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Promoting Socio-Economic and Environmental Tourism Principles: A Decision Analytics Approach for Measuring Attractiveness Levels

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ABSTRACT

The purpose of this investigation is to construct a decision mechanism for determining sustainable tourism attractiveness levels. The main aim is to propose an integrated model that merges neutrosophic logic with decision-making techniques to evaluate sustainable tourism attractiveness. For this purpose, the Interval-Valued Neutrosophic based Ranking Comparison – Modified Preference Selection Index – Opportunity Losses-Based Polar Coordinate Distance hybrid method (IVN–RANCOM–MPSI–OPLO–POCOD) approach is developed. IVN-RANCOM determines the weights of subjective criteria, while IVN-MPSI assigns weights to objective criteria. The OPLO-POCOD method is used to identify and rank how attractive each province is for sustainable tourism. The applicability of the hybrid neutrosophic decision analytics approach is tested in seven provinces located in the Eastern Black Sea region of Türkiye. By applying the hybrid method, the sustainable tourism attractiveness levels of these provinces are determined. The findings indicate that Rize Province has the highest level of sustainable tourism attractiveness. The most significant criteria identified in this study are "highland tourism centers", "number of blue flag beaches", and "number of festivals". Robustness and consistency analyses are presented, along with implications for both industry and academia.

1. Introduction

In recent years, the tourism industry has increasingly adopted sustainable practices, showing greater awareness of its environmental and social impacts [1,2]. The diffusion of the sustainable

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tourism concept represents a significant milestone in tourism studies and in the effective transfer of academic knowledge to the industry [3]. The core components of sustainable tourism cover environmental, economic, social, cultural, and political factors [4]. Within this context, numerous studies in academic literature have extensively examined the environmental dimension [5], the community aspect [6], and the economic component of sustainable tourism [7], exploring these interrelationships in depth. Similarly, the intellectual foundations of the sustainable tourism concept remain a dominant topic of discourse across academia, economics, politics, and governance [8]. In the past 25 years, scholarly publications on sustainable tourism have risen by nearly 20% [9]. In addition, studies on sustainable tourism have been conducted at macro, meso, and micro levels, synthesizing studies related to the topic [10]. Businesses operating in the tourism sector should actively promote environmentally sustainable behaviors among tourists, emphasizing both individual responsibilities and practical measures necessary for sustainable practices [11]. However, gaps and uncertainties persist in the existing literature concerning the perceived attractiveness of sustainable tourism.

Despite its conceptual abstraction, tourism attractiveness can be measured in comparing destinations and evaluating competitive performance [12]. Tourism attractiveness is often considered an important factor in assessing how appealing a destination is [13]. Furthermore, evaluating tourism attractiveness allows destinations to identify and strengthen their weaker aspects within the framework of sustainable tourism [14]. It emphasized that tourism attractiveness is usually based on five main dimensions: “natural, social, historical, recreational, and infrastructural features” [15]. Additionally, the inclusion of price level and visitor satisfaction expands these dimensions to a total of seven [12]. It is indicated that tourism attractiveness is shaped by both the availability of resources and tourists’ perceived values [16].

In 2023, international tourism recovered strongly, reaching 1.3 billion arrivals after three years of COVID-19 travel restrictions. During this period, destinations worldwide generated USD 1.5 trillion in international tourism receipts, while total tourism revenue amounted to USD 3.4 trillion, contributing 3% to the global gross domestic product [17]. Destination attractiveness shows how tourists think a place can meet their needs and make them satisfied [18]. The elements of destination attractiveness encompass “natural, man-made, artificial, purpose-built, heritage, and special event-related features” [19]. However, the short-term profit-driven approach adopted by stakeholders in the tourism sector may lead to irreversible damage to tourism resources, ultimately undermining the potential long-term benefits of tourism. Consequently, sustainability has emerged as a critical concern for destination managers in response to the rapid global growth of tourism.

Like in other regions, tourism stakeholders in the studied destinations must follow sustainable tourism principles to reduce the negative effects of tourism activities. Sustainable tourism entails utilizing tourism resources in a manner that ensures their continued social, cultural, economic, and environmental viability [20]. Sustainable tourism should address the fundamental needs of marginalized groups within local tourist destinations, contributing to the reduction of inequality and absolute poverty. Simultaneously, it should empower local communities by fostering self-esteem and providing opportunities to escape poverty and ignorance. Furthermore, sustainable tourism should stimulate national, regional, and local economic growth while ensuring that this growth is equitably distributed across different social groups [21]. In this context, assessing the attractiveness of tourism destinations and ensuring their sustainability remains essential for the tourism industry.

In research on sustainable tourism attractiveness, both qualitative and quantitative analytical methods have been employed. Specifically, clustering and multiple regression analyses using key indicators from 2000 to 2020 have been conducted to examine sustainability as a determinant of tourism attractiveness [22]. These findings emphasize the role of attractiveness factors in the advancement of sustainable tourism.

This study is principally motivated by the objective of developing a decision support system (DSS) that utilizes quantitative analytical techniques to systematically assess and determine levels of sustainable tourism attractiveness. Accordingly, the main aim of this study is to propose a tool that facilitates the evaluation of sustainable tourism attractiveness across provinces, through the development of a comprehensive model that combines qualitative insights with quantitative metrics. This motivation is driven not only by the need to raise awareness regarding the current sustainable tourism attractive levels of tourism destinations but also by the aim of guiding sustainable tourism investments.

To achieve this objective, the Interval-Valued Neutrosophic based Ranking Comparison – Modified Preference Selection Index – Opportunity Losses-Based Polar Coordinate Distance hybrid method (IVN–RANCOM–MPSI–OPLO-POCOD) is developed. There are different types of neutrosophic sets in literature [23,24]. In this study, IVN set operations are utilized. This hybrid approach integrates IVN sets [25] within a fuzzy framework to improve the multi-criteria decision-making (MCDM) process. The evaluation of provinces' sustainable tourism attractiveness levels based on qualitative parameters is conducted through linguistic evaluations using IVN sets. Additionally, IVN numbers are employed to catch the impact levels of experts.

The determination of the importance levels of qualitative and quantitative criteria is conducted through both weighting approaches (subjective and objective). The RANCOM method [26], developed based on IVN sets, is proposed for subjective approach. The MPSI method [27], also based on IVN sets, is suggested for objective criteria weighting. By considering both approaches equally, the final criterion weights are obtained. These weights are then used to determine the sustainable tourism attractiveness levels of the provinces using the OPLO-POCOD method [28].

As a result, the IVN-RANCOM-MPSI-OPLO-POCOD hybrid method, which integrates multiple approaches within a comprehensive framework, offers an optimal decision-making process for assessing sustainable tourism attractiveness levels.

1.1 Study Aims

This study aims to develop a DSS to measure sustainable tourism attractiveness in provinces. This DSS utilizes expert opinions and MCDM methods, as determining sustainable tourism attraction levels is a typical decision process. The sub-objectives of the study are as follows:

i. *Expert approach and quantitative data integration* – To offer a method that combines expert opinions and numerical data to assess sustainable tourism attractiveness levels.
ii. *Criterion weight calculation* – The study combines subjective IVN-RANCOM and objective IVN-MPSI methods to calculate final criterion weights, providing a comprehensive weighting approach.
iii. *Sustainable tourism attraction scores* – The study uses the OPLO-POCOD method to obtain and rank sustainable tourism attraction scores for provinces.
iv. *Applicability to the case study* – The hybrid method is used in a case study to evaluate the sustainable tourism attractiveness of seven provinces in Türkiye’s Eastern Black Sea region.
v. *Case study evaluation* – The case study model involves eight experts, seven qualitative criteria, and ten quantitative criteria. The qualitative criteria include aspects such as the attitudes and behaviors of the local population towards tourists, architectural and

infrastructure aspects of tourism areas, as well as conservation levels. Quantitative criteria include factors such as sunshine duration, temperature, and the number of tourism-related facilities.

1.2 Study Contributions

This study makes important contributions to sustainable tourism and MCDM methods. These are outlined as follows:

i. *Development of the DSS* – The study helps develop a comprehensive DSS to evaluate the sustainable tourism attractiveness levels of provinces. The system integrates expert opinions and MCDM methods to provide an effective tool for decision-makers in tourism management.
ii. *Integration of expert opinions and quantitative data* – The study presents a new method that combines expert opinions with quantitative data. This hybrid approach makes decision-making more reliable and complete when assessing sustainable tourism attractiveness.
iii. *Methodological innovation in MCDM* – The paper introduces the IVN-RANCOM-MPSI-OPLO-POCOD hybrid method, combining different MCDM techniques such as IVN sets, RANCOM, MPSI, and OPLO-POCOD to create an innovative decision-making framework. This methodology advances the field by incorporating neutrosophic logic applications and expert evaluations based on linguistic expressions.
iv. *Dual criterion weighting approaches* – A key contribution of this research is combining subjective and objective methods to weight criteria. To achieve this, the study applies IVN-RANCOM for capturing subjective judgments and IVN-MPSI for deriving objective weights, offering a robust and holistic framework for evaluating the significance of diverse criteria in sustainable tourism.
v. *Sustainable tourism attraction scoring* – Through the OPLO-POCOD method, the study systematically calculates and ranks the sustainable tourism attractiveness of provinces. This ranking is essential for identifying regions with the highest tourism potential and can guide future tourism development efforts.
vi. *Contribution to the tourism industry* – The findings and methodology offer significant practical contributions to the tourism industry, particularly in regions looking to assess and improve their tourism attractiveness. The DSS and the developed hybrid method provide actionable insights for stakeholders in tourism management.
vii. *Validation and sensitivity analysis* – The results of the study were checked with sensitivity analysis to ensure they are reliable. Using three sensitivity analyses improves the reliability of the results and supports the use of the method for sustainable tourism assessment.
viii. *Implications for tourism management and policy* – The study offers useful information for tourism stakeholders and governments. It offers a framework for assessing tourism sustainability, which can be used to guide strategic planning and policy decisions to enhance sustainable tourism practices in various provinces.

These contributions collectively provide a novel and practical approach for assessing sustainable tourism attraction levels and integrating diverse criteria. The rest of the paper is organized as follows: Section 2 presents the literature review. Section 3 provides information on the methodology. Section

4 presents the case study application for the Eastern Black Sea region of Türkiye, based on the proposed method. Section 5 discusses the research results and presents the implications. Finally, Section 6 concludes the paper with the conclusion section.

2. Literature Review

The tourism literature extensively incorporates fuzzy sets alongside MCDM methods to address various decision-making challenges in the sector. Several studies have demonstrated the applicability of these approaches in different tourism-related contexts. For example, fuzzy AHP has been used to address the problem of selecting locations for international tourist hotels [29]. The fuzzy DEMATEL method, which combines geographic information systems (GIS) with MCDM techniques, has been applied for ecotourism [30]. In medical tourism, MABAC-AHP methods have been used for the selection and evaluation of medical tourism areas, while fuzzy SWARA based PROMETHEE methods have been applied to rank sustainable medical tourism destinations [31].

Additionally, an innovative MCDM approach has been proposed to address issues related to q-ROF knowledge, considering thermodynamic parameters such as energy, exergy (work potential), and entropy in the context of low-carbon tourism destination selection [32]. A hybrid model comprising gray based MCDM methods have been developed to evaluate personnel performance within the tourism sector [33]. Another study has introduced a fuzzy-based hybrid model that integrates Entropy, the Gini coefficient, and TOPSIS methods to balance constructability during the development of tourist attraction centers [34].

In sustainable tourism, fuzzy AHP and fuzzy TOPSIS methods have been used to evaluate the feasibility of sustainable tourism in a green economy framework [35]. The VIKOR method has been utilized for designing trails and optimizing the spatial distribution in semi-mountainous and mountainous areas [36]. A hybrid model using Data Envelopment Analysis and AHP methods has been developed to address the candidate selection problem in sustainable and green tourism [37]. Furthermore, a GIS-based hybrid model with fuzzy AHP methods has been used for suitability assessment in geothermal tourism areas [38]. Fuzzy TOPSIS methods have also been implemented in destination recommendation systems to enhance tourist experiences [39].

Recent studies have also introduced several advanced aggregation operators and decision-making models to address environmental and ecological challenges in tourism. For instance, "the dependent hesitant fuzzy linguistic geometric Bonferroni mean (DHFLGBM)" operator has been proposed to evaluate the environmental carrying capacity of ecotourism areas [40]. In the context of forest ecotourism, two aggregation operators based on IVIFWDHM and IVIFWDGHM have been developed for ecological assessments of forest ecotourism demonstration areas [41].

Furthermore, an MCDM model integrating FUCOM and fuzzy MARCOS methods has been utilized to evaluate the status of spa centers within medical tourism [42]. An integrated model combining SWARA and MULTIMOORA methods under "interval-valued Pythagorean fuzzy sets (IVPFS)" has been introduced to assess sustainable tourism performance [43]. Finally, modified fuzzy AHP-MAIRCA methods have been used to evaluate how overtourism affects local communities after COVID-19 [44]. These innovative approaches highlight the ongoing evolution and refinement of fuzzy-based MCDM methods in tourism research. A literature review on MCDM research is presented in Table 1.

In the second phase of the literature review, studies utilizing neutrosophic sets, criterion weighting methods, and alternative ranking methods that constitute the IVN-RANCOM-MPSI-OPLO-POCOD hybrid method are examined. The IVN-VIKOR method is applied to the terminal location selection problem [45]. Additionally, an application of energy planning utilizing the neutrosophic AHP approach is discussed [46]. The extended IVN-EDAS method is introduced, utilizing sustainable development goals to assess and guide decision-making processes in complex scenarios [47]. Broumi *et al.* [48] proposed a decision-making method using interval-valued pentapartitioned neutrosophic (IVPN) sets and showed its use with a numerical example.

Table 1
Literature reviews on the tourism industry with MCDM methods

Studies	Methods	Topic
Chou *et al.* [29]	Fuzzy AHP	Selection of international tourist hotel locations
Gigović *et al.* [30]	Fuzzy DEMATEL	Sustainable development of ecotourism
Ghasemi *et al.* [31]	Fuzzy SWARA-PROMETHEE	Ranking of sustainable medical tourism destinations
Zhang *et al.* [32]	q-ROF	Selection of low-carbon tourism destinations
Genç *et al.* [33]	Gray AHP, MOORA, MAUT	Evaluation of personnel performance in the tourism sector
Huang *et al.* [34]	Fuzzy Entropy-TOPSIS	Evaluation of the construction of tourist attraction centers
Li *et al.* [35]	Fuzzy AHP-TOPSIS	Evaluation of sustainable tourism
Kolkos *et al.* [36]	VIKOR	Evaluation of development in semi-mountainous and mountainous areas
Langović *et al.* [37]	DEA-AHP	Selection for sustainable and green tourism
Islam *et al.* [38]	GIS-Fuzzy AHP	Assessment of geothermal tourism areas
Buasri & Sangpradid [39]	Fuzzy TOPSIS	Evaluation for enhancing tourist experience
Liu & Wang [40]	DHFLGBM	Environmental carrying capacity of ecotourism
Wu *et al.* [41]	IVIFWDHM, IVIFWDGHM	Ecological assessment of forest ecotourism areas
Mijajlovic *et al.* [42]	FUCOM, F-MARCOS	Evaluation of spa centers in medical tourism
He *et al.* [43]	SWARA, MULTIMOORA	Evaluation of sustainable community-based tourism
García Mestanza & Bakhat [44]	Fuzzy AHP-MAIRCA	Evaluation of over-tourism Post-COVID-19

The RANCOM method [26] integrated with various methods in the literature. RANCOM has been shown to give more reliable and consistent results than AHP, especially when there are many criteria. In addition, the efficient weights similarity coefficient is proposed as a metric to assess and compare the relative performance of various subjective weighting approaches, enabling a systematic evaluation of AHP and RANCOM results [49]. A case example of housing location selection problems demonstrates the integration of criterion weights determined by both methods, which are then used in hybrid MCDM methods [50]. The importance of determining expert-based criterion weights to reduce the complexities in decision-making processes and minimize potential errors in expert judgments is emphasized. Consequently, The study shows that the RANCOM method is effective in solving complex problems. A hybrid DSS consisting of RANCOM and ESP-SPOTIS methods is applied to solve the electric vehicle selection problem [51], while the IVIF-RANCOM-WISP DSS is employed for the location selection of offshore wind power plants [52]. Also, a hybrid IF-RCC-RANCOM-MACONT DSS is proposed for evaluating the logistics activities in the agriculture-food sector [53].

The DSS consisting of MPSI-MARA methods is applied to the selection problem of underground mine development support systems [27]. Other studies include the evaluation of the multi-branch banks using MPSI-MARA methods [54], the selection of unmanned aerial vehicles using MPSI-SPOTIS methods [55], and the sustainability performance of deposit banks using a hybrid model that includes MSD-MPSI-RAWEC methods [56].

The MPSI-RAPS method is used to assess the ICT levels of 14 countries [57], and the implementation of the MPSI-ARLON method is used to compute supply chain performance [23]. The IVSF-MPSI-ERUNS approach is used to evaluate sustainable digital transformation maturity performance of universites [58]. The OPLO-POCOD method [28], a new method with limited application in literature, has been used in limited studies, including customer ranking for businesses and stock fund evaluations [59]. A literature review on MCDM research used in this research is shown in Table 2.

