Low-carbon tourism strategy evaluation and selection using interval-valued intuitionistic fuzzy additive ratio assessment approach based on similarity measures

Arunodaya Raj Mishra¹ · Ayushi Chandel² · Parvaneh Saeidi³

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Abstract

Recently, the assessment and selection of most suitable low-carbon tourism strategy has gained an extensive consideration from sustainable perspectives. Owing to participation of multiple qualitative and quantitative attributes, the low-carbon tourism strategy (LCTS) selection process can be considered as multi-criteria decision-making (MCDM) problem. As uncertainty is usually occurred in LCTSs evaluation, the theory of interval-valued intuitionistic fuzzy sets (IVIFSs) has been established as more flexible and efficient tool to model the uncertain decision-making problems. The idea of the present study is to develop an extended method using additive ratio assessment (ARAS) framework and similarity measures in a way to find an effective solution to the decision-making problems using IVIFSs. The bases of the proposed method are the IVIFSs operators, some modifications in the traditional ARAS framework and a calculation procedure of the weights of the criteria. To calculate criterion weight, new similarity measures for IVIFSs are developed aiming at the achievement of more realistic weights. Also, a comparison is demonstrated to the currently used similarity measures in order to show the efficiency of the developed approach. To confirm that the developed IVIF-ARAS approach can be successfully employed to practical decision-making problems, a case study of LCTS selection problem is considered. The final results from the developed approach and the extant models are compared for the validation of the proposed approach in this study.

Keywords Interval-valued intuitionistic fuzzy sets · Similarity measure · MCDM · ARAS · Low-carbon tourism

✉ Arunodaya Raj Mishra
arunodaya87@outlook.com

Ayushi Chandel
ashuchandel.95@gmail.com

¹ Department of Mathematics, Government College Jaitwara, Satna, Madhya Pradesh 485221, India

² Department of Computer Science & Engineering, ITM University, Gwalior, Madhya Pradesh 474001, India

³ Facultad de Ciencias Administrativas y Económicas, Universidad Tecnológica Indoamérica, Quito, Ecuador

1 Introduction

During these days, a series of new ideas and policies have emerged, namely “carbon footprint” (He et al., 2020), “low-carbon economy (LCE)” (Bonsu, 2020), “low-carbon technology” (Shi et al., 2020), “low-carbon development” (Chen et al., 2020), “low-carbon lifestyle” (Cheng et al., 2020), “low-carbon supply chain (LCSC)” (Shaharudin et al., 2019), “low-carbon society (LCS)” (Berger et al., 2020), “low-carbon city” (Harris et al., 2020) and “low-carbon world (Cojoianu et al., 2020)”. In the contextual of global warming, the “LCE” based on low energy consumption and pollution has become a global hot spot (He & Tu, 2020). Developed countries in Europe and the USA vigorously promote the “low-carbon revolution” (Wen & Jing, 2011) with energy efficiency and low emissions as the core, focus on the progress of “low-carbon technology”, and make major adjustments to industries, energy, technology, trade and other policies in order to seize the opportunities and occupy the industrial commanding heights.

With the increasing global warming and environmental concerns, a wave of LCE action has received a great attention. Low-carbon tourism, as an extension of LCE, is a significant way to achieve the sustainable growth of the tourism sector and a development of future economic growth (Zhang et al., 2020). The low-carbon method mentions the lessening of CO₂ and other GHG emissions through policy management, technological innovation, and alterations in individual life activities in the combined efforts of the government, organizations, and individuals to make a way of economic growth of low-carbon emission. The low-carbon mode can not only encounter the requirements of economic development, but also guard the environment (Mu et al., 2011; Su, 2019).

The low-carbon tourism (LCT) enterprise has immense social value and economic importance (He & Wang, 2014). In 2008, Gössling et al. (2012) presented the concern of LCT and asserted that it is sustainable. Also, United Nations World Tourism Organization (UNWTO) (2008) produced data on universal Tourism Carbon Emissions (TCEs), which benefits the academic circles and the tourism sector to achieve intuitive perception of the problem of TCEs. Given the contextual pervasiveness of a low-carbon idea, several authors have focused their attention on this phenomenon and presented considerable researches (Sect. 2.1). Though there is no universal definition of LCT, the key prominence is that energy consumption and CO₂ emissions initiated by the actions, goods and services of tourism are minimized (Chiesa & Gautam, 2009; Filimonau et al., 2011). In recent years, a few of previous studies highlighted the important role of low-carbon tourism in the literature review (Lee et al., 2018; Puška et al., 2019; Thongdejsri & Nitivattananon, 2019; Zhang, 2017; Zhang & Zhang, 2020). He et al. (2021) gave a framework for conceptualizing the emerging sustainable community-based tourism using a SWARA (step-wise weight assessment ratio analysis)–MULTIMOORA (multi-objective optimization based on ratio analysis with full multiplicative form) methodology.

However, the selection of desirable LCT strategy can be regarded as multi-criteria decision-making (MCDM) problem due to occurrence of several tangible and intangible attributes (Zhang, 2017). Recently, several MCDM methods have been effectively implemented for solving various practical decision-making problems. Nonetheless, the majority of MCDM methods work with crisp numbers, which might be insufficient when working on real-life problems. In real-life applications, the selection of the optimal options often relies on fuzzy and uncertain information. Thus, the majority of MCDM approaches are extended in a way to be applicable to fuzzy environments. In some instances, fuzzy numbers may be still inadequate because of the natural vagueness

of subjective decisions made by decision experts (DEs) or the vagueness of the complicated socio-economic situations. As decision-making problems turn out to be more complex, recognizing a distinctive alternative becomes more challenging for DEs. In this situation, the fuzzy doctrine is applied for evaluating the best alternative due to its resemblance to human analysis. In addition, we observe that information may also suffer from some limitations, which results in insufficiency and lack of accuracy. Such flaws of traditional FSs or crisp sets can be dealt by employing the IFSSs, which can capture DEs' judgments (Büyüközkan & Göçer, 2017).

When DEs make a decision to assess and choose an appropriate option, this generally recommends a complicated problem concerning numerous criteria. To manage it effectively, additive ratio assessment (ARAS) method is an appropriate approach to adopt. ARAS mainly relies upon the inspiration that the philosophy of complex domains with contradictory attributes can be explained by applying easy relative associations as pioneered by Zavadskas and Turskis (2010). The outcome of the paper arrives from its proposal of a new MCDM method incorporating the interval-valued intuitionistic fuzzy sets (IVIFSs)-similarity measures and conventional ARAS approach. In the extended ARAS method, the performance evaluations of alternatives are articulated in terms of IVIFSs, whereas similarity measure is applied for criteria evaluation in a decision-making setting, where DE expresses their individual performance evaluation with IVIFNs. The developed method was found more flexible in determining group performance evaluations over the others. Combining the similarity measure and ARAS approach on IVIFSs facilitates DEs to employ the advantages of the similarity measure, which are attained because of its capability in estimating problems linearly and ARAS approach offered by its capability in assessing experts' preferences efficiently. This association on IVIFSs offers a simple and more effective approach to solving complicated decision-making problems. It also offers a useful, sensible and logical outcome in decision-making procedure on IVIFSs considerable strength in relating the uncertain and fuzzy atmosphere as a benefit on the fuzzy and intuitionistic fuzzy outlines of similarity measure and ARAS method. Then, the proposed method is implemented on low-carbon tourism strategy (LCTS) selection problem. This combination has a contribution to existing body of knowledge through pioneering an incorporated framework and making use of a real-life problem to develop the LCTS process. The main benefit of intuitionistic fuzzy sets (IFSs) compared to the crisp or a conventional fuzzy doctrine is that IFSs distinguish the negative and the positive suggestion for membership and non-membership options (Büyüközkan & Göçer, 2017). The IVIFSs doctrine was pioneered by Atanassov and Gargov (1989) for handling the uncertainty in the information and fuzziness in DE's opinions in realistic decision-making concerns. The prime outcome of IVIFSs is that both the belongingness membership grade (BG) and the non-belongingness grade (NG) of an element to IVIFSs are considered and measured on interval values instead of exact numbers. As a result, there is a significant need to explore more effectual and suitable mathematical methods by employing the IVIFSs consecutively to better tackle low-carbon tourism strategy selection problems with higher levels of uncertainty and ambiguity. On the contrary, IVIFNs offer an opportunity for providing a model of a higher sufficiency for evaluating the complicated real-life problems. IVIF-ARAS is known as a discrete method whose usefulness is established in the present research.

However, according to the above discussions, in this study, an attempt has been carried out to develop a comprehensive framework to evaluate and selection the LCTSs in Indian tourism areas. Therefore, the main contributions of this study are provided as follows:

Firstly, a new comprehensive framework to evaluate and selection of LCTSs in the Indian tourism areas has been developed.

Secondly, an extended ARAS approach under IVIF environment is introduced to evaluate and selection of LCTSs in the Indian tourism areas.

Thirdly, a survey and literature review related to similarity measure for IVIFSs is conducted. Novel similarity measures for IVIFSs are developed to obtain more realistic weights. Also, comparative discussion is made with extant method to show superiority of developed ones.

Fourthly, the result of IVIF-ARAS is compared with the IVIF-TOPSIS, IVIF-COPRAS, ANP-GCI and IVIF-MABAC methods to illustrate the proficiency and consistency of proposed framework.

The remaining study is organized as Sect. 2 that confers the literature review related to low-carbon tourism strategy evaluation and ARAS method. Section 3 offers the basic concepts of IVIFSs, proposes a novel similarity measure and develops an extended IVIF-ARAS methodology. Section 4 demonstrates a case study of LCTS selection which displays the practicality and usefulness of developed model. Lastly, Sect. 5 concludes the study and recommends for future study.

2 Literature review

2.1 An overview on low-carbon tourism

Tourism is one of the fastest developing industries in the globe. As travel demands will only continue to grow, both tourism operators and tourists will undoubtedly become the producers of today's global greenhouse effect. They have the accountability and commitment to sponsor and practice low-carbon green tourism. The root cause of such events is the global warming mainly caused by industrial development, together with the increase in the total emissions of individual carbon dioxide in transportation and various consumption behaviors in the tourism industry (Yu & Tsung-Lin, 2020). By comparing with issues about an LCE, LCT only acknowledged attention much later. However, in the commencement of this century, tourism or research into the association with the tourism development and CO₂ emissions has gained growing concentration, and the idea of "LCT" was not put forward until 2008. Gössling et al. (2012) gave the concern of "moving toward low-carbon tourism: new opportunities for destinations and tour operators." Gössling et al. (2015) authorize the predominance of transportation in tourism carbon emissions. Durbarray and Seetanah (2015) explore the association between tourism carbon emissions (TCEs) and climate change. Tourism operator priorities and inspirations for carbon offset choices by ecologically licensed tourism enterprises, the significance of communications in employing carbon label structures, as well as the carbon literacy of hotel staff and tourists' understanding of a LCT product were inspected by Zeppel & Beaumont (2013), Gössling and Buckley (2016), Teng et al. (2014), McKercher et al. (2010) and Juvan and Dolnicar (2014), respectively. Correspondingly, Horng et al. (2014) focused on the significance of low-carbon edification in the determination to attain TCEs reductions. McLennan et al. (2014) criticized the detail that the uptake of carbon offsetting projects has been apparently quite low in the tourism industry, notwithstanding the extensive variety of these structures.

Despite the sustainable efforts in LCT, as opposed to the assessment of an LCE (Huang & Mauerhofer, 2016; Zhou et al., 2015), to our information, some researchers have developed to the assessment of LCT, particularly regarding the meso/macro-tourism destinations. For instance, Cheng et al. (2013) discussed an assessment index scheme containing

27 diverse assessment indices concerned with the environment, management and attitudes to LCT attractions. They applied a wetland as a case study, while Luo et al. (2014) gave a structure dynamics scheme of a de-carbonated tourist attraction with 12 level variables. Furthermore, preceding relevant studies on assessment indices of LCT development have been accompanied, containing: the association and growth tendencies between revenues, energy consumption, garbage emission and carbon intensity, as explored by (Xu et al., 2011). Taiwan's LCT development suitability assessment indicators were recognized by (Cho et al., 2016). They created a thorough assessment index scheme containing of 53 indicators, which discusses transportation, travel agencies, hotel accommodation, destinations, local communities and food service.

Though, the outcomes of discussed researches are always tough to implement to real policy-making in LCT development as (a) various indicators may diminish the efficiency of management in maximum cases, (b) the linear assessment does not resemble well with indicators which have multifaceted interdependence between them and (c) some indicators, namely resident population and information scheme construction are beyond the LCT structure, notwithstanding their association with LCT. That means, the index structure is too generalized. Thus, this paper aims to present a new decision-making method which can be applied to assess LCTs and offer some countermeasures to propose LCT. The key outcome of this study is to determine the LCTs and set up a widespread and effective regional assessment indicator structure of LCT.

2.2 A review of fuzzy decision-making approach

MCDM approaches are adopted for the aim of selecting the optimal alternative from the available alternatives set over various conflicting criteria. The criterion information is determined to achieve the optimum outcome in MCDM approaches. Recently, in decision-making settings, FSs and their extensions have obtained more attention from the scholars, which was mainly due to the increase of complexity and widespread changes of today's environment. As a result, lots of MCDM methods including elimination and choice expressing reality (ELECTRE) (Amirghodsi et al., 2020; Kilic et al., 2020; Mishra et al., 2020d), TOPSIS (Rani et al., 2020a, 2020c), TODIM (an acronym in Portuguese for interactive MCDM) (Mishra et al., 2020a, 2020b, 2020c, 2020d; Wang et al., 2020), VIKOR (Rafieyan et al., 2020; Rani et al., 2019), PROMETHEE (Preference ranking organization method for enrichment of evaluations) (Greco et al., 2021; Makan & Fadili, 2020), WASPAS (weighted aggregated sum product assessment), complex proportional assessment (COPRAS) (Mishra et al., 2019, 2020c; Rani et al., 2020b), ARAS (Heidary Dahooie et al., 2019; Zavadskas & Turskis, 2010), and others were generalized in an uncertain decision-making context with varied weight-determination approaches.

The IVIFSs doctrine was pioneered by Atanassov and Gargov (1989) for handling the uncertainty in the information and fuzziness in DE's opinions in real decision-making problems. Various author(s) have utilized IVIFSs to construct MCDM approaches for solving real-life problems under uncertain situations (Mishra et al., 2020a, 2020b; Wang & Wan, 2020; Chen et al., 2021). First, Xu (2007b) proposed various aggregation operators for IVIFSs and presented an application of the intuitionistic fuzzy weighted geometric average (IFWGA) and IVIF-weighted arithmetic average (IVIFWAA) operators to MCDM problems by utilizing the score value and accuracy value of IVIFNs. Bai (2013) introduced an enhanced version of score function to efficiently rank the order of the IVIFNs and

developed score function based IVIF-TOPSIS approach to evaluate MCDM problem with completely unknown weight information.

Mishra and Rani (2018b) studied an extended WASPAS model using entropy, divergence and similarity measures for evaluating reservoir flood control management policy. Narayanamoorthy et al. (2019) gave a model using fuzzy VIKOR under interval-valued intuitionistic hesitant fuzzy entropy for selection of industrial robots. Yeni and Özçelik (2019) proposed a new method using combinative distance-based assessment (CODAS) approach under IVIFSs for handling group decision-making problem. Abdullah et al. (2019) presented a novel decision-making method based on modification of DEMATEL approach under IVIFS environment and Choquet integral for solving sustainable solid waste management problems. Mishra et al. (2020b) suggested a novel TODIM method to assess and select desirable vehicle insurance company under IVIFSs environment.

Alternatively, several researchers have made effective use of ARAS and fuzzy ARAS in various disciplines, e.g., sustainable development, economics, engineering, and construction (see Table 1). The assessment provided in Table 1 implies the combined similarity measure and ARAS for IVIFSs on decision making is unique and has not been implemented before.

3 Research method and materials

3.1 Preliminaries

Here, we present some fundamental notions of IVIFSs.

Definition 1 (Atanassov & Gargov, 1989). Let $U = \{u_1, u_2, \dots, u_n\}$ be a common world-wide set. The IVIFS S in U is an object based on the mathematical view as follows:

$$S = \{ \langle u_i, \mu_S(u_i), \nu_S(u_i) \rangle : u_i \in U \}, \quad (1)$$

where $\mu_S, \nu_S : U \rightarrow [0, 1]$ hold $\sup(\mu_S(u_i)) + \sup(\nu_S(u_i)) \leq 1$. The intervals $\mu_S(u_i)$ and $\nu_S(u_i)$ stand for BG and NG of an object u_i in the set U , respectively.

For simplicity, suppose $\mu_S(u_i) = [\mu_S^-(u_i), \mu_S^+(u_i)]$ and $\nu_S(u_i) = [\nu_S^-(u_i), \nu_S^+(u_i)]$, then

$$S = \{ \langle u_i, [\mu_S^-(u_i), \mu_S^+(u_i)], [\nu_S^-(u_i), \nu_S^+(u_i)] \rangle : u_i \in U \},$$

where $0 \leq \mu_S^+(u_i) + \nu_S^+(u_i) \leq 1$, $\mu_S^-(u_i) \geq 0$ and $\nu_S^-(u_i) \geq 0$. The interval $\pi_S(u_i) = [\pi_S^-(u_i), \pi_S^+(u_i)] = [1 - \mu_S^+(u_i) - \nu_S^+(u_i), 1 - \mu_S^-(u_i) - \nu_S^-(u_i)]$ signifies the hesitancy grade of u_i to S .

According to Definition 1, an IVIFS is considered by interval-valued BG and NG based on ordered pair. For a given $u_i \in U$, the pair $([\mu_S^-(u_i), \mu_S^+(u_i)], [\nu_S^-(u_i), \nu_S^+(u_i)])$ is called an IVIFN (Xu, 2007b). To make it easy, an IVIFN is made typically simpler as $P = ([\alpha, \beta], [\gamma, \delta])$, where $[\alpha, \beta] \subset [0, 1]$, $[\gamma, \delta] \subset [0, 1]$ and $\beta + \delta \leq 1$.

Dymova and Sevastjanov (2016) made an analysis on Definition 1, which was originally offered by Atanassov and Gargov (1989).

