the MCDM method and the weight assigned to each dimension.

The rankings of the top 10 universities varied little according to different methods. These universities are located in Ankara, Istanbul, Kocaeli, and Izmir, which are attractive cities in terms of employment, infrastructure, and transportation opportunities. Four of the universities in these cities are state-owned technical universities (Orta Dogu Teknik Univ, Istanbul Teknik Univ, Yildiz Teknik Univ, Gebze Teknik Univ.), and they have a sizeable academic staff with developed industrial relations. Others (Koc Univ., Sabanci Univ., Ozyegin Univ, Ihsan Dog. Bilkent Univ.) are private foundation universities with high R&D budgets.

The graphs created to show the differences between the university rankings obtained through the methods (GRA and PROMETHEE) and the IEUI rankings in Table 6 are presented in Fig. 1. According to Fig. 1a, which shows differences in rankings according to TUBITAK weight, it is understood that the rankings align closely with minor variances, except for a few universities (18, 25, 44, and 50). Notably, the differences are more significant in the ranking based on the PROMETHEE method, owing to distinct mathematical perspectives in calculations. Another reason for this is the relatively high variation in the values of dimension D2 (Intellectual Property Pool), as highlighted in Fig. 2.

Figures 1b and 1c show the differences between the MCDM (GRA and PROMETHEE) rankings and EIUI rankings based on entropy weights and equal weights, respectively. Notably, the differences are particularly evident after the top 10 universities. The minor differences between the rankings obtained by the different MCDM methods can be attributed to differences in the mathematical formulations and computations of the method used to solve the decision problem. According to Fig. 1a–c, which show the difference between the EIUI ranking declared according to the total score given in Table 7 and the GRA and PROMETHEE rankings, although MCDM methods give similar results, it is observed that the deviations increase for different dimension weights.

The Visual PROMETHEE software provides GAIA planes in Figs. 3, 4 and 5, indicating the relative position of the dimensions, universities, and decision (π) axis for more in-depth analysis and understanding of ranking. In the GAIA plane, criteria are shown with axes originating from the center, while universities are represented by dots. The decision axis (thick line) is a visual representation of the weights of the dimensions in the GAIA plane, indicating the importance of each dimension to the decision maker. Dimensions positioned closely reflect similar preferences. The position of the decision axis is closer to the dimension with a higher weight. For the entropy weight, since the total weight of D2 (Intellectual Property Pool) and D3 (Cooperation and Interaction) is 0.715 (see Table 4), the decision axis is close to them (Fig. 3). Likewise, the decision axis in Fig. 5 is close to D1 and D4 for the TUBITAK weight because the total weight of D1 (Scientific and Technological Research Capabilities) and D4 (Economic and Social Contribution) equals 0.55.

Figure 3 represents GAIA planes based on entropy weight, with a quality level of 90,9%, indicating a reliable and informative analysis. The position of universities relative to the decision axis reflects their ranking, with those aligned with the decision axis being ranked higher. As shown in Fig. 3, universities (U1-Orta Dogu Teknik Univ, U2-Sabanci Univ, U3-Istanbul Teknik Univ, U4-Yildiz Teknik Univ, U5-Ihsan Dog Bilkent Univ, and U6-Koc Univ) located in the direction of the decision axis have similar and high performance for all dimensions. Conversely, universities located opposite to the decision axis have lower performance. The farther a university is from the direction of the decision axis, the lower its ranking.

The position of universities according to the dimensions is another important evaluation issue. For instance, U9-Ozyegin Univ has high performance for dimensions (D2 and D3) but exhibits low performance in the other dimensions (D1-Scientific and Technological Research Capabilities and D4-Economic and Social Contribution). Improving its performance value in terms of D1 and D4 would consequently enhance U9's ranking. As illustrated in Fig. 4, representing the GAIA plane for equal weight of criteria, the decision axis aligns with the u-axis, indicating that all criteria are equal. Figure 5 represents the GAIA plane for the entropy weight of criteria. As can be seen in Fig. 5, the decision axis is closer to D1 and D4. The primary distinction among Figs. 3, 4 and 5 lies in the positioning of the decision axis. As the location of the decision axis changes, the ranking of universities correspondingly shifts.

The length of the criterion axes indicates the discriminative power of that criterion among universities. Longer axes imply a higher discriminative power. Dimensions D2 and D4 in Fig. 3, 4 and 5 exhibit nearly the same length, and both are longer than D1 and D3. It can be concluded that these two dimensions differentiate universities from each other.