Table 2
Literature reviews on studies utilizing neutrosophic sets as well as the related criterion weighting and alternative ranking methods

Studies	Methods	Topic
Kara *et al.* [23]	MPSI-ARLON	Evaluation of supply chain performance
Więckowski *et al.* [26]	RANCOM	Developing a novel criteria weighting method
Gligorić *et al.* [27]	MPSI-MARA	Selection of an underground mine
Sheikh & Senfi [28]	OPLO-POCOD	Evaluation of businesses and stock fund
Bausys & Zavadskas [45]	IVN-VIKOR	Selection of logistics terminal location
Bolturk & Kahraman [46]	IVN-AHP	Evaluation of energy planning application
Karaşan & Kahraman [47]	IVN-EDAS	Evaluation of sustainable development goals
Broumi *et al.* [48]	IVPN	Numerical example
Shekhovtsov [49]	AHP, RANCOM	Evaluating performance of weighting methods
Więckowski *et al.* [50]	AHP, RANCOM	Selection of housing location
Więckowski *et al.* [51]	RANCOM, ESP-SPOTIS	Selection of electric vehicle
Rani *et al.* [52]	IVIF-RANCOM-WISP	Selection of the offshore wind power plant's location.
Mishra *et al.* [53]	IF-RCC-RANCOM-MACONT	Evaluation of logistics activities in the agriculture sector
Yılmaz [54]	MPSI-MARA	Evaluation of financial performance
Torres *et al.* [55]	MPSI-SPOTIS	Selection of unmanned aerial vehicles
Akbulut & Aydın [56]	MSD-MPSI-RAWEC	Evaluation of deposit banks
Sheikh & Senfi [59]	OPLO-POCOD	Developing a novel alternative ranking method
Babaçoğlu *et al.* [58]	IVSF-MPSI-ERUNS	Evaluation of digital maturity performance

3. Methodology Framework

The IVN-RANCOM-MPSI-OPLO-POCOD hybrid method is proposed in this paper to determine sustainable tourism attractiveness levels. This hybrid method serves as the methodological approach of the study, providing the DSS that operates across five stages. In *Stage 1*, experts are identified based on their experience using IVN sets. In *Stage 2*, subjective weights are calculated using IVN-RANCOM. In *Stage 3*, objective weights are calculated using the IVN-MPSI method. In *Stage 4*, the criterion weights from IVN-RANCOM and IVN-MPSI are combined. Finally, in *Stage 5*, the OPLO-POCOD method is used to rank the sustainable tourism attractiveness levels of the provinces. The sub-steps of the IVN-RANCOM-MPSI-OPLO-POCOD hybrid method are illustrated in Figure 1.

3.1 Preliminaries of Interval-valued Neutrosophic Sets

Definition 1. In the context of the universe $\mathfrak{O}$, the fuzzy set $\widetilde{\mathfrak{N}}$ is defined as an IVN set. The set $\widetilde{\mathfrak{N}}$ is formulated as $\widetilde{\mathfrak{N}} = \left\{\langle \rho, \left[T^L_{\widetilde{\mathfrak{N}}}(\rho), T^U_{\widetilde{\mathfrak{N}}}(\rho)\right], \left[I^L_{\widetilde{\mathfrak{N}}}(\rho), I^U_{\widetilde{\mathfrak{N}}}(\rho)\right], \left[F^L_{\widetilde{\mathfrak{N}}}(\rho), F^U_{\widetilde{\mathfrak{N}}}(\rho)\right] \mid \rho \in \mathrm{P}\rangle\right\}$. Here, the value $T^L_{\widetilde{\mathfrak{N}}}(\rho)$ represents a lower level of truth membership, the value $T^U_{\widetilde{\mathfrak{N}}}(\rho)$ represents upper level of truth membership, $I_{\widetilde{\mathfrak{N}}}^{L}(\rho)$ denotes a lower level of indeterminacy membership, $I_{\widetilde{\mathfrak{N}}}^{U}(\rho)$ denotes upper level of indeterminacy membership, $F_{\widetilde{\mathfrak{N}}}^{L}(\rho)$ corresponds to a lower level of falsity membership, $F_{\widetilde{\mathfrak{N}}}^{U}(\rho)$ corresponds to an upper level of falsity membership, with $0 \leq T_{\widetilde{\mathfrak{N}}}^{L}(\rho) \leq T_{\widetilde{\mathfrak{N}}}^{U}(\rho) \leq 1$, $0 \leq I_{\widetilde{\mathfrak{N}}}^{L}(\rho) \leq I_{\widetilde{\mathfrak{N}}}^{U}(\rho) \leq 1$, and $0 \leq F_{\widetilde{\mathfrak{N}}}^{L}(\rho) \leq F_{\widetilde{\mathfrak{N}}}^{U}(\rho) \leq 1$ within the universal set P. Also, it is crucial to highlight that these functions adhere to specific conditions regulating their behavior within the established theoretical framework: $0 \leq T_{\widetilde{\mathfrak{N}}}^{L}(\rho) + I_{\widetilde{\mathfrak{N}}}^{L}(\rho) + F_{\widetilde{\mathfrak{N}}}^{L}(\rho) \leq 3$ and $0 \leq T_{\widetilde{\mathfrak{N}}}^{U}(\rho) + I_{\widetilde{\mathfrak{N}}}^{U}(\rho) + F_{\widetilde{\mathfrak{N}}}^{U}(\rho) \leq 3$ [25,60].

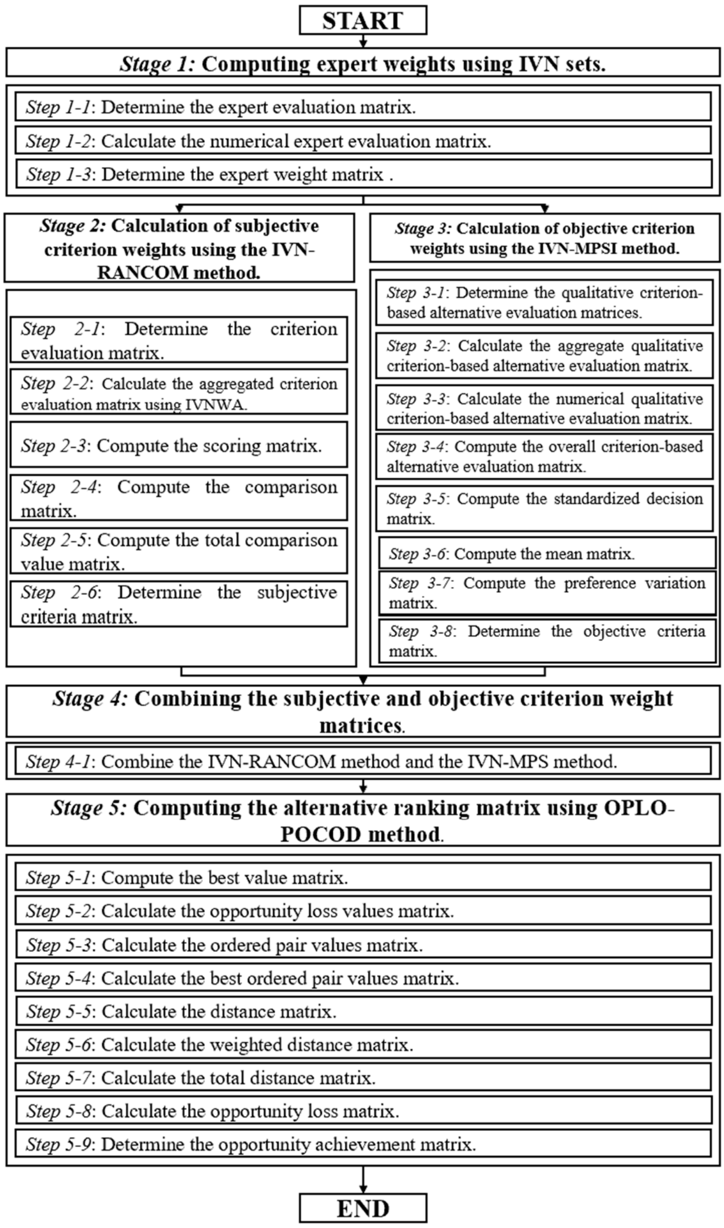

Fig. 1. Framework of the IVN-RANCOM-MPSI-OPLO-POCOD hybrid method

Definition 2. Consider that $\widetilde{\mathfrak{N}}_1$ and $\widetilde{\mathfrak{N}}_2$ are two IVN sets within the universe P. The operations between these two IVN sets are shown below [25,61]:

(i) $$\tilde{\mathfrak{N}}_1 \oplus \tilde{\mathfrak{N}}_2 = \left\{ \begin{pmatrix} \left[\left(T^L_{\tilde{\mathfrak{N}}_1}(\rho) + T^L_{\tilde{\mathfrak{N}}_2}(\rho) - \left(T^L_{\tilde{\mathfrak{N}}_1}(\rho)T^L_{\tilde{\mathfrak{N}}_2}(\rho)\right)\right), \left(T^U_{\tilde{\mathfrak{N}}_1}(\rho) + T^U_{\tilde{\mathfrak{N}}_2}(\rho) - \left(T^U_{\tilde{\mathfrak{N}}_1}(\rho)T^U_{\tilde{\mathfrak{N}}_2}(\rho)\right)\right)\right], \\ \left[\left(I^L_{\tilde{\mathfrak{N}}_1}(\rho)I^L_{\tilde{\mathfrak{N}}_2}(\rho)\right), \left(I^U_{\tilde{\mathfrak{N}}_1}(\rho)I^U_{\tilde{\mathfrak{N}}_2}(\rho)\right)\right], \\ \left[\left(F^L_{\tilde{\mathfrak{N}}_1}(\rho)F^L_{\tilde{\mathfrak{N}}_2}(\rho)\right), \left(F^U_{\tilde{\mathfrak{N}}_1}(\rho)F^U_{\tilde{\mathfrak{N}}_2}(\rho)\right)\right] \end{pmatrix} \mid \rho \in \mathrm{P} \right\},$$

(ii) $$\tilde{\mathfrak{N}}_1 \otimes \tilde{\mathfrak{N}}_2 = \left\{ \begin{pmatrix} \left[\left(T^L_{\tilde{\mathfrak{N}}_1}(\rho)T^L_{\tilde{\mathfrak{N}}_2}(\rho)\right), \left(T^U_{\tilde{\mathfrak{N}}_1}(\rho)T^U_{\tilde{\mathfrak{N}}_2}(\rho)\right)\right], \\ \left[\left(I^L_{\tilde{\mathfrak{N}}_1}(\rho) + I^L_{\tilde{\mathfrak{N}}_2}(\rho) - \left(I^L_{\tilde{\mathfrak{N}}_1}(\rho)I^L_{\tilde{\mathfrak{N}}_2}(\rho)\right)\right), \left(I^U_{\tilde{\mathfrak{N}}_1}(\rho) + I^U_{\tilde{\mathfrak{N}}_2}(\rho) - \left(I^U_{\tilde{\mathfrak{N}}_1}(\rho)I^U_{\tilde{\mathfrak{N}}_2}(\rho)\right)\right)\right], \\ \left[\left(F^L_{\tilde{\mathfrak{N}}_1}(\rho) + F^L_{\tilde{\mathfrak{N}}_2}(\rho) - \left(F^L_{\tilde{\mathfrak{N}}_1}(\rho)F^L_{\tilde{\mathfrak{N}}_2}(\rho)\right)\right), \left(F^U_{\tilde{\mathfrak{N}}_1}(\rho) + F^U_{\tilde{\mathfrak{N}}_2}(\rho) - \left(F^U_{\tilde{\mathfrak{N}}_1}(\rho)F^U_{\tilde{\mathfrak{N}}_2}(\rho)\right)\right)\right] \end{pmatrix} \mid \rho \in \mathrm{P} \right\},$$

(iii) $$\alpha\tilde{\mathfrak{N}}_1 = \left\{ \begin{pmatrix} \left[\left(1 - \left(1 - T^L_{\tilde{\mathfrak{N}}_1}(\rho)\right)^\alpha\right), \left(1 - \left(1 - T^U_{\tilde{\mathfrak{N}}_1}(\rho)\right)^\alpha\right)\right] \\ \left[\left(I^L_{\tilde{\mathfrak{N}}_1}(\rho)\right)^\alpha, \left(I^U_{\tilde{\mathfrak{N}}_1}(\rho)\right)^\alpha\right] \\ \left[\left(F^L_{\tilde{\mathfrak{N}}_1}(\rho)\right)^\alpha, \left(F^U_{\tilde{\mathfrak{N}}_1}(\rho)\right)^\alpha\right] \end{pmatrix} \mid \rho \in \mathrm{P} \right\} \text{ for } \alpha > 0,$$

(iv) $$\tilde{\mathfrak{N}}_1{}^\alpha = \left\{ \begin{pmatrix} \left[\left(T^L_{\tilde{\mathfrak{N}}_1}(\rho)\right)^\alpha, \left(T^U_{\tilde{\mathfrak{N}}_1}(\rho)\right)^\alpha\right], \\ \left[\left(1 - \left(1 - I^L_{\tilde{\mathfrak{N}}_1}(\rho)\right)^\alpha\right), \left(1 - \left(1 - I^U_{\tilde{\mathfrak{N}}_1}(\rho)\right)^\alpha\right)\right] \\ \left[\left(1 - \left(1 - F^L_{\tilde{\mathfrak{N}}_1}(\rho)\right)^\alpha\right), \left(1 - \left(1 - F^U_{\tilde{\mathfrak{N}}_1}(\rho)\right)^\alpha\right)\right] \end{pmatrix} \mid \rho \in \mathrm{P} \right\} \text{ for } \alpha > 0.$$

Consistent with the specifications outlined by Arshi *et al.* [61], *Definition 2* is required to meet the following criteria:

(i) $\tilde{\mathfrak{N}}_1 \oplus \tilde{\mathfrak{N}}_2 = \tilde{\mathfrak{N}}_2 \oplus \tilde{\mathfrak{N}}_1$,

(ii) $\tilde{\mathfrak{N}}_1 \otimes \tilde{\mathfrak{N}}_2 = \tilde{\mathfrak{N}}_2 \otimes \tilde{\mathfrak{N}}_1$,

(iii) $\alpha(\tilde{\mathfrak{N}}_1 \oplus \tilde{\mathfrak{N}}_2) = \alpha\tilde{\mathfrak{N}}_1 \oplus \alpha\tilde{\mathfrak{N}}_2$ for $\alpha > 0$,

(iv) $(\tilde{\mathfrak{N}}_1 \otimes \tilde{\mathfrak{N}}_2)^\alpha = \tilde{\mathfrak{N}}_1{}^\alpha \otimes \tilde{\mathfrak{N}}_2{}^\alpha$ for $\alpha > 0$,

(v) $\alpha_1\tilde{\mathfrak{N}}_1 \oplus \alpha_2\tilde{\mathfrak{N}}_1 = (\alpha_1 + \alpha_2)\tilde{\mathfrak{N}}_1$ for $\alpha_1, \alpha_2 > 0$,

(vi) $\tilde{\mathfrak{N}}_1{}^{\alpha_1} \otimes \tilde{\mathfrak{N}}_1{}^{\alpha_2} = \tilde{\mathfrak{N}}_1{}^{(\alpha_1+\alpha_2)}$ for $\alpha_1, \alpha_2 > 0$.

Definition 3. Let assume that $\tilde{\mathfrak{N}}_1$ is IVN set within the universe $\mathfrak{O}$. The score function $\left(Sc(\tilde{\mathfrak{N}}_1)\right)$ is computed by engaging Eq. (1) [60]. In Eq. (1), 1 is added to the score function to eliminate negative values.

$$Sc(\tilde{\mathfrak{N}}_1) = \frac{\left(2 + T^L_{\tilde{\mathfrak{N}}_1}(\rho) + T^U_{\tilde{\mathfrak{N}}_1}(\rho) - 2I^L_{\tilde{\mathfrak{N}}_1}(\rho) - 2I^U_{\tilde{\mathfrak{N}}_1}(\rho) - F^L_{\tilde{\mathfrak{N}}_1}(\rho) - F^U_{\tilde{\mathfrak{N}}_1}(\rho)\right)}{4} + 1; Sc(\tilde{\mathfrak{N}}_1) \in [0,2]. \quad (1)$$

Definition 4. Let assume that $\tilde{\mathfrak{N}}_1$ and $\tilde{\mathfrak{N}}_2$ are two IVN sets within the universe $\mathfrak{O}$. The score functions can be shown as $Sc(\tilde{\mathfrak{N}}_1)$ and $Sc(\tilde{\mathfrak{N}}_2)$, respectively. The relationship between $\tilde{\mathfrak{N}}_1$ and $\tilde{\mathfrak{N}}_2$ can be shown as follows:

(i) If $Sc(\tilde{\mathfrak{N}}_1) > Sc(\tilde{\mathfrak{N}}_2)$, then $\tilde{\mathfrak{N}}_1 > \tilde{\mathfrak{N}}_2$.

(ii) If $Sc(\tilde{\mathfrak{N}}_1) > Sc(\tilde{\mathfrak{N}}_2)$ then $\tilde{\mathfrak{N}}_1 > \tilde{\mathfrak{N}}_2$.

(iii) If $Sc(\tilde{\mathfrak{N}}_1) = Sc(\tilde{\mathfrak{N}}_2)$ then $\tilde{\mathfrak{N}}_1 = \tilde{\mathfrak{N}}_2$.

Definition 5. Consider that $\tilde{\mathfrak{N}}_q = \left\{\langle\rho, \left[T^L_{\tilde{\mathfrak{N}}_q}(\rho), T^U_{\tilde{\mathfrak{N}}_q}(\rho)\right], \left[I^L_{\tilde{\mathfrak{N}}_q}(\rho), I^U_{\tilde{\mathfrak{N}}_q}(\rho)\right], \left[F^L_{\tilde{\mathfrak{N}}_q}(\rho), F^U_{\tilde{\mathfrak{N}}_q}(\rho)\right] \mid \rho \in \mathrm{P}\rangle\right\}$ with $q = \{1,2, \ldots, Q\}$ are IVN sets within the universal set P. The IVNWA aggregation operator can be calculated by engaging Eq. (2) [62]:

$$IVNWA\left(\widetilde{\mathfrak{N}}_1, \widetilde{\mathfrak{N}}_2, \ldots, \widetilde{\mathfrak{N}}_q, \ldots, \widetilde{\mathfrak{N}}_Q\right) = \oplus_{q=1}^{Q} \varpi_q \widetilde{\mathfrak{N}}_q = \left\{ \left(\begin{array}{c} \left[1-\prod_{q=1}^{Q}\left(1-T_{\widetilde{\mathfrak{N}}_q}^{L}(\rho)\right)^{\varpi_q}, 1-\prod_{q=1}^{Q}\left(1-T_{\widetilde{\mathfrak{N}}_q}^{U}(\rho)\right)^{\varpi_q}\right], \\ \left[\prod_{q=1}^{Q}\left(F_{\widetilde{\mathfrak{N}}_q}^{L}(\rho)\right)^{\varpi_q}, \prod_{q=1}^{Q}\left(F_{\widetilde{\mathfrak{N}}_q}^{U}(\rho)\right)^{\varpi_q}\right], \\ \left[\prod_{q=1}^{Q}\left(I_{\widetilde{\mathfrak{N}}_q}^{L}(\rho)\right)^{\varpi_q}, \prod_{q=1}^{Q}\left(I_{\widetilde{\mathfrak{N}}_q}^{U}(\rho)\right)^{\varpi_q}\right] \end{array} \right) \mid \rho \in \mathrm{P} \right\}, \tag{2}$$

herein, ϖ represents the corresponding weight vector where $\varpi_q \epsilon [0,1]$ within $\sum_{q=1}^{Q} \varpi_q = 1$.