Table 1 Summary of relevant research on the ARAS method from the literature

Author(s)	Environment	Benchmark	Application(s)	Application Type
Zavadskas and Turskis (2010)	Crisp sets (CSs)	ARAS approach	Microclimate in offices	Real case study
Turskis et al. (2010)	Fuzzy sets (FSs)	Combined AHP & ARAS approaches	Logistic centers location	Real-life problem
Turskis (2010)	Grey numbers (GNs)	Grey ARAS	Supplier selection	Real-life problem
Kersulienne and Turskis (2011)	FSs	SWARA and ARAS approaches	Architect assessment	Real-life problem
Dadelo et al. (2012)	CSs	ARAS approaches	Elite security Personnel	Illustrative
Chatterjee and Bose (2013)	FSs	ARAS approach	Vendors for wind farm	Real-life problem
Zamani et al. (2014)	FSs	ARAS & ANP approaches	Brand extension	Real-life problem
Safaei Ghadikolaei et al. (2014)	FSs	AHP, COPRAS, VIKOR, & ARAS approaches	Financial performance assessment	Real-life problem
Shariati et al. (2014)	FSs	ARAS method	Waste dump site assessment	Real-life problem
Akhavan et al. (2015)	FSs	FQSPM, COPRAS TOPSIS, ARAS, MOORA methods	Partner assessment and strategic alliance planning	Real-life problem
Zavadskas et al. (2015)	FSs	Fuzzy ARAS & AHP	Evaluation of deep water port	Real-life problem
Varmazyar et al. (2016)	CSs	DEMATEL, TOSIS, ANP, & ARAS methods	Performance assessment	Real-life problem
Liao et al. (2016)	FSs	Fuzzy AHP, goal programming, ARAS	Green supplier assessment	Illustrative
Balezentis and Streimikiene (2017)	CSs	ARAS and Monte Carlo simulation	Energy generation scenarios	Illustrative
Ecer (2018)	FSs	ARAS and Fuzzy AHP	Mobile banking	Real-life problem
Dahooie et al. (2018)	GNs	Grey ARAS and SWARA	Personnel assessment	Real-life problem
Buyukozkan and Goeer (2018)	IVIFSs	Combined AHP & ARAS methods	Digital supply chain selection	Real-life problem
Dahooie et al. (2019)	CSs	Integrated Fuzzy C-means (FCM) and ARAS approaches	Financial performance	Real-life problem
Iordache et al. (2019)	Interval type-2 hesitant fuzzy sets	Integrated interval type-2 hesitant fuzzy sets with ARAS method	Underground site selection	Real-life problem
Bahrami et al. (2019)	CSs	Combined best worst method (BWM) and ARAS	Mineral prospectively mapping	Real-life problem

Table 1 (continued)

Author(s)	Environment	Benchmark	Application(s)	Application Type
Fu (2019)	CSs	Integrated multi-choice goal programming (MCGP), AHP and ARAS methods	Catering supplier selection	Real-life problem
Kumar et al. (2019)	CSs	Combined AHP & ARAS methods	Composite process	Real-life problem
Radovic et al. (2018)	Rough set	Combined rough set with ARAS method	Transportation performance	Real-life problem
Dahooie et al. (2019)	Interval-valued intuitive fuzzy	Combined ARAS and interval-valued intuitive fuzzy methods	Business Intelligence	Real-life problem
Mishra et al. (2019b)	IFSs	IF-Information measures-based ARAS method	IT personnel selection	Real-life problem
Liao et al. (2019)	Hesitant fuzzy linguistic term sets	Integrated BWM and ARAS methodology	Digital supply chain finance supplier selection	Real-life problem
Ghenai et al. (2020)	CSs	Combined SWARA and ARAS method	Renewable energy systems	Real-life problem
Goswami & Mitra (2020)	CSs	Integrated AHP-COPRAS and ARAS	Best mobile model	Real-life problem
Rani et al., (2020d)	PFSS	Integrated SWARA-ARAS	Healthcare waste treatment method selection	Real-life problem
Mishra et al. (2021a)	HFSs	ARAS method	Drug selection to treat the mild symptoms of COVID-19	Real-life problem
Mishra et al. (2021b)	Single-values neutrosophic sets	ARAS method	Electric vehicle charging station selection	Real-life problem

Definition 2 (Dymova & Sevastjanov, 2016). An IVIFS S in U is an element based on mathematical set:

$$S = \{ \langle u_i, \mu_S(u_i), \nu_S(u_i) \rangle : u_i \in U \}, \quad (2)$$

where $\mu_S, \nu_S : U \rightarrow [0, 1]$ satisfies the constraint $\sup(\mu_S(u_i)) + \inf(\nu_S(u_i)) \leq 1$ and $\inf(\mu_S(u_i)) + \sup(\nu_S(u_i)) \leq 1$. The intervals $\mu_S(u_i)$ and $\nu_S(u_i)$ signify the BG and NG of an object u_i in the set U , respectively.

Definition 3 Atanassov and Gargov (1989). Assume $S, T \in IVIFSs(U)$, then, some operations could be explained as follows:

- (a) $S \subseteq T$ iff $\mu_S^-(u_i) \leq \mu_T^-(u_i)$, $\mu_S^+(u_i) \leq \mu_T^+(u_i)$, $\nu_S^-(u_i) \geq \nu_T^-(u_i)$ and $\nu_S^+(u_i) \geq \nu_T^+(u_i)$ for each $u_i \in U$;
- (b) $S = T$ iff $S \subseteq T$ and $S \supseteq T$;
- (c) $S^c = \{ \langle u_i, [\nu_S^-(u_i), \nu_S^+(u_i)], [\mu_S^-(u_i), \mu_S^+(u_i)] \rangle : u_i \in U \}$;
- (d) $S \cup T = \left\{ \left\langle u_i, [\mu_S^-(u_i) \vee \mu_T^-(u_i), \mu_S^+(u_i) \vee \mu_T^+(u_i)], [\nu_S^-(u_i) \wedge \nu_T^-(u_i), \nu_S^+(u_i) \wedge \nu_T^+(u_i)] \right\rangle : u_i \in U \right\}$;
- (e) $S \cap T = \left\{ \left\langle u_i, [\mu_S^-(u_i) \wedge \mu_T^-(u_i), \mu_S^+(u_i) \wedge \mu_T^+(u_i)], [\nu_S^-(u_i) \vee \nu_T^-(u_i), \nu_S^+(u_i) \vee \nu_T^+(u_i)] \right\rangle : u_i \in U \right\}$.

Definition 4 (Xu, 2007b). Consider $S = \langle [\alpha, \beta], [\gamma, \delta] \rangle$ as an IVIFN. Then,

$$\mathbb{S}(S) = \frac{1}{2}(\alpha + \beta - \gamma - \delta), \quad \mathbb{h}(S) = \frac{1}{2}(\alpha + \beta + \gamma + \delta), \quad (3)$$

are called score and accuracy values of S . Also, $\mathbb{S}(S) \in [-1, 1]$ and $\mathbb{h}(S) \in [0, 1]$.

Since $\mathbb{S}(S) \in [-1, 1]$, then Xu et al. (2015) normalized the score value as follows:

Definition 5 (Xu et al., 2015): Let $S = \langle [\alpha, \beta], [\gamma, \delta] \rangle$ be an IVIFN. Then,

$$\mathbb{S}^*(S) = \frac{1}{2}(\mathbb{S}(S) + 1), \quad \mathbb{h}^{\circ}(S) = 1 - \mathbb{h}(S), \quad (4)$$

are known as the improved score and uncertainty functions, respectively. It is clearly observable that $\mathbb{S}^*(S) \in [0, 1]$ and $\mathbb{h}^{\circ}(S) \in [0, 1]$.

Definition 6 (Xu, 2007b) Let $S = \langle [\alpha, \beta], [\gamma, \delta] \rangle$ be an IVIFN and $\xi \in \mathbb{R}$ be an arbitrary real number, then

$$\xi S = \langle [1 - (1 - \alpha)^{\xi}, 1 - (1 - \beta)^{\xi}], [\gamma^{\xi}, \delta^{\xi}] \rangle. \quad (5)$$

Based on Eq. (1), the definition offered by Xu (2007b) is used as follows:

Let $S = \{S_1, S_2, \dots, S_t\}$ be the set of ' t ' IVIFNs such that $S_k = \langle [\alpha_k, \beta_k], [\gamma_k, \delta_k] \rangle$, $k = 1(1)t$. Then, the IVIF-weighted averaging (IVIFWA) and IVIF-weighted geometric operator (IVIFWG) are given by

$$\bigoplus_{k=1}^t \xi_k S_k = \left\langle \left[1 - \prod_{k=1}^t (1 - \alpha_k)^{\xi_k}, 1 - \prod_{k=1}^t (1 - \beta_k)^{\xi_k} \right], \left[\prod_{k=1}^t (\gamma_k)^{\xi_k}, \prod_{k=1}^t (\delta_k)^{\xi_k} \right] \right\rangle. \quad (6)$$

$$\bigotimes_{k=1}^t \xi_k S_k = \left\langle \left[\prod_{k=1}^t (\alpha_k)^{\xi_k}, \prod_{k=1}^t (\beta_k)^{\xi_k} \right], \left[1 - \prod_{k=1}^t (1 - \gamma_k)^{\xi_k}, 1 - \prod_{k=1}^t (1 - \delta_k)^{\xi_k} \right] \right\rangle. \quad (7)$$

Definition 7 (Xu & Chen, 2008). A function $Sim : IVIFS(U) \times IVIFS(U) \rightarrow [0, 1]$ is said to be similarity measure on $IVIFS(U)$, if it fulfills the given requirements:

- (S1) $0 \leq Sim(R, S) \leq 1$;
- (S2) $Sim(R, S) = 1 \Leftrightarrow R = S$;
- (S3) $Sim(R, S) = Sim(S, R)$;
- (S4) For all $R, S, C \in IVIFS(U)$, if $R \subseteq S \subseteq T$, then $Sim(R, C) \leq Sim(R, S)$ and $Sim(R, C) \leq Sim(S, C)$.

3.2 Interval-valued intuitionistic fuzzy similarity measures

Here, we first review similarity measures (SMs) for IVIFSs. Corresponding to the advantages and practicality of SMs for IFSs, we present SMs for IVIFSs to propose weight determining approach. Then, the results of the IVIF-similarity measures are presented with mathematical evidence and descriptive examples.

3.2.1 Review of the similarity measures for IVIFSs

The idea SM is one of the topics with the highest level of attractiveness in IFSs doctrine. It describes the degree of homogeneity between the two IFSs. A SM is a powerful method for decision making (Mishra, 2016; Mishra & Rani, 2017; Sahu et al., 2021), pattern recognition (Meng & Chen, 2016) and image processing (Balasubramaniam & Ananthi, 2014); it has received more consideration in current decades. Dengfeng and Chuntian (2002) first introduced a SM for IFSs. Subsequently, Xu & Chen (2008) developed a sequence of similarity and distance measures, which are different combinations and extensions of the various distance measures for IFSs and IVIFSs. There are various types of SMs, e.g., entropy measures, similarity persuaded by cosine similarity and interval comparison (Song & Wang, 2017; Song et al., 2019). In real-life applications, in many cases, information is not available sufficiently, and this is difficult to recognize the precise numbers for the BG and NG. Nonetheless, the decision information may be presented by IVIFSs. Xu (2007a) extended several SMs formulae of IFSs to IVIFSs using IVIF-distance measures. Hu and Li (2013) proposed a system to develop SMs based on entropy measures for IVIFSs. Ye (2013) and Ye (2012) developed the SMs for IVIFSs based on Dice SM and IF-cosine SM (angular coefficient). Meng and Chen (2016) presented new entropy for IVIFSs and a method to develop a SM for IVIFSs. Pekala and Balicki (2017) presented inclusion measure and SM on IVIFSs connected with lexicographical order and discussed various elegant properties. Rani et al. (2018) developed entropy and similarity measures for IVIFSs based on exponential and discussed VIKOR approach for correlative MCDM problems under

Table 2 Summary of currently used similarity measures for IVIFSs

Author (s)

Xu, (2007a)

$$\begin{aligned}
 Sim_{X_1}(R, S) &= 1 - \frac{1}{4} \sum_{i=1}^n w_i \left(\left| \mu_R^-(u_i) - \mu_S^-(u_i) \right| + \left| \nu_R^-(u_i) - \nu_S^-(u_i) \right| \right. \\
 &\quad \left. + \left| \mu_R^+(u_i) - \mu_S^+(u_i) \right| + \left| \nu_R^+(u_i) - \nu_S^+(u_i) \right| \right) \\
 Sim_{X_2}(R, S) &= 1 - \sqrt{\frac{1}{4} \sum_{i=1}^n w_i \left(\left(\mu_R^-(u_i) - \mu_S^-(u_i) \right)^2 + \left(\nu_R^-(u_i) - \nu_S^-(u_i) \right)^2 \right. \\
 &\quad \left. + \left(\mu_R^+(u_i) - \mu_S^+(u_i) \right)^2 + \left(\nu_R^+(u_i) - \nu_S^+(u_i) \right)^2 \right)} \\
 Sim_{X_3}(R, S) &= 1 - \sum_{i=1}^n w_i \max \left(\left| \mu_R^-(u_i) - \mu_S^-(u_i) \right|, \left| \nu_R^-(u_i) - \nu_S^-(u_i) \right|, \right. \\
 &\quad \left. \left| \mu_R^+(u_i) - \mu_S^+(u_i) \right|, \left| \nu_R^+(u_i) - \nu_S^+(u_i) \right| \right) \\
 Sim_{X_4}(R, S) &= 1 - \sqrt{\sum_{i=1}^n w_i \max \left(\left(\mu_R^-(u_i) - \mu_S^-(u_i) \right)^2, \left(\nu_R^-(u_i) - \nu_S^-(u_i) \right)^2, \right. \\
 &\quad \left. \left(\mu_R^+(u_i) - \mu_S^+(u_i) \right)^2, \left(\nu_R^+(u_i) - \nu_S^+(u_i) \right)^2 \right)}
 \end{aligned}$$

Xu & Chen
(2008)

$$\begin{aligned}
 Sim_{XC_1}(R, S) &= 1 - \left[\frac{1}{4n} \sum_{i=1}^n \left(\left| \mu_R^-(u_i) - \mu_S^-(u_i) \right|^p + \left| \mu_R^+(u_i) - \mu_S^+(u_i) \right|^p \right. \right. \\
 &\quad \left. \left. + \left| \nu_R^-(u_i) - \nu_S^-(u_i) \right|^p + \left| \nu_R^+(u_i) - \nu_S^+(u_i) \right|^p \right) \right]^{1/p}, \quad p > 0, \\
 Sim_{XC_2}(R, S) &= 1 - \left[\frac{1}{n} \sum_{i=1}^n \max \left(\left| \mu_R^-(u_i) - \mu_S^-(u_i) \right|^p, \left| \mu_R^+(u_i) - \mu_S^+(u_i) \right|^p, \right. \right. \\
 &\quad \left. \left. \left| \nu_R^-(u_i) - \nu_S^-(u_i) \right|^p, \left| \nu_R^+(u_i) - \nu_S^+(u_i) \right|^p \right) \right]^{1/p}, \quad p > 0.
 \end{aligned}$$

If let $p \rightarrow +\infty$ in $Sim_{XC_1}(R, S)$ and $p = 1$ in $Sim_{XC_2}(R, S)$ then

$$\begin{aligned}
 Sim_{XC_1}^\infty(R, S) &= 1 - \left[\max_i \left(\left| \mu_R^-(u_i) - \mu_S^-(u_i) \right|, \left| \mu_R^+(u_i) - \mu_S^+(u_i) \right|, \right. \right. \\
 &\quad \left. \left. \left| \nu_R^-(u_i) - \nu_S^-(u_i) \right|, \left| \nu_R^+(u_i) - \nu_S^+(u_i) \right| \right) \right] \\
 Sim_{XC_2}^1(R, S) &= 1 - \left[\frac{1}{n} \sum_{i=1}^n \max \left(\left| \mu_R^-(u_i) - \mu_S^-(u_i) \right|, \left| \mu_R^+(u_i) - \mu_S^+(u_i) \right|, \right. \right. \\
 &\quad \left. \left. \left| \nu_R^-(u_i) - \nu_S^-(u_i) \right|, \left| \nu_R^+(u_i) - \nu_S^+(u_i) \right| \right) \right]
 \end{aligned}$$

Wei et al.
(2011)

$$Sim_w(R, S) = \frac{1}{n} \sum_{i=1}^n \frac{2 - \min \{ \mu_i^-, \nu_i^- \} - \min \{ \mu_i^+, \nu_i^+ \}}{2 + \max \{ \mu_i^-, \nu_i^- \} + \max \{ \mu_i^+, \nu_i^+ \}},$$

$$\text{where } \mu_i^- = \left| \mu_R^-(u_i) - \mu_S^-(u_i) \right|, \quad \nu_i^- = \left| \nu_R^-(u_i) - \nu_S^-(u_i) \right|,$$

$$\mu_i^+ = \left| \mu_R^+(u_i) - \mu_S^+(u_i) \right|, \quad \nu_i^+ = \left| \nu_R^+(u_i) - \nu_S^+(u_i) \right|.$$

Ye (2012)

$$Sim_{Y_1}(R, S) = \frac{1}{n} \sum_{i=1}^n \frac{2(\mu_R \mu_S + \nu_R \nu_S)}{\mu_R^2 + \nu_R^2 + \mu_S^2 + \nu_S^2},$$

$$\text{where } \mu_R = p_1 \mu_R^-(u_i) + p_2 \mu_R^+(u_i), \nu_R = q_1 \nu_R^-(u_i) + q_2 \nu_R^+(u_i),$$

$$\mu_S = p_1 \mu_S^-(u_i) + p_2 \mu_S^+(u_i) \text{ and } \nu_S = q_1 \nu_S^-(u_i) + q_2 \nu_S^+(u_i), \text{ such that } p_1, p_2, q_1, q_2 \in [0, 1],$$

$$p_1 + p_2 = 1 \text{ and } q_1 + q_2 = 1 \text{ are adjusting weight values}$$

Table 2 (continued)

Author (s)