The direction of the criteria axes is also essential in demonstrating how closely the criteria are related. As shown in Figs. 3, 4 and 5, the axes of D2 and D3 are close to each other, meaning that Universities with a high "intellectual property" also tend to have a "Cooperation and interaction capacity". Similarly, the axes of D1 and D4 are close to each other. That is, a university with high "Scientific and technological research capabilities" also has high "economic and social contribution". This insight highlights the interrelationships between dimensions.

Conclusion

Today, universities are not considered only for education and research but also for their active role in the country's economy through entrepreneurship. With the recognition that new enterprises can create relatively more new jobs, universities have increased their focus on their role in entrepreneurial ecosystem in addition to their core roles of research and teaching. Universities need to develop and strengthen their entrepreneurial and innovative aspects in order to serve the country by ensuring economic development and building an innovative country. Therefore, it is very necessary for the universities to become the entrepreneurial university.

This study conducted a literature review on the theoretical information and methods used to investigate the primary factors and causes that form and define the entrepreneurial university model. TUBITAK has been publishing the Entrepreneurial and Innovative University Index (EIUI) annually since 2012, utilizing four dimensions and ranking universities based on subjective weight to each dimension. Based on EIUI data, the study focused on assessing the impact of different MCDM methods with different dimension weights on ranking order. The dimensions and sub-criteria of EIUI were accepted as they were developed by TUBITAK, and the study is limited to EIUI ranking in its current form.

In order to eliminate the subjectivity in dimension weighting, the entropy method as an objective weighting method was also used. Subsequently, the universities were ranked using MCDM methods (GRA and PROMETHEE), which have their own characteristics and advantages. According to the results, the ranking of some universities has changed significantly (U18, U25, U44, U50), some slightly (U11, U12, U32). Notably, the ranking of the top 10 universities remained essentially unchanged. The results obtained depend not only on the MCDM method chosen but also on the criteria weights. This study revealed that criterion weights were the most influential factor in ranking, leading to different results with the support of graphs. However, in this inference, the effect of normalization methods on the ranking was not considered. Future studies could benefit from examining the effects of different normalization methods on the ranking outcomes.

GAIA plane added visual richness to the results that help decision makers for a comprehensive assessment considering various dimensions. The position of each university, represented by a point in the GAIA plane, is related to its evaluations on dimensions in such a way that universities with similar performance will be closer to each other. The universities (U1 to U6) close to the optimal line in the GAIA plane (Figs. 3, 4, 5) perform well for all criteria. Universities below the optimal line and around dimensions D2 and D3 are good at these dimensions but have low values for other dimensions. Similar comments can be made for universities above the optimal line. Thus, this plane shows which dimension or dimensions universities need to improve to rise to the top in the EIUE rankings.

Appendix

See Tables 7, 8, and 9.