3.2 Novel IVN-RANCOM-MPSI-OPLO-POCOD Hybrid Method

In IVN-RANCOM-MPSI-OPLO-POCOD, the decision model encompasses experts $\left(\iota = \{\iota_1, \iota_2, \ldots, \iota_g, \ldots, \iota_G\}\ (g = 1,2, \ldots, G)\right)$, qualitative criteria $(\pi = \{\pi_1, \pi_2, \ldots, \pi_h, \ldots, \pi_H\}\ (h = 1,2, \ldots, H))$, quantitative criteria $\left(\lambda = \{\lambda_1, \lambda_2, \ldots, \lambda_j, \ldots, \lambda_J\}\ (j = 1,2, \ldots, J)\right)$, overall criteria $\left(\mu = \{\mu_1, \mu_2, \ldots, \mu_k, \ldots, \mu_K\}\ (k = 1,2, \ldots, K); (H + J = K)\right)$, and alternatives $\left(\nu = \{\nu_1, \nu_2, \ldots, \nu_f, \ldots, \nu_F\}\ (f = 1,2, \ldots, F)\right)$. The experts combine the qualitative criteria using the IVNWA operator. This hybrid method is conducted in five stages. The steps are as follows:

- ***Stage 1*** *– Computing expert weights using IVN sets*.

Step 1-1: Initially, Table 3 is used to define the expertise levels. Then, these expertise levels are converted into IVN sets $\left(\widetilde{\mathfrak{P}} = [\widetilde{\mathfrak{P}}_g]_G\right)$.

Table 3
Linguistics variables

LVs for expertise/criteria/alternatives	IVN sets
Certainly-low (CL)	[0.05,0.15], [0.75,0.85], [0.85,0.95]
Very-low (VL)	[0.15,0.25], [0.65,0.75], [0.75,0.85]
Low (L)	[0.25,0.35], [0.55,0.65], [0.65,0.75]
Below-average (BA)	[0.35,0.45], [0.45,0.55], [0.55,0.65]
Average (A)	[0.40,0.50], [0.40,0.55], [0.50,0.60]
Above-average (AA)	[0.45,0.65], [0.35,0.45], [0.45,0.55]
High (H)	[0.55,0.65], [0.25,0.35], [0.35,0.45]
Very-high (VH)	[0.65,0.75], [0.15,0.25], [0.25,0.35]
Certainly-high (CH)	[0.75,0.85], [0.05,0.15], [0.15,0.25]

Step 1-2: A score function $\left(Sc(\widetilde{\mathfrak{P}}_g)\right)$ (Eq. (3)) This approach is used to convert IVN numbers into precise, crisp values, enabling the construction of a numerical expert evaluation matrix for subsequent analysis $\left(\mathfrak{P} = [\mathfrak{P}_g]_G\right)$:

$$\mathfrak{P}_g = Sc(\widetilde{\mathfrak{P}}_g) = \frac{\left(2+T_{\widetilde{\mathfrak{P}}_g}^{L}(\mathfrak{o})+T_{\widetilde{\mathfrak{P}}_g}^{U}(\mathfrak{o})-2I_{\widetilde{\mathfrak{P}}_g}^{L}(\mathfrak{o})-2I_{\widetilde{\mathfrak{P}}_g}^{U}(\mathfrak{o})-F_{\widetilde{\mathfrak{P}}_g}^{L}(\mathfrak{o})-F_{\widetilde{\mathfrak{P}}_g}^{U}(\mathfrak{o})\right)}{4} + 1; Sc(\widetilde{\mathfrak{P}}_g) \in [0,2]. \tag{3}$$

Step 1-3: To obtain the weights of experts $\left(\Omega = [\Omega_g]_G\right)$, the normalization process shown in Eq. (4).

$$\mathit{\Omega}_g = \frac{\mathfrak{P}_g}{\sum_{g=1}^{G}\mathfrak{P}_g}; (g = 1,2, \dots, G). \tag{4}$$

wherein, the expert weight matrix $\left(\mathit{\Omega} = \left(\mathit{\Omega}_1, \mathit{\Omega}_2, \dots, \mathit{\Omega}_g, \dots, \mathit{\Omega}_{\mathcal{R}}\right)\right)$ is defined, where each $\mathit{\Omega}_g \in [0,1]$, within the constraint as $\sum_{g=1}^{G}\mathit{\Omega}_g = 1$.

- ***Stage 2** – Calculation of subjective criterion weights using the IVN-RANCOM method.*

***Step 2-1**:* Using Table 3, each expert $\left(\iota_g\right)$ determines the importance level of each criterion $\left(\iota_g\right)$. Then, the IVN -based criterion evaluation matrix $\left(\widetilde{\mathfrak{Q}} = \left[\widetilde{\mathfrak{Q}}_{kg}\right]_{KG}\right)$ can be determined.

***Step 2-2**:* To synthesize the evaluations provided by experts across all criteria, the IVNWA aggregation operator is employed, allowing for a comprehensive and systematic aggregation of expert judgments, as shown in Eq. (5), thereby determining the aggregate overall criteria evaluation matrix $\left(\widetilde{\mathfrak{Q}} = \left[\widetilde{\mathfrak{Q}}_k\right]_K\right)$.

$$\widetilde{\mathfrak{Q}}_k = IVNWA\left(\widetilde{\mathfrak{Q}}^{(\iota_1)}, \widetilde{\mathfrak{Q}}^{(\iota_2)}, \dots, \widetilde{\mathfrak{Q}}^{(\iota_g)}, \dots, \widetilde{\mathfrak{Q}}^{(\iota_G)}\right) = \bigoplus_{g=1}^{G}\mathit{\Omega}_g\widetilde{\mathfrak{Q}}^{(\iota_g)}$$
$$= \left\{\left(\begin{matrix} \left[1-\prod_{g=1}^{G}\left(1-T^{L}_{\widetilde{\mathfrak{Q}}^{(\iota_g)}}(\rho)\right)^{\mathit{\Omega}_g}, 1-\prod_{g=1}^{G}\left(1-T^{U}_{\widetilde{\mathfrak{Q}}^{(\iota_g)}}(\rho)\right)^{\mathit{\Omega}_g}\right], \\ \left[\prod_{g=1}^{G}\left(F^{L}_{\widetilde{\mathfrak{Q}}^{(\iota_g)}}(\rho)\right)^{\mathit{\Omega}_g}, \prod_{g=1}^{G}\left(F^{U}_{\widetilde{\mathfrak{Q}}^{(\iota_g)}}(\rho)\right)^{\mathit{\Omega}_g}\right], \\ \left[\prod_{g=1}^{G}\left(I^{L}_{\widetilde{\mathfrak{Q}}^{(\iota_g)}}(\rho)\right)^{\mathit{\Omega}_g}, \prod_{g=1}^{G}\left(I^{U}_{\widetilde{\mathfrak{Q}}^{(\iota_g)}}(\rho)\right)^{\mathit{\Omega}_g}\right] \end{matrix}\right) \middle| \, \rho \in \mathrm{P}\right\}. \tag{5}$$

herein, the expert weight matrix $\left(\mathit{\Omega} = \left(\mathit{\Omega}_1, \mathit{\Omega}_2, \dots, \mathit{\Omega}_g, \dots, \mathit{\Omega}_{\mathcal{R}}\right)\right)$ and $\mathit{\Omega}_g \in [0,1]$ are within the constraint as $\sum_{g=1}^{G}\mathit{\Omega}_g = 1$.

***Step 2-3**:* A score function $\left(Sc\left(\widetilde{\mathfrak{Q}}_k\right)\right)$ (Eq. (6)) is used to transform IVN numbers into crisp values, facilitating the construction of a numerical criterion evaluation matrix for subsequent analysis $(\mathfrak{Q} = [\mathfrak{Q}_k]_K)$ as call scoring matrix. These scoring values are used for IVN-RANCOM are obtained through the scoring approach [26]:

$$\mathfrak{Q}_{kg} = Sc\left(\widetilde{\mathfrak{Q}}_k\right) = \frac{\left(2+T^{L}_{\widetilde{\mathfrak{Q}}_k}(\rho)+T^{U}_{\widetilde{\mathfrak{Q}}_k}(\rho)-2I^{L}_{\widetilde{\mathfrak{Q}}_k}(\rho)-2I^{U}_{\widetilde{\mathfrak{Q}}_k}(\rho)-F^{L}_{\widetilde{\mathfrak{Q}}_k}(\rho)-F^{U}_{\widetilde{\mathfrak{Q}}_k}(\rho)\right)}{4} + 1; Sc\left(\widetilde{\mathfrak{Q}}_k\right) \in [0,2]. \tag{6}$$

***Step 2-4**:* A comparison matrix $(\mathfrak{M} = [\mathfrak{M}_{kk'}]_{KK})$ is constructed by considering the values from the scoring matrix $(\mathfrak{Q} = [\mathfrak{Q}_k]_K)$. Eq. (7) is used to create the comparison matrix:

$$\mathfrak{M}_{kk'} = \begin{cases} \text{If } \mathfrak{Q}_k > \mathfrak{Q}_{k'} \text{ then } 1 \\ \text{If } \mathfrak{Q}_k = \mathfrak{Q}_{k'} \text{ then } 0.5 \\ \text{If } \mathfrak{Q}_k < \mathfrak{Q}_{k'} \text{ then } 0 \end{cases}; (k, k' = 1,2, \dots, K). \tag{7}$$

***Step 2-5**:* By engaging Eq. (8), the comparison values are summed to obtain the total comparison value matrix $(\mathfrak{K} = [\mathfrak{K}_k]_K)$:

$$\mathfrak{K}_k = \sum_{k=1}^{K} \mathfrak{M}_{kk'} \,; (k, k' = 1,2, \dots, K). \tag{8}$$

Step 2-6*:* To determine the subjective criteria weights, the normalization process shown in Eq. (9) is applied, resulting in the subjective criteria matrix ($\Psi = [\Psi_k]_K$).

$$\Psi_k = \frac{\mathfrak{K}_k}{\sum_{k=1}^{K} \mathfrak{K}_k} ; (k = 1,2, \dots, K), \tag{9}$$

wherein, the subjective criteria weight matrix $\left(\Psi = (\Psi_1, \Psi_2, \dots, \Psi_k, \dots, \Psi_K)\right)$ and $\Psi_k \in [0,1]$, have the constraint as $\sum_{k=1}^{K} \Psi_k = 1$.

- ***<u>Stage 3</u>*** *<u>– Calculation of objective criterion weights using the IVN-MPSI method</u>.*

Step 3-1*:* Initially, Table 3 is used to calculate the values of alternatives based on qualitative criteria, and each alternative (ν_f) is evaluated by each expert (ι_g) depending on each qualitative criterion (π_h). Then, linguistic expressions are converted into IVN numbers, resulting in the qualitative criterion-based alternative evaluation matrix $\left(\tilde{\mathfrak{J}}^{(\iota_g)} = \left[\tilde{\mathfrak{J}}^{(\iota_g)}{}_{fH}\right]_{FH}\right)$, where $\left(\left[T^L_{\tilde{\mathfrak{J}}^{(\iota_g)}}(\rho), T^U_{\tilde{\mathfrak{J}}^{(\iota_g)}}(\rho)\right], \left[I^L_{\tilde{\mathfrak{J}}^{(\iota_g)}}(\rho), I^U_{\tilde{\mathfrak{J}}^{(\iota_g)}}(\rho)\right], \left[F^L_{\tilde{\mathfrak{J}}^{(\iota_g)}}(\rho), F^U_{\tilde{\mathfrak{J}}^{(\iota_g)}}(\rho)\right]\right)$ are generated with IVN numbers.

Step 3-2*:* To integrate the assessments provided by multiple experts, the IVNWA aggregation operator is employed, enabling a systematic and comprehensive consolidation of expert judgments, as shown in Eq. (10), thereby determining the aggregate qualitative criterion-based alternative evaluation matrix $\left(\tilde{\mathfrak{J}} = [\tilde{\mathfrak{J}}_{fH}]_{FH}\right)$:

$$\begin{aligned}\tilde{\mathfrak{J}}_{fH} &= IVNWA\left(\tilde{\mathfrak{J}}^{(\iota_1)}, \tilde{\mathfrak{J}}^{(\iota_2)}, \dots, \tilde{\mathfrak{J}}^{(\iota_g)}, \dots, \tilde{\mathfrak{J}}^{(\iota_G)}\right) = \oplus_{g=1}^{G} \Omega_g \tilde{\mathfrak{J}}^{(\iota_g)} \\ &= \left\{\left(\begin{array}{c}\left[1-\prod_{g=1}^{G}\left(1-T^L_{\tilde{\mathfrak{J}}^{(\iota_g)}}(\rho)\right)^{\Omega_g}, 1-\prod_{g=1}^{G}\left(1-T^U_{\tilde{\mathfrak{J}}^{(\iota_g)}}(\rho)\right)^{\Omega_g}\right], \\ \left[\prod_{g=1}^{G}\left(F^L_{\tilde{\mathfrak{J}}^{(\iota_g)}}(\rho)\right)^{\Omega_g}, \prod_{g=1}^{G}\left(F^U_{\tilde{\mathfrak{J}}^{(\iota_g)}}(\rho)\right)^{\Omega_g}\right], \\ \left[\prod_{g=1}^{G}\left(I^L_{\tilde{\mathfrak{J}}^{(\iota_g)}}(\rho)\right)^{\Omega_g}, \prod_{g=1}^{G}\left(I^U_{\tilde{\mathfrak{J}}^{(\iota_g)}}(\rho)\right)^{\Omega_g}\right]\end{array}\right) \middle|\, \rho \in \mathrm{P}\right\}.\end{aligned} \tag{10}$$

herein, the expert weight matrix $\left(\Omega = \left(\Omega_1, \Omega_2, \dots, \Omega_g, \dots, \Omega_{\mathcal{R}}\right)\right)$ and $\Omega_g \in [0,1]$ have the constraint as $\sum_{g=1}^{G} \Omega_g = 1$.

Step 3-3*:* A score function $\left(Sc(\tilde{\mathfrak{J}}_{fh})\right)$ (Eq. (11)) is used to transform IVN numbers into crisp values, thereby generating the numerical evaluation matrix of alternatives based on qualitative criteria $\left(\mathfrak{J} = [\mathfrak{J}_{fh}]_{FH}\right)$.

$$\mathfrak{J}_{fh} = Sc(\tilde{\mathfrak{J}}_{fh}) = \frac{\left(2+T^L_{\tilde{\mathfrak{J}}_{fh}}(\rho)+T^U_{\tilde{\mathfrak{J}}_{fh}}(\rho)-2I^L_{\tilde{\mathfrak{J}}_{fh}}(\rho)-2I^U_{\tilde{\mathfrak{J}}_{fh}}(\rho)-F^L_{\tilde{\mathfrak{J}}_{fh}}(\rho)-F^U_{\tilde{\mathfrak{J}}_{fh}}(\rho)\right)}{4} + 1; Sc(\tilde{\mathfrak{J}}_{fh}) \in [0,2]. \tag{11}$$

Step 3-4: The numerical criterion-based alternative evaluation matrix $\left(\mathfrak{I} = \left[\mathfrak{I}_{fh}\right]_{FH}\right)$ and the quantitative criterion-based alternative evaluation matrix $\left(\mathfrak{H} = \left[\mathfrak{H}_{fj}\right]_{fJ}\right)$ are combined. Thus, the overall criterion-based alternative evaluation matrix $\left(\mathfrak{Z} = \left[\mathfrak{Z}_{fk}\right]_{FK}\right)$ can be obtained.

Step 3-5: The matrix $\left(\mathfrak{Z} = \left[\mathfrak{Z}_{fk}\right]_{FK}\right)$ is standardized by engaging Eq. (12) as standardized matrix $\left(\mathfrak{Y} = \left[\mathfrak{Y}_{fk}\right]_{FK}\right)$.

$$\mathfrak{Y}_{fk} = \begin{cases} \dfrac{\mathfrak{Z}_{fk}}{\underset{1\le\cdots<f<\cdots\le F}{max}(\mathfrak{Z}_{fk})} \text{ for } k \in \mu^+ \\ \dfrac{\underset{1\le\cdots<f<\cdots\le F}{min}(\mathfrak{Z}_{fk})}{\mathfrak{Z}_{fk}} \text{ for } k \in \mu^- \end{cases} ; (f = 1,2,\dots,F; k = 1,2,\dots,K). \tag{12}$$

Step 3-6: Mean values are computed by engaging Eq. (13). Thus, the mean matrix $(\mathfrak{X} = [\mathfrak{X}_k]_K)$ can be obtained.

$$\mathfrak{X}_k = \frac{1}{F}\sum_{f=1}^{f} \mathfrak{Y}_{fk} \,; (k = 1,2,\dots,K). \tag{13}$$

Step 3-7: Preference variation values are computed by engaging Eq. (14). Thus, the preference variation matrix $(\mathfrak{W} = [\mathfrak{W}_k]_K)$ can be obtained.

$$\mathfrak{W}_k = \sum_{f=1}^{F}\left(\mathfrak{Y}_{fk} - \mathfrak{X}_k\right)^2 ; (k = 1,2,\dots,K). \tag{14}$$

Step 3-8: The normalization process shown in Eq. (15) is applied, resulting in the objective criteria matrix $(\Phi = [\Phi_k]_K)$.

$$\Phi_k = \frac{\mathfrak{W}_k}{\sum_{k=1}^{K}\mathfrak{W}_k}; (k = 1,2,\dots,K). \tag{15}$$

wherein, the objective criteria weight matrix $\left(\Phi = (\Phi_1, \Phi_2, \dots, \Phi_k, \dots, \Phi_K)\right)$ and $\Phi_k \in [0,1]$, have the constraint as $\sum_{k=1}^{K}\Phi_k = 1$.