Ye (2013)

$$\begin{aligned}
 Sim_{Y_2}(R, S) &= \frac{1}{n} \sum_{i=1}^n \frac{\left(\mu_R^-(u_i) \mu_S^-(u_i) + \mu_R^+(u_i) \mu_S^+(u_i) + v_R^-(u_i) v_S^-(u_i) \right. \\
 &\quad \left. + v_R^+(u_i) v_S^+(u_i) + \pi_R^-(u_i) \pi_S^-(u_i) + \pi_R^+(u_i) \pi_S^+(u_i) \right)}{\sqrt{\mu_R^{-2}(u_i) + \mu_R^{+2}(u_i) + v_R^{-2}(u_i) + v_R^{+2}(u_i) + \pi_R^{-2}(u_i) + \pi_R^{+2}(u_i)}} \\
 &\quad \times \sqrt{\mu_S^{-2}(u_i) + \mu_S^{+2}(u_i) + v_S^{-2}(u_i) + v_S^{+2}(u_i) + \pi_S^{-2}(u_i) + \pi_S^{+2}(u_i)}} \\
 Sim_{HL_1}(R, S) &= \frac{\sum_{i=1}^n \left\{ 2 - \left(\left| \mu_R^-(u_i) - \mu_S^-(u_i) \right| \vee \left| v_R^+(u_i) - v_S^+(u_i) \right| \right)^2 \right. \\
 &\quad \left. - \left(\left| \mu_R^-(u_i) - \mu_S^-(u_i) \right| \vee \left| v_R^+(u_i) - v_S^+(u_i) \right| \right) \right\}}{\sum_{i=1}^n \left\{ 2 + \left(\left| \mu_R^-(u_i) - \mu_S^-(u_i) \right| \vee \left| v_R^+(u_i) - v_S^+(u_i) \right| \right)^3 \right. \\
 &\quad \left. + \left(\left| \mu_R^-(u_i) - \mu_S^-(u_i) \right| \vee \left| v_R^+(u_i) - v_S^+(u_i) \right| \right)^2 \right\}} \\
 Sim_{HL_2}(R, S) &= \frac{\sum_{i=1}^n \left\{ 16 - 2 \left(\left| \mu_R^-(u_i) - \mu_S^-(u_i) \right| \vee \left| v_R^+(u_i) - v_S^+(u_i) \right| \right)^2 \right. \\
 &\quad \left. - 2 \left(\left| \mu_R^-(u_i) - \mu_S^-(u_i) \right| \vee \left| v_R^+(u_i) - v_S^+(u_i) \right| \right) \right\}}{\sum_{i=1}^n \left\{ 16 + 2 \left(\left| \mu_R^-(u_i) - \mu_S^-(u_i) \right| \vee \left| v_R^+(u_i) - v_S^+(u_i) \right| \right)^3 \right. \\
 &\quad \left. + 2 \left(\left| \mu_R^-(u_i) - \mu_S^-(u_i) \right| \vee \left| v_R^+(u_i) - v_S^+(u_i) \right| \right)^2 \right\}}
 \end{aligned}$$

Wu et al. (2014)

$$\begin{aligned}
 Sim_{wu}(R, S) &= \frac{1}{n} \sum_{i=1}^n \frac{4 - (\mu_j^- + \mu_j^+ + v_j^- + v_j^+) + (\pi_j^- + \pi_j^+)}{4 + (\mu_j^- + \mu_j^+ + v_j^- + v_j^+) + (\pi_j^- + \pi_j^+)} \\
 \text{where } \mu_j^\alpha &= \left| \mu_R^\alpha(u_i) - \mu_S^\alpha(u_i) \right|, \quad v_j^\alpha = \left| v_R^\alpha(u_i) - v_S^\alpha(u_i) \right| \\
 \text{and } \pi_j^\alpha &= \left| \pi_R^\alpha(u_i) - \pi_S^\alpha(u_i) \right|; \quad \alpha = \{-, +\}
 \end{aligned}$$

Meng and Chen (2016)

$$\begin{aligned}
 Sim_M(R, S) &= \frac{1}{n} \sum_{i=1}^n \frac{4 - \min \{ \mu_i^-, v_i^- \} - \min \{ \mu_i^+, v_i^+ \}}{4 + \max \{ \mu_i^-, v_i^- \} + \max \{ \mu_i^+, v_i^+ \}}, \\
 \text{where } \mu_i^- &= \left| \mu_R^-(u_i) - \mu_S^-(u_i) \right|, \quad v_i^- = \left| v_R^-(u_i) - v_S^-(u_i) \right|, \\
 \mu_i^+ &= \left| \mu_R^+(u_i) - \mu_S^+(u_i) \right|, \quad v_i^+ = \left| v_R^+(u_i) - v_S^+(u_i) \right|.
 \end{aligned}$$

Pekala and

Balicki (2017)

$$Sim_{PB_1}(R, S) = 1 - \frac{1}{n} \sum_{i=1}^n \max \left(\left| \mu_R^-(u_i) - \mu_S^-(u_i) \right|, \left| v_R^-(u_i) - v_S^-(u_i) \right|, \left| \mu_R^+(u_i) - \mu_S^+(u_i) \right|, \left| v_R^+(u_i) - v_S^+(u_i) \right| \right)$$

$$Sim_{PB_2}(R, S) = Inc(R, S) \wedge Inc(S, R), \text{ where}$$

$$Inc(R, S) = \begin{cases} 1, & R = S = \emptyset \\ \frac{|R \wedge S|}{|R|}, & \text{otherwise} \end{cases} \quad \text{and } |R| = \sum_{u_i \in U} \frac{\mu_R^- + \mu_R^+ + 2 - v_R^- - v_R^+}{4}$$

Rani et al.

(2018)

$$Sim_{RA}(R, S) = 1 - \frac{1 - \exp \left[-\frac{1}{4n} \sum_{i=1}^n \left(\left| \sqrt{\mu_R^-(u_i)} - \sqrt{\mu_S^-(u_i)} \right| + \left| \sqrt{v_R^-(u_i)} - \sqrt{v_S^-(u_i)} \right| + \left| \sqrt{\mu_R^+(u_i)} - \sqrt{\mu_S^+(u_i)} \right| + \left| \sqrt{v_R^+(u_i)} - \sqrt{v_S^+(u_i)} \right| \right) \right]}{1 - \exp(-1)}.$$

Author (s)

Mishra, and
Rani (2018a)

$$Sim_{MR_1}(R, S) = 1 - \left[\frac{1}{n(t+1)^p} \sum_{i=1}^n \max \left(\left| \begin{array}{l} (t\mu_R^-(u_i) - v_R^-(u_i)) \\ -(t\mu_S^-(u_i) - v_S^-(u_i)) \end{array} \right|, \left| \begin{array}{l} (t\mu_R^+(u_i) - v_R^+(u_i)) \\ -(t\mu_S^+(u_i) - v_S^+(u_i)) \end{array} \right|, \right. \right. \\ \left. \left. \left| \begin{array}{l} (tv_R^-(u_i) - \mu_R^-(u_i)) \\ -(tv_S^-(u_i) - \mu_S^-(u_i)) \end{array} \right|, \left| \begin{array}{l} (tv_R^+(u_i) - \mu_R^+(u_i)) \\ -(tv_S^+(u_i) - \mu_S^+(u_i)) \end{array} \right| \right) \right]$$

where $t = 1, 2, 3, \dots$ categories the level of uncertainty and $p = 1, 2, 3, \dots$ be the L_p -norm

Mishra and
Rani (2018b)

$$Sim_{MR_2}(R, S) = 1 - \frac{1 - \exp \left[-\frac{1}{4n} \sum_{i=1}^n \left(|\mu_R^-(x_i) - \mu_S^-(x_i)| + |\mu_R^+(x_i) - \mu_S^+(x_i)| + |\nu_R^-(x_i) - \nu_S^-(x_i)| + |\nu_R^+(x_i) - \nu_S^+(x_i)| \right) \right]}{1 - \exp(-1)}.$$

IVIF environment. Mishra and Rani (2018a) proposed biparametric SM for IVIFSs to assess the plant location selection problem. Table 2 summarizes the earlier research works carried out into similarity measures for IVIFSs.

3.2.2 New IVIF-similarity measures

Based on Intarapaiboon (2014) for IFSs, we propose the following SMs for IVIFSs.

$$Sim_1(R, S) = \frac{\sum_{i=1}^n \left[\min \{ \mu_R^-(u_i), \mu_S^-(u_i) \} + \min \{ \mu_R^+(u_i), \mu_S^+(u_i) \} + \min \{ (1 - \nu_R^-(u_i)), (1 - \nu_S^-(u_i)) \} + \min \{ (1 - \nu_R^+(u_i)), (1 - \nu_S^+(u_i)) \} \right]}{\sum_{i=1}^n \left[\max \{ \mu_R^-(u_i), \mu_S^-(u_i) \} + \max \{ \mu_R^+(u_i), \mu_S^+(u_i) \} + \max \{ (1 - \nu_R^-(u_i)), (1 - \nu_S^-(u_i)) \} + \max \{ (1 - \nu_R^+(u_i)), (1 - \nu_S^+(u_i)) \} \right]}. \quad (8)$$

Theorem 1: Function $Sim_1(R, S)$ is valid SM for IVIFSs(U).

Proof (S_1) & (S_2) : Both are obvious from the definition of Eq. (8).

(S_3) : Let $Sim_1(R, S), R, S \in IVIFSs(U)$ and $R = S$, i.e., $\mu_R^-(u_i) = \mu_S^-(u_i)$, $\mu_R^+(u_i) = \mu_S^+(u_i)$, $\nu_R^-(u_i) = \nu_S^-(u_i)$ and $\nu_R^+(u_i) = \nu_S^+(u_i)$. Therefore, from Eq. (1), we obtain $Sim_1(R, S) = 1$.

Again, let $Sim_1(R, S) = 1$. Then, from Eq. (8), we have

$$\begin{aligned} & \sum_{i=1}^n \left[\min \{ \mu_R^-(u_i), \mu_S^-(u_i) \} + \min \{ \mu_R^+(u_i), \mu_S^+(u_i) \} + \min \{ (1 - \nu_R^-(u_i)), (1 - \nu_S^-(u_i)) \} + \min \{ (1 - \nu_R^+(u_i)), (1 - \nu_S^+(u_i)) \} \right] \\ &= \sum_{i=1}^n \left[\max \{ \mu_R^-(u_i), \mu_S^-(u_i) \} + \max \{ \mu_R^+(u_i), \mu_S^+(u_i) \} + \max \{ (1 - \nu_R^-(u_i)), (1 - \nu_S^-(u_i)) \} + \max \{ (1 - \nu_R^+(u_i)), (1 - \nu_S^+(u_i)) \} \right] \end{aligned} \quad (9)$$

Since

$$\forall_{u_i \in U}, \min \{ \mu_R^-(u_i), \mu_S^-(u_i) \} \leq \max \{ \mu_R^-(u_i), \mu_S^-(u_i) \},$$

$$\min \{ \mu_R^+(u_i), \mu_S^+(u_i) \} \leq \max \{ \mu_R^+(u_i), \mu_S^+(u_i) \}, \min \{ (1 - \nu_R^-(u_i)), (1 - \nu_S^-(u_i)) \} \\ \leq \max \{ (1 - \nu_R^-(u_i)), (1 - \nu_S^-(u_i)) \}$$

and $\min \{ (1 - \nu_R^+(u_i)), (1 - \nu_S^+(u_i)) \} \leq \max \{ (1 - \nu_R^+(u_i)), (1 - \nu_S^+(u_i)) \}$. Therefore, Eq. (9) will be true when $\mu_R^-(u_i) = \mu_S^-(u_i)$, $\mu_R^+(u_i) = \mu_S^+(u_i)$, $(1 - \nu_R^-(u_i)) = (1 - \nu_S^-(u_i))$ and $(1 - \nu_R^+(u_i)) = (1 - \nu_S^+(u_i))$. It implies that $R = S$.

(S_4): Let $R, S, C \in IVIFSs(U)$ and $R \subseteq S \subseteq C$, i.e., $\mu_R^-(u_i) \leq \mu_S^-(u_i) \leq \mu_C^-(u_i)$, $\mu_R^+(u_i) \leq \mu_S^+(u_i) \leq \mu_C^+(u_i)$, $\nu_R^-(u_i) \geq \nu_S^-(u_i) \geq \nu_C^-(u_i)$ and $\nu_R^+(u_i) \geq \nu_S^+(u_i) \geq \nu_C^+(u_i)$, $\forall u_i \in U$.

Again, $\forall u_i \in U$, $(1 - \nu_R^-(u_i)) \leq (1 - \nu_S^-(u_i)) \leq (1 - \nu_C^-(u_i))$ and $(1 - \nu_R^+(u_i)) \leq (1 - \nu_S^+(u_i)) \leq (1 - \nu_C^+(u_i))$.

Hence,

$$Sim_1(R, C) = \frac{\sum_{i=1}^n \left[\min \{ \mu_R^-(u_i), \mu_C^-(u_i) \} + \min \{ \mu_R^+(u_i), \mu_C^+(u_i) \} \right. \\ \left. + \min \{ (1 - \nu_R^-(u_i)), (1 - \nu_C^-(u_i)) \} + \min \{ (1 - \nu_R^+(u_i)), (1 - \nu_C^+(u_i)) \} \right]}{\sum_{i=1}^n \left[\max \{ \mu_R^-(u_i), \mu_C^-(u_i) \} + \max \{ \mu_R^+(u_i), \mu_C^+(u_i) \} \right. \\ \left. + \max \{ (1 - \nu_R^-(u_i)), (1 - \nu_C^-(u_i)) \} + \max \{ (1 - \nu_R^+(u_i)), (1 - \nu_C^+(u_i)) \} \right]} \\ Sim_1(R, C) = \frac{\sum_{i=1}^n [\mu_R^-(u_i) + \mu_R^+(u_i) + (1 - \nu_R^-(u_i)) + (1 - \nu_R^+(u_i))]}{\sum_{i=1}^n [\mu_C^-(u_i) + \mu_C^+(u_i) + (1 - \nu_C^-(u_i)) + (1 - \nu_C^+(u_i))]} \quad (10)$$

Similarly

$$Sim_1(R, S) = \frac{\sum_{i=1}^n [\mu_R^-(u_i) + \mu_R^+(u_i) + (1 - \nu_R^-(u_i)) + (1 - \nu_R^+(u_i))]}{\sum_{i=1}^n [\mu_S^-(u_i) + \mu_S^+(u_i) + (1 - \nu_S^-(u_i)) + (1 - \nu_S^+(u_i))]} \quad (11)$$

From Eqs. (10) and (11), we obtain

$$Sim_1(R, S) \geq Sim_1(R, C).$$

On a similar line, we obtain $Sim_1(S, C) \geq Sim_1(R, C)$.

After that, another IVIF-SM for IVIFSs, which is introduced from combining $Sim_1(R, S)$, and a notion of SMs and lattice, is presented. Generally, a lattice of a non-empty function is based on a hierarchical structure prepared by a partial order such that, for every two objects in the lattice, a lub (supremum) and a glb (infimum) exist. Within a lattice, similarity for two conceptions within is generally evaluated through the use of information of their supremum and infimum, for instance, the depth from the root to the supremum.

Through utilizing the IVIFSs as the subset relationship and a lattice concept that is given in Eq. (8) as a partial order, it is possible to assemble a lattice. For any pair of IVIFSs, the infimum and supremum can be computed from intersection and union, respectively. Thus, the similarity measure is given by

$$Sim_2(R, S) = \sqrt{Sim_1(R, C_{RS}) \times Sim_1(S, C_{RS})}, \quad (12)$$

where $C_{RS} = R \cup S$ and $Sim_1(R, S)$ is given by Eq. (8).

Theorem 2 Mapping $Sim_2(R, S)$ is a valid SM for IVIFSs.

Proof (S_1) & (S_2) : Both are straightforward.

(S_3) : Let $R, S \in IVIFSs$ and $R = S$. Since $C_{RS} = R \cup S$. Therefore $R = S = C_{RS}$ and $Sim_1(R, S)$ is satisfied (S_3) . Hence $Sim_1(R, S) = 1$. Again let $Sim_2(R, S) = 1$. Therefore, $Sim_1(R, C_{RS}) = Sim_1(S, C_{RS}) = 1$, when $C_{RS} = R \cup S$ and $Sim_1(R, S)$ satisfies (S_3) . Hence, $R = S = C_{RS}$.

(S_4) : Let $R, S, C \in IVIFSs(U)$ and $R \subseteq S \subseteq C$. Then $R \cup S = S$, $R \cup C = C$ and $S \cup C = C$.

$$\begin{aligned} \text{Now } Sim_2(R, C) &= \sqrt{Sim_1(R, C_{RC}) \times Sim_1(C, C_{RC})} \\ Sim_2(R, C) &= \sqrt{Sim_1(R, C) \times Sim_1(C, C)} \end{aligned}$$

$$Sim_2(R, C) = \sqrt{Sim_1(R, C)}$$

On a similar line, $Sim_2(R, S) = \sqrt{Sim_1(R, S)}$.

Since $Sim_1(R, S)$ holds (S_4) , i.e., $Sim_1(R, S) \geq Sim_1(R, C)$, $Sim_2(R, S) \geq Sim_2(R, C)$.

Similarity, $Sim_2(S, C) \geq Sim_2(R, C)$. [Proved].

Here, if we take R and S as intervals illustration, the information conceded by them is obtained by not only in the terms of bounds (lower and upper), but also the length of the interval. Based on Song et al. (2014), we extend the following similarity measure for IVIFSs as

$$\begin{aligned} Sim_3(R, S) &= \frac{1}{4n} \sum_{i=1}^n \left[\sqrt{\mu_R^-(u_i) \mu_S^-(u_i)} + \sqrt{\mu_R^+(u_i) \mu_S^+(u_i)} + 2 \sqrt{v_R^-(u_i) v_S^-(u_i)} \right. \\ &+ 2 \sqrt{v_R^+(u_i) v_S^+(u_i)} + \sqrt{\pi_R^-(u_i) \pi_S^-(u_i)} + \sqrt{\pi_R^+(u_i) \pi_S^+(u_i)} \\ &\left. + \sqrt{(1 - v_R^-(u_i))(1 - v_S^-(u_i))} + \sqrt{(1 - v_R^+(u_i))(1 - v_S^+(u_i))} \right] \end{aligned} \quad (13)$$

Theorem 3 Function $Sim_3(R, S)$ given by Eq. (13) is valid SM for IVIFSs (U) .