Table 7 Scores of the first 50 universities according to the 2022 EIUI

Univ. code	University name	Total score	Dimension			
			D1	D2	D3	D4
U1	ORTA DOĞU TEKNİK UNIV	83.61	81.67	74.00	88.68	86.00
U2	SABANCI UNIV	77.89	77.13	68.75	94.16	72.58
U3	İSTANBUL TEKNİK UNIV	74.15	75.67	60.40	83.64	74.53
U4	YILDIZ TEKNİK UNIV	73.88	64.20	65.60	71.40	83.23
U5	İHSAN DOĞ. BİLKENT UNIV	69.85	75.40	62.55	79.48	65.40
U6	KOÇ UNIV	67.74	81.33	58.65	73.16	63.80
U7	BOĞAZİÇİ UNIV	65.93	63.13	45.95	78.20	69.30
U8	GEBZE TEKNİK UNIV	64.85	63.60	53.85	70.28	67.43
U9	ÖZYEĞİN UNIV	63.18	44.00	86.40	65.84	57.13
U10	İZMİR YÜKSEK TEK. ENS	62.02	63.00	56.15	78.44	54.35
U11	HACETTEPE UNIV	59.82	75.87	36.80	67.48	60.55
U12	EGE UNIV	58.85	63.00	46.40	71.64	55.50
U13	ERCİYES UNIV	56.49	59.27	36.75	56.68	65.20
U14	ANKARA UNIV	55.11	69.33	24.80	66.04	58.10
U15	İSTANBUL UNIV	53.8	65.07	42.95	56.52	53.30
U16	GAZİ UNIV	53.45	63.53	39.35	55.04	55.70
U17	İSTANBUL UNIV. CERRAHPAŞA	51.05	60.27	57.40	43.28	49.28
U18	İSTANBUL MEDİPOL UNIV	50.49	41.67	79.65	53.12	37.58
U19	TOBB EKON. VE TEK. UNIV	50.3	42.07	44.65	50.68	55.98
U20	BURSA ULUDAĞ UNIV	50.16	45.67	32.65	63.80	52.08
U21	MARMARA UNIV	50.15	55.27	28.65	64.00	50.35
U22	ESKİŞEHİR TEKNİK UNIV	49.72	42.67	57.20	54.16	45.85
U23	DOKUZ EYLÜL UNIV	49.51	54.20	36.95	61.52	46.50
U24	BAHÇEŞEHİR UNIV	48.73	39.20	38.00	50.36	56.65
U25	YEDİTEPE UNIV	48.66	39.87	58.50	58.40	40.95
U26	YAŞAR UNIV	48.52	35.27	53.80	48.88	50.60
U27	KARADENİZ TEKNİK UNIV	48.51	51.13	40.30	55.72	47.15
U28	ATILIM UNIV	47.28	38.40	38.00	51.88	52.38
U29	ÇUKUROVA UNIV	47.24	49.07	37.30	58.52	44.48
U30	AKDENİZ UNIV	46.75	49.27	35.20	49.84	49.68
U31	KOCAELİ UNIV	44.92	42.53	19.20	53.88	53.08
U32	ESK. OSMANGAZİ UNIV	44.6	48.00	25.05	58.04	44.73
U33	FIRAT UNIV	43.73	56.00	28.85	33.76	52.80
U34	SAKARYA UNIV	43.64	47.87	17.45	42.56	55.80
U35	ONDOKUZ MAYIS UNIV	42.84	49.13	25.80	43.84	48.38
U36	ACIBADEM M. ALİ AYD. UNIV	42.25	39.60	30.00	64.96	35.18
U37	ATATÜRK UNIV	41.86	53.47	35.45	41.92	40.65
U38	KADİR HAS UNIV	41.48	40.80	9.10	63.16	44.35
U39	SÜLEYMAN DEMİREL UNIV	40.71	44.40	18.15	47.00	46.68
U40	ABDULLAH GÜL UNIV	40.56	52.47	42.00	48.16	30.63
U41	SELÇUK UNIV	40.03	50.60	25.85	47.76	38.30
U42	İZMİR EKONOMİ UNIV	39.98	34.40	30.55	52.40	39.03

Table 7 (continued)

Univ. code	University name	Total score	Dimension			
			D1	D2	D3	D4
U43	KONYA TEKNİK UNIV	39.75	41.93	13.85	54.92	42.40
U44	BURSA TEKNİK UNIV	39.5	37.40	45.15	64.24	21.98
U45	ANKARA YIL. BEYAZIT UNIV	37.93	43.20	11.40	39.92	47.98
U46	ÇANKAYA UNIV	37.87	46.27	36.20	33.56	38.23
U47	PAMUKKALE UNIV	37.83	37.67	14.95	38.24	49.10
U48	İSTANBUL OKAN UNIV	37.61	28.93	17.40	45.56	46.00
U49	ÇAN. ONSEKİZ MART UNIV	36.43	35.93	20.30	35.88	45.05
U50	HASAN KALYONCU UNIV	36.27	35.60	24.00	0.76	64.85