- ***Stage 4** – Combining the subjective and objective criterion weight matrices*.

Step 4-1: The criterion weight matrices obtained using IVN-RANCOM $(\Psi = [\Psi_k]_K)$ and IVN-MPS $(\Phi = [\Phi_k]_K)$ are combined to reach the criteria weight matrix $(\tau = [\tau_k]_K)$, as given by Eq. (16):

$$\tau_k = \varsigma\Psi_k + (1-\varsigma)\Phi_k; (k = 1,2,\dots,K). \tag{16}$$

herein, ς indicates the subjective criteria weighting parameter and $\varsigma \in [0,1]$.

- ***Stage 5** – Generating the alternative prioritization matrix*.

Step 5-1: The overall criterion-based alternative evaluation matrix $\left(\mathfrak{Z} = \left[\mathfrak{Z}_{fk}\right]_{HK}\right)$ is used for the OPLO-POCOD method. Initially, the best value matrix $(\mathfrak{V} = [\mathfrak{V}_k]_K)$ is calculated by using Eq. (17):

$$\mathfrak{V}_k = \begin{cases} \underset{1\le\cdots<f<\cdots\le F}{max}\left(\mathfrak{Z}_{fk}\right) \text{ for } k \in \mu^+ \\ \underset{1\le\cdots<f<\cdots\le F}{min}(\mathfrak{Z}_{hk}) \text{ for } k \in \mu^- \end{cases} ; (k = 1,2,\dots,K). \tag{17}$$

***Step 5-2**: The distances between overall criterion-based alternative values and the best value are calculated using Eq. (18) as opportunity loss values matrix $\left(\mathfrak{U} = \left[\mathfrak{U}_{fk}\right]_{FK}\right)$.

$$\mathfrak{U}_{fk} = \left|\mathfrak{Z}_{fk} - \mathfrak{V}_k\right|; (f = 1,2, \dots, F; k = 1,2, \dots, K). \tag{18}$$

***Step 5-3**: The overall criterion-based alternative values and opportunity loss values are combined into ordered pair values using Eq. (19), resulting in the ordered pair values matrix $\left(\mathfrak{T} = \left[\mathfrak{T}_{fk}\right]_{FK}\right)$.

$$\mathfrak{T}_{fk} = \left(\mathfrak{Z}_{fk}, \mathfrak{U}_{fk}\right); (f = 1,2, \dots, F; k = 1,2, \dots, K). \tag{19}$$

***Step 5-4**: The best value within the pair values are determined separately for cost-based and benefit-based criteria using Eq. (20). Thus, the best-ordered pair values ($\mathfrak{S} = [\mathfrak{S}_k]_K$) is obtained.

$$\mathfrak{S}_k = \begin{cases} \left(\left(\max_{1\le\cdots<f<\cdots\le F}\left(\mathfrak{Z}_{fk}\right)\right), \left(\min_{1\le\cdots<f<\cdots\le F}\left(\mathfrak{U}_{fk}\right)\right)\right) \text{ for } k \in \mu^+ \\ \left(\left(\min_{1\le\cdots<f<\cdots\le F}\left(\mathfrak{Z}_{fk}\right)\right), \left(\min_{1\le\cdots<f<\cdots\le F}\left(\mathfrak{U}_{fk}\right)\right)\right) \text{for } k \in \mu^- \end{cases}; (k = 1,2, \dots, K). \tag{20}$$

***Step 5-5**: The distances between the pair values and the best pair values are performed by using Eq. (21) as the distance matrix $\left(\mathfrak{A} = \left[\mathfrak{A}_{fk}\right]_{HK}\right)$.

$$\mathfrak{A}_{fk} = \begin{cases} \sqrt{\left(\mathfrak{Z}_{fk} - \left(\max_{1\le\cdots<f<\cdots\le F}\left(\mathfrak{Z}_{fk}\right)\right)\right)^2 + \left(\mathfrak{U}_{fk} - \left(\min_{1\le\cdots<f<\cdots\le F}\left(\mathfrak{U}_{fk}\right)\right)\right)^2} \text{ for } k \in \mu^- \\ \sqrt{\left(\mathfrak{Z}_{fk} - \left(\min_{1\le\cdots<f<\cdots\le F}\left(\mathfrak{Z}_{fk}\right)\right)\right)^2 + \left(\mathfrak{U}_{fk} - \min_{1\le\cdots<f<\cdots\le F}\left(\mathfrak{U}_{fk}\right)\right)^2} \text{ for } k \in \mu^- \end{cases}; \tag{21}$$

$(f = 1,2, \dots, F; k = 1,2, \dots, K)$.

***Step 5-6**: The weighted distance matrix is derived from the distance matrix $\left(\mathfrak{B} = \left[\mathfrak{B}_{fk}\right]_{FK}\right)$ using Eq. (22):

$$\mathfrak{B}_{fk} = \tau_k \mathfrak{A}_{fk}; (f = 1,2, \dots, F; k = 1,2, \dots, K). \tag{22}$$

***Step 5-7**: The weighted distance values for each alternative are summed (Eq. (23)), achiving in the overall distance matrix $\left(\mathfrak{C} = \left[\mathfrak{C}_f\right]_F\right)$.

$$\mathfrak{C}_f = \sum_{k=1}^{K} \mathfrak{B}_{fk}; (f = 1,2, \dots, F). \tag{23}$$

***Step 5-8**: The total distance values are normalized using Eq. (24) as the degree opportunity loss matrix $\left(\mathfrak{D} = \left[\mathfrak{D}_f\right]_F\right)$.

$$\mathfrak{D}_f = \frac{\mathfrak{C}_f}{\sum_{f=1}^{F} \mathfrak{C}_f}; (f = 1,2, \dots, F). \tag{24}$$

***Step 5-9**:* The degree of opportunity loss values is subtracted from 1 to obtain the opportunity achievement values by engaging Eq. (25). Consequently, the opportunity achievement matrix $\left(\rho = [\rho_f]_F\right)$ is obtained, representing the final alternative values and their rankings.

$$\rho_f = 1 - \mathfrak{D}_f; (f = 1,2, \dots, F). \tag{25}$$

4. Case Study: Determining the sustainable tourism attraction levels of the provinces located in Eastern Black Sea Region of Türkiye

This case study has two primary objectives. The first is to shown the proposed IVN-RANCOM-MPSI-OPLO-POCOD approach for determining sustainable tourism attraction levels. The second is to identify and rank the sustainable tourism attractiveness of the seven provinces located in Türkiye's Eastern Black Sea region. In this context, eight experts were involved, and 17 criteria were established, consisting of seven qualitative and 10 quantitative parameters. The method was applied to the decision model.

4.1 Decision Design for Case Study

4.1.1 Expert group for evaluating sustainable tourism attraction

An expert group was established to determine the sustainable tourism attraction levels of the provinces in Türkiye's Eastern Black Sea region. This expert group was selected from different fields of expertise to ensure a comprehensive evaluation from various perspectives. Thus, simultaneous assessment from different viewpoints was made possible for determining the sustainable tourism attractions of the regions. Expert-1 contributes to the tourism sector in the Eastern Black Sea region as a business owner. Expert-2 works as a business manager at a tourism agency in the Eastern Black Sea region. Expert-3, as a local government representative, is responsible for planning and executing tourism activities in the region. Expert-4 is a professor with research in the tourism field, focusing on tourism activities in the region. Expert-5 serves as a tourism destination manager and is responsible for conducting planning. Expert-6 works as a cultural heritage expert and specializes in the region's cultural heritage. Expert-7 is a professor conducting research on the development of regional tourism. Expert-8 is responsible for the management of festivals and events in the region.

Information about these experts and their levels of expertise is presented in Table 4. As a result of interviews with these experts, both the criterion evaluation matrix and matrices for the provinces' assessments based on qualitative parameters were developed. Thus, the initial matrices required for the research were created based on linguistic evaluations.

Table 4
Expert group

Experts	Expertise level	Professions
ι_1	Average (A)	Business owner in the tourism sector
ι_2	Above-average (AA)	Business Manager in the tourism sector
ι_3	Very-high (VH)	Local government representative in the tourism industry
ι_4	High (H)	Professor conducting research in the field of tourism
ι_5	Certainly-high (CH)	Tourism destination manager
ι_6	Very-high (VH)	Cultural heritage expert
ι_7	Below-average (BA)	Professor conducting research in the field of tourism
ι_8	Average (A)	Festival and event organization manager

The decision model developed for understanding the sustainable tourism attractiveness levels of the provinces using the hybrid method is shown in Figure 2.

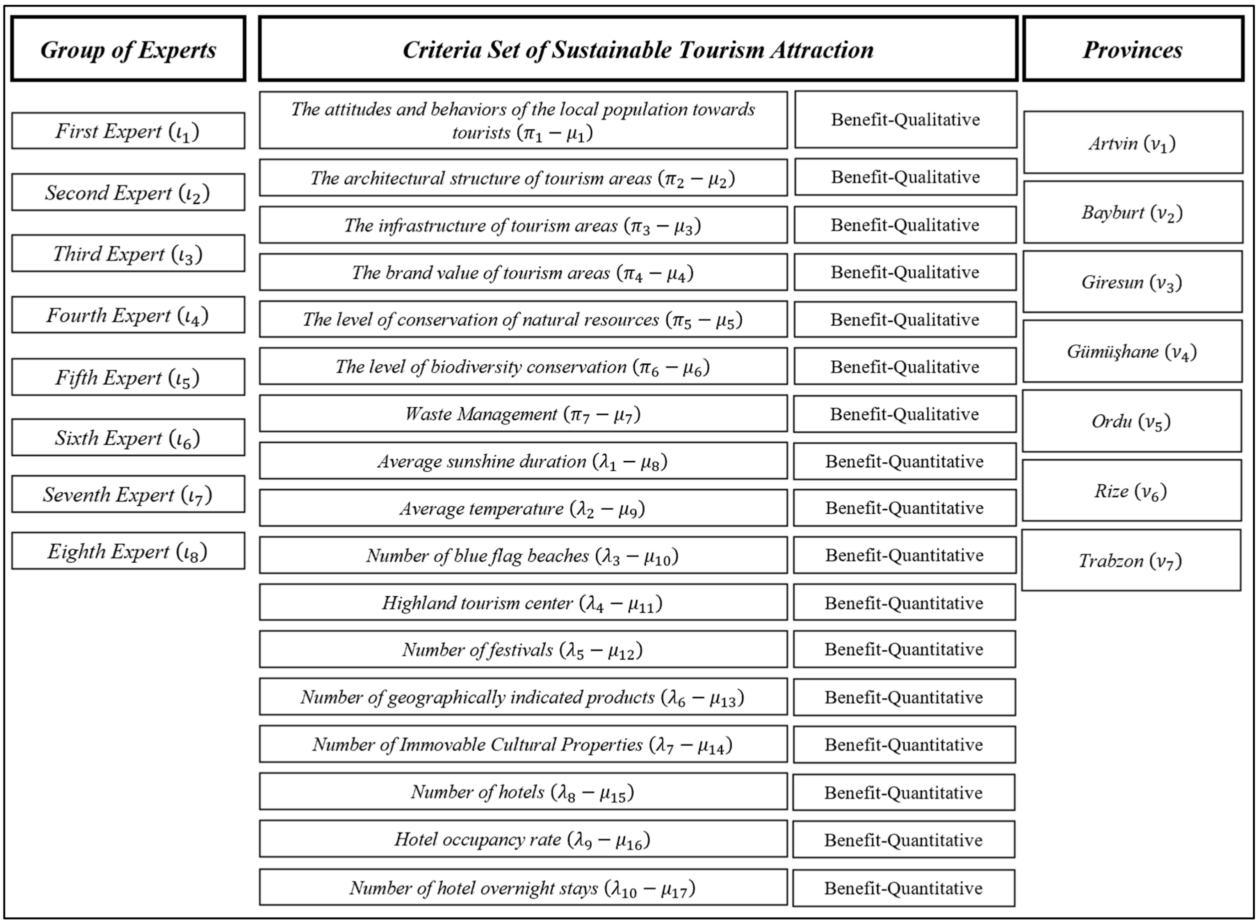

Fig. 2. The decision model for determining sustainable tourism attractiveness levels

4.1.2 Criteria for Sustainable Tourism Attraction Levels

In this study, 17 criteria, including seven qualitative and 10 quantitative criteria, were established to assess the level of sustainable tourism attractiveness. These criteria are:

i. *The attitudes and behaviors of the local population towards tourists* $(\pi_1 - \mu_1)$ – This criterion shows how welcoming and supportive the local community is toward tourists visiting a destination [63,64]. In sustainable tourism, positive and strong interaction between local people and tourists is expected [65]. The hospitality extended to tourists directly influences the experiences tourists gain from destinations in a positive manner. This is strongly connected to how culturally sensitive the local people are. Specifically, this criterion, which reflects the norms of the local community, enhances sustainable tourism performance and increases the attractiveness level of the destination.
ii. *The architectural structure of tourism areas* $(\pi_2 - \mu_2)$ – This criterion relates to the design and appearance of buildings and infrastructure at a tourism destination. In sustainable tourism, architectural structure is important for tourist experience and affects the environmental and cultural impacts of tourism activities [66]. Well-designed architectural structures in tourism areas should harmonize with the region's natural and cultural landscape while prioritizing sustainability. Furthermore, the architectural style should

reflect local culture and heritage, enhancing the sense of authenticity and strengthening the destination’s cultural identity. Features that align with local traditions and the natural environment increase the destination's appeal, making it more attractive to tourists. Therefore, this criterion is considered a significant qualitative factor in determining the sustainable tourism attractiveness level, as it directly influences tourists’ perceptions and experiences of the destination. Given its impact on the overall sustainability and appeal of the tourism area, it is included as one of the qualitative criteria in the decision model.

iii. *The infrastructure of tourism areas* $(\pi_3 - \mu_3)$ – This criterion refers to the infrastructure systems within a tourism destination, such as waste management, healthcare, and communication networks. In sustainable tourism, infrastructure is crucial for efficient tourism operations, visitor satisfaction, and minimizing environmental impacts [67]. Sustainable infrastructure should be eco-friendly, energy-efficient, and aligned with sustainability principles, which enhance both the tourist experience and the destination's appeal [68].

iv. *The brand value of tourism areas* $(\pi_4 - \mu_4)$ – This criterion refers to the reputation of a destination for tourism. In sustainable tourism, a strong brand value shows the destination’s ability to provide authentic experiences and promote its cultural heritage [69]. A well-established brand enhances the destination's attractiveness by creating positive associations and encouraging repeat visits [70]. It also influences tourists' decisions, as they are more likely to visit destinations with a strong, recognizable brand that aligns with their values and expectations.

v. *The level of conservation of natural resources* $(\pi_5 - \mu_5)$ – This criterion indicates the extent to which a tourism destination preserves its natural environment, including land, water, flora, and fauna. This criterion emphasizes the protecting and managing natural resources for future generations [71]. A well-conserved destination balances tourism and nature, and reduces pollution, habitat damage, and resource overuse. Sustainable practices like reducing waste, saving energy, and protecting biodiversity help maintain the natural health of a destination [72]. This criterion is crucial for determining the sustainable tourism attractiveness level, as it directly influences both the destination's environmental sustainability and its appeal to eco-conscious tourists.

vi. *The level of biodiversity conservation* $(\pi_6 - \mu_6)$ – This criterion refers to the efforts made by a tourism destination to protect and sustain its biodiversity, including various species of plants, animals, and ecosystems [73]. In sustainable tourism, this criterion highlights the importance of maintaining ecological balance by preserving the natural habitats and the diversity of life within a destination. Effective biodiversity conservation involves actions such as protecting endangered species [74]. High levels of biodiversity conservation enhance a destination's attractiveness by offering tourists unique natural experiences, fostering environmental stewardship, and promoting long-term ecological health. This criterion is crucial for determining the sustainable tourism attractiveness level, as it ensures the protection of the environment while supporting the destination's natural beauty and appeal.

vii. *Waste management* $(\pi_7 - \mu_7)$ – This criterion indicates the strategies and practices employed by a tourism destination to handle, reduce, and dispose of waste in an environmentally responsible manner. Effective waste management is crucial to minimizing the environmental impact of tourism activities [75]. It involves the proper collection, recycling, and disposal of waste materials such as plastic, paper, and organic waste, as well as reducing waste generation through sustainable practices. Good waste management practices not only contribute to the cleanliness and aesthetic value of a destination but also reduce pollution, prevent environmental degradation, and promote resource conservation [76]. Destinations with good waste management show environmental responsibility and are more attractive to eco-conscious tourists. Therefore, waste management is an important factor in sustainable tourism attractiveness.

viii. *Average sunshine duration* $(\lambda_1 - \mu_8)$ – This criterion indicates to the total amount of sunlight a tourism destination receives over a specific period, typically measured in hours per year. This quantitative criterion is important for sustainable tourism attraction as it influences the overall visitor experience [77]. A longer sunshine duration often corresponds to favorable weather conditions for outdoor activities, beach tourism, and nature-based experiences, which are key elements for many destinations. Additionally, sunlight can enhance the aesthetic appeal of natural landscapes, creating a more inviting environment for tourists. Destinations with an optimal balance of sunshine, alongside environmental sustainability, can attract more visitors seeking a pleasant and comfortable climate for their stay. Thus, average sunshine duration is a significant quantitative criterion.

ix. *Average temperature* $(\lambda_2 - \mu_9)$ – Average temperature refers to the typical temperature range of a tourism destination over a defined period, such as a year. This factor is important for sustainable tourism because it directly affects tourists' comfort and preferences. Ideal average temperatures can enhance outdoor recreational activities, such as hiking, sightseeing, and beach tourism, making a destination more appealing [78]. Destinations with moderate temperatures are generally more attractive as they offer pleasant conditions for tourists year-round. Keeping a balance between temperature and environmental protection is important for a good visitor experience and less impact on ecosystems.

x. *Number of blue flag beaches* $(\lambda_3 - \mu_{10})$ – The number of blue flag beaches is a quantitative criterion that refers to the certification awarded to beaches meeting high environmental and safety standards. The number of blue flag beaches serves as an parameter of a destination's commitment to environmental sustainability. Destinations with a higher number of blue flag beaches are typically more attractive to eco-conscious tourists, as they indicate a clean, safe, and environmentally responsible location [79]. Blue flag beaches increase a destination's appeal and support long-term tourism sustainability by protecting marine ecosystems and encouraging eco-friendly practices [80].