Proof (S1): For each $x, y \in [0, \infty]$, we obtain.

$$0 \leq \sqrt{xy} \leq \frac{x+y}{2}.$$

Since $0 \leq \mu_R^-(u_i), \mu_R^+(u_i) \leq 1, 0 \leq v_R^-(u_i), v_R^+(u_i) \leq 1, 0 \leq \pi_R^-(u_i), \pi_R^+(u_i) \leq 1,$
 $0 \leq \mu_S^-(u_i), \mu_S^+(u_i) \leq 1, 0 \leq v_S^-(u_i), v_S^+(u_i) \leq 1, 0 \leq \pi_S^-(u_i), \pi_S^+(u_i) \leq 1,$
 $0 \leq (1 - v_R^-(u_i)), (1 - v_R^+(u_i)) \leq 1$ and $0 \leq (1 - v_S^-(u_i)), (1 - v_S^+(u_i)) \leq 1$, we have

$$\begin{aligned}
0 &\leq \sqrt{\mu_R^-(u_i)\mu_S^-(u_i)} \leq \frac{\mu_R^-(u_i) + \mu_S^-(u_i)}{2}, 0 \leq \sqrt{\nu_R^-(u_i)\nu_S^-(u_i)} \leq \frac{\nu_R^-(u_i) + \nu_S^-(u_i)}{2}, \\
0 &\leq \sqrt{\mu_R^+(u_i)\mu_S^+(u_i)} \leq \frac{\mu_R^+(u_i) + \mu_S^+(u_i)}{2}, 0 \leq \sqrt{\nu_R^+(u_i)\nu_S^+(u_i)} \leq \frac{\nu_R^+(u_i) + \nu_S^+(u_i)}{2}, \\
0 &\leq \sqrt{\pi_R^-(u_i)\pi_S^-(u_i)} \leq \frac{\pi_R^-(u_i) + \pi_S^-(u_i)}{2}, 0 \leq \sqrt{\pi_R^+(u_i)\pi_S^+(u_i)} \leq \frac{\pi_R^+(u_i) + \pi_S^+(u_i)}{2}, \\
0 &\leq \sqrt{(1 - \nu_R^-(u_i))(1 - \nu_S^-(u_i))} \leq \frac{(1 - \nu_R^-(u_i)) + (1 - \nu_S^-(u_i))}{2}, \\
0 &\leq \sqrt{(1 - \nu_R^+(u_i))(1 - \nu_S^+(u_i))} \leq \frac{(1 - \nu_R^+(u_i)) + (1 - \nu_S^+(u_i))}{2}
\end{aligned}$$

Now,

$$\begin{aligned}
0 &\leq \left[\sqrt{\mu_R^-(u_i)\mu_S^-(u_i)} + \sqrt{\mu_R^+(u_i)\mu_S^+(u_i)} + 2\sqrt{\nu_R^-(u_i)\nu_S^-(u_i)} \right. \\
&\quad + 2\sqrt{\nu_R^+(u_i)\nu_S^+(u_i)} + \sqrt{\pi_R^-(u_i)\pi_S^-(u_i)} + \sqrt{\pi_R^+(u_i)\pi_S^+(u_i)} \\
&\quad \left. + \sqrt{(1 - \nu_R^-(u_i))(1 - \nu_S^-(u_i))} + \sqrt{(1 - \nu_R^+(u_i))(1 - \nu_S^+(u_i))} \right] \\
&\leq \frac{\mu_R^-(u_i) + \mu_S^-(u_i)}{2} + \frac{\mu_R^+(u_i) + \mu_S^+(u_i)}{2} + 2\frac{\nu_R^-(u_i) + \nu_S^-(u_i)}{2} + 2\frac{\nu_R^+(u_i) + \nu_S^+(u_i)}{2} \\
&\quad + \frac{\pi_R^-(u_i) + \pi_S^-(u_i)}{2} + \frac{\pi_R^+(u_i) + \pi_S^+(u_i)}{2} + \frac{(1 - \nu_R^-(u_i)) + (1 - \nu_S^-(u_i))}{2} \\
&\quad + \frac{(1 - \nu_R^+(u_i)) + (1 - \nu_S^+(u_i))}{2} \\
&= 2 + \frac{\mu_R^-(u_i) + \nu_R^-(u_i) + \pi_R^-(u_i)}{2} + \frac{\mu_R^+(u_i) + \nu_R^+(u_i) + \pi_R^+(u_i)}{2} + \frac{\mu_S^-(u_i) + \nu_S^-(u_i) + \pi_S^-(u_i)}{2} \\
&\quad + \frac{\mu_S^+(u_i) + \nu_S^+(u_i) + \pi_S^+(u_i)}{2} = 4, \quad \forall_{u_i \in U}.
\end{aligned}$$

Hence,

$$\begin{aligned}
0 \leq \frac{1}{4n} \sum_{i=1}^n & \left[\sqrt{\mu_R^-(u_i) \mu_S^-(u_i)} + \sqrt{\mu_R^+(u_i) \mu_S^+(u_i)} + 2\sqrt{v_R^-(u_i) v_S^-(u_i)} \right. \\
& + 2\sqrt{v_R^+(u_i) v_S^+(u_i)} + \sqrt{\pi_R^-(u_i) \pi_S^-(u_i)} + \sqrt{\pi_R^+(u_i) \pi_S^+(u_i)} \\
& \left. + \sqrt{(1 - v_R^-(u_i))(1 - v_S^-(u_i))} + \sqrt{(1 - v_R^+(u_i))(1 - v_S^+(u_i))} \right] \leq 1.
\end{aligned}$$

Thus, $0 \leq Sim_3(R, S) \leq 1$.

(S_2) : It is obvious from the definition.

(S_3) : From Eq. (14), $\sqrt{xy}$ has its maximum degree $\frac{(x+y)}{2}$, when $x = y$. As a result, let $Sim_3(R, S) = 1$

$$\begin{aligned}
& \Leftrightarrow \left[\sqrt{\mu_R^-(u_i) \mu_S^-(u_i)} + \sqrt{\mu_R^+(u_i) \mu_S^+(u_i)} + 2\sqrt{v_R^-(u_i) v_S^-(u_i)} \right. \\
& + 2\sqrt{v_R^+(u_i) v_S^+(u_i)} + \sqrt{\pi_R^-(u_i) \pi_S^-(u_i)} + \sqrt{\pi_R^+(u_i) \pi_S^+(u_i)} \\
& \left. + \sqrt{(1 - v_R^-(u_i))(1 - v_S^-(u_i))} + \sqrt{(1 - v_R^+(u_i))(1 - v_S^+(u_i))} \right] = 4; \forall u_i \in U.
\end{aligned}$$

$$\Leftrightarrow \mu_R^-(u_i) = \mu_S^-(u_i), \mu_R^+(u_i) = \mu_S^+(u_i), v_R^-(u_i) = v_S^-(u_i), v_R^+(u_i) = v_S^+(u_i),$$

$$\pi_R^-(u_i) = \pi_S^-(u_i), \pi_R^+(u_i) = \pi_S^+(u_i), (1 - v_R^-(u_i)) = (1 - v_S^-(u_i)) \text{ and}$$

$$(1 - v_R^+(u_i)) = (1 - v_S^+(u_i)).$$

$$\Leftrightarrow R = S.$$

Hence,

$Sim_3(R, S) = 1$ iff $R = S$.

(S_4) : Let $R, S, C \in IVIFSs(U)$ and $R \subseteq S \subseteq C$, i.e., $0 \leq \mu_R^-(u_i) \leq \mu_S^-(u_i) \leq \mu_C^-(u_i) \leq 1$, $0 \leq \mu_R^+(u_i) \leq \mu_S^+(u_i) \leq \mu_C^+(u_i) \leq 1$, $0 \leq v_R^-(u_i) \leq v_S^-(u_i) \leq v_C^-(u_i) \leq 1$, $0 \leq v_R^+(u_i) \leq v_S^+(u_i) \leq v_C^+(u_i) \leq 1$.

Therefore, from Eq. (13), we obtain

$$\begin{aligned}
Sim_3(A, C) = \frac{1}{4n} \sum_{i=1}^n & \left[\sqrt{\mu_R^-(u_i) \mu_C^-(u_i)} + \sqrt{\mu_R^+(u_i) \mu_C^+(u_i)} + 2\sqrt{v_R^-(u_i) v_C^-(u_i)} \right. \\
& + 2\sqrt{v_R^+(u_i) v_C^+(u_i)} + \sqrt{\pi_R^-(u_i) \pi_C^-(u_i)} + \sqrt{\pi_R^+(u_i) \pi_C^+(u_i)} \\
& \left. + \sqrt{(1 - v_R^-(u_i))(1 - v_C^-(u_i))} + \sqrt{(1 - v_R^+(u_i))(1 - v_C^+(u_i))} \right] \quad (15)
\end{aligned}$$

$$\begin{aligned}
Sim_3(B, C) = \frac{1}{4n} \sum_{i=1}^n & \left[\sqrt{\mu_S^-(u_i) \mu_C^-(u_i)} + \sqrt{\mu_S^+(u_i) \mu_C^+(u_i)} + 2\sqrt{v_S^-(u_i) v_C^-(u_i)} \right. \\
& + 2\sqrt{v_S^+(u_i) v_C^+(u_i)} + \sqrt{\pi_S^-(u_i) \pi_C^-(u_i)} + \sqrt{\pi_S^+(u_i) \pi_C^+(u_i)} \\
& \left. + \sqrt{(1 - v_S^-(u_i))(1 - v_C^-(u_i))} + \sqrt{(1 - v_S^+(u_i))(1 - v_C^+(u_i))} \right].
\end{aligned} \quad (16)$$

For $a_1, a_2, b_1, b_2 \in [0, 1]$, $a_1 + b_1 \leq 1$ and $a_2 + b_2 \leq 1$, we define a function F as

$$F(x_1, x_2, y_1, y_2) \equiv f(x_1, y_1) + g(x_2, y_2), \quad (17)$$

where

$$f(x_1, y_1) = \left[\sqrt{a_1 x_1} + 2\sqrt{b_1 y_1} + \sqrt{(1 - a_1 - b_1)(1 - x_1 - y_1)} + \sqrt{(1 - b_1)(1 - y_1)} \right] \quad (18)$$

and

$$g(x_2, y_2) = \left[\sqrt{a_2 x_2} + 2\sqrt{b_2 y_2} + \sqrt{(1 - a_2 - b_2)(1 - x_2 - y_2)} + \sqrt{(1 - b_2)(1 - y_2)} \right] \quad (19)$$

such that $x_1, x_2, y_1, y_2 \in [0, 1]$, $x_1 + y_1, x_2 + y_2 \in [0, 1]$.

Now,

$$\frac{\partial f}{\partial x_1} = \frac{\sqrt{a_1}}{2\sqrt{x_1}} - \frac{\sqrt{(1 - a_1 - b_1)}}{2\sqrt{1 - x_1 - y_1}} \quad \text{and} \quad \frac{\partial f}{\partial y_1} = \frac{\sqrt{b_1}}{\sqrt{y_1}} - \frac{\sqrt{(1 - a_1 - b_1)}}{2\sqrt{1 - x_1 - y_1}} - \frac{\sqrt{1 - b_1}}{2\sqrt{1 - y_1}} \quad (20)$$

Given that $a_1 \leq x_1 \leq 1b_1 \leq 1$, then we get.

$$\frac{\partial f}{\partial x_1} \Big|_{y_1=b_1} = \frac{\sqrt{a_1}}{2\sqrt{x_1}} - \frac{\sqrt{(1 - a_1 - b_1)}}{2\sqrt{1 - x_1 - y_1}} = \frac{(a_1 - x_1)(1 - b_1)}{2\sqrt{x_1(1 - x_1 - y_1)}(\sqrt{a_1(1 - x_1 - y_1)} + \sqrt{x_1(1 - a_1 - b_1)})} \quad (21)$$

$\frac{\partial f}{\partial x_1} \Big|_{y_1=b_1} \leq 0$, that means f is a decreasing mapping of x_1 when $y_1 = b_1$. For $0 \leq x_1 \leq a_1$, $b_1 \leq 1$, we obtain $\left(\frac{\partial f}{\partial x_1}\right)_{y_1=b_1} \geq 0$, i.e., f is an increasing mapping of x_1 , when $x_1 \leq a_1$ and $y_1 = b_1$.

Again, for $\frac{\partial f}{\partial y_1}$, we get

$$\frac{\partial f}{\partial y_1} \Big|_{x_1=a_1} = \frac{(b_1 - y_1)(1 - a_1)}{2\sqrt{y_1(1 - x_1 - y_1)}(\sqrt{b_1(1 - x_1 - y_1)} + \sqrt{y_1(1 - a_1 - b_1)})} + \frac{(b_1 - y_1)}{2\sqrt{y_1(1 - y_1)}(\sqrt{b_1(1 - y_1)} + \sqrt{y_1(1 - b_1)})} \quad (22)$$

which provides that f is an increasing mapping of y_1 for $x_1 = a_1$, $y_1 \leq b_1$, but decreasing mapping when $x_1 = a_1$, $y_1 \geq b_1$.

Similarly,

$$\frac{\partial g}{\partial x_2} = \frac{\sqrt{a_2}}{2\sqrt{x_2}} - \frac{\sqrt{(1-a_2-b_2)}}{2\sqrt{1-x_2-y_2}} \text{ and } \frac{\partial g}{\partial y_2} = \frac{\sqrt{b_2}}{\sqrt{y_2}} - \frac{\sqrt{(1-a_2-b_2)}}{2\sqrt{1-x_2-y_2}} - \frac{\sqrt{1-b_2}}{2\sqrt{1-y_2}} \quad (23)$$

From Eq. (23), In $0 \leq a_2 \leq x_2 \leq 1$ and $b_2 \leq 1$, g is a decreasing function of x_2 at $y_2 = b_2$, in $x_2 \leq a_2$, g is an increasing function of x_2 at $y_2 = b_2$. On a similar manner, g is a decreasing function of y_2 for $x_2 = a_2$, $y_2 \geq b_2$, but an increasing function when $x_2 = a_2$, $y_2 \leq b_2$.

Given that $a_1 = \mu_R^-(u_i)$, $a_2 = \mu_R^+(u_i)$, $b_1 = v_R^-(u_i)$, $b_2 = v_R^+(u_i)$, satisfying

$$a_1 = \mu_R^-(u_i) \leq \mu_S^-(u_i) \leq \mu_C^-(u_i)$$

$$a_2 = \mu_R^+(u_i) \leq \mu_S^+(u_i) \leq \mu_C^+(u_i), \quad v_C^-(u_i) \leq v_S^-(u_i) \leq v_R^-(u_i) = b_1, \\ v_C^+(u_i) \leq v_S^+(u_i) \leq v_R^+(u_i) = b_2, \text{ we obtain}$$

$$f(\mu_C^-(x_i), b_1) \leq f(\mu_B^-(x_i), b_1) \leq f(a_1, b_1)$$

$$g(\mu_C^+(x_i), b_2) \leq g(\mu_B^+(x_i), b_2) \leq g(a_2, b_2)$$

$$f(a_1, v_C^-(x_i)) \leq f(a_1, v_B^-(x_i)) \leq f(a_1, b_1)$$

$$g(a_2, v_C^+(x_i)) \leq g(a_2, v_B^+(x_i)) \leq g(a_2, b_2).$$

Since $f(x_1, y_1)$ and $g(x_2, y_2)$ continues concave function,

$$f(\mu_C^-(u_i), v_C^-(u_i)) \leq f(\mu_S^-(u_i), v_S^-(u_i)), \quad g(\mu_C^+(u_i), v_C^+(u_i)) \leq g(\mu_S^+(u_i), v_S^+(u_i)).$$

Therefore, $F = f(x_1, y_1) + g(x_2, y_2)$ is also a continuous concave mapping.

Now,

Table 3 Comparison of different IVIF-SMs under various counter-intuitive cases

$R_i S_i$	([0.2, 0.3], [0.4, 0.6]) ([0.3, 0.4], [0.4, 0.6])	([0.2, 0.3], [0.4, 0.6]) ([0.3, 0.4], [0.3, 0.5])	([0.2, 0.3], [0.3, 0.5]) ([0.3, 0.4], [0.4, 0.6])	([0.2, 0.3], [0.3, 0.5]) ([0.3, 0.4], [0.3, 0.5])
$Sim_{XC_1}(R, S)$	0.90	0.90	0.90	0.95
$Sim_{XC_2}(R, S)$	0.90	0.90	0.90	0.90
$Sim_W(R, S)$	0.9091	0.8182	0.8182	0.9091
$Sim_{Y_2}(R, S)$	0.9765	0.9754	0.9277	0.9737
$Sim_{Wu}(R, S)$	0.9048	0.8182	0.8182	0.9048
$Sim_M(R, S)$	0.9524	0.9048	0.9048	0.9524
$Sim_{PB_1}(R, S)$	0.9000	0.9000	0.9000	0.9000
$Sim_{MR_2}(R, S)$	0.9228	0.8495	0.8495	0.9228
$Sim_1(R, S)$	0.8824	0.7895	0.7895	0.8947
$Sim_3(R, S)$	0.9844	0.9937	0.9656	0.9950

Bold character indicates counter-intuitive cases

$$\begin{aligned}
& \left[\sqrt{\mu_R^-(u_i) \mu_C^-(u_i)} + \sqrt{\mu_R^+(u_i) \mu_C^+(u_i)} + 2\sqrt{v_R^-(u_i) v_C^-(u_i)} \right. \\
& \quad + 2\sqrt{v_R^+(u_i) v_C^+(u_i)} + \sqrt{\pi_R^-(u_i) \pi_C^-(u_i)} + \sqrt{\pi_R^+(u_i) \pi_C^+(u_i)} \\
& \quad \left. + \sqrt{(1 - v_R^-(u_i))(1 - v_C^-(u_i))} + \sqrt{(1 - v_R^+(u_i))(1 - v_C^+(u_i))} \right] \\
& \leq \left[\sqrt{\mu_S^-(u_i) \mu_C^-(u_i)} + \sqrt{\mu_S^+(u_i) \mu_C^+(u_i)} + 2\sqrt{v_S^-(u_i) v_C^-(u_i)} \right. \\
& \quad + 2\sqrt{v_S^+(u_i) v_C^+(u_i)} + \sqrt{\pi_S^-(u_i) \pi_C^-(u_i)} + \sqrt{\pi_S^+(u_i) \pi_C^+(u_i)} \\
& \quad \left. + \sqrt{(1 - v_S^-(u_i))(1 - v_C^-(u_i))} + \sqrt{(1 - v_S^+(u_i))(1 - v_C^+(u_i))} \right], \quad \forall u_i \in U. \\
& \Rightarrow Sim_3(R, C) \leq Sim_3(S, C).
\end{aligned}$$

Similarly, $Sim_3(R, C) \leq Sim_3(S, C)$.

Thus, $Sim_3(R, S)$ satisfies (S_4) . Hence $Sim_3(R, S)$ holds all essential axioms of SM for IVIFSs.