Table 8 Normalization values, distance, and grey relational coefficients matrix

Univ. code	Normalization				Distance				Grey relational coefficient			
	D1	D2	D3	D4	D1	D2	D3	D4	D1	D2	D3	D4
U1	1.0000	0.8396	0.9413	1.0000	0.0000	0.1604	0.0587	0.0000	1.0000	0.7571	0.8950	1.0000
U2	0.9140	0.7717	1.0000	0.7903	0.0860	0.2283	0.0000	0.2097	0.8533	0.6865	1.0000	0.7045
U3	0.8862	0.6636	0.8874	0.8208	0.1138	0.3364	0.1126	0.1792	0.8146	0.5978	0.8161	0.7361
U4	0.6688	0.7309	0.7563	0.9567	0.3312	0.2691	0.2437	0.0433	0.6015	0.6501	0.6723	0.9202
U5	0.8812	0.6915	0.8428	0.6783	0.1188	0.3085	0.1572	0.3217	0.8080	0.6184	0.7608	0.6085
U6	0.9937	0.6410	0.7752	0.6533	0.0063	0.3590	0.2248	0.3467	0.9875	0.5821	0.6898	0.5905
U7	0.6485	0.4767	0.8291	0.7392	0.3515	0.5233	0.1709	0.2608	0.5872	0.4886	0.7453	0.6572
U8	0.6574	0.5789	0.7443	0.7099	0.3426	0.4211	0.2557	0.2901	0.5934	0.5428	0.6617	0.6328
U9	0.2857	1.0000	0.6968	0.5490	0.7143	0.0000	0.3032	0.4510	0.4118	1.0000	0.6225	0.5258
U10	0.6460	0.6087	0.8317	0.5057	0.3540	0.3913	0.1683	0.4943	0.5855	0.5610	0.7482	0.5028
U11	0.8900	0.3583	0.7143	0.6025	0.1100	0.6417	0.2857	0.3975	0.8197	0.4380	0.6364	0.5571
U12	0.6460	0.4825	0.7589	0.5236	0.3540	0.5175	0.2411	0.4764	0.5855	0.4914	0.6747	0.5121
U13	0.5752	0.3577	0.5987	0.6751	0.4248	0.6423	0.4013	0.3249	0.5407	0.4377	0.5548	0.6062
U14	0.7661	0.2031	0.6989	0.5642	0.2339	0.7969	0.3011	0.4358	0.6813	0.3855	0.6242	0.5343
U15	0.6852	0.4379	0.5970	0.4893	0.3148	0.5621	0.4030	0.5107	0.6137	0.4708	0.5537	0.4947
U16	0.6561	0.3913	0.5812	0.5267	0.3439	0.6087	0.4188	0.4733	0.5925	0.4510	0.5442	0.5137
U17	0.5942	0.6248	0.4552	0.4264	0.4058	0.3752	0.5448	0.5736	0.5520	0.5713	0.4786	0.4657
U18	0.2415	0.9127	0.5606	0.2437	0.7585	0.0873	0.4394	0.7563	0.3973	0.8513	0.5323	0.3980
U19	0.2491	0.4599	0.5345	0.5310	0.7509	0.5401	0.4655	0.4690	0.3997	0.4807	0.5179	0.5160
U20	0.3173	0.3047	0.6749	0.4701	0.6827	0.6953	0.3251	0.5299	0.4228	0.4183	0.6060	0.4855
U21	0.4994	0.2529	0.6771	0.4432	0.5006	0.7471	0.3229	0.5568	0.4997	0.4009	0.6076	0.4731
U22	0.2604	0.6223	0.5717	0.3729	0.7396	0.3777	0.4283	0.6271	0.4034	0.5696	0.5386	0.4436
U23	0.4791	0.3603	0.6505	0.3831	0.5209	0.6397	0.3495	0.6169	0.4898	0.4387	0.5886	0.4476
U24	0.1947	0.3739	0.5310	0.5416	0.8053	0.6261	0.4690	0.4584	0.3831	0.4440	0.5160	0.5217
U25	0.2073	0.6391	0.6171	0.2964	0.7927	0.3609	0.3829	0.7036	0.3868	0.5808	0.5663	0.4154

Table 8 (continued)