xi. *Highland tourism center* $(\lambda_4 - \mu_{11})$ – This criterion refers to tourism destinations in high-altitude or mountainous areas with natural scenery, cooler weather, and outdoor activities like hiking, cycling, and wildlife watching. From a quantitative perspective, this criterion considers the number, size, and accessibility of highland tourism centers in each region. These centers attract eco, adventure, and cultural tourism, letting visitors experience natural environments and support the local economy.

xii. *Number of festivals* $(\lambda_5 - \mu_{12})$ – This criterion indicates the quantity of cultural, traditional, and artistic events organized within a tourism destination over a certain period. Festivals are important attractions that show a region's culture and heritage and give tourists unique experiences for cultural exchange and learning [81]. A higher number of well-organized and diverse festivals can significantly enhance a destination's appeal, contributing to local economic development.

xiii. *Number of geographically indicated products* $(\lambda_6 - \mu_{13})$ – It is a key criterion for determining sustainable tourism appeal, as it reflects a destination's cultural heritage and local authenticity. These products, recognized for their unique qualities tied to a specific region, enhance tourists' experiences by offering genuine, locally produced goods [82]. They support the local economy, encourage sustainable practices, and strengthen cultural identity, making the destination more attractive and sustainable in the long term.

xiv. *Number of immovable cultural properties* $(\lambda_7 - \mu_{14})$ – This criterion refers to the count of historically or culturally significant buildings, monuments, and other structures in a tourism destination that are protected due to their cultural value [83]. This criterion is essential for determining the sustainable tourism appeal of a location, as such properties attract visitors interested in heritage, history, and culture. Preserving and promoting these cultural assets increases a destination's attractiveness and supports cultural sustainability by protecting local heritage for future generations. Therefore, a higher number of immovable cultural properties indicates a richer cultural tourism offering and adds to the destination's overall sustainability and appeal.

xv. *Number of hotels* $(\lambda_8 - \mu_{15})$ – This criterion refers to the number of registered hotels in a tourism destination. It is important for sustainability because accommodation availability affects tourist satisfaction and access. A higher number of hotels shows that a destination can host more visitors and offer different prices, facilities, and services. In sustainable tourism, hotel distribution and quality also show how well a region manages tourism growth with less environmental and social impact. Thus, this criterion contributes to the overall appeal of the destination by ensuring sufficient infrastructure to support a steady flow of tourists.

xvi. *Hotel occupancy rate* $(\lambda_9 - \mu_{16})$ – This criterion shows the percentage of hotel rooms occupied by guests in a given period. It is important for measuring a destination's attractiveness and sustainability. A higher occupancy rate typically indicates a strong demand for tourism services, suggesting that the destination is popular and capable of attracting a consistent flow of visitors [84]. However, it also reflects how efficiently the tourism infrastructure, particularly accommodation, is utilized. In the context of sustainable tourism, a balanced occupancy rate is essential, as excessively high rates may lead to overcrowding, strain on resources, and environmental degradation, while very low rates may signal a lack of demand or insufficient promotion. Therefore, this criterion helps gauge the destination's appeal, visitor satisfaction, and capacity to manage tourism sustainably.

xvii. *Number of hotel overnight stays* $(\lambda_{10} - \mu_{17})$ – Number of hotel overnight stays refers to the total nights guests spend in hotels over a certain period. It is an important indicator of a destination's attractiveness and how long tourists stay. A higher number of overnight stays suggests that tourists are staying longer at the destination, which may imply that the location offers a variety of attractions and services that encourage extended visits [85]. From a sustainable tourism perspective, a balance is needed, as an excessively high number of overnight stays could lead to overnight accommodation. Therefore, this criterion helps assess the destination's ability to attract and retain tourists while maintaining sustainability.

4.1.3. Provinces located in the Eastern Black Sea Region of Türkiye

There are seven provinces in the Eastern Black Sea region of Türkiye. These provinces are “Artvin, Bayburt, Giresun, Gümüşhane, Ordu, Rize, and Trabzon”. The tourism destinations of these provinces are explained as follows:

i. *Artvin Province* (ν_1) – Artvin, a province bordering Georgia in Türkiye, is distinguished by its abundant natural and cultural resources. The province is geographically divided by the Çoruh River and is home to diverse tourism assets, including towering mountains, lush natural forests, crater lakes, and verdant plateaus. These features allow many tourism activities such as mountain climbing, trekking, rafting, and canoeing, adding to the region's variety of tourism options. Furthermore, Artvin is home to the Camili Biosphere Reserve, which holds the distinction of being Türkiye's first and only biosphere reserve, further enhancing the province's appeal as a sustainable tourism destination.

ii. *Bayburt Province* (ν_2) – Bayburt is one of the smallest provinces in Türkiye in terms of both area and population. Despite its size, Bayburt is an ancient settlement with significant historical value. The province is home to notable tourist attractions, including a majestic castle, a grand mosque from the Seljuk period, and the Aydıntepe Underground City. These historical sites, along with its rich cultural heritage, make Bayburt an appealing destination for tourists interested in exploring Türkiye's ancient history and architecture. Bayburt's mix of history and culture makes it an important destination for heritage tourism in the region.

iii. *Giresun Province* (ν_3) – Giresun Province is home to numerous tourist destinations, enriched by its historical, natural, and cultural resources. The region's castles, scenic plateaus, waterfalls, and travertines have significantly enhanced its tourism appeal in recent years. Additionally, the Giresun Chubby Hazelnut, a product with geographical indication from the European Union, is cultivated in the area, further contributing to the province's unique identity. These attractions, combined with the region's rich agricultural heritage, make Giresun an increasingly prominent destination for both nature and cultural tourism.

iv. *Gümüşhane Province* (ν_4) – Situated along the historic Silk Road, Gümüşhane Province holds a strategic position and is home to a diverse array of historical, natural, and cultural assets, having been a hub for various civilizations throughout its history. The province boasts a rich cultural heritage and offers significant potential in sectors such as cultural tourism, rural tourism, plateau tourism, and cave tourism. However, despite these advantages, Gümüşhane has yet to achieve the desired level of development in its tourism industry. This untapped potential presents opportunities for future growth and promotion of the region as a prominent tourist destination.

v. *Ordu Province* (ν_5) – Ordu province's social and cultural structure offers sustainable tourism. The province is distinguished by its pristine coastlines, which remain largely untouched compared to other regions, and its blue-flagged beaches, positioning it as a promising destination for seaside tourism. In addition to coastal tourism, Ordu also holds substantial potential for a variety of other tourism activities, including plateau tourism, trekking, and paragliding. These diverse tourism assets contribute to the region's rich and multifaceted tourism potential.

vi. *Rize Province* (ν_6) – Rize Province is characterized by a diverse and striking landscape, with coastal plains formed by the alluvium deposited by rivers, alongside steep cliffs that define its coastal strip. The province is abundant in natural beauty, featuring rugged valleys, mountains, glacial lakes, plateaus, historical arch bridges, castles, and streams. Rize's appeal lies in its well-preserved plateaus and unspoiled natural environments, making it a prominent destination for plateau tourism. The province continues to attract tourists through its picturesque landscapes and the preservation of its unique natural and cultural assets.

vii. *Trabzon Province* (ν_7) – Trabzon is one of the most popular destinations in the region, known for its cultural heritage and natural beauty. Its strategic geographical location and history of hosting numerous civilizations contribute to its significance as a cultural hub. In addition to its cultural assets, Trabzon is also distinguished by its striking natural landscapes. Notable tourist attractions such as Uzungöl and the Sumela Monastery continue to captivate visitors, making the province a prominent destination for both cultural and nature-based tourism.

4.2. Assessing the Sustainable Tourism Attraction Levels of the Provinces Located in the Eastern Black Sea Region of Türkiye

The hybrid model steps were applied in order to assess and rank the sustainable tourism attractiveness of provinces in the Eastern Black Sea region, and the final results were obtained.

- ***Stage 1** – Computing expert weights using IVN sets*.

In the first stage of determining sustainable tourism attraction levels, an expert group was consulted to establish the levels of expertise, as summarized in Table 3, with detailed expertise levels and corresponding IVN number-based evaluations provided in Table A.1 (Appendix). Subsequently, the IVN sets underwent deneutrosophication (Eq. (3)), resulting in the numerical expert evaluation matrix, which is also presented in Table A.1. Finally, the expert weights was computed (Eq. (4)), with the calculated expert weights summarized in Table 5.

Table 5
The expert weights $\left(\Omega = \left[\Omega_g\right]_G\right)$

Experts	ι_1	ι_2	ι_3	ι_4	ι_5	ι_6	ι_7	ι_8
Ω_g	0.1	0.11	0.15	0.13	0.17	0.15	0.09	0.1

- ***Stage 2** – Calculation of subjective criterion weights using the IVN-RANCOM method.*

In the second stage, the experts first assessed the criteria using Table 3, resulting in the criterion evaluation matrix presented in Table A.2. These linguistic evaluations were converted into IVN numbers, creating the IVN criterion matrix (Table A.3). Subsequently, the aggregate matrix was computed using Eq. (5), as shown in Table A.4. The IVN sets were then deneutrosophicated using the score function (Eq. (6)), yielding the scoring matrix for IVN-RANCOM (Table A.5). Based on the scoring matrix values, Eq. (7) was applied to generate the comparison matrix (Table A.6), followed by the summation of comparison values using Eq. (8) to obtain the total comparison value matrix, also reported in Table A.6. Finally, the subjective criterion weights were derived using IVN-RANCOM through Eq. (8), which is presented in Table 6.

- ***Stage 3** – Calculation of objective criterion weights using the IVN-MPSI method.*

In the third stage, the experts first evaluated the alternatives using Table 3, resulting in the criterion evaluation matrix shown in Table A.7. These linguistic assessments were subsequently converted into IVN numbers, producing the IVN qualitative criterion-based alternative evaluation matrix (Table A.8). The IVNWA aggregation operator (Eq. (10)) was then applied, in conjunction with the expert weight matrix presented in Table 5, to obtain the aggregated qualitative criterion-based alternative evaluation matrix (Table A.9). Following this, the IVN sets were deneutrosophicated using the score function (Eq. (5)), yielding the numerical qualitative criterion-based alternative evaluation matrix for the first seven criteria (Table A.10). By integrating this numerical matrix with the quantitative criterion-based alternative evaluation matrix, the overall criterion-based alternative evaluation matrix was established (Table A.10). The standardized matrix was obtained (Eq. (12)), and the mean matrix and preference variation matrix were subsequently derived via Eqs. (13) and (14), respectively (Table A.11). Finally, objective criteria weights were determined using IVN-MPSI through Eq. (15), which is presented in Table 6.

- ***Stage 4*** *– Combining the subjective and objective criterion weight matrices*.

In the fourth stage, subjective and objective weights were combined (Eq. (16)) ($\varsigma = 0.5$). This combination facilitated the computation of the final criteria weight matrix, which is presented in Table 6.

Table 6
All-criteria weights matrices

Method	Criteria	μ_1	μ_2	μ_3	μ_4	μ_5	μ_6	μ_7	μ_8	μ_9
IVN-RANCOM	Ψ_k	0.0727	0.1142	0.1003	0.0796	0.1073	0.0934	0.0865	0.0588	0.0657
	Rank	7th	1st	3rd	6th	2nd	4th	5th	9th	8th
	Criteria	μ_{10}	μ_{11}	μ_{12}	μ_{13}	μ_{14}	μ_{15}	μ_{16}	μ_{17}	
	Ψ_k	0.0519	0.0381	0.0173	0.0450	0.0311	0.0242	0.0104	0.0035	
	Rank	10th	12th	15th	11th	13th	14th	16th	17th	
IVN-MPSI	**Criteria**	μ_1	μ_2	μ_3	μ_4	μ_5	μ_6	μ_7	μ_8	μ_9
	Φ_k	0.0239	0.0118	0.0101	0.0183	0.0141	0.0101	0.0099	0.0619	0.0465
	Rank	9th	14th	16th	10th	12th	15th	17th	6th	7th
	Criteria	μ_{10}	μ_{11}	μ_{12}	μ_{13}	μ_{14}	μ_{15}	μ_{16}	μ_{17}	
	Φ_k	0.1555	0.2094	0.1344	0.0452	0.0952	0.1246	0.0166	0.0125	
	Rank	2nd	1st	3rd	8th	5th	4th	11th	13th	
Final	**Criteria**	μ_1	μ_2	μ_3	μ_4	μ_5	μ_6	μ_7	μ_8	μ_9
	τ_k	0.0483	0.0630	0.0552	0.0490	0.0607	0.0517	0.0482	0.0603	0.0561
	Rank	13th	6th	10th	12th	7th	11th	14th	8th	9th
	Criteria	μ_{10}	μ_{11}	μ_{12}	μ_{13}	μ_{14}	μ_{15}	μ_{16}	μ_{17}	
	τ_k	0.1037	0.1237	0.0759	0.0451	0.0632	0.0744	0.0135	0.0080	
	Rank	2nd	1st	3rd	15th	5th	4th	16th	17th	

- ***Stage 5*** *– Generating the alternative prioritization matrix through the OPLO-POCOD method*.

In the fifth stage, the evaluation of alternatives proceeded through a series of computational steps. Initially, the best value matrix was calculated (Eq. (17)) (Table A.12). Subsequently, the opportunity loss values matrix was determined via Eq. (18) (Table A.13), followed by the calculation of the ordered pair values (Eq. (19)) (Table A.14) and the best ordered pair values matrix through Eq. (20) (Table A.15). The distance matrix was then obtained using Eq. (21) (Table A.16), and, incorporating the final criteria weight matrix from Table 6, the weighted distance matrix was computed via Eq. (22) (Table A.17). The total distance matrix was calculated using Eq. (23), with the opportunity loss matrix derived through Eq. (24) (Table A.18). Finally, the opportunity achievement matrix was determined using Eq. (25), as presented in Table 7.

Table 7
Opportunity achievement matrix $\left(\rho = [\rho_f]_F\right)$

	Artvin (ν_1)	**Bayburt** (ν_2)	**Giresun** (ν_3)	**Gümüşhane** (ν_4)	**Ordu** (ν_5)	**Rize** (ν_6)	**Trabzon** (ν_7)
ρ_f	0.8142	0.7994	0.8574	0.8211	0.8512	0.9983	0.8584
Rank	6th	7th	3rd	5th	4th	1st	2nd

5. Results and Implications

The proposed IVN-RANCOM-MPSI-OPLO-POCOD was applied to assess the sustainable tourism attraction levels of the provinces. The model determined the sustainable tourism attractiveness of seven provinces using opinions from eight experts and 17 criteria. By implementing the algorithm steps developed for IVN-RANCOM-MPSI-OPLO-POCOD, five distinct outputs were obtained, corresponding to each stage of the algorithm:

i. *Case study result 1* – The experts' influence levels were determined using IVN and linguistic expressions. The experts were ranked depending on their influence levels as follows: fifth expert $(\iota_5)(\Omega_5 = 0.1700)$ > third expert $(\iota_3)(\Omega_3 = 0.1500)$ = sixth expert $(\iota_6)(\Omega_6 = 0.1500)$ > fourth expert $(\iota_4)(\Omega_4 = 0.1300)$ > second expert $(\iota_2)(\Omega_2 = 0.1100)$ > first expert $(\iota_1)(\Omega_1 = 0.1000)$ = eight expert $(\iota_8)(\Omega_8 = 0.1000)$ > seventh expert $(\iota_7)(\Omega_7 = 0.0900)$. The fifth expert had the highest influence, while the seventh had the lowest. Therefore, the decision-making process considered the experts' influence levels.

ii. *Case study result 2* – The IVN-RANCOM method was used to calculate subjective weights, giving the following ranking of criteria importance: "the architectural structure of tourism areas" $(\mu_2)(\Psi_2 = 0.1142)$ > "the level of conservation of natural resources" $(\mu_5)(\Psi_5 = 0.1073)$ > "the infrastructure of tourism areas" $(\mu_3)(\Psi_3 = 0.1003)$ > "the level of biodiversity conservation" $(\mu_6)(\Psi_6 = 0.0934)$ > "waste management" $(\mu_7)(\Psi_7 = 0.0865)$ > "the brand value of tourism areas" $(\mu_4)(\Psi_4 = 0.0796)$ > "the attitudes and behaviors of the local population towards tourists" $(\mu_1)(\Psi_1 = 0.0727)$ > *Average temperature* $(\mu_9)(\Psi_9 = 0.0657)$ > "average sunshine duration" $(\mu_8)(\Psi_8 = 0.0588)$ > "number of blue flag beaches" $(\mu_{10})(\Psi_{10} = 0.0519)$ > "number of geographically indicated products" $(\mu_{13})(\Psi_{13} = 0.0450)$ > "highland tourism center" $(\mu_{11})(\Psi_{11} = 0.0381)$ > "number of immovable cultural properties number of immovable cultural properties" $(\mu_{14})(\Psi_{14} = 0.0311)$ > "number of hotels" $(\mu_{15})(\Psi_{15} = 0.0242)$ > "number of festivals" $(\mu_{12})(\Psi_{12} = 0.0173)$ > "hotel occupancy rate" $(\mu_{16})(\Psi_{16} = 0.0104)$ > "number of hotel overnight stays" $(\mu_{17})(\Psi_{17} = 0.0035)$. According to the subjective weighting, the most important criterion was the architectural structure of tourism areas, while the least important was the number of hotel overnight stays.