Assuming the weights of u_i , we discuss the weighted SM for IVIFSs as follows:

$$\begin{aligned}
Sim_{3w}(R, S) = \frac{1}{4} \sum_{i=1}^n w_i & \left[\sqrt{\mu_R^-(u_i) \mu_S^-(u_i)} + \sqrt{\mu_R^+(u_i) \mu_S^+(u_i)} + 2\sqrt{v_R^-(u_i) v_S^-(u_i)} \right. \\
& + 2\sqrt{v_R^+(u_i) v_S^+(u_i)} + \sqrt{\pi_R^-(u_i) \pi_S^-(u_i)} + \sqrt{\pi_R^+(u_i) \pi_S^+(u_i)} \\
& \left. + \sqrt{(1 - v_R^-(u_i))(1 - v_S^-(u_i))} + \sqrt{(1 - v_R^+(u_i))(1 - v_S^+(u_i))} \right]. \quad (24)
\end{aligned}$$

3.2.3 Numerical comparison

To demonstrate the advantage of the IVIF-similarity measures, we compared the developed approach and the similarity measures that exist in literature.

Example 3.1 Let R_i and S_i be two IVIFSs, we evaluate the SMs between R_i and S_i by numerous IVIF-SMs presented in Table 3.

In Table 2, from first and second columns, we obtain that $Sim_{XC_i}(R_1, S_1) = Sim_{XC_i}(R_2, S_2)$, ($i = 1, 2$), $Sim_{PB_1}(R_1, S_1) = Sim_{PB_1}(R_2, S_2)$, when $R_1 = R_2, S_1 \neq S_2$. Similarly, from third column and fourth columns, we find $Sim_{XC_2}(R_3, S_3) = Sim_{XC_2}(R_4, S_4)$, $Sim_{PB_1}(R_3, S_3) = Sim_{PB_1}(R_4, S_4)$, when $R_3 = R_4, S_3 \neq S_4$. Consequently, from first column and fourth columns,

Fig. 1 Flow diagram of the proposed IVIF-ARAS method

we get that $Sim_W(R_1, S_1) = Sim_W(R_4, S_4)$, $Sim_{Wu}(R_1, S_1) = Sim_{Wu}(R_4, S_4)$, $Sim_M(R_1, S_1) = Sim_M(R_4, S_4)$, $Sim_{MR_2}(R_1, S_1) = Sim_{MR_2}(R_4, S_4)$, when $R_1 \neq R_4$, $S_1 \neq S_4$. On the similar line, from second and third columns, $Sim_W(R_2, S_2) = Sim_W(R_3, S_3)$, $Sim_{Wu}(R_2, S_2) = Sim_{Wu}(R_3, S_3)$, $Sim_M(R_2, S_2) = Sim_M(R_3, S_3)$, $Sim_{MR_2}(R_2, S_2) = Sim_{MR_2}(R_3, S_3)$, $Sim_1(R_2, S_2) = Sim_1(R_3, S_3)$, when $R_2 \neq R_3$, $S_2 \neq S_3$. Therefore, we can observe that the SMs $Sim_{XC_1}(R, S)$, $Sim_{XC_2}(R, S)$, $Sim_W(R, S)$, $Sim_{Wu}(R, S)$, $Sim_M(R, S)$, $Sim_{PB_1}(R, S)$, $Sim_{MR_2}(R, S)$ and $Sim_1(R, S)$ are not reasonable. Therefore, we conclude that the proposed IVIF-SMs $Sim_{Y_2}(R, S)$, $Sim_2(R, S)$ and $Sim_3(R, S)$ overcome these shortcomings. As a result, novel IVIF-SMs are more reasonable than existing ones.

Example 3.2 Let $R = \{\langle u, [0.2, 0.3], [0.4, 0.6] \rangle : u \in U\}$, $S = \{\langle u, [0.3, 0.4], [0.3, 0.5] \rangle : u \in U\}$.

and $T = \{\langle u, [0.3, 0.4], [0.4, 0.6] \rangle : u \in U\}$ be three IVIFSs.

For each $u \in U$, the NG of R and T is same, but the change of the BG of R and T is from $[0.2, 0.3]$ into $[0.3, 0.4]$, while for each $u \in U$, the NG between R and S is different from $[0.4, 0.6]$ into $[0.3, 0.5]$ and the BG is the same as that of R and T . Consequently, R is more similar to T than to S . We now evaluate $Sim_1(R, S)$, $Sim_{XC_1}^\infty(R, S)$ and $Sim_{XC_2}^1(R, S)$. Then, $Sim_1(R, S) = 0.8182$ and $Sim_1(R, T) = 0.9091$, which point out that *IVIFS* R is more similar to T than to S , which is consistent with intuition.

Next, we calculate the SMs $Sim_{XC_1}^\infty(R, S)$ and $Sim_{XC_2}^1(R, S)$; then $Sim_{XC_1}^\infty(R, S) = Sim_{XC_1}^\infty(R, T) = Sim_{XC_2}^1(R, S) = Sim_{XC_2}^1(R, T) = 0.9$, which are not reasona-

ble. Therefore, the SMs $Sim_1(R, S)$, Eq. (8), Eq. (11) and Eq. (12) are demonstrated to be more reasonable than $Sim_{XC_1}^\infty(R, S)$ and $Sim_{XC_2}^1(R, S)$ in some cases.

3.3 Proposed interval-valued intuitionistic fuzzy ARAS approach

The process of decision making comprises a logical and systematic way to choose a feasible one with multiple alternatives. In real-life decision-making problems, some problems consider only a single criterion for each one of the alternatives, and the problem is concentrated on single-criterion decision making which is simpler because the outcome is obtained completely by choosing the one with premium single criterion, while many concerns are assessed over various criteria. It revolves such problems into MCDM procedures, where numerous MCDM methods implement the significance (weights) of coefficients. This study is mainly aimed at the implementation of IVIF-ARAS method in a way to select the best low-carbon tourism strategy (LCTS). Here, the criteria weights for LCTS are computed by proposed IVIF similarity measure. When the weights are calculated, IVIF-ARAS approach is implemented to determine the desirable LCTS. IVIF-ARAS method implements logical comparison in the ratio of the sum to estimate the weights and normalization of the attribute values in order to obtain the utility degree of the alternative in IVIFSs. Figure 1 displays the workflow of the developed method and is briefly described as follows:

Step 1: The formulation of the alternative and criteria.

The main aim of the MCDM process is choosing the best options from a set of m options $M = \{M_1, M_2, \dots, M_m\}$ under the set of criteria $S = \{S_1, S_2, \dots, S_n\}$. Thus, a group of ℓ DEs $E = \{E_1, E_2, \dots, E_\ell\}$ should be constructed to reach the best alternative(s).

Step 2: The construction of the decision matrix for DEs and aggregated IVIF-decision matrix (AIVIF-DM).

Let $Z = (\xi_{ij}^{(k)})_{m \times n}$ be DEs assessment matrices and $\lambda = (\lambda_1, \lambda_2, \dots, \lambda_\ell)^T$ be the DEs weight, where $\sum_{k=1}^\ell \lambda_k = 1$, $\lambda_k \in [0, 1]$. Therefore, the AIVIF-DM $\hat{Z} = (\hat{\xi}_{ij})_{m \times n}$ is computed as follows:

$$\hat{\xi}_{ij} = \left(\left(\xi_{ij}^{(1)} \oplus \xi_{ij}^{(2)} \oplus \dots \oplus \xi_{ij}^{(\ell)} \right) / \ell \right); i = 1(1)m, j = 1(1)n. \quad (25)$$

where $\hat{\xi}_{ij}$ is an IVIFN.

Step 3: The calculation of the weight vector of criteria.

In a decision-making problem, all criteria are not having equal importance. Let $w = (w_1, w_2, \dots, w_n)^T$ such that $\sum_{j=1}^n w_j = 1, w_j \in [0, 1]$ be a criterion weight vector. Successively to achieve w , we apply the following procedure:

$$w_j = \frac{\sum_{i=1}^m \sum_{t=1, t \neq i}^m (1 - Sim(\hat{\xi}_{ij}, \hat{\xi}_{it}))}{\sum_{j=1}^n \sum_{i=1}^m \sum_{t=1, t \neq i}^m (1 - Sim(\hat{\xi}_{ij}, \hat{\xi}_{it}))}, j = 1(1)n. \quad (26)$$

Step 4: Determine optimal performance rating

$$\mathbb{R}_0 = \begin{cases} \max \hat{\xi}_{ij}, & j \in S_b \\ \min \hat{\xi}_{ij}, & j \in S_n \end{cases} \quad (27)$$

where S_b and S_n stand for the benefit-type and cost-type attributes, respectively.

Step 5: The generation of normalized AIVIF-DM.

All of the individual decision judgments involved need to be integrated into a group judgment in order to construct normalized AIVIF-DM $\mathbb{N} = (\varsigma_{ij})_{m \times n}$ such that

$$\varsigma_{ij} = \begin{cases} \left\langle \left[\mu_{ij}^-, \mu_{ij}^+ \right], \left[v_{ij}^-, v_{ij}^+ \right] \right\rangle, & j \in S_b \\ \left\langle \left[v_{ij}^-, v_{ij}^+ \right], \left[\mu_{ij}^-, \mu_{ij}^+ \right] \right\rangle, & j \in S_n \end{cases}; i = 1(1)m, \quad (28)$$

Step 6: The construction of weighted normalized AIVIF-DM (WNAIVIF-DM).

When the weight vector $w = (w_1, w_2, \dots, w_n)^T$ of the criteria $S_j : j = 1(1)n$ is obtained, the WNAIVIF-DM $\mathbb{N}_w = (\tilde{\zeta}_{ij})_{m \times n}$ is created as follows:

$$\tilde{\zeta}_{ij} = \bigoplus_{j=1}^n w_j \varsigma_{ij} = \left\langle \left[1 - \prod_{j=1}^n (1 - \mu_{ij}^-)^{w_j}, 1 - \prod_{j=1}^n (1 - \mu_{ij}^+)^{w_j} \right], \left[\prod_{j=1}^n (v_{ij}^-)^{w_j}, \prod_{j=1}^n (v_{ij}^+)^{w_j} \right] \right\rangle, \quad (29)$$

where $\tilde{\zeta}_{ij} = \left\langle \left[\tilde{\mu}_{ij}^-, \tilde{\mu}_{ij}^+ \right], \left[\tilde{v}_{ij}^-, \tilde{v}_{ij}^+ \right] \right\rangle$ is the weighted IVIFN.

Step 7: Scoring the values of WNAIVIF-DM.

By Eq. (4), the score values of WNAIVIF-DM $\mathbb{N}_w = (\tilde{\zeta}_{ij})_{m \times n}$ are computed by

$$\mathbb{S}^*(\tilde{\zeta}_{ij}) = \left[\frac{1}{2} \left(\left(\frac{\tilde{\mu}_{ij}^- + \tilde{\mu}_{ij}^+ - \tilde{v}_{ij}^- - \tilde{v}_{ij}^+}{2} \right) + 1 \right) \right]; i = 1(1)m, j = 1(1)n. \quad (30)$$

Step 8: The computation of general performance value and degree of utility.

The general performance rating of each alternative is evaluated using the following equation:

$$\Lambda_i = \sum_{j=1}^n \mathbb{S}^*(\tilde{\zeta}_{ij}), \quad i = 1(1)m. \quad (31)$$

The largest value is measured as the best, while the smallest value is the worst. According to the process of evaluation, the best function Λ_i is directly and proportionally associated with $\tilde{\zeta}_{ij}$ and weights w_j of the examined criteria and their relative effect upon the final results. Thus, the bigger value of Λ_i , the more efficient the alternative. The alternatives priority is evaluated based on the value of Λ_i . As a result, this is appropriate to estimate and rank the alternatives once the proposed method is implemented.

For estimating the alternatives, it is significant not only to assess the optimal alternative but also to assess the comparative performance of given alternatives regarding the optimal one. As a result, the degree of variant utility is calculated using comparison method and the examined variant with the ideally optimal one $\mathbb{R}_0$. The utility degree $\mathbb{Q}_i$ of each option $M_i : i = 1(1)m$ is computed by

Table 4 Detail description of the selected criteria for evaluation of LCTS selection (Zhang, 2017)

Dimension	Criteria	Type
Social	Education of low-carbon environment (S_1)	Benefit
	Carbon literacy of residents (S_2)	Benefit
	Carbon literacy of tourists (S_3)	Benefit
	Special plans for low-carbon tourism (S_4)	Benefit
Economy	Proportion of low-carbon tourist (S_5)	Benefit
	Proportion of green hotel (S_6)	Benefit
	Proportion of green catering enterprise (S_7)	Benefit
	Low-carbon transportation (S_8)	Benefit
	Tourism carbon intensity (S_9)	Cost
Environmental	Air pollution index (S_{10})	Cost
	Noise pollution level (S_{11})	Cost
	Environmental protection (S_{12})	Benefit

Fig. 2 Hierarchical structure of selecting criteria for LCTS selection

$$Q_i = \frac{\Lambda_i}{R_0}; i = 1(1)m. \quad (32)$$

It is observed that $Q_i \in [0, 1]$ and it could be structured in an increasing sequence. According to the utility function, the relative efficiency of a feasible option can be evaluated.

Step 9: The selection of the most desirable one.

The given options are graded in ascending order Q_i , i.e., the option with the maximum degree of Q_i is the optimal one. Hence, the best alternative could be specified by

$$M^* = \left\{ M_i \mid \max_i Q_i; i = 1(1)m \right\}, \quad (33)$$

where M^* is the optimal alternative, $i = 1(1)m$.

Table 5 The scale for the criteria rating and the LCTS options based on LVs

LVs	IVIFNs
Extremely low (EL)/extremely bad (EB)	$\langle [0.05, 0.10], [0.85, 0.90] \rangle$
Very low (VL)/very bad (VB)	$\langle [0.10, 0.20], [0.70, 0.75] \rangle$
Low (L)/bad (B)	$\langle [0.20, 0.30], [0.55, 0.65] \rangle$
Medium low (ML)/medium bad (MB)	$\langle [0.30, 0.40], [0.45, 0.55] \rangle$
Medium (M)/fair (F)	$\langle [0.45, 0.55], [0.35, 0.40] \rangle$
Medium high (MH)/medium good (MG)	$\langle [0.55, 0.65], [0.25, 0.30] \rangle$
High (H)/good (G)	$\langle [0.65, 0.75], [0.15, 0.20] \rangle$
Very high (VH)/very good (VG)	$\langle [0.75, 0.90], [0.05, 0.10] \rangle$
Extremely high (EH)/extremely good (EG)	$\langle [0.90, 1.00], [0.00, 0.00] \rangle$

4 Results and discussion

4.1 Case study: low-carbon tourism strategy (LCTS) selection

In this study, an approach containing ARAS and SMs for IVIFNs is applied to explain the LCTS selection problem.

In order to define LCTSs, we create a group of DEs. They constructed some strategies that have been executed in other LCT destinations in India. Then, we have studied the related literature to articulate option LCTSs for India. Lastly, we have determined 15 LCT development strategies, which are denoted as $M_1, M_2, \dots, M_{15}$. Though every strategy for carbon emission reduction is a decent proposal, it is essential to rank each of the different strategies so that they can be applied in a systematic way. Commonly, economic, environmental and social aspects are taken and revealed in the criteria for any assessment of LCTSs. In this problem, these LCTSs are assessed over the considered 12 criteria and are specified in Table 4 and Fig. 2.

Here, Table 5 depicts the linguistic values (LVs) in term of IVIFNs for the criteria and the LCTS options. Table 6 shows the LVs (E_1, E_2, E_3) based on DEs for the criteria of considered LCTS options.

Using Eq. (25), the AIVIF-DM for LCTSs is computed using the DEs' opinions and mentioned in Table 7. Corresponding to Table 7 and Eq. (26), the criterion weight based on a SM Eq. (13) is evaluated by

$$w_j = \{0.0768, 0.0377, 0.0826, 0.0693, 0.0523, 0.0818, 0.0732, 0.1886, 0.0715, 0.1533, 0.0421, 0.0708\}.$$

The first step in using the proposed IVIF-ARAS approach is the determination of the optimum performance degree (R_0) of LCTS options, and this is done by using Eq. (27) and is presented in Table 8.

Using Eq. (28), the normalized AIVIF-DM is evaluated in Table 8, and the WNAIVIF-DM for LCTS options is formed based on Table 9 and Eq. (29) and given in Table 10.

Using Table 10 and Eq. (30), the score values $S^*(\xi_{ij})$ of IVIFNs are given in Table 11. Based on Eqs. (31) and (32), overall performance rating (Λ_i) and degree of utility or relative quality (Q_i) of each LCTS option are computed and demonstrated in Table 10. Then, the ranking order of LCTSs is determined as $M_{11} > M_4 > M_{10} > M_{14} > M_5 > M_7 > M_9 > M_{13} > M_2 > M_6 > M_{12} > M_8 > M_{15} > M_1 > M_3$. Hence, the desirable LCTS alternative is M_{11} .