Univ. code	Normalization				Distance				Grey relational coefficient			
	D1	D2	D3	D4	D1	D2	D3	D4	D1	D2	D3	D4
U26	0.1201	0.5783	0.5152	0.4471	0.8799	0.4217	0.4848	0.5529	0.3623	0.5425	0.5077	0.4749
U27	0.4210	0.4036	0.5884	0.3932	0.5790	0.5964	0.4116	0.6068	0.4634	0.4560	0.5485	0.4518
U28	0.1795	0.3739	0.5473	0.4748	0.8205	0.6261	0.4527	0.5252	0.3787	0.4440	0.5248	0.4877
U29	0.3818	0.3648	0.6184	0.3514	0.6182	0.6352	0.3816	0.6486	0.4471	0.4405	0.5672	0.4353
U30	0.3856	0.3376	0.5255	0.4326	0.6144	0.6624	0.4745	0.5674	0.4487	0.4302	0.5131	0.4684
U31	0.2579	0.1307	0.5687	0.4857	0.7421	0.8693	0.4313	0.5143	0.4025	0.3651	0.5369	0.4930
U32	0.3616	0.2063	0.6133	0.3553	0.6384	0.7937	0.3867	0.6447	0.4392	0.3865	0.5639	0.4368
U33	0.5133	0.2555	0.3533	0.4815	0.4867	0.7445	0.6467	0.5185	0.5067	0.4018	0.4360	0.4909
U34	0.3590	0.1080	0.4475	0.5283	0.6410	0.8920	0.5525	0.4717	0.4382	0.3592	0.4751	0.5146
U35	0.3831	0.2160	0.4612	0.4123	0.6169	0.7840	0.5388	0.5877	0.4477	0.3894	0.4813	0.4597
U36	0.2023	0.2704	0.6874	0.2062	0.7977	0.7296	0.3126	0.7938	0.3853	0.4066	0.6153	0.3864
U37	0.4652	0.3409	0.4407	0.2917	0.5348	0.6591	0.5593	0.7083	0.4832	0.4314	0.4720	0.4138
U38	0.2250	0.0000	0.6681	0.3495	0.7750	1.0000	0.3319	0.6505	0.3922	0.3333	0.6010	0.4346
U39	0.2933	0.1171	0.4951	0.3858	0.7067	0.8829	0.5049	0.6142	0.4144	0.3616	0.4975	0.4487
U40	0.4463	0.4256	0.5075	0.1351	0.5537	0.5744	0.4925	0.8649	0.4745	0.4654	0.5038	0.3663
U41	0.4109	0.2167	0.5032	0.2550	0.5891	0.7833	0.4968	0.7450	0.4591	0.3896	0.5016	0.4016
U42	0.1037	0.2775	0.5529	0.2663	0.8963	0.7225	0.4471	0.7337	0.3581	0.4090	0.5279	0.4053
U43	0.2465	0.0614	0.5799	0.3190	0.7535	0.9386	0.4201	0.6810	0.3989	0.3476	0.5434	0.4234
U44	0.1606	0.4664	0.6797	0.0000	0.8394	0.5336	0.3203	1.0000	0.3733	0.4837	0.6095	0.3333
U45	0.2705	0.0298	0.4193	0.4061	0.7295	0.9702	0.5807	0.5939	0.4067	0.3401	0.4627	0.4571
U46	0.3287	0.3506	0.3512	0.2538	0.6713	0.6494	0.6488	0.7462	0.4269	0.4350	0.4352	0.4012
U47	0.1656	0.0757	0.4013	0.4237	0.8344	0.9243	0.5987	0.5763	0.3747	0.3510	0.4551	0.4645
U48	0.0000	0.1074	0.4797	0.3752	1.0000	0.8926	0.5203	0.6248	0.3333	0.3590	0.4900	0.4445
U49	0.1327	0.1449	0.3760	0.3604	0.8673	0.8551	0.6240	0.6396	0.3657	0.3690	0.4448	0.4388

Table 8 (continued)

Univ. code	Normalization				Distance				Grey relational coefficient			
	D1	D2	D3	D4	D1	D2	D3	D4	D1	D2	D3	D4
U50	0.1264	0.1928	0.0000	0.6697	0.8736	0.8072	1.0000	0.3303	0.3640	0.3825	0.3333	0.6022

Table 9 Positive, negative, and net outranking flow values (preference level)