iii. *Case study result 3* – The IVN-MPSI method was used to determine objective weights, giving the following ranking: "highland tourism center" $(\mu_{11})(\Phi_{11} = 0.2094)$ > "number of blue flag beaches" $(\mu_{10})(\Phi_{10} = 0.1555)$ > "number of festivals" $(\mu_{12})(\Phi_{12} = 0.1344)$ > "number of hotels" $(\mu_{15})(\Phi_{15} = 0.1246)$ > "number of immovable cultural properties" $(\mu_{14})(\Phi_{14} = 0.0952)$ > "average sunshine duration" $(\mu_8)(\Phi_8 = 0.0619)$ > "average temperature" $(\mu_9)(\Phi_9 = 0.0465)$ > "number of geographically indicated products" $(\mu_{13})(\Phi_{13} = 0.0452)$ > "the attitudes and behaviors of the local population towards tourists" $(\mu_1)(\Phi_1 = 0.0239)$ > "the brand value of tourism areas" $(\mu_4)(\Phi_4 = 0.0183)$ > "hotel occupancy rate" $(\mu_{16})(\Phi_{16} = 0.0166)$ > "the level of conservation of natural resources" $(\mu_5)(\Phi_5 = 0.0141)$ > "number of hotel overnight stays" $(\mu_{17})(\Phi_{17} = 0.0125)$ > "the architectural structure of tourism areas" $(\mu_2)(\Phi_2 = 0.0118)$ > "the level of biodiversity conservation" $(\mu_6)(\Phi_6 = 0.0101)$ > "the infrastructure of tourism areas" $(\mu_3)(\Phi_3 = 0.0101)$ > "waste management" $(\mu_7)(\Phi_7 = 0.0099)$. In this ranking, "highland tourism center" emerged as the most significant criterion, whereas "waste management" had the lowest criterion weight.

iv. *Case study result 4* – Under the scenario where subjective and objective criterion weights were assigned equal importance, the final criterion weights and rankings were obtained as follows: "highland tourism center" $(\mu_{11})(\tau_{11} = 0.1237)$ > "number of blue flag beaches" $(\mu_{10})(\tau_{10} = 0.1037)$ > "number of festivals" $(\mu_{12})(\tau_{12} = 0.0759)$ > "number of hotels" $(\mu_{15})(\tau_{15} = 0.0744)$ > "number of immovable cultural properties" $(\mu_{14})(\tau_{14} = 0.0632)$ > "the architectural structure of tourism" $(\mu_2)(\tau_2 = 0.0630)$ > "the level of conservation of natural resources" $(\mu_5)(\tau_5 = 0.0607)$ > "average sunshine duration" $(\mu_8)(\tau_8 = 0.0603)$ > "average temperature" $(\mu_9)(\tau_9 = 0.0561)$ > "the infrastructure of tourism areas" $(\mu_3)(\tau_3 = 0.0552)$ > "the level of biodiversity conservation" $(\mu_6)(\tau_6 = 0.0517)$ > "the brand value of tourism areas" $(\mu_4)(\tau_4 = 0.0490)$ > "the attitudes and behaviors of the local population towards tourists" $(\mu_1)(\tau_1 = 0.0483)$ > "waste management" $(\mu_7)(\tau_7 = 0.0482)$ > "number of geographically indicated products" $(\mu_{13})(\tau_{13} = 0.0451)$ > "hotel occupancy rate" $(\mu_{16})(\tau_{16} = 0.0135)$ > "number of hotel overnight stays" $(\mu_{17})(\tau_{17} = 0.0080)$. As per the final criterion weighs, "highland tourism center" remained the most important criterion, while "number of hotel overnight stays" retained the lowest weight. Figure 3 shows the subjective, objective, and final criterion weights.

v. *Case study result 5* – The sustainable tourism attraction levels of the provinces in Türkiye's Eastern Black Sea region were determined using the OPLO-POCOD method, producing the following ranking: " *Rize* $(\nu_6)(\rho_6 = 0.9983)$ > *Trabzon* $(\nu_7)(\rho_7 = 0.8584)$ > *Giresun* $(\nu_3)(\rho_3 = 0.8574)$ > *Ordu* $(\nu_5)(\rho_5 = 0.8512)$ > *Gümüşhane* $(\nu_4)(\rho_4 = 0.8211)$ > *Artvin* $(\nu_1)(\rho_1 = 0.8142)$ > *Bayburt* $(\nu_2)(\rho_2 = 0.7994)$". Accordingly, *Rize* was identified as the province with the highest sustainable tourism attraction level.

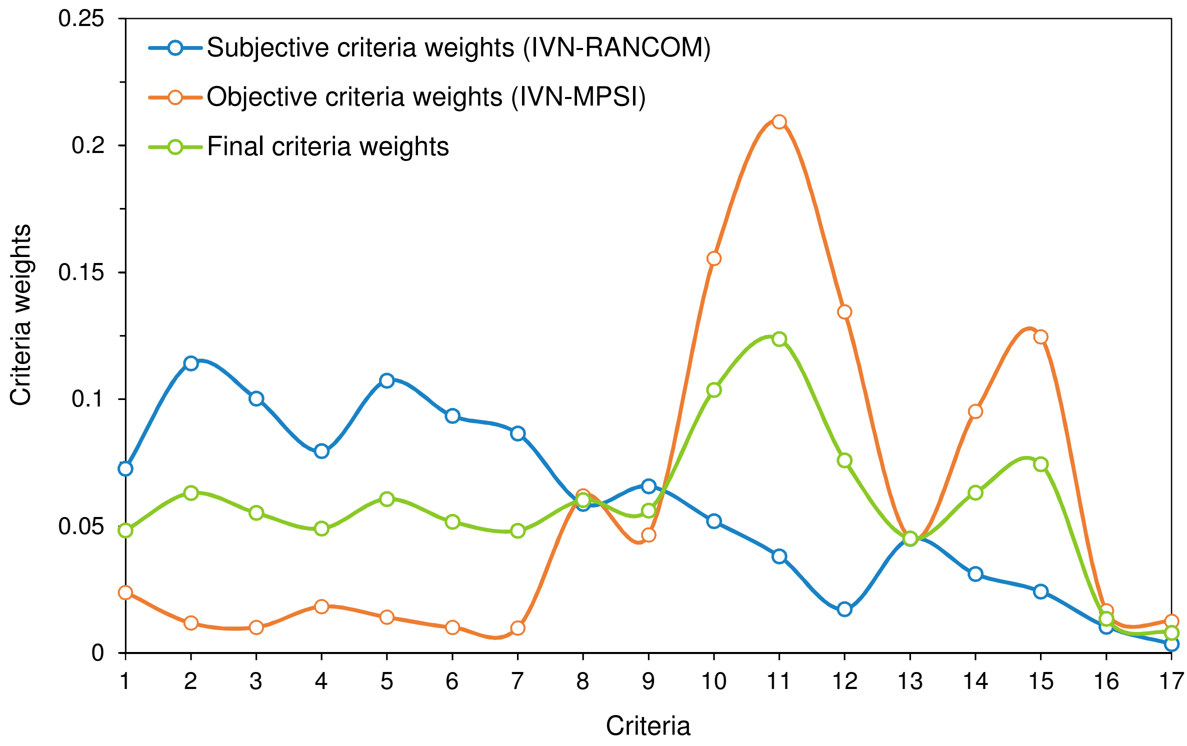

Fig. 3. All criteria weigh according to all criteria weighing methods

In conclusion, the IVN-RANCOM-MPSI-OPLO-POCOD hybrid method proved to be a successfully applicable DSS for determining sustainable tourism attraction levels.

5.1 Sensitivity Checks

Sensitivity analysis scenarios were created to test the robustness of the IVN-RANCOM-MPSI-OPLO-POCOD results and evaluate the benefits of the method. The first benefit lies in the method's capability to simultaneously utilize both quantitative and qualitative parameters. In this context, sensitivity analysis scenario-1 was constructed to determine sustainable tourism attraction levels based solely on qualitative criteria and solely on quantitative criteria. These results were compared with those obtained using IVN-RANCOM-MPSI-OPLO-POCOD.

The second advantage of this hybrid method is that it assesses sustainable tourism attractiveness using both subjective and objective criteria. The combination of subjective and objective criteria weightings is facilitated by the ς parameter. When the ς parameter is set to 0, results are derived exclusively from objective criteria weightings, whereas setting it to 1 yields results solely based on subjective criteria weightings. Additionally, assigning values between 0 and 1 to the ς parameter allows for varying contributions from the criteria weighting methods in the calculation of the overall criterion weights. sensitivity analysis scenario 2 was used to analyze the results by assigning values between 0 and 1 to the ς parameter. In sensitivity checks scenario-3, the effect of removing provinces from the model was analyzed to see if the top-ranked province would change.

The application of sensitivity analysis scenario-1 revealed that when sustainable tourism attraction levels were determined solely based on qualitative criteria, the ranking changed, with Artvin being identified as the province with the highest attraction level. Comparing this outcome with the research findings, where Rize ranked highest, it was found that Rize dropped to fifth place in this scenario. On the other hand, the results obtained by considering only quantitative parameters were consistent with the research findings, indicating that quantitative parameters played a relatively more dominant role. Figure 4 presents the results of sensitivity analysis scenario 1.

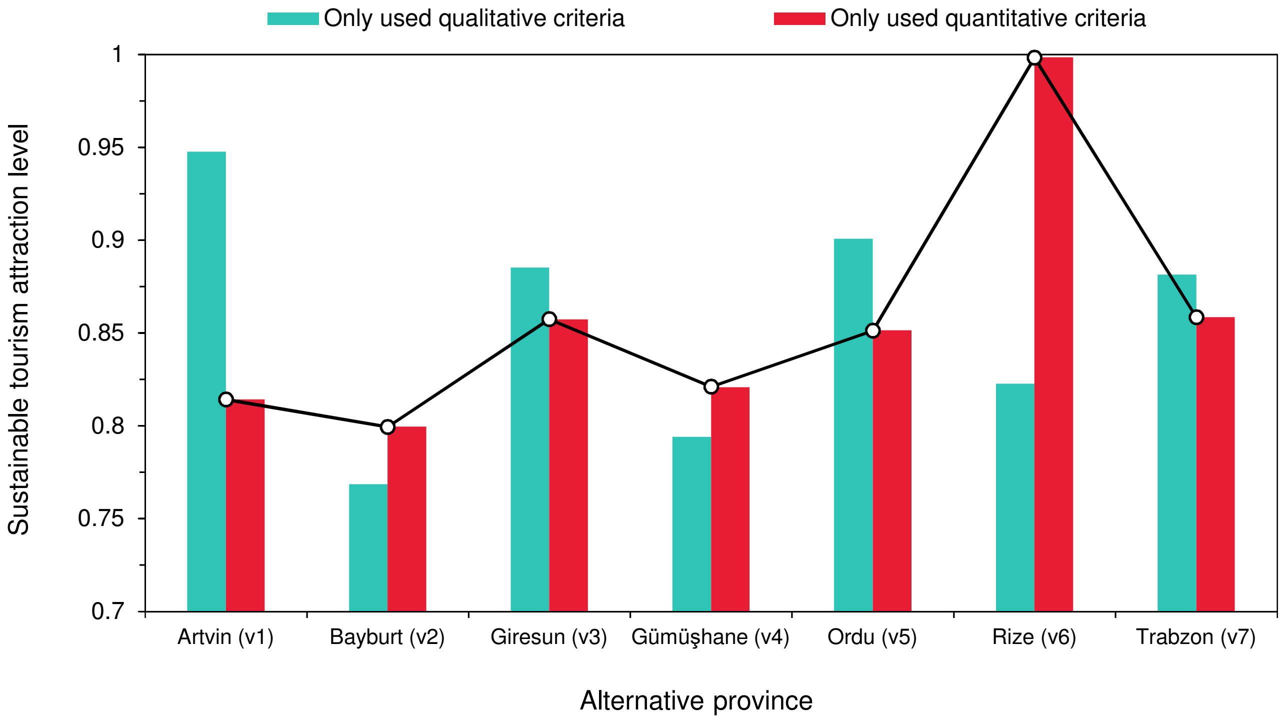

Fig. 4. Sensitivity analysis scenario-1

In sensitivity analysis scenario-2, it was observed that the rankings obtained using only subjective criteria weighting were identical to those obtained using only objective criteria weighting, regardless of the value assigned to the ς parameter. This consistency supports the robustness of the decision model's structure. The results of sensitivity analysis scenario-2 are shown in Figure 5.

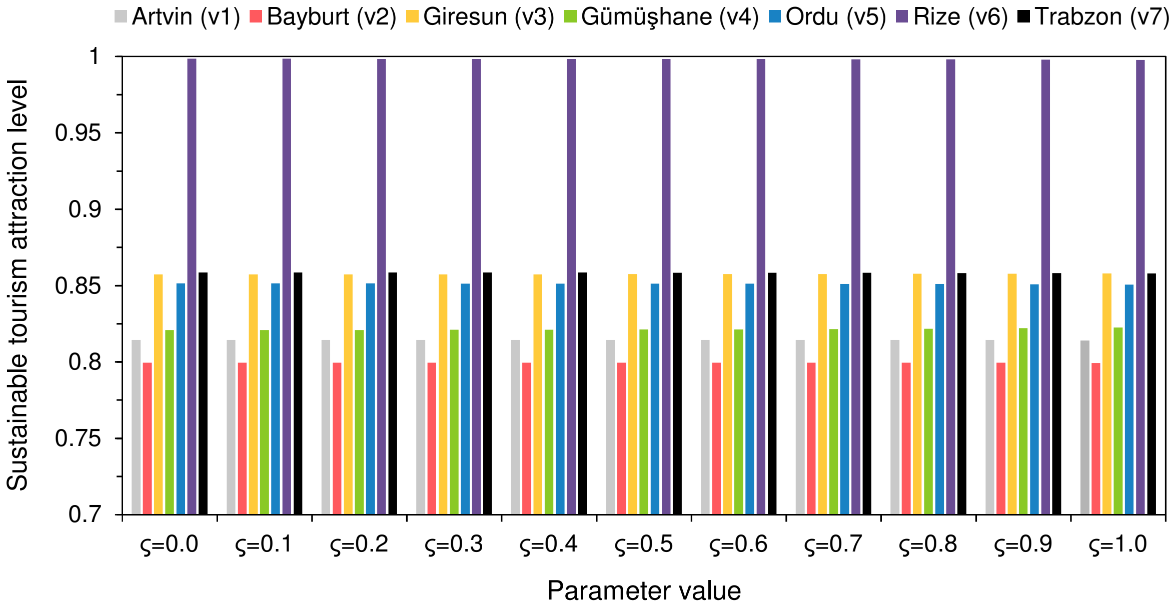

Fig. 5. Sensitivity analysis scenario-2

In sensitivity analysis scenario-3, province with the lowest sustainable tourism attractiveness was removed from the model, and the IVN-RANCOM-MPSI-OPLO-POCOD method was applied again. In all applications, Rize consistently emerged as the province with the highest sustainable tourism attraction level. This result reinforces the validity of the provinces selected for comparison within the decision model. Figure 6 presents the results of sensitivity analysis scenario 3.

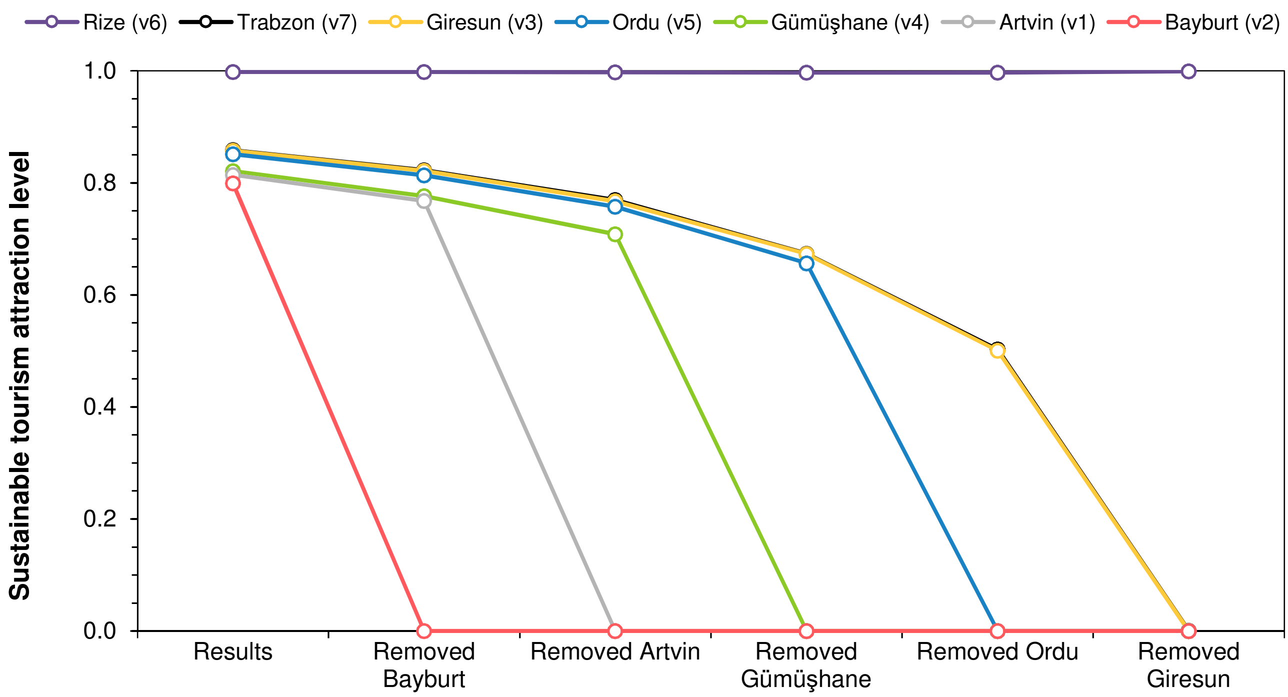

Fig. 6. Sensitivity analysis scenario-3

Ultimately, all sensitivity analysis scenarios support the results obtained through IVN-RANCOM-MPSI-OPLO-POCOD, confirming that this neutrosophic decision analytics approach produces robust outcomes.

5.2 Comparative Analysis

A comparison was made between IVN-RANCOM-MPSI-OPLO-POCOD and other ranking methods for assessing sustainable tourism attractiveness. In this comparison, various methods from the literature were employed, including ALWAS [86], AROMAN [87], ARTASI [88], RAM [89], and TOPSIS [90]. The sustainable tourism attraction levels of the provinces were determined using these methods, and the results were compared with those obtained from the IVN-RANCOM-MPSI-OPLO-POCOD hybrid method. Table 8 presents the ranking of the provinces according to their sustainable tourism attraction levels.