Table 6 Linguistic evaluation of each LCTS and individual rank of the attributes

	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	S_{11}	S_{12}
M_1	(ML, L, ML)	(MH, MH, H)	(L, ML, ML)	(VH, VH, H)	(M, ML, M)	(ML, L, L)	(M, ML, M)	(ML, ML, M)	(L, VL, VL)	(L, ML, L)	(H, H, VH)	(H, H, MH)
M_2	(ML, ML, ML)	(H, H, MH)	(MH, H, H)	(VH, H, H)	(M, ML, ML)	(M, ML, L)	(L, L, VL)	(M, ML, MH)	(VH, VH, H)	(L, L, ML)	(VH, VH, VH)	(MH, MH, H)
M_3	(ML, L, L)	(VH, H, VH)	(L, ML, L)	(VH, VH, VH)	(MH, M, ML)	(L, L, L)	(ML, L, ML)	(L, L, MH)	(ML, L, ML)	(ML, L, L)	(VH, VH, H)	(MH, MH, MH)
M_4	(MH, H, MH)	(MH, H, MH)	(MH, MH, MH)	(MH, M, M)	(MH, M, M)	(MH, M, ML)	(H, MH, M)	(MH, H, MH)	(H, MH, M)	(VH, VH, H)	(M, ML, M)	(H, VH, VH)
M_5	(MH, H, H)	(MH, H, H)	(MH, H, MH)	(M, M, ML)	(H, MH, M)	(H, MH, MH)	(H, H, MH)	(M, MH, ML)	(MH, M, ML)	(H, H, MH)	(VL, VL, L)	(H, VH, H)
M_6	(MH, MH, MH)	(VH, H, H)	(MH, M, MH)	(MH, MH, M)	(H, H, M)	(H, MH, M)	(MH, M, M)	(M, M, ML)	(MH, M, ML)	(H, MH, MH)	(ML, L, ML)	(H, H, H)
M_7	(H, MH, MH)	(VH, VH, VH)	(H, H, H)	(MH, MH, MH)	(VH, VH, MH)	(MH, H, MH)	(L, VL, L)	(H, MH, H)	(ML, L, L)	(H, H, H)	(L, L, ML)	(MH, MH, M)
M_8	(H, MH, H)	(MH, M, MH)	(H, MH, VH)	(H, MH, VH)	(H, M, M)	(M, ML, ML)	(ML, ML, M)	(MH, H, ML)	(L, L, L)	(H, MH, ML)	(VL, L, VL)	(H, MH, H)
M_9	(MH, M, MH)	(MH, M, M)	(H, VH, VH)	(H, H, H)	(H, VH, M)	(H, H, MH)	(M, MH, ML)	(M, ML, L)	(ML, ML, L)	(MH, M, ML)	(VL, VL, VL)	(MH, M, M)
M_{10}	(VH, H, H)	(VH, VH, VH)	(H, H, VH)	(MH, M, M)	(VH, H, MH)	(H, MH, H)	(ML, ML, ML)	(H, MH, M)	(ML, L, L)	(H, VH, MH)	(ML, M, M)	(MH, MH, H)
M_{11}	(H, MH, MH)	(VH, H, H)	(H, VH, H)	(VH, H, MH)	(VH, VH, MH)	(M, ML, ML)	(L, ML, VL)	(MH, M, M)	(VH, VH, H)	(MH, M, MH)	(ML, ML, M)	(MH, H, H)
M_{12}	(H, H, MH)	(MH, MH, M)	(H, MH, MH)	(ML, ML, ML)	(H, M, MH)	(H, MH, M)	(ML, L, VL)	(MH, M, M)	(ML, ML, ML)	(MH, M, M)	(ML, M, MH)	(MH, MH, M)
M_{13}	(ML, M, ML)	(VH, H, MH)	(H, M, H)	(MH, MH, MH)	(VH, H, MH)	(VH, H, MH)	(M, ML, ML)	(M, ML, M)	(VH, H, MH)	(VH, H, H)	(VL, VL, L)	(H, H, MH)
M_{14}	(L, ML, L)	(VH, H, H)	(H, M, VH)	(M, ML, ML)	(VH, MH, M)	(VH, VH, H)	(ML, L, MH)	(VH, H, VH)	(VH, VH, H)	(MH, M, M)	(VL, L, VL)	(H, MH, MH)
M_{15}	(ML, M, M)	(MH, M, H)	(MH, M, M)	(H, VH, MH)	(MH, M, ML)	(M, M, M)	(MH, H, H)	(M, MH, M)	(ML, ML, L)	(H, ML, ML)	(VL, VL, VL)	(H, MH, M)

4.2 Comparative study

A comparison is presented for the purpose of validating the outcomes of IVIF-ARAS methodology with IVIF-TOPSIS model. To facilitate the comparative study, we prefer the IVIF-TOPSIS method proposed by Bai (2013) with the above MCDM problem given by.

The TOPSIS model begins with the evaluation of the IVIF-ideal solution ξ^+ (IVIF-IS) and the IVIF-anti-ideal solution ξ^- (IVIF-AIS). Let S_b and S_n be the sets benefit-type and cost-type criteria, respectively. According to IVIFSs doctrine and the conventional TOPSIS model, ξ^+ and ξ^- are given by

$$\xi^+ = \left\{ \left(M_i, \left\langle \max_i [\mu_{ij}^-, \mu_{ij}^+] | j \in S_b, \min_i [\mu_{ij}^-, \mu_{ij}^+] | j \in S_n \right\rangle, \left\langle \min_i [\nu_{ij}^-, \nu_{ij}^+] | j \in S_b, \max_i [\nu_{ij}^-, \nu_{ij}^+] | j \in S_n \right\rangle \right) : i = 1, 2, \dots, m \right\}, \quad (34)$$

$$\xi^- = \left\{ \left(M_i, \left\langle \min_i [\mu_{ij}^-, \mu_{ij}^+] | j \in S_b, \max_i [\mu_{ij}^-, \mu_{ij}^+] | j \in S_n \right\rangle, \left\langle \max_i [\nu_{ij}^-, \nu_{ij}^+] | j \in S_b, \min_i [\nu_{ij}^-, \nu_{ij}^+] | j \in S_n \right\rangle \right) : i = 1, 2, \dots, m \right\}. \quad (35)$$

Thus, the corresponding IVIF-IS and IVIF-AIS in the above decision-making problem can be obtained by Eqs. (34, 35), mentioned as follows:

$$\begin{aligned} \xi^+ = \{ & ([0.6871, 0.8158], [0.1040, 0.1587]), ([0.7500, 0.9000], [0.0500, 0.1000]), \\ & ([0.7203, 0.8643], [0.0721, 0.1260]), ([0.7500, 0.9000], [0.0500, 0.1000]), ([0.6959, 0.8482], \\ & [0.0855, 0.1442]), ([0.7203, 0.8643], [0.0721, 0.1260]), ([0.6194, 0.7203], [0.1778, 0.2289]), \\ & ([0.7203, 0.8643], [0.0721, 0.1260]), ([0.1347, 0.2348], [0.6459, 0.7151]), ([0.6871, \\ & 0.8158], [0.1040, 0.1587]), ([0.1000, 0.2000], [0.7000, 0.7500]), ([0.7203, 0.8643], [0.0721, 0.1260]), \\ \xi^- = \{ & ([0.2348, 0.3351], [0.5144, 0.6148]), ([0.4856, 0.5862], [0.3129, 0.3634]), ([0.2348, \\ & 0.3351], [0.5144, 0.6148]), ([0.3541, 0.4549], [0.4138, 0.4946]), ([0.3541, 0.4549], [0.4138, \\ & 0.4946]), ([0.2348, 0.3351], [0.5144, 0.6148]), ([0.1680, 0.2681], [0.5960, 0.6818]), ([0.3396, \\ & 0.4449], [0.4229, 0.5023]), ([0.7203, 0.8643], [0.0721, 0.1260]), ([0.2348, 0.3351], [0.5144, \\ & 0.6148]), ([0.7500, 0.9000], [0.0500, 0.1000]), ([0.1500, 0.2000], [0.5189, 0.6194]) \}. \end{aligned}$$

Based on Eq. (24), a weighted similarity measure between the alternatives, and IVIF-IS and IVIF-AIS are given by

$$\begin{aligned} Sim_{3w}(M_i, \xi^+) = & \frac{1}{4} \sum_{i=1}^n w_i \left[\sqrt{\mu_{\mathbb{M}_i}^-(u_i) \mu_{\xi^+}^-(u_i)} + \sqrt{\mu_{\mathbb{M}_i}^+(u_i) \mu_{\xi^+}^+(u_i)} + 2 \sqrt{\nu_{\mathbb{M}_i}^-(u_i) \nu_{\xi^+}^-(u_i)} \right. \\ & + 2 \sqrt{\nu_{\mathbb{M}_i}^+(u_i) \nu_{\xi^+}^+(u_i)} + \sqrt{\pi_{\mathbb{M}_i}^-(u_i) \pi_{\xi^+}^-(u_i)} + \sqrt{\pi_{\mathbb{M}_i}^+(u_i) \pi_{\xi^+}^+(u_i)} \\ & \left. + \sqrt{(1 - \nu_{\mathbb{M}_i}^-(u_i))(1 - \nu_{\xi^+}^-(u_i))} + \sqrt{(1 - \nu_{\mathbb{M}_i}^+(u_i))(1 - \nu_{\xi^+}^+(u_i))} \right], \quad (36) \end{aligned}$$

Table 7 The AIVIF-DM for the LCTS selection

	S_1	S_2	S_3	S_4	S_5	S_6
M_1	[0.2681,0.3684], [0.4811,0.5815]	[0.5862,0.6871], [0.2109,0.2621]	[0.2681,0.3684], [0.4811,0.5815]	[0.7203,0.8643], [0.0721,0.1260]	[0.4040,0.5047], [0.3806,0.4448]	[0.2348,0.3351], [0.5144,0.6148]
M_2	[0.3000,0.4000], [0.4500,0.5500]	[0.6194,0.7203], [0.1778,0.2289]	[0.6194,0.7203], [0.1778,0.2289]	[0.6871,0.8158], [0.1040,0.1587]	[0.3541,0.4549], [0.4138,0.4946]	[0.3247,0.4216], [0.4425,0.5229]
M_3	[0.2348,0.3351], [0.5144,0.6148]	[0.7203,0.8643], [0.0721,0.1260]	[0.2348,0.3351], [0.5144,0.6148]	[0.7500,0.9000], [0.0500,0.1000]	[0.4425,0.5445], [0.3402,0.4041]	[0.2000,0.3000], [0.5500,0.6500]
M_4	[0.5862,0.6871], [0.2109,0.2621]	[0.5862,0.6871], [0.2109,0.2621]	[0.5500,0.6500], [0.2500,0.3000]	[0.4856,0.5862], [0.3129,0.3634]	[0.4856,0.5862], [0.3129,0.3634]	[0.4425,0.5445], [0.3402,0.4041]
M_5	[0.6194,0.7203], [0.1778,0.2289]	[0.6194,0.7203], [0.1778,0.2289]	[0.5862,0.6871], [0.2109,0.2621]	[0.4040,0.5047], [0.3806,0.4448]	[0.5575,0.6598], [0.2359,0.2884]	[0.5862,0.6871], [0.2109,0.2621]
M_6	[0.5500,0.6500], [0.2500,0.3000]	[0.6871,0.8158], [0.1040,0.1587]	[0.5189,0.6194], [0.2797,0.3302]	[0.5189,0.6194], [0.2797,0.3302]	[0.5931,0.6959], [0.1990,0.2520]	[0.5575,0.6598], [0.2359,0.2884]
M_7	[0.5862,0.6871], [0.2109,0.2621]	[0.7500,0.9000], [0.0500,0.1000]	[0.5862,0.6871], [0.2109,0.2621]	[0.5500,0.6500], [0.2500,0.3000]	[0.6959,0.8482], [0.0855,0.1442]	[0.5862,0.6871], [0.2109,0.2621]
M_8	[0.6194,0.7203], [0.1778,0.2289]	[0.5189,0.6194], [0.2797,0.3302]	[0.6598,0.7939], [0.1233,0.1817]	[0.6871,0.8158], [0.1040,0.1587]	[0.5269,0.6301], [0.2639,0.3175]	[0.3541,0.4549], [0.4138,0.4946]
M_9	[0.5189,0.6194], [0.2797,0.3302]	[0.4856,0.5862], [0.3129,0.3634]	[0.7203,0.8643], [0.0721,0.1260]	[0.6500,0.7500], [0.1500,0.2000]	[0.6363,0.7759], [0.1379,0.2000]	[0.6194,0.7203], [0.1778,0.2289]
M_{10}	[0.6871,0.8158], [0.1040,0.1587]	[0.7500,0.9000], [0.0500,0.1000]	[0.6871,0.8158], [0.1040,0.1587]	[0.4856,0.5862], [0.3129,0.3634]	[0.6598,0.7939], [0.1233,0.1817]	[0.6194,0.7203], [0.1778,0.2289]
M_{11}	[0.5862,0.6871], [0.2109,0.2621]	[0.6871,0.8158], [0.1040,0.1587]	[0.6871,0.8158], [0.1040,0.1587]	[0.6598,0.7939], [0.1233,0.1817]	[0.6959,0.8482], [0.0855,0.1442]	[0.3541,0.4549], [0.4138,0.4946]
M_{12}	[0.6194,0.7203], [0.1778,0.2289]	[0.5189,0.6194], [0.2797,0.3302]	[0.5862,0.6871], [0.2109,0.2621]	[0.3541,0.4549], [0.4138,0.4946]	[0.5575,0.6598], [0.2359,0.2884]	[0.5575,0.6598], [0.2359,0.2884]
M_{13}	[0.3541,0.4549], [0.4138,0.4946]	[0.6598,0.7939], [0.1233,0.1817]	[0.5931,0.6959], [0.1990,0.2520]	[0.5500,0.6500], [0.2500,0.3000]	[0.6598,0.7939], [0.1233,0.1817]	[0.6598,0.7939], [0.1233,0.1817]
M_{14}	[0.2348,0.3351], [0.5144,0.6148]	[0.6871,0.8158], [0.1040,0.1587]	[0.6363,0.7759], [0.1379,0.2000]	[0.3541,0.4549], [0.4138,0.4946]	[0.6045,0.7493], [0.1636,0.2289]	[0.7203,0.8643], [0.0721,0.1260]
M_{15}	[0.4040,0.5047], [0.3806,0.4448]	[0.5575,0.6598], [0.2359,0.2884]	[0.4856,0.5862], [0.3129,0.3634]	[0.6598,0.7939], [0.1233,0.1817]	[0.4425,0.5445], [0.3402,0.4041]	[0.4500,0.5500], [0.3500,0.4000]

Table 7 (continued)

S_7	S_1	S_2	S_3	S_4	S_5	S_6
S_7		S_8	S_9	S_{10}	S_{11}	S_{12}
[0.4040,0.5047], [0.3806,0.4448]		[0.3541,0.4549], [0.4138,0.4946]	[0.1347,0.2348], [0.6459,0.7151]	[0.2348,0.3351], [0.5144,0.6148]	[0.6871,0.8158], [0.1040,0.1587]	[0.6194,0.7203], [0.1778,0.2289]
[0.1680,0.2681], [0.5960,0.6818]		[0.4425,0.5445], [0.3402,0.4041]	[0.7203,0.8643], [0.0721,0.1260]	[0.2348,0.3351], [0.5144,0.6148]	[0.7500,0.9000], [0.0500,0.1000]	[0.5862,0.6871], [0.2109,0.2621]
[0.2681,0.3684], [0.4811,0.5815]		[0.3396,0.4449], [0.4229,0.5023]	[0.2681,0.3684], [0.4811,0.5815]	[0.2348,0.3351], [0.5144,0.6148]	[0.7203,0.8643], [0.0721,0.1260]	[0.5500,0.6500], [0.2500,0.3000]
[0.5575,0.6598], [0.2359,0.2884]		[0.5862,0.6871], [0.2109,0.2621]	[0.5575,0.6598], [0.2359,0.2884]	[0.6194,0.7203], [0.1778,0.2289]	[0.4040,0.5047], [0.3806,0.4448]	[0.7203,0.8643], [0.0721,0.1260]
[0.6194,0.7203], [0.1778,0.2289]		[0.4425,0.5445], [0.3402,0.4041]	[0.4425,0.5445], [0.3402,0.4041]	[0.5862,0.6871], [0.2109,0.2621]	[0.1347,0.2348], [0.6459,0.7151]	[0.6871,0.8158], [0.1040,0.1587]
[0.4856,0.5862], [0.3129,0.3634]		[0.4040,0.5047], [0.3806,0.4448]	[0.4425,0.5445], [0.3402,0.4041]	[0.6500,0.7500], [0.1500,0.2000]	[0.2681,0.3684], [0.4811,0.5815]	[0.1500,0.2000], [0.5189,0.6194]
[0.1680,0.2681], [0.5960,0.6818]		[0.6194,0.7203], [0.1778,0.2289]	[0.2348,0.3351], [0.5144,0.6148]	[0.5205,0.6256], [0.2565,0.3208]	[0.2348,0.3351], [0.5144,0.6148]	[0.6194,0.7203], [0.1778,0.2289]
[0.3541,0.4549], [0.4138,0.4946]		[0.5205,0.6256], [0.2565,0.3208]	[0.2000,0.3000], [0.5500,0.6500]	[0.6598,0.7939], [0.1233,0.1817]	[0.1347,0.2348], [0.6459,0.7151]	[0.6194,0.7203], [0.1778,0.2289]
[0.4425,0.5445], [0.3402,0.4041]		[0.3247,0.4216], [0.4425,0.5229]	[0.2681,0.3684], [0.4811,0.5815]	[0.5189,0.6194], [0.2797,0.3302]	[0.1000,0.2000], [0.7000,0.7500]	[0.6194,0.7203], [0.1778,0.2289]
[0.3000,0.4000], [0.4500,0.5500]		[0.5575,0.6598], [0.2359,0.2884]	[0.2348,0.3351], [0.5144,0.6148]	[0.4856,0.5862], [0.3129,0.3634]	[0.4040,0.5047], [0.3806,0.4448]	[0.5189,0.6194], [0.2797,0.3302]
[0.2042,0.3048], [0.5575,0.6448]		[0.4856,0.5862], [0.3129,0.3634]	[0.7203,0.8643], [0.0721,0.1260]	[0.6871,0.8158], [0.1040,0.1587]	[0.3541,0.4549], [0.4138,0.4946]	[0.6194,0.7203], [0.1778,0.2289]
[0.2042,0.3048], [0.5575,0.6448]		[0.4856,0.5862], [0.3129,0.3634]	[0.3000,0.4000], [0.4500,0.5500]	[0.4856,0.5862], [0.3129,0.3634]	[0.4425,0.5445], [0.3402,0.4041]	[0.5862,0.6871], [0.2109,0.2621]
[0.4425,0.5445], [0.3402,0.4041]		[0.4040,0.5047], [0.3806,0.4448]	[0.6598,0.7939], [0.1233,0.1817]	[0.4444,0.5519], [0.3120,0.3926]	[0.1347,0.2348], [0.6459,0.7151]	[0.6194,0.7203], [0.1778,0.2289]

Table 7 (continued)

S_1	S_2	S_3	S_4	S_5	S_6
[0.3684,0.4722], [0.3955,0.4751]	[0.7203,0.8643], [0.0721,0.1260]	[0.7203,0.8643], [0.0721,0.1260]	[0.4856,0.5862], [0.3129,0.3634]	[0.1347,0.2348], [0.6459,0.7151]	[0.5862,0.6871], [0.2109,0.2621]
[0.6194,0.7203], [0.1778,0.2289]	[0.4856,0.5862], [0.3129,0.3634]	[0.2681,0.3684], [0.4811,0.5815]	[0.4444,0.5519], [0.3120,0.3926]	[0.1000,0.2000], [0.7000,0.7500]	[0.5575,0.6598], [0.2359,0.2884]