Univ Code	W_{Eq}			W_{Ent}			W_{TUB}		
	ϕ_i^{net}	ϕ_i^+	ϕ_i^-	ϕ_i^{net}	ϕ_i^+	ϕ_i^-	ϕ_i^{net}	ϕ_i^+	ϕ_i^-
U1	0.964	0.980	0.015	0.948	0.972	0.025	0.970	0.984	0.013
U2	0.911	0.951	0.041	0.906	0.950	0.044	0.910	0.952	0.042
U3	0.858	0.921	0.064	0.823	0.906	0.082	0.873	0.932	0.059
U4	0.770	0.865	0.096	0.781	0.877	0.096	0.811	0.892	0.080
U5	0.797	0.882	0.085	0.802	0.890	0.088	0.779	0.872	0.093
U6	0.766	0.867	0.101	0.736	0.850	0.113	0.736	0.851	0.116
U7	0.652	0.802	0.149	0.565	0.757	0.192	0.702	0.833	0.131
U8	0.634	0.796	0.162	0.583	0.774	0.191	0.671	0.820	0.150
U9	0.420	0.682	0.262	0.616	0.790	0.173	0.468	0.703	0.235
U10	0.565	0.749	0.184	0.597	0.772	0.175	0.519	0.725	0.206
U11	0.492	0.720	0.228	0.314	0.617	0.303	0.498	0.729	0.231
U12	0.505	0.717	0.212	0.481	0.711	0.230	0.485	0.705	0.220
U13	0.282	0.605	0.324	0.145	0.526	0.381	0.349	0.639	0.290
U14	0.310	0.634	0.324	0.031	0.488	0.457	0.340	0.649	0.309
U15	0.286	0.614	0.327	0.264	0.608	0.344	0.231	0.582	0.350
U15	0.062	0.500	0.437	0.211	0.574	0.363	−0.026	0.450	0.476
U16	0.266	0.587	0.322	0.201	0.562	0.361	0.259	0.583	0.324
U18	−0.121	0.408	0.529	0.255	0.606	0.351	−0.248	0.347	0.595
U19	−0.004	0.456	0.460	0.078	0.504	0.426	0.081	0.498	0.417
U20	0.014	0.480	0.466	−0.060	0.452	0.512	0.064	0.501	0.436
U21	0.063	0.501	0.438	−0.065	0.441	0.506	0.045	0.489	0.444
U22	−0.071	0.412	0.483	0.166	0.538	0.372	−0.125	0.382	0.508
U23	0.037	0.481	0.444	0.038	0.474	0.436	−0.040	0.440	0.480
U24	−0.141	0.384	0.525	−0.117	0.394	0.511	−0.013	0.447	0.460
U25	−0.116	0.415	0.531	0.177	0.561	0.385	−0.190	0.381	0.571
U26	−0.218	0.361	0.579	−0.002	0.476	0.478	−0.157	0.389	0.546
U27	0.002	0.468	0.465	0.067	0.507	0.440	−0.064	0.429	0.493
U28	−0.201	0.356	0.557	−0.142	0.383	0.524	−0.111	0.402	0.513
U29	−0.089	0.414	0.502	−0.038	0.434	0.471	−0.163	0.377	0.541
U30	−0.152	0.384	0.536	−0.170	0.379	0.549	−0.157	0.380	0.537
U31	−0.270	0.320	0.591	−0.424	0.250	0.675	−0.170	0.370	0.541
U32	−0.229	0.345	0.574	−0.304	0.308	0.613	−0.272	0.322	0.594
U33	−0.212	0.371	0.584	−0.324	0.317	0.641	−0.202	0.372	0.574
U34	−0.287	0.322	0.608	−0.499	0.221	0.719	−0.184	0.370	0.554
U35	−0.343	0.292	0.635	−0.431	0.251	0.682	−0.342	0.291	0.633
U36	−0.366	0.289	0.654	−0.298	0.322	0.619	−0.422	0.266	0.688
U37	−0.333	0.309	0.642	−0.282	0.329	0.611	−0.453	0.251	0.704
U38	−0.422	0.257	0.679	−0.564	0.197	0.760	−0.395	0.270	0.665
U39	−0.471	0.229	0.700	−0.580	0.178	0.757	−0.458	0.232	0.690
U40	−0.252	0.358	0.609	−0.082	0.442	0.524	−0.427	0.273	0.700
U41	−0.438	0.251	0.689	−0.461	0.239	0.700	−0.542	0.199	0.741
U42	−0.565	0.193	0.758	−0.461	0.248	0.709	−0.577	0.185	0.762
U43	−0.508	0.215	0.723	−0.606	0.171	0.778	−0.517	0.216	0.732

Table 9 (continued)

Univ Code	W_{Eq}			W_{Ent}			W_{TUB}		
	ϕ_i^{net}	ϕ_i^+	ϕ_i^-	ϕ_i^{net}	ϕ_i^+	ϕ_i^-	ϕ_i^{net}	ϕ_i^+	ϕ_i^-
U44	−0.251	0.349	0.599	0.014	0.478	0.464	−0.342	0.307	0.649
U45	−0.581	0.180	0.762	−0.731	0.118	0.848	−0.530	0.204	0.734
U46	−0.501	0.219	0.720	−0.383	0.268	0.651	−0.603	0.168	0.771
U47	−0.648	0.153	0.800	−0.757	0.105	0.862	−0.546	0.199	0.745
U48	−0.695	0.128	0.823	−0.729	0.114	0.843	−0.616	0.159	0.775
U49	−0.728	0.110	0.838	−0.733	0.116	0.849	−0.677	0.131	0.807
U50	−0.445	0.256	0.702	−0.559	0.200	0.759	−0.223	0.367	0.590

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Declarations

Conflict of interest The authors confirm that there is no conflict of interest to declare for this study.

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