Table 8
Ranking according to comparative analysis

Methods	Ranking	Best	Second-best	Worst
IVN-RANCOM-MPSI-OPLO-POCOD	$v_6 > v_7 > v_3 > v_5 > v_4 > v_1 > v_2$	Rize	Trabzon	Bayburt
ALWAS	$v_6 > v_5 > v_3 > v_7 > v_1 > v_4 > v_2$	Rize	Ordu	Bayburt
AROMAN	$v_5 > v_6 > v_3 > v_7 > v_1 > v_4 > v_2$	Ordu	Rize	Bayburt
ARTASI	$v_5 > v_6 > v_3 > v_7 > v_1 > v_4 > v_2$	Ordu	Rize	Bayburt
RAM	$v_5 > v_6 > v_3 > v_7 > v_1 > v_4 > v_2$	Ordu	Rize	Bayburt
TOPSIS	$v_5 > v_6 > v_3 > v_7 > v_1 > v_4 > v_2$	Ordu	Rize	Bayburt

Figure 7 shows the normalized results thus providing a comparable format.

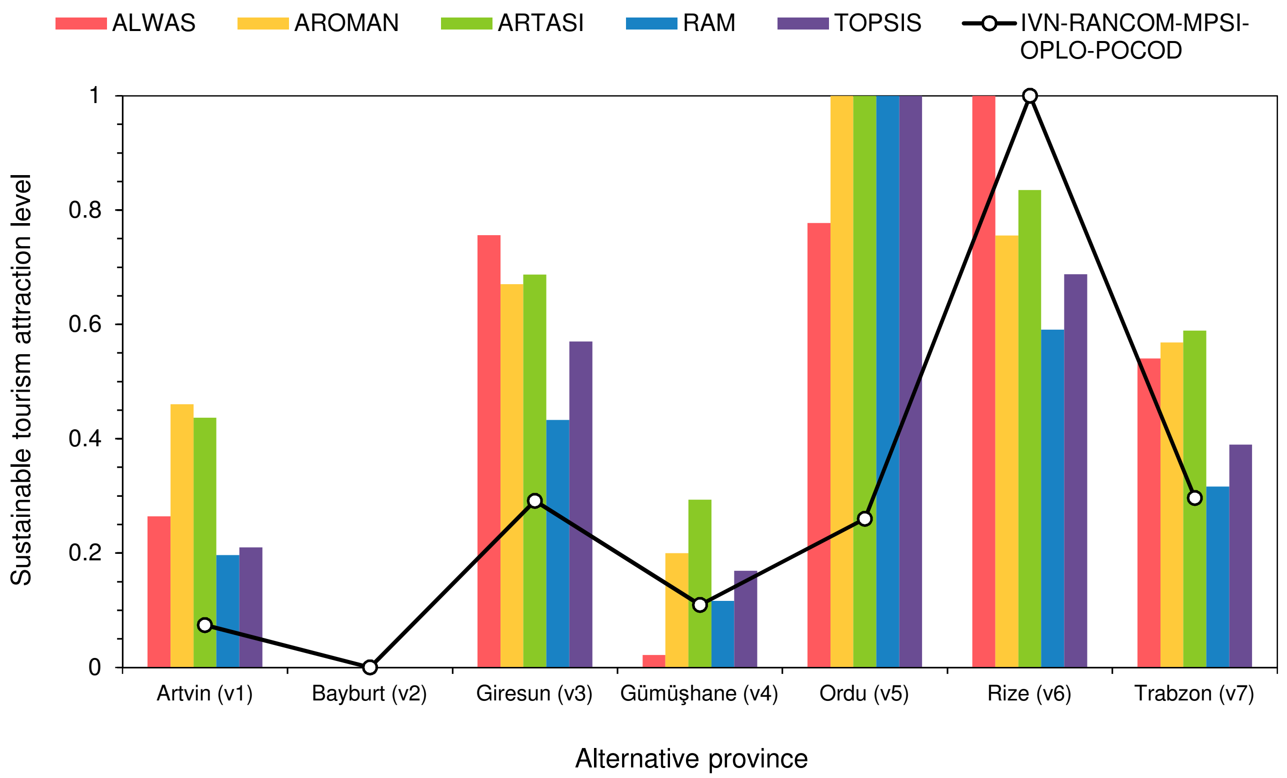

Fig. 7. Comparative analysis

Therefore, the comparison results are as follows:

i. When comparing IVN-RANCOM-MPSI-OPLO-POCOD with the ALWAS method, both identified Rize as the province with the highest sustainable tourism attraction level and Bayburt as the province with the lowest.
ii. In contrast, when comparing IVN-RANCOM-MPSI-OPLO-POCOD with AROMAN, ARTASI, RAM, and TOPSIS methods, Ordu emerged as the province with the highest sustainable tourism attraction level, while Bayburt consistently ranked as the lowest. In these methods, Rize was identified as the second-best province in terms of sustainable tourism attraction level.

These findings suggest that IVN-RANCOM-MPSI-OPLO-POCOD provides more precise calculations, yielding more accurate and reliable results.

5.3 Research Implications

The results and contributions of this study offer important insights for research and practice in sustainable tourism and decision-making systems. The main implications are as follows:

i. *Advancement of decision analytics tools in tourism* – The development of IVN-RANCOM-MPSI-OPLO-POCOD provides a novel framework for constructing DSSs in sustainable tourism. This approach can be further explored and refined for broader application in tourism management and policy development.
ii. *Integration of qualitative and quantitative data* – The study's successful integration of both expert opinions and quantitative data demonstrates the potential for combining subjective and objective data to enhance decision-making processes. Future research can expand on this methodological approach to address complex decision-making challenges in other sectors.
iii. *Methodological contributions to MCDM* – The proposed hybrid method offers valuable insights into the application of MCDM techniques, particularly the use of IVN sets and neutrosophic logic in decision-making. Researchers can apply and extend this methodology to other domains that require MCDM, such as environmental management and urban planning.
iv. *Potential for broader application in tourism destinations* – The approach presented in this study can be adapted to assess the sustainable tourism attraction levels of other regions beyond Türkiye's Eastern Black Sea region. Future studies can apply this hybrid method to other geographical areas, allowing comparisons of sustainable tourism practices on a global scale.
v. *Progress of multi-criteria decision models for sustainable development* – The research highlights the importance of incorporating both qualitative and quantitative criteria in sustainable development decision models. This framework can inform future research aimed at improving sustainable tourism practices by considering diverse factors such as environmental conservation, infrastructure, and community engagement.
vi. *Insights for tourism stakeholders and policymakers* – The findings give useful guidance for tourism managers, local governments, and policymakers. The DSS developed can guide strategic planning and resource allocation to optimize the sustainability of tourism destinations, particularly in underdeveloped or emerging tourist areas.

vii. *Enhancing stakeholder involvement in tourism planning* – By integrating expert opinions in the decision process, the study emphasizes the importance of stakeholder engagement. Future research can study how different groups like local communities, tourists, and business owners contribute to sustainable tourism development.

viii. *Improvement of tourism attractiveness evaluation models* – The study proposes a more refined approach for evaluating tourism attractiveness by incorporating both expert judgment and objective criteria. Researchers can further improve evaluation models by exploring additional criteria or refining existing ones to better capture the complexities of tourism sustainability.

ix. *Encouragement of cross-disciplinary research* – The interdisciplinary nature of this study, blending tourism management, decision science, and environmental sustainability, encourages cross-disciplinary research. Future studies can explore the intersection of these fields to develop more comprehensive frameworks for assessing and managing sustainable tourism.

x. *Implications for future methodological innovations* – The hybrid method presented in this research can serve as a foundation for future methodological innovations in the field of MCDM. Researchers can build upon IVN-RANCOM-MPSI-OPLO-POCOD by incorporating new techniques or adapting it to different contexts, potentially advancing the overall field of DSSs.

xi. *Application to other sectors of sustainable development* – The framework established in this study can be adapted to other sectors of sustainable development, such as sustainable agriculture, urban development, and environmental conservation. Future research could extend this methodology to evaluate sustainability in different industries and contexts.

Therefore, this research lays the foundation for future studies in sustainable tourism and MCDM, offering both theoretical and practical contributions that can inform policy, management practices, and further academic exploration in the field.

6. Conclusion

The main goal of this study was to develop a DSS to assess sustainable tourism attractiveness of provinces in Türkiye’s Eastern Black Sea region. Through the application of expert opinion-based MCDM methods, particularly the IVN-RANCOM-MPSI-OPLO-POCOD hybrid method, this research successfully integrated both qualitative and quantitative criteria. By using fuzzy logic with IVN sets and combining subjective and objective weighting methods, the study contributed to MCDM and sustainable tourism assessment. The methodology presented an innovative framework for determining sustainable tourism potential.

The case study results revealed valuable insights into the relative importance of different criteria for assessing sustainable tourism attraction. Among the qualitative criteria, "the architectural structure of tourism areas" emerged as the most critical factor. Among the quantitative criteria, the "highland tourism center" was identified as the most significant. The hybrid method enabled the calculation of final criterion weights by integrating both IVN-RANCOM and IVN-MPSI approaches, which contributed to a more balanced and accurate assessment process. The results also demonstrated that Rize emerged as the province with the highest sustainable tourism attraction level in the study area.

Furthermore, the robustness of the findings was confirmed through three sensitivity analyses, ensuring the reliability of the results. Comparative analysis with other established methods revealed minor discrepancies but consistent outcomes, further validating the strength of the IVN-RANCOM-MPSI-OPLO-POCOD hybrid method. These comparisons highlighted that the proposed approach offers comparable or even superior results, thereby reinforcing its methodological robustness. Combining fuzzy logic and IVN sets with traditional MCDM methods is an important step in improving DSSs for sustainable tourism management.

In conclusion, this study supports sustainable tourism assessment. The new hybrid method helps policymakers and tourism managers measure destination sustainability. The method combines expert opinions and numerical data for more accurate and valid decisions. It also improves MCDM methods and opens new directions for future research.

6.1 Study Limitations

Limitations are as follows:

i. *Expert opinion bias* – The results of the DSS are heavily reliant on the judgments of the experts involved in the evaluation process. Although efforts were made to mitigate bias, subjective opinions may still influence the outcome, especially when assessing qualitative criteria. Future studies could use more diverse experts to reduce bias and improve result reliability.
ii. *Data availability and quality* – The study used available qualitative and quantitative data, but data limitations and inconsistencies between provinces may affect accuracy. This limitation could affect the robustness of the conclusions drawn from the analysis.
iii. *Complexity of the hybrid method* – IVN-RANCOM-MPSI-OPLO-POCOD introduced in this study is complex and requires advanced knowledge of MCDM techniques and neutrosophic logic. While the method provides detailed and comprehensive results, its complexity may hinder its adoption by practitioners.
iv. *Sensitivity to weighting approaches* – Although sensitivity analysis was done, the results still depend on the chosen weighting methods, which can affect the final results. Future studies could try different weighting methods or compare approaches to make the decision process more robust.
v. *Limited consideration of dynamic factors* – The study considered a static snapshot of the sustainable tourism attraction levels of the provinces. However, tourism dynamics are subject to continuous changes in both demand and supply factors. Future research could incorporate temporal data and consider the dynamic nature of tourism development to provide more accurate long-term projections and analyses.

6.2 Future Research Directions

Future research directions are as follows:

i. Future studies could include more regions in Türkiye or other countries. This would help assess the generalizability and applicability of IVN-RANCOM-MPSI-OPLO-POCOD in different socio-cultural, economic, and environmental contexts, thus providing sustainable tourism attraction levels.

ii. Future research could use real-time data and changing variables in decision-making. Considering time-based changes in tourism, environment, and other factors would make the system more flexible and responsive to changes in demand and supply.
iii. Future research could combine IVN-RANCOM-MPSI-OPLO-POCOD with GIS to show tourism attractiveness on maps and improve spatial decision-making.

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Conflicts of Interest
The authors declare no conflicts of interest.

Declaration on the Use of Artificial Intelligence Tools
During the preparation of this work the authors used Grammarly and DeepL solely for language editing and proofreading. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Appendix: Supplementary Tables

Table A.1
Levels of expertise and score function values

Expert	Experience	IVN numbers	$Sc(\widetilde{\mathfrak{P}}_g)$
ι_1	Average (A)	$[0.40,0.50], [0.40,0.55], [0.50,0.60]$	1.0000
ι_2	Above Average (AA)	$[0.45,0.65], [0.35,0.45], [0.45,0.55]$	1.1000
ι_3	Very High (VH)	$[0.65,0.75], [0.15,0.25], [0.25,0.35]$	1.5000
ι_4	High (H)	$[0.55,0.65], [0.25,0.35], [0.35,0.45]$	1.3000
ι_5	Certainly High (CH)	$[0.75,0.85], [0.05,0.15], [0.15,0.25]$	1.7000
ι_6	Very High (VH)	$[0.65,0.75], [0.15,0.25], [0.25,0.35]$	1.5000
ι_7	Below Average (BA)	$[0.35,0.45], [0.45,0.55], [0.55,0.65]$	0.9000
ι_8	Average (A)	$[0.40,0.50], [0.40,0.55], [0.50,0.60]$	1.0000

Table A.2
Linguistic expressions-based criterion evaluation matrix

ι_g	μ_1	μ_2	μ_3	μ_4	μ_5	μ_6	μ_7	μ_8	μ_9	μ_{10}	μ_{11}	μ_{12}	μ_{13}	μ_{14}	μ_{15}	μ_{16}	μ_{17}
ι_1	CH	CH	VH	CH	CH	CH	CH	BA	BA	VL	BA	CL	AA	BA	CL	CL	VL
ι_2	VH	VH	VH	CH	CH	CH	CH	A	A	BA	L	VL	L	AA	VL	CL	CL
ι_3	VH	CH	CH	VH	H	H	H	AA	AA	BA	L	L	VL	VL	L	VL	VL
ι_4	H	VH	VH	H	CH	CH	CH	BA	BA	A	VL	VL	L	L	AA	L	VL
ι_5	VH	VH	VH	VH	VH	VH	VH	BA	BA	BA	BA	VL	A	L	BA	L	L
ι_6	VH	CH	CH	H	CH	VH	H	A	AA	AA	BA	L	AA	VL	VL	VL	L
ι_7	CH	VH	VH	CH	VH	VH	VH	A	A	L	BA	VL	A	A	A	L	VL
ι_8	VH	VH	VH	VH	VH	VH	VH	BA	BA	BA	A	L	BA	L	L	L	VL

Table A.3
IVN number-based criterion evaluation matrix

ι_g	μ_1						μ_2						μ_3					
	T^L	T^U	I^L	I^U	F^L	F^U	T^L	T^U	I^L	I^U	F^L	F^U	T^L	T^U	I^L	I^U	F^L	F^U
ι_1	0.75	0.85	0.05	0.15	0.15	0.25	0.75	0.85	0.05	0.15	0.15	0.25	0.65	0.75	0.15	0.25	0.25	0.35
ι_2	0.65	0.75	0.15	0.25	0.25	0.35	0.65	0.75	0.15	0.25	0.25	0.35	0.65	0.75	0.15	0.25	0.25	0.35
ι_3	0.65	0.75	0.15	0.25	0.25	0.35	0.75	0.85	0.05	0.15	0.15	0.25	0.75	0.85	0.05	0.15	0.15	0.25
ι_4	0.55	0.65	0.25	0.35	0.35	0.45	0.65	0.75	0.15	0.25	0.25	0.35	0.65	0.75	0.15	0.25	0.25	0.35
ι_5	0.65	0.75	0.15	0.25	0.25	0.35	0.65	0.75	0.15	0.25	0.25	0.35	0.65	0.75	0.15	0.25	0.25	0.35
ι_6	0.65	0.75	0.15	0.25	0.25	0.35	0.75	0.85	0.05	0.15	0.15	0.25	0.75	0.85	0.05	0.15	0.15	0.25
ι_7	0.75	0.85	0.05	0.15	0.15	0.25	0.65	0.75	0.15	0.25	0.25	0.35	0.65	0.75	0.15	0.25	0.25	0.35
ι_8	0.65	0.75	0.15	0.25	0.25	0.35	0.65	0.75	0.15	0.25	0.25	0.35	0.65	0.75	0.15	0.25	0.25	0.35
	⋮						⋮						⋮					
ι_g	μ_{15}						μ_{16}						μ_{17}					
	T^L	T^L	T^L	T^L	T^L	T^L	T^L	T^L	T^L	T^L	T^L	T^L	T^L	T^L	T^L	T^L	T^L	T^L
ι_1	0.05	0.15	0.75	0.05	0.15	0.75	0.05	0.15	0.75	0.05	0.15	0.75	0.15	0.25	0.65	0.75	0.75	0.85
ι_2	0.15	0.25	0.65	0.15	0.25	0.65	0.15	0.25	0.65	0.15	0.25	0.65	0.05	0.15	0.75	0.85	0.85	0.95
ι_3	0.25	0.35	0.55	0.25	0.35	0.55	0.25	0.35	0.55	0.25	0.35	0.55	0.15	0.25	0.65	0.75	0.75	0.85
ι_4	0.45	0.55	0.35	0.45	0.55	0.35	0.45	0.55	0.35	0.45	0.55	0.35	0.15	0.25	0.65	0.75	0.75	0.85
ι_5	0.35	0.45	0.45	0.35	0.45	0.45	0.35	0.45	0.45	0.35	0.45	0.45	0.25	0.35	0.55	0.65	0.65	0.75
ι_6	0.15	0.25	0.65	0.15	0.25	0.65	0.15	0.25	0.65	0.15	0.25	0.65	0.25	0.35	0.55	0.65	0.65	0.75
ι_7	0.40	0.50	0.40	0.40	0.50	0.40	0.40	0.50	0.40	0.40	0.50	0.40	0.15	0.25	0.65	0.75	0.75	0.85
ι_8	0.25	0.35	0.55	0.25	0.35	0.55	0.25	0.35	0.55	0.25	0.35	0.55	0.15	0.25	0.65	0.75	0.75	0.85

Table A.4
The aggregate overall criteria evaluation matrix with IVN numbers

	μ_1						⋯	μ_{17}					
	T^L	T^U	I^L	I^U	F^L	F^U		T^L	T^U	I^L	I^U	F^L	F^U
$\tilde{\mathfrak{Q}}_k$	0.6608	0.7630	0.1301	0.2370	0.2370	0.3392	⋯	0.1733	0.2736	0.6259	0.7264	0.7264	0.8267