Table 8 Evaluation of the optimal interval-valued intuitionistic fuzzy performance rating of LCTSs

	S_1	S_2	S_3	S_4	S_5	S_6
R_0	[0.6871,0.8158], [0.1040,0.1587]	[0.7500,0.9000], [0.0500,0.1000]	[0.7203,0.8643], [0.0721,0.1260]	[0.7500,0.9000], [0.0500,0.1000]	[0.6959,0.8482], [0.0855,0.1442]	[0.7203,0.8643], [0.0721,0.1260]
S_7	[0.6194,0.7203], [0.1778,0.2289]	S_8 [0.7203,0.8643], [0.0721,0.1260]	S_9 [0.1347,0.2348], [0.6459,0.7151]	S_{10} [0.2348,0.3351], [0.5144,0.6148]	S_{11} [0.1000,0.2000], [0.7000,0.7500]	S_{12} [0.7203,0.8643], [0.0721,0.1260]

Table 9 Normalized AIVIF-DM for the LCSTS selection

	S_1	S_2	S_3	S_4	S_5	S_6
R_0	[0.6871,0.8158], [0.1040,0.1587]	[0.7500,0.9000], [0.0500,0.1000]	[0.7203,0.8643], [0.0721,0.1260]	[0.7500,0.9000], [0.0500,0.1000]	[0.6959,0.8482], [0.0855,0.1442]	[0.7203,0.8643], [0.0721,0.1260]
M_1	[0.2681,0.3684], [0.4811,0.5815]	[0.5862,0.6871], [0.2109,0.2621]	[0.2681,0.3684], [0.4811,0.5815]	[0.7203,0.8643], [0.0721,0.1260]	[0.4040,0.5047], [0.3806,0.448]	[0.2348,0.3351], [0.5144,0.6148]
M_2	[0.3000,0.4000], [0.4500,0.5500]	[0.6194,0.7203], [0.1778,0.2289]	[0.6194,0.7203], [0.1778,0.2289]	[0.6871,0.8158], [0.1040,0.1587]	[0.3541,0.4549], [0.4138,0.4946]	[0.3247,0.4216], [0.4425,0.5229]
M_3	[0.2348,0.3351], [0.5144,0.6148]	[0.7203,0.8643], [0.0721,0.1260]	[0.2348,0.3351], [0.5144,0.6148]	[0.7500,0.9000], [0.0500,0.1000]	[0.4425,0.5445], [0.3402,0.4041]	[0.2000,0.3000], [0.5500,0.6500]
M_4	[0.5862,0.6871], [0.2109,0.2621]	[0.5862,0.6871], [0.2109,0.2621]	[0.5500,0.6500], [0.2500,0.3000]	[0.4856,0.5862], [0.3129,0.3634]	[0.4856,0.5862], [0.3129,0.3634]	[0.4425,0.5445], [0.3402,0.4041]
M_5	[0.6194,0.7203], [0.1778,0.2289]	[0.6194,0.7203], [0.1778,0.2289]	[0.5862,0.6871], [0.2109,0.2621]	[0.4040,0.5047], [0.3806,0.4448]	[0.5575,0.6598], [0.2359,0.2884]	[0.5862,0.6871], [0.2109,0.2621]
M_6	[0.5500,0.6500], [0.2500,0.3000]	[0.6871,0.8158], [0.1040,0.1587]	[0.5189,0.6194], [0.2797,0.3302]	[0.5189,0.6194], [0.2797,0.3302]	[0.5931,0.6959], [0.1990,0.2520]	[0.5575,0.6598], [0.2359,0.2884]
M_7	[0.5862,0.6871], [0.2109,0.2621]	[0.7500,0.9000], [0.0500,0.1000]	[0.6500,0.7500], [0.1500,0.2000]	[0.5500,0.6500], [0.2500,0.3000]	[0.6959,0.8482], [0.0855,0.1442]	[0.5862,0.6871], [0.2109,0.2621]
M_8	[0.6194,0.7203], [0.1778,0.2289]	[0.5189,0.6194], [0.2797,0.3302]	[0.6598,0.7939], [0.1233,0.1817]	[0.6871,0.8158], [0.1040,0.1587]	[0.5269,0.6301], [0.2639,0.3175]	[0.3541,0.4549], [0.4138,0.4946]
M_9	[0.5189,0.6194], [0.2797,0.3302]	[0.4856,0.5862], [0.3129,0.3634]	[0.7203,0.8643], [0.0721,0.1260]	[0.6500,0.7500], [0.1500,0.2000]	[0.6363,0.7759], [0.1379,0.2000]	[0.6194,0.7203], [0.1778,0.2289]
M_{10}	[0.6871,0.8158], [0.1040,0.1587]	[0.7500,0.9000], [0.0500,0.1000]	[0.6871,0.8158], [0.1040,0.1587]	[0.4856,0.5862], [0.3129,0.3634]	[0.6598,0.7939], [0.1233,0.1817]	[0.6194,0.7203], [0.1778,0.2289]
M_{11}	[0.5862,0.6871], [0.2109,0.2621]	[0.6871,0.8158], [0.1040,0.1587]	[0.6871,0.8158], [0.1040,0.1587]	[0.6598,0.7939], [0.1233,0.1817]	[0.6959,0.8482], [0.0855,0.1442]	[0.3541,0.4549], [0.4138,0.4946]
M_{12}	[0.6194,0.7203], [0.1778,0.2289]	[0.5189,0.6194], [0.2797,0.3302]	[0.5862,0.6871], [0.2109,0.2621]	[0.3541,0.4549], [0.4138,0.4946]	[0.5575,0.6598], [0.2359,0.2884]	[0.5575,0.6598], [0.2359,0.2884]
M_{13}	[0.3541,0.4549], [0.4138,0.4946]	[0.6598,0.7939], [0.1233,0.1817]	[0.5931,0.6959], [0.1990,0.2520]	[0.5500,0.6500], [0.2500,0.3000]	[0.6598,0.7939], [0.1233,0.1817]	[0.6598,0.7939], [0.1233,0.1817]
M_{14}	[0.2348,0.3351], [0.5144,0.6148]	[0.6871,0.8158], [0.1040,0.1587]	[0.6363,0.7759], [0.1379,0.2000]	[0.3541,0.4549], [0.4138,0.4946]	[0.6045,0.7493], [0.1636,0.2289]	[0.7203,0.8643], [0.0721,0.1260]

Table 9 (continued)

	S_1	S_2	S_3	S_4	S_5	S_6
M_{15}	[0.4040,0.5047], [0.3806,0.4448]	[0.5575,0.6598], [0.2359,0.2884]	[0.4856,0.5862], [0.3129,0.3634]	[0.6598,0.7939], [0.1233,0.1817]	[0.4425,0.5445], [0.3402,0.4041]	[0.4500,0.5500], [0.3500,0.4000]
S_7		S_8	S_9	S_{10}	S_{11}	S_{12}
[0.6194,0.7203], [0.1778,0.2289]		[0.7203,0.8643], [0.0721,0.1260]	[0.6459,0.7151], [0.1347,0.2348]	[0.5144,0.6148], [0.2348,0.3351]	[0.7000,0.7500], [0.1000,0.2000]	[0.7203,0.8643], [0.0721,0.1260]
[0.4040,0.5047], [0.3806,0.4448]		[0.3541,0.4549], [0.4138,0.4946]	[0.6459,0.7151], [0.1347,0.2348]	[0.5144,0.6148], [0.2348,0.3351]	[0.1040,0.1587], [0.6871,0.8158]	[0.6194,0.7203], [0.1778,0.2289]
[0.1680,0.2681], [0.5960,0.6818]		[0.4425,0.5445], [0.3402,0.4041]	[0.0721,0.1260], [0.7203,0.8643]	[0.5144,0.6148], [0.2348,0.3351]	[0.0500,0.1000], [0.7500,0.9000]	[0.5862,0.6871], [0.2109,0.2621]
[0.2681,0.3684], [0.4811,0.5815]		[0.3396,0.4449], [0.4229,0.5023]	[0.4811,0.5815], [0.2681,0.3684]	[0.5144,0.6148], [0.2348,0.3351]	[0.0721,0.1260], [0.7203,0.8643]	[0.5500,0.6500], [0.2500,0.3000]
[0.5575,0.6598], [0.2359,0.2884]		[0.5862,0.6871], [0.2109,0.2621]	[0.2359,0.2884], [0.5575,0.6598]	[0.1778,0.2289], [0.6194,0.7203]	[0.3806,0.4448], [0.4040,0.5047]	[0.7203,0.8643], [0.0721,0.1260]
[0.6194,0.7203], [0.1778,0.2289]		[0.4425,0.5445], [0.3402,0.4041]	[0.3402,0.4041], [0.4425,0.5445]	[0.2109,0.2621], [0.5862,0.6871]	[0.6459,0.7151], [0.1347,0.2348]	[0.6871,0.8158], [0.1040,0.1587]
[0.4856,0.5862], [0.3129,0.3634]		[0.4040,0.5047], [0.3806,0.4448]	[0.3402,0.4041], [0.4425,0.5445]	[0.1500,0.2000], [0.6500,0.7500]	[0.4811,0.5815], [0.2681,0.3684]	[0.1500,0.2000], [0.5189,0.6194]
[0.1680,0.2681], [0.5960,0.6818]		[0.6194,0.7203], [0.1778,0.2289]	[0.5144,0.6148], [0.2348,0.3351]	[0.2565,0.3208], [0.5205,0.6256]	[0.5144,0.6148], [0.2348,0.3351]	[0.6194,0.7203], [0.1778,0.2289]
[0.3541,0.4549], [0.4138,0.4946]		[0.5205,0.6256], [0.2565,0.3208]	[0.5500,0.6500], [0.2000,0.3000]	[0.1233,0.1817], [0.6598,0.7939]	[0.6459,0.7151], [0.1347,0.2348]	[0.6194,0.7203], [0.1778,0.2289]
[0.4425,0.5445], [0.3402,0.4041]		[0.3247,0.4216], [0.4425,0.5229]	[0.4811,0.5815], [0.2681,0.3684]	[0.2797,0.3302], [0.5189,0.6194]	[0.7000,0.7500], [0.1000,0.2000]	[0.6194,0.7203], [0.1778,0.2289]
[0.3000,0.4000], [0.4500,0.5500]		[0.5575,0.6598], [0.2359,0.2884]	[0.5144,0.6148], [0.2348,0.3351]	[0.3129,0.3634], [0.4856,0.5862]	[0.3806,0.4448], [0.4040,0.5047]	[0.5189,0.6194], [0.2797,0.3302]
[0.2042,0.3048], [0.5575,0.6448]		[0.4856,0.5862], [0.3129,0.3634]	[0.0721,0.1260], [0.7203,0.8643]	[0.1040,0.1587], [0.6871,0.8158]	[0.4138,0.4946], [0.3541,0.4549]	[0.6194,0.7203], [0.1778,0.2289]

Table 9 (continued)

S_1	S_2	S_3	S_4	S_5	S_6
[0.2042,0.3048], [0.5575,0.6448]	[0.4856,0.5862], [0.3129,0.3634]	[0.4500,0.5500], [0.3000,0.4000]	[0.3129,0.3634], [0.4856,0.5862]	[0.3402,0.4041], [0.4425,0.5445]	[0.5862,0.6871], [0.2109,0.2621]
[0.4425,0.5445], [0.3402,0.4041]	[0.4040,0.5047], [0.3806,0.4448]	[0.1233,0.1817], [0.6598,0.7939]	[0.3120,0.3926], [0.4444,0.5519]	[0.6459,0.7151], [0.1347,0.2348]	[0.6194,0.7203], [0.1778,0.2289]
[0.3684,0.4722], [0.3955,0.4751]	[0.7203,0.8643], [0.0721,0.1260]	[0.0721,0.1260], [0.7203,0.8643]	[0.3129,0.3634], [0.4856,0.5862]	[0.6459,0.7151], [0.1347,0.2348]	[0.5862,0.6871], [0.2109,0.2621]
[0.6194,0.7203], [0.1778,0.2289]	[0.4856,0.5862], [0.3129,0.3634]	[0.4811,0.5815], [0.2681,0.3684]	[0.3120,0.3926], [0.4444,0.5519]	[0.7000,0.7500], [0.1000,0.2000]	[0.5575,0.6598], [0.2359,0.2884]

Table 10 The WNAIVIF-DM for LCTS selection

	S_1	S_2	S_3	S_4	S_5	S_6
R_0	[0.0854,0.1218], [0.8404,0.8682]	[0.0509,0.0831], [0.8932,0.9169]	[0.0999,0.1521], [0.8048,0.8427]	[0.0916,0.1475], [0.8125,0.8525]	[0.0604,0.0939], [0.8793,0.9037]	[0.0990,0.1507], [0.8065,0.8441]
M_1	[0.0237,0.0347], [0.9454,0.9592]	[0.0327,0.0429], [0.9430,0.9508]	[0.0255,0.0372], [0.9414,0.9562]	[0.0845,0.1293], [0.8334,0.8663]	[0.0267,0.0361], [0.9507,0.9585]	[0.0217,0.0328], [0.9471,0.9610]
M_2	[0.0270,0.0385], [0.9405,0.9551]	[0.0358,0.0469], [0.9370,0.9459]	[0.0767,0.0999], [0.8671,0.8853]	[0.0774,0.1106], [0.8548,0.8802]	[0.0226,0.0312], [0.9549,0.9639]	[0.0316,0.0438], [0.9355,0.9483]
M_3	[0.0203,0.0309], [0.9502,0.9633]	[0.0469,0.0725], [0.9056,0.9249]	[0.0219,0.0331], [0.9466,0.9606]	[0.0916,0.1475], [0.8125,0.8525]	[0.0301,0.0403], [0.9452,0.9537]	[0.0181,0.0288], [0.9523,0.9654]
M_4	[0.0655,0.0854], [0.8873,0.9023]	[0.0327,0.0429], [0.9430,0.9508]	[0.0638,0.0831], [0.8918,0.9053]	[0.0450,0.0593], [0.9226,0.9323]	[0.0342,0.0451], [0.9410,0.9484]	[0.0467,0.0623], [0.9156,0.9286]
M_5	[0.0715,0.0932], [0.8758,0.8929]	[0.0358,0.0469], [0.9370,0.9459]	[0.0703,0.0915], [0.8794,0.8953]	[0.0450,0.0593], [0.9226,0.9323]	[0.0417,0.0548], [0.9272,0.9370]	[0.0696,0.0907], [0.8805,0.8963]
M_6	[0.0595,0.0775], [0.8990,0.9117]	[0.0429,0.0618], [0.9182,0.9330]	[0.0586,0.0767], [0.9001,0.9125]	[0.0352,0.0475], [0.9352,0.9454]	[0.0459,0.0604], [0.9190,0.9305]	[0.0645,0.0844], [0.8886,0.9033]
M_7	[0.0655,0.0854], [0.8873,0.9023]	[0.0509,0.0831], [0.8932,0.9169]	[0.0831,0.1082], [0.8550,0.8755]	[0.0538,0.0702], [0.9084,0.9200]	[0.0604,0.0939], [0.8793,0.9037]	[0.0696,0.0907], [0.8805,0.8963]
M_8	[0.0715,0.0932], [0.8758,0.8929]	[0.0272,0.0358], [0.9531,0.9591]	[0.0852,0.1223], [0.8412,0.8686]	[0.0774,0.1106], [0.8548,0.8802]	[0.0384,0.0507], [0.9327,0.9418]	[0.0351,0.0484], [0.9304,0.9440]
M_9	[0.0546,0.0715], [0.9068,0.9184]	[0.0247,0.0327], [0.9571,0.9626]	[0.0999,0.1521], [0.8048,0.8427]	[0.0702,0.0916], [0.8768,0.8945]	[0.0515,0.0752], [0.9016,0.9193]	[0.0760,0.0990], [0.8682,0.8864]
M_{10}	[0.0854,0.1218], [0.8404,0.8682]	[0.0509,0.0831], [0.8932,0.9169]	[0.0915,0.1304], [0.8295,0.8589]	[0.0450,0.0593], [0.9226,0.9323]	[0.0548,0.0793], [0.8963,0.9147]	[0.0760,0.0990], [0.8682,0.8864]
M_{11}	[0.0655,0.0854], [0.8873,0.9023]	[0.0429,0.0618], [0.9182,0.9330]	[0.0915,0.1304], [0.8295,0.8589]	[0.0450,0.0593], [0.9226,0.9323]	[0.0604,0.0939], [0.8793,0.9037]	[0.0351,0.0484], [0.9304,0.9440]
M_{12}	[0.0715,0.0932], [0.8758,0.8929]	[0.0272,0.0358], [0.9531,0.9591]	[0.0703,0.0915], [0.8794,0.8953]	[0.0298,0.0412], [0.9407,0.9524]	[0.0417,0.0548], [0.9272,0.9370]	[0.0645,0.0844], [0.8886,0.9033]
M_{13}	[0.0330,0.0455], [0.9345,0.9474]	[0.0398,0.0578], [0.9241,0.9377]	[0.0716,0.0936], [0.8752,0.8924]	[0.0538,0.0702], [0.9084,0.9200]	[0.0548,0.0793], [0.8963,0.9147]	[0.0844,0.1212], [0.8426,0.8698]
M_{14}	[0.0203,0.0309], [0.9502,0.9633]	[0.0429,0.0618], [0.9182,0.9330]	[0.0801,0.1162], [0.8490,0.8755]	[0.0298,0.0412], [0.9407,0.9524]	[0.0474,0.0698], [0.9097,0.9258]	[0.0990,0.1507], [0.8065,0.8441]

Table 10 (continued)