Table A.5
Scoring matrix for the RANCOM method

	μ_1	μ_2	μ_3	μ_4	μ_5	μ_6	μ_7	μ_8	μ_9	μ_{10}	μ_{11}	μ_{12}	⋯	μ_{17}
$\mathfrak{Q}_k$	1.5283	1.5949	1.5734	1.5324	1.5939	1.5612	1.5391	0.9677	0.9839	0.8962	0.8154	0.5657	⋯	0.5473

Table A.6
Comparison matrix and total comparison value matrix

	μ_1	μ_2	μ_3	μ_4	μ_5	μ_6	μ_7	μ_8	μ_9	μ_{10}	μ_{11}	μ_{12}	μ_{13}	μ_{14}	μ_{15}	μ_{16}	μ_{17}	$\mathfrak{K}_k$
μ_1	0.5	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	10.5
μ_2	1	0.5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	16.5
μ_3	1	0	0.5	1	0	1	1	1	1	1	1	1	1	1	1	1	1	14.5
μ_4	1	0	0	0.5	0	0	0	1	1	1	1	1	1	1	1	1	1	11.5
μ_5	1	0	1	1	0.5	1	1	1	1	1	1	1	1	1	1	1	1	15.5
μ_6	1	0	0	1	0	0.5	1	1	1	1	1	1	1	1	1	1	1	13.5
μ_7	1	0	0	1	0	0	0.5	1	1	1	1	1	1	1	1	1	1	12.5
μ_8	0	0	0	0	0	0	0	0.5	0	1	1	1	1	1	1	1	1	8.5
μ_9	0	0	0	0	0	0	0	1	0.5	1	1	1	1	1	1	1	1	9.5
μ_{10}	0	0	0	0	0	0	0	0	0	0.5	1	1	1	1	1	1	1	7.5
μ_{11}	0	0	0	0	0	0	0	0	0	0	0.5	1	0	1	1	1	1	5.5
μ_{12}	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0	0	1	1	2.5
μ_{13}	0	0	0	0	0	0	0	0	0	0	1	1	0.5	1	1	1	1	6.5
μ_{14}	0	0	0	0	0	0	0	0	0	0	0	1	0	0.5	1	1	1	4.5
μ_{15}	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0.5	1	1	3.5
μ_{16}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	1	1.5
μ_{17}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0.5

Table A.7
Qualitative criterion-based evaluation matrix according to linguistic expressions

ν_f	ι_1							ι_2							⋯	ι_8						
	π_1	π_2	π_3	π_4	π_5	π_6	π_7	π_1	π_2	π_3	π_4	π_5	π_6	π_7		π_1	π_2	π_3	π_4	π_5	π_6	π_7
ν_1	AA	A	L	H	H	H	L	VH	BA	A	VH	CH	VH	AA	⋯	VH	A	A	BA	VH	AA	AA
ν_2	AA	A	L	L	BA	AA	L	CL	L	A	BA	AA	AA	BA	⋯	A	A	BA	L	H	AA	AA
ν_3	VH	AA	L	VH	AA	AA	L	BA	L	A	VL	AA	A	A	⋯	CH	VH	H	H	VH	H	VH
ν_4	BA	A	L	VH	L	H	L	L	L	BA	L	AA	BA	BA	⋯	H	BA	AA	AA	VH	AA	H
ν_5	VH	VH	L	VH	AA	AA	L	BA	BA	AA	L	H	A	AA	⋯	CH	VH	VH	AA	VH	H	H
ν_6	L	A	L	VH	A	H	L	AA	BA	AA	AA	A	A	CL	⋯	AA	AA	A	AA	A	BA	BA
ν_7	L	AA	L	VH	A	AA	L	H	A	H	A	H	AA	AA	⋯	H	VH	H	AA	BA	BA	A

Table A.8
Qualitative criterion-based alternative evaluation matrix according to IVN numbers*

ι_g	ν_f	π_1						π_2						⋯	π_7					
		T^L	T^U	I^L	I^U	F^L	F^U	T^L	T^U	I^L	I^U	F^L	F^U		T^L	T^U	I^L	I^U	F^L	F^U
	ν_1	0.45	0.55	0.35	0.45	0.45	0.55	0.40	0.50	0.40	0.50	0.50	0.60	⋯	0.25	0.35	0.55	0.65	0.65	0.75
	ν_2	0.45	0.55	0.35	0.45	0.45	0.55	0.40	0.50	0.40	0.50	0.50	0.60	⋯	0.25	0.35	0.55	0.65	0.65	0.75
	ν_3	0.65	0.75	0.15	0.25	0.25	0.35	0.45	0.55	0.35	0.45	0.45	0.55	⋯	0.25	0.35	0.55	0.65	0.65	0.75
ι_1	ν_4	0.35	0.45	0.45	0.55	0.55	0.65	0.40	0.50	0.40	0.50	0.50	0.60	⋯	0.25	0.35	0.55	0.65	0.65	0.75
	ν_5	0.65	0.75	0.15	0.25	0.25	0.35	0.65	0.75	0.15	0.25	0.25	0.35	⋯	0.25	0.35	0.55	0.65	0.65	0.75
	ν_6	0.25	0.35	0.55	0.65	0.65	0.75	0.40	0.50	0.40	0.50	0.50	0.60	⋯	0.25	0.35	0.55	0.65	0.65	0.75
	ν_7	0.25	0.35	0.55	0.65	0.65	0.75	0.45	0.55	0.35	0.45	0.45	0.55	⋯	0.25	0.35	0.55	0.65	0.65	0.75

*IVN numbers are shown only for the first expert. The same transformation is applied for the other experts

Table A.9
Aggregate qualitative criterion-based alternative evaluation matrix

ν_f	π_1						⋯	π_7					
	T^L	T^U	I^L	I^U	F^L	F^U		T^L	T^U	I^L	I^U	F^L	F^U
ν_1	0.4573	0.5653	0.3207	0.4347	0.4347	0.5427	⋯	0.2810	0.3832	0.5137	0.6168	0.6168	0.7190
ν_2	0.2628	0.3652	0.5314	0.6348	0.6348	0.7372	⋯	0.2593	0.3612	0.5361	0.6388	0.6388	0.7407
ν_3	0.4396	0.5507	0.3238	0.4493	0.4493	0.5604	⋯	0.2880	0.3942	0.4954	0.6058	0.6058	0.7120
ν_4	0.2903	0.3932	0.5025	0.6068	0.6068	0.7097	⋯	0.2635	0.3669	0.5281	0.6331	0.6331	0.7365
ν_5	0.4514	0.5615	0.3147	0.4385	0.4385	0.5486	⋯	0.3002	0.4037	0.4910	0.5963	0.5963	0.6998
ν_6	0.3412	0.4427	0.4552	0.5573	0.5573	0.6588	⋯	0.1854	0.2864	0.6122	0.7136	0.7136	0.8146
ν_7	0.3684	0.4714	0.4242	0.5286	0.5286	0.6316	⋯	0.2659	0.3677	0.5299	0.6323	0.6323	0.7341

Table A.10
Overall criterion-based alternative evaluation matrix

ν_f	μ_1	μ_2	μ_3	μ_4	μ_5	μ_6	μ_7	μ_8	μ_9	μ_{10}	μ_{11}	μ_{12}	⋯	μ_{17}
ν_1	1.1335	0.8608	0.7040	0.9501	1.2200	1.0973	0.7668	4.90	12.40	0.00	1.00	5.00	⋯	1.55
ν_2	0.7309	0.7521	0.6635	0.6182	0.8650	0.8443	0.7228	2.30	7.10	0.00	0.00	1.00	⋯	1.87
ν_3	1.1086	0.8802	0.7741	0.8707	0.9443	0.8566	0.7905	2.00	14.70	0.00	5.00	16.00	⋯	1.60
ν_4	0.7871	0.6959	0.6763	0.8154	0.8938	0.8618	0.7345	5.80	9.60	0.00	1.00	2.00	⋯	1.38
ν_5	1.1298	0.9605	0.8484	0.8411	0.9322	0.8107	0.8083	4.50	14.60	2.00	5.00	11.00	⋯	1.55
ν_6	0.8857	0.8382	0.7640	0.9394	0.8168	0.8442	0.5731	4.50	14.80	0.00	5.00	9.00	⋯	2.01
ν_7	0.9435	0.9731	0.8870	1.0540	0.8157	0.7697	0.7357	4.20	14.50	0.00	3.00	2.00	⋯	1.74

Table A.11
Standardized decision matrix, mean matrix, and preference variation matrix

ν_f	μ_1	μ_2	μ_3	μ_4	μ_5	μ_6	μ_7	μ_8	μ_9	μ_{10}	μ_{11}	μ_{12}	⋯	μ_{17}
ν_1	1.0000	0.8846	0.7937	0.9014	1.0000	1.0000	0.9486	0.8448	0.8378	0.0000	0.2000	0.3125	⋯	0.7711
ν_2	0.6448	0.7729	0.7480	0.5865	0.7090	0.7694	0.8943	0.3966	0.4797	0.0000	0.0000	0.0625	⋯	0.9303
ν_3	0.9780	0.9046	0.8727	0.8261	0.7740	0.7807	0.9780	0.3448	0.9932	0.0000	1.0000	1.0000	⋯	0.7960
ν_4	0.6944	0.7152	0.7624	0.7736	0.7327	0.7854	0.9087	1.0000	0.6486	0.0000	0.2000	0.1250	⋯	0.6866
ν_5	0.9967	0.9871	0.9565	0.7980	0.7641	0.7388	1.0000	0.7759	0.9865	1.0000	1.0000	0.6875	⋯	0.7711
ν_6	0.7814	0.8614	0.8614	0.8912	0.6695	0.7693	0.7090	0.7759	1.0000	0.0000	1.0000	0.5625	⋯	1.0000
ν_7	0.8323	1.0000	1.0000	1.0000	0.6686	0.7015	0.9101	0.7241	0.9797	0.0000	0.6000	0.1250	⋯	0.8657
$\mathfrak{X}_k$	0.8468	0.8751	0.8564	0.8253	0.7597	0.7921	0.9070	0.6946	0.8465	0.1429	0.5714	0.4107	⋯	0.8316
$\mathfrak{W}_k$	0.1317	0.0653	0.0554	0.1011	0.0777	0.0555	0.0548	0.3411	0.2562	0.8571	1.1543	0.7411	⋯	0.0689

Table A.12
Best value matrix

	μ_1	μ_2	μ_3	μ_4	μ_5	μ_6	μ_7	μ_8	μ_9	μ_{10}	μ_{11}	μ_{12}	⋯	μ_{17}
$\mathfrak{B}_k$	1.1335	0.9731	0.8870	1.0540	1.2200	1.0973	0.8083	5.8000	14.8000	2.0000	5.0000	16.0000	⋯	2.0100

Table A.13
Opportunity loss values matrix

ν_f	μ_1	μ_2	μ_3	μ_4	μ_5	μ_6	μ_7	μ_8	μ_9	μ_{10}	μ_{11}	μ_{12}	⋯	μ_{17}
ν_1	0.0000	0.1123	0.1830	0.1040	0.0000	0.0000	0.0415	0.9000	2.4000	2.0000	4.0000	11.0000	⋯	0.4600
ν_2	0.4027	0.2210	0.2236	0.4358	0.3550	0.2530	0.0855	3.5000	7.7000	2.0000	5.0000	15.0000	⋯	0.1400
ν_3	0.0250	0.0929	0.1130	0.1833	0.2757	0.2407	0.0178	3.8000	0.1000	2.0000	0.0000	0.0000	⋯	0.4100
ν_4	0.3464	0.2771	0.2107	0.2386	0.3262	0.2355	0.0738	0.0000	5.2000	2.0000	4.0000	14.0000	⋯	0.6300
ν_5	0.0037	0.0126	0.0386	0.2129	0.2878	0.2866	0.0000	1.3000	0.2000	0.0000	0.0000	5.0000	⋯	0.4600
ν_6	0.2478	0.1348	0.1230	0.1146	0.4032	0.2531	0.2352	1.3000	0.0000	2.0000	0.0000	7.0000	⋯	0.0000
ν_7	0.1901	0.0000	0.0000	0.0000	0.4042	0.3276	0.0726	1.6000	0.3000	2.0000	2.0000	14.0000	⋯	0.2700

Table A.14
Ordered pair values matrix

ν_f	μ_1		μ_2		μ_3		μ_4		μ_5		μ_6		μ_7		⋯	μ_{17}	
	$\mathfrak{Z}_{hk}$	$\mathfrak{U}_{hk}$	$\mathfrak{Z}_{hk}$	$\mathfrak{U}_{hk}$	$\mathfrak{Z}_{hk}$	$\mathfrak{U}_{hk}$	$\mathfrak{Z}_{hk}$	$\mathfrak{U}_{hk}$	$\mathfrak{Z}_{hk}$	$\mathfrak{Z}_{hk}$	$\mathfrak{Z}_{hk}$	$\mathfrak{U}_{hk}$	$\mathfrak{Z}_{hk}$	$\mathfrak{U}_{hk}$		$\mathfrak{Z}_{hk}$	$\mathfrak{U}_{hk}$
ν_1	1.13	0.00	0.86	0.11	0.70	0.18	0.95	0.10	1.55	1.55	1.10	0.00	0.77	0.04	⋯	12.40	2.40
ν_2	0.73	0.40	0.75	0.22	0.66	0.22	0.62	0.44	1.87	1.87	0.84	0.25	0.72	0.09	⋯	7.10	7.70
ν_3	1.11	0.02	0.88	0.09	0.77	0.11	0.87	0.18	1.60	1.60	0.86	0.24	0.79	0.02	⋯	14.70	0.10
ν_4	0.79	0.35	0.70	0.28	0.68	0.21	0.82	0.24	1.38	1.38	0.86	0.24	0.73	0.07	⋯	9.60	5.20
ν_5	1.13	0.00	0.96	0.01	0.85	0.04	0.84	0.21	1.55	1.55	0.81	0.29	0.81	0.00	⋯	14.60	0.20
ν_6	0.89	0.25	0.84	0.13	0.76	0.12	0.94	0.11	2.01	2.01	0.84	0.25	0.57	0.24	⋯	14.80	0.00
ν_7	0.94	0.19	0.97	0.00	0.89	0.00	1.05	0.00	1.74	1.74	0.77	0.33	0.74	0.07	⋯	14.50	0.30

Table A.15
Best ordered pair values matrix

	μ_1		μ_2		μ_3		μ_4		μ_5		μ_6		μ_7		⋯	μ_{17}	
	$\mathfrak{Z}_{hk}$	$\mathfrak{U}_{hk}$	$\mathfrak{Z}_{hk}$	$\mathfrak{U}_{hk}$	$\mathfrak{Z}_{hk}$	$\mathfrak{U}_{hk}$	$\mathfrak{Z}_{hk}$	$\mathfrak{U}_{hk}$	$\mathfrak{Z}_{hk}$	$\mathfrak{U}_{hk}$	$\mathfrak{Z}_{hk}$	$\mathfrak{U}_{hk}$	$\mathfrak{Z}_{hk}$	$\mathfrak{U}_{hk}$		$\mathfrak{Z}_{hk}$	$\mathfrak{U}_{hk}$
$\mathfrak{S}_k$	1.13	0.00	0.97	0.00	0.89	0.00	1.05	0.00	1.22	0.00	1.10	0.00	0.81	0.00	⋯	2.01	0.00

Table A.16
Distance matrix

ν_f	μ_1	μ_2	μ_3	μ_4	μ_5	μ_6	μ_7	μ_8	μ_9	μ_{10}	μ_{11}	⋯	μ_{16}	μ_{17}
ν_1	0.000	0.159	0.259	0.147	0.000	0.000	0.059	1.273	3.394	2.828	5.657	⋯	9.645	0.651
ν_2	0.569	0.312	0.316	0.616	0.502	0.358	0.121	4.950	10.889	2.828	7.071	⋯	14.920	0.198
ν_3	0.035	0.131	0.160	0.259	0.390	0.340	0.025	5.374	0.141	2.828	0.000	⋯	10.380	0.580
ν_4	0.490	0.392	0.298	0.337	0.461	0.333	0.104	0.000	7.354	2.828	5.657	⋯	19.502	0.891
ν_5	0.005	0.018	0.055	0.301	0.407	0.405	0.000	1.838	0.283	0.000	0.000	⋯	0.000	0.651
ν_6	0.350	0.191	0.174	0.162	0.570	0.358	0.333	1.838	0.000	2.828	0.000	⋯	6.718	0.000
ν_7	0.269	0.000	0.000	0.000	0.572	0.463	0.103	2.263	0.424	2.828	2.828	⋯	9.588	0.382

Table A.17
Weighted distance matrix

ν_f	μ_1	μ_2	μ_3	μ_4	μ_5	μ_6	μ_7	μ_8	μ_9	μ_{10}	μ_{11}	μ_{12}	⋯	μ_{17}
ν_1	0.000	0.010	0.014	0.007	0.000	0.000	0.003	0.077	0.190	0.293	0.700	1.180	⋯	0.005
ν_2	0.027	0.020	0.017	0.030	0.030	0.019	0.006	0.299	0.611	0.293	0.875	1.609	⋯	0.002
ν_3	0.002	0.008	0.009	0.013	0.024	0.018	0.001	0.324	0.008	0.293	0.000	0.000	⋯	0.005
ν_4	0.024	0.025	0.016	0.017	0.028	0.017	0.005	0.000	0.413	0.293	0.700	1.502	⋯	0.007
ν_5	0.000	0.001	0.003	0.015	0.025	0.021	0.000	0.111	0.016	0.000	0.000	0.536	⋯	0.005
ν_6	0.017	0.012	0.010	0.008	0.035	0.019	0.016	0.111	0.000	0.293	0.000	0.751	⋯	0.000
ν_7	0.013	0.000	0.000	0.000	0.035	0.024	0.005	0.137	0.024	0.293	0.350	1.502	⋯	0.003

Table A.18
Total distance matrix and the opportunity loss matrix

	Artvin (ν_1)	**Bayburt** (ν_2)	**Giresun** (ν_3)	**Gümüşhane** (ν_4)	**Ordu** (ν_5)	**Rize** (ν_6)	**Trabzon** (ν_7)
$\mathfrak{C}_f$	195.7367	211.3184	150.2433	188.4412	156.7704	1.808082	149.1818
$\mathfrak{D}_f$	0.185797	0.200587	0.142614	0.178872	0.148809	0.001716	0.141606

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