	S_1	S_2	S_3	S_4	S_5	S_6
M_{15}	[0.0390, 0.0525], [0.9285, 0.9397]	[0.0303, 0.0398], [0.9470, 0.9542]	[0.0534, 0.0703], [0.9085, 0.9198]	[0.0720, 0.1037], [0.8650, 0.8885]	[0.0301, 0.0403], [0.9452, 0.9537]	[0.0477, 0.0632], [0.9177, 0.9278]
S_7		S_8	S_9	S_{10}	S_{11}	S_{12}
[0.0683, 0.0890], [0.8812, 0.8977]		[0.2136, 0.3139], [0.6090, 0.6766]	[0.0715, 0.0859], [0.8665, 0.9016]	[0.1048, 0.1361], [0.8008, 0.8457]	[0.0494, 0.0567], [0.9076, 0.9345]	[0.0863, 0.1319], [0.8301, 0.8636]
[0.0372, 0.0501], [0.9317, 0.9424]		[0.0791, 0.1081], [0.8467, 0.8757]	[0.0715, 0.0859], [0.8665, 0.9016]	[0.1048, 0.1361], [0.8008, 0.8457]	[0.0046, 0.0072], [0.9843, 0.9915]	[0.0661, 0.0863], [0.8849, 0.9009]
[0.0134, 0.0226], [0.9628, 0.9724]		[0.1043, 0.1378], [0.8160, 0.8429]	[0.0053, 0.0096], [0.9768, 0.9896]	[0.1048, 0.1361], [0.8008, 0.8457]	[0.0022, 0.0044], [0.9880, 0.9956]	[0.0606, 0.0790], [0.8957, 0.9096]
[0.0226, 0.0331], [0.9479, 0.9611]		[0.0753, 0.1051], [0.8502, 0.8782]	[0.0458, 0.0604], [0.9102, 0.9311]	[0.1048, 0.1361], [0.8008, 0.8457]	[0.0031, 0.0057], [0.9863, 0.9939]	[0.0550, 0.0716], [0.9065, 0.9183]
[0.0579, 0.0759], [0.8997, 0.9130]		[0.1533, 0.1968], [0.7456, 0.7768]	[0.0191, 0.0240], [0.9591, 0.9707]	[0.0296, 0.0391], [0.9292, 0.9509]	[0.0200, 0.0245], [0.9626, 0.9716]	[0.0863, 0.1319], [0.8301, 0.8636]
[0.0683, 0.0890], [0.8812, 0.8977]		[0.1043, 0.1378], [0.8160, 0.8429]	[0.0293, 0.0363], [0.9434, 0.9575]	[0.0357, 0.0455], [0.9214, 0.9441]	[0.0428, 0.0515], [0.9191, 0.9408]	[0.0790, 0.1129], [0.8519, 0.8778]
[0.0475, 0.0625], [0.9183, 0.9286]		[0.0930, 0.1241], [0.8334, 0.8583]	[0.0293, 0.0363], [0.9434, 0.9575]	[0.0246, 0.0336], [0.9361, 0.9569]	[0.0272, 0.0360], [0.9461, 0.9588]	[0.0114, 0.0157], [0.9546, 0.9667]
[0.0134, 0.0226], [0.9628, 0.9724]		[0.1666, 0.2136], [0.7220, 0.7572]	[0.0503, 0.0659], [0.9016, 0.9248]	[0.0444, 0.0576], [0.9047, 0.9306]	[0.0300, 0.0394], [0.9408, 0.9550]	[0.0661, 0.0863], [0.8849, 0.9009]
[0.0315, 0.0434], [0.9375, 0.9498]		[0.1294, 0.1691], [0.7737, 0.8070]	[0.0555, 0.0723], [0.8913, 0.9175]	[0.0200, 0.0303], [0.9382, 0.9652]	[0.0428, 0.0515], [0.9191, 0.9408]	[0.0661, 0.0863], [0.8849, 0.9009]
[0.0419, 0.0559], [0.9241, 0.9358]		[0.0714, 0.0981], [0.8575, 0.8849]	[0.0458, 0.0604], [0.9102, 0.9311]	[0.0491, 0.0596], [0.9043, 0.9292]	[0.0494, 0.0567], [0.9076, 0.9345]	[0.0661, 0.0863], [0.8849, 0.9009]
[0.0258, 0.0367], [0.9432, 0.9572]		[0.1425, 0.1840], [0.7615, 0.7910]	[0.0503, 0.0659], [0.9016, 0.9248]	[0.0359, 0.0669], [0.8952, 0.9214]	[0.0200, 0.0245], [0.9626, 0.9716]	[0.0505, 0.0661], [0.9137, 0.9245]
[0.0166, 0.0263], [0.9581, 0.9684]		[0.1178, 0.1533], [0.8032, 0.8262]	[0.0053, 0.0096], [0.9768, 0.9896]	[0.0167, 0.0261], [0.9441, 0.9693]	[0.0222, 0.0283], [0.9572, 0.9674]	[0.0661, 0.0863], [0.8849, 0.9009]

Table 10 (continued)

S_1	S_2	S_3	S_4	S_5	S_6
[0.0166,0.0263], [0.9581,0.9684]	[0.1178,0.1533], [0.8032, 0.8262]	[0.0418,0.0555], [0.9175,0.9366]	[0.0559,0.0669], [0.8952,0.9214]	[0.0174,0.0216], [0.9663,0.9747]	[0.0606,0.0790], [0.8957,0.9096]
[0.0419,0.0559], [0.9241,0.9358]	[0.0930,0.1241], [0.8334,0.8583]	[0.0094,0.0142], [0.9707,0.9836]	[0.0557,0.0736], [0.8831,0.9129]	[0.0428,0.0515], [0.9191,0.9408]	[0.0661,0.0863], [0.8849,0.9009]
[0.03310,0.0457,1], [0.9344, 0.9470]	[0.2136,0.3139], [0.6090,0.6766]	[0.0053, 0.0096], [0.9768,0.9896]	[0.0559,0.0669], [0.8952,0.9214]	[0.0428,0.0515], [0.9191,0.9408]	[0.0606,0.0790], [0.8957,0.9096]
[0.0683,0.0890], [0.8812,0.8977]	[0.1178,0.1533], [0.8032, 0.8262]	[0.0458,0.0604], [0.9102,0.9311]	[0.0557,0.0736], [0.8831,0.9129]	[0.0494,0.0567], [0.9076,0.9345]	[0.0561, 0.0735], [0.9028,0.9157]

Table 11 Score value, overall performance rating and degree of utility of each LCTS option

	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	S_{11}	S_{12}	Λ_i	Q_i
R_0	0.8336	0.9000	0.8713	0.9000	0.8513	0.8713	0.7510	0.8713	0.2054	0.3228	0.1900	0.8713	8.4393	1.0000
M_1	0.3611	0.7136	0.3611	0.8713	0.7510	0.3228	0.5106	0.4571	0.2054	0.3228	0.8336	0.7510	6.4614	0.7656
M_2	0.3975	0.7510	0.7510	0.8336	0.4571	0.4226	0.2446	0.5556	0.8713	0.3228	0.9000	0.7136	7.2207	0.8556
M_3	0.3228	0.8713	0.3228	0.9000	0.5556	0.2825	0.3611	0.4443	0.3611	0.3228	0.8713	0.6713	6.2869	0.7450
M_4	0.7136	0.7136	0.6713	0.5996	0.5996	0.5556	0.6833	0.7136	0.6833	0.7510	0.5106	0.8713	8.0664	0.9558
M_5	0.7510	0.7510	0.7136	0.5106	0.6833	0.7136	0.7510	0.5556	0.5556	0.7136	0.2054	0.8336	7.7379	0.9169
M_6	0.6713	0.8336	0.6370	0.6370	0.7243	0.6833	0.5996	0.5106	0.5556	0.7838	0.3611	0.2179	7.2151	0.8549
M_7	0.7136	0.9000	0.7838	0.6713	0.8513	0.7136	0.2446	0.7510	0.3228	0.6479	0.3228	0.7510	7.6737	0.9093
M_8	0.7510	0.6370	0.5556	0.8336	0.6503	0.4571	0.4571	0.6479	0.2825	0.8081	0.2054	0.7510	7.0366	0.8338
M_9	0.6370	0.8081	0.8713	0.7838	0.7873	0.7510	0.5556	0.4226	0.3611	0.6370	0.1900	0.7510	7.5558	0.8953
M_{10}	0.8336	0.9000	0.8336	0.5996	0.8081	0.7510	0.3975	0.6833	0.3228	0.5996	0.5106	0.6370	7.8767	0.9333
M_{11}	0.7136	0.8336	0.8336	0.8081	0.8513	0.4571	0.2865	0.5996	0.8713	0.8336	0.4571	0.7510	8.2964	0.9831
M_{12}	0.7510	0.6370	0.7136	0.4571	0.6833	0.6833	0.2865	0.5996	0.3975	0.5996	0.5556	0.7136	7.0777	0.8387
M_{13}	0.4571	0.5556	0.7243	0.6713	0.8081	0.8081	0.5556	0.5106	0.8081	0.5676	0.2054	0.7510	7.4228	0.8796
M_{14}	0.3228	0.8336	0.7873	0.4571	0.7552	0.8713	0.4762	0.8713	0.8713	0.5996	0.2054	0.7136	7.7647	0.9201
M_{15}	0.5106	0.6833	0.5996	0.8081	0.5556	0.5587	0.7510	0.5996	0.3611	0.5676	0.1900	0.6833	6.8685	0.8139

$$\begin{aligned}
Sim_{3w}(M_i, \xi^-) = & \frac{1}{4} \sum_{i=1}^n w_i \left[\sqrt{\mu_{\mathbb{M}_i}^-(u_i) \mu_{\xi^-}^-(u_i)} + \sqrt{\mu_{\mathbb{M}_i}^+(u_i) \mu_{\xi^-}^+(u_i)} + 2 \sqrt{v_{\mathbb{M}_i}^-(u_i) v_{\xi^-}^-(u_i)} \right. \\
& + 2 \sqrt{v_{\mathbb{M}_i}^+(u_i) v_{\xi^-}^+(u_i)} + \sqrt{\pi_{\mathbb{M}_i}^-(u_i) \pi_{\xi^-}^-(u_i)} + \sqrt{\pi_{\mathbb{M}_i}^+(u_i) \pi_{\xi^-}^+(u_i)} \\
& \left. + \sqrt{(1 - v_{\mathbb{M}_i}^-(u_i))(1 - v_{\xi^-}^-(u_i))} + \sqrt{(1 - v_{\mathbb{M}_i}^+(u_i))(1 - v_{\xi^-}^+(u_i))} \right].
\end{aligned} \quad (37)$$

To measure the separation between LCTS alternatives, we adopt the IVIF-SMs given in Eqs. (36 and 37) to determine the weighted SM $Sim_{3w}(M_i, \xi^+)$ to the alternatives M_i and the IS ξ^+ and the weighted SM $Sim_{3w}(M_i, \xi^-)$ to the alternatives M_i and the AIS ξ^- depicted in Table 12.

Step 6: Assessment of relative closeness index (CI).

The relative CI of each option regarding IVIF-ISs is computed by

$$C_c(M_i) = \frac{Sim_{3w}(M_i, \xi^+)}{Sim_{3w}(M_i, \xi^+) + Sim_{3w}(M_i, \xi^-)}, \quad i = 1(1)m. \quad (38)$$

Using Eq. (38), the relative CI $C_c(M_i)$ of each LCTS option is calculated and given in Table 12.

Step 7: Select the highest value, denoted by $C_c(M_k)$ to the values $C_c(M_i)$, $i = 1, 2, \dots, m$. And hence M_k is the best alternative.

According to relative CC values (see Table 11), M_7 is obtained as the best LCTS option since it has the highest relative CC value (0.9780), while M_3 is the last one.

The result achieved by the developed approach was also compared to the different current decision-making approaches. IVIF-MABAC (Mishra et al., 2020a; Xue et al., 2016) is one of the simplest and most conventional MCDM methods, which is generally implemented as a standard tool for comparing the results obtained from different MCDM methods. A further MCDM approach, TOPSIS (Bai, 2013) describes the idea for choosing the option with minimum discrimination to IS and the maximum discrimination from the AIS, while generalized Choquet integral Yildiz and Ergul (2015) represents measurable evidence in intervals form, while fuzzy measures are real numbers. As a result, all these methods can be implemented for LCTS selection. Initially, DEs can utilize these MCDM methods to evaluate LCTS options and then calculate and compare their ranking outcomes and take the final decision. The computations of criteria weight are concluded with proposed similarity measures, whereas the outcomes are evaluated by the proposed one, MABAC, TOPSIS, COPRAS (Mishra et al., 2020c) and ANP-GCI approaches on IVIFSs. Table 13 depicts that LCTSs M_{11} , M_8 and M_4 normally share the first rank. As a result, LCTS M_{11} comes out as the optimal one as per these comparisons, while the option M_3 is last in all methods. The outcomes indicate almost same preferences in all approaches. The proposed method can be easily understood and straightforwardly implemented. The performance of the IVIF-ARAS method was better than that of the extant approaches in the framework of decision making for LCTS selection on IVIFSs.

Next, Fig. 3 specifies the ranks obtained by three approaches assign various LCTSs as the most desirable ones; a definite degree of deviation can be examined. Two of the four current approaches that were compared to recognize the LCTS M_{11} to be optimal, while one of them classify M_{11} as the second one, as depicted in Fig. 3. According to the results, the remaining preference order is different for LCTS selection, representing a clear benefit

Table 12 Results of IVIF-TOPSIS method for LCTS selection

LCTSs	$Sim(M_i, \xi^+)$	$Sim(M_i, \xi^-)$	$C_c(M_i)$	Ranking
M_1	0.9169	0.9666	0.4868	13
M_2	0.9108	0.9793	0.4819	14
M_3	0.9071	0.9742	0.4822	15
M_4	0.9690	0.9423	0.5070	6
M_5	0.9701	0.9342	0.5094	4
M_6	0.9539	0.9533	0.5002	12
M_7	0.9780	0.9304	0.5125	2
M_8	0.9764	0.9249	0.5135	1
M_9	0.9662	0.9317	0.5091	5
M_{10}	0.9750	0.9355	0.5103	3
M_{11}	0.9540	0.9399	0.5037	9
M_{12}	0.9578	0.9563	0.5004	11
M_{13}	0.9553	0.9515	0.5010	10
M_{14}	0.9517	0.9300	0.5058	7
M_{15}	0.9647	0.9473	0.5046	8

by its useful and efficient evaluation process. Also, if the number of LCTS alternatives increases, the advantage will become more apparent. The outcomes of the new method introduced in this paper and those of the existing methods are depicted in Table 13. From Table 13, the correlation coefficients are greater than 0.8 except IVIF-TOPSIS (Bai, 2013). Also, the WS coefficients are greater than 0.808 except IVIF-TOPSIS method. The properties of the WS coefficient (Sařabun & Urbaniak, 2020) specify that it is a suitable procedure for comparing the similarity of priorities, which means the similarity of preference order of LCTS option is high. As a result, it can be said that there is a highly strong relationship between ranking results. Thus, it can be concluded that the outcome of the developed approach has consistency with the extant approaches. When compared to currently employed procedures, IVIF-ARAS has the following advantages:

- (a) The IVIF-ARAS works on the basis of a broader standard of ARAS with SMs to select the strategies to implement of LCTSs toward the achievements of sustainable development problems in comparison with IVIF-MABAC, IVIF-TOPSIS (Compromise programming), ANP-GCI and IVIF-COPRAS (Mishra et al., 2020c) methods because IVIF-ARAS model considers the score values (deviations) from optimal option while the extant models only consider a single attribute of the minimum discrimination from IVIF-IS and maximum discrimination from IVIF-AIS.
- (b) The proposed model only evaluates IVIF-IS, whereas IVIF-TOPSIS needs to obtain both IVIF-IS and IVIF-AIS, and IVIF-WASPAS model (Mishra & Rani, 2018b) utilizes IVIFWAO and IVIFWGO and IVIF-COPRAS (Mishra et al., 2020c) utilizes IVIFWAO to obtain the final outcomes. To conclude with, it can be said that for MCDM methods with more attributes or options, IVIF-ARAS is capable of to some extent increasing the operational effectiveness with a higher operability.

Table 13 Comparison of ranking results of IVIF-ARAS method with extant methods

LCTSs	IVIF-TOPSIS (Bai, 2013)	GCI method Yildiz and Ergul (2015)	IVIF-MABAC (Xue et al., 2016)	Proposed IVIF-ARAS method
M_1	13	14	13	14
M_2	14	11	10	9
M_3	15	15	15	15
M_4	6	2	1	2
M_5	4	3	5	5
M_6	12	9	7	10
M_7	2	8	9	6
M_8	1	13	12	12
M_9	5	6	8	7
M_{10}	3	4	4	3
M_{11}	9	1	2	1
M_{12}	11	10	11	11
M_{13}	10	7	6	8
M_{14}	7	5	3	4
M_{15}	8	12	14	13
Correlation coefficient (rs)	0.482	0.964	0.946	–
WS coefficient	0.6054	0.9720	0.9211	–

5 Conclusions

The selection of most appropriate LCTS is directly affected by numerous diverse attributes; therefore, this selection problem can be assumed as MCDM problem. In comparison with conventional crisp sets or FSs or IFSs, IVIFSs offer better opportunities for handling real-life problems. Therefore, the developed method is extended with IVIFSs to implement its advantages. In this paper, we first combine similarity measures and ARAS method under IVIFSs context. Then, developed approach is utilized to choose the desirable low-carbon tourism strategy among 15 available options. In this paper, firstly novel similarity measures have been developed for IVIFSs because proposed measures are verified to be the important issues to handle the uncertainty. Secondly, the ARAS method has introduced using similarity measure and concepts of IVIFSs, where the DEs and attribute weights are completely unknown. The proposed similarity measures have been applied to compute the attribute weights. Further, a case study of LCTS selection has been taken to exemplify the practicality and feasibility of the present IVIF-ARAS approach. An assessment index procedure for LCTS options is developed, which comprises three dimensions: social, economy and environmental of criteria. These criteria involve of four, five and three sub-criteria, respectively, which are broadly assumed based on the literatures, research reports and DEs' knowledge in different regions. In addition, comparison has been discussed to confirm the strength of the results obtained by the introduced approach. The key outcomes of the IVIF-ARAS method are (i) sound process that can be constructive for choosing most desirable one among others, (ii) it is latest and straightforward method distinguished by its effectiveness in IVIFSs background and (iii) it employs a procedure to obtain more realistic attribute weights that increases the permanence of developed method. By comparing with

Fig. 3 LCTS options rankings for different MCDM methodologies

extant models, the IVIF-ARAS approach delivers a precise and proficient result of MCDM problems on IVIFSs setting.

Also, some potential limitations need to be considered in further study, which are: (i) this work miscarries to tackle with multifaceted LCTS assessment problem with inter-dependent criteria, (ii) more sustainability indicators can be considered in the assessment index structure, and (iii) further, the attitude of each expert is not calculated methodically.

In future studies, we will integrate the ARAS approach with different decision support methods, namely AHP, CRITIC, DEMATEL, SWARA, WASPAS and so on, and further consider the interaction among the criteria by using the Choquet integral. In addition, this research will be continued with anticipation that the method can be applied to other sustainable and green supplier selection problems, for example, sustainable supplier selection, medical waste treatment method selection and others.

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