



An integrated fuzzy intuitionistic sustainability assessment framework for manufacturing supply chain: a study of UK based firms

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Abstract

The increasing importance of sustainability has put pressure on organisations to assess their supply chain sustainability performance, which requires a holistic set of key performance indicators (KPIs) related to strategic, tactical and operational decision making of firms. This paper presents a comprehensive set of KPIs for sustainable supply chain management using a mixed method approach including analysing data from the literature survey, content analysis of sustainability reports of manufacturing firms and expert interviews. A 3-level hierarchical model is developed by classifying the identified KPIs into key sustainability dimensions as well as key supply chain decision-making areas including strategic, tactical and operational. A novel multi-attribute decision-making (MADM) based sustainability assessment framework is proposed. The proposed framework integrates value focussed thinking (VFT), intuitionistic fuzzy (IF) Analytic Hierarchy Process (AHP) and IF Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) methods. The novelty of the research lies in (1) using a rigorous mixed method approach for KPIs identification and industrial validation (2) the development of a novel integrated intuitionistic sustainability assessment framework for decision making and (3) the innovative application of the proposed framework and associated methodologies in the context not explored before. The practical data on the performance ratings of various KPIs were obtained from the experts and a novel intuitionistic fuzzy TOPSIS was applied to benchmark the organisations for their sustainability performance. Furthermore, the case study shows the applicability of the proposed framework to evaluate and identify the problem areas of the organisations and yield guidance on KPIs by recognising the most significant areas requiring improvement. This research contributes to the practical implication by providing an innovative sustainability assessment framework for supply chain managers to evaluate and manage sustainability performance by making informed decisions related to KPIs.

Keywords Supply chain management · Sustainability · Values focussed thinking · Intuitionistic fuzzy analytic hierarchy process · Intuitionistic fuzzy TOPSIS

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1 Introduction

The supply chain considering the triple bottom line including economic, environmental and societal dimensions of sustainability plays a vital role in achieving Sustainable Development Goals. Even though the area of sustainable supply chain management (SSCM) has received much attention from both quantitative and empirical modelling researchers within the last two decades, the research into the development of practical decision-making tools and frameworks for manufacturing supply chain sustainability is still evolving (Korpela et al. 2001; Soheilrad et al. 2017; Taleizadeh et al. 2018). Seuring and Müller (2008) provided critical attributes of sustainable supply chain management by identifying the simultaneous consideration of economic, environmental and social impacts of the supply chain. Similarly, Fahimnia et al. (2015) performed a review and bibliometric analysis of green supply chain management and stated the need for considering sustainability holistically within the supply chain. It is apparent that the firms are continuously striving to comply with the increasing regulatory pressure for environmental sustainability (Dangelico and Pujari 2010; Montabon et al. 2007). With sustainable development goals of the United Nations and pressure on firms to achieve these by 2030, there is a greater need than ever before to develop frameworks and methodologies to effectively measure and manage key performance indicators (KPIs) for sustainability performance evaluation and improvement of the organisations.

Enhancing sustainability performance has gained paramount importance among the supply chain managers (Beamon and Chen 2001; Esmaelikia et al. 2016; Wang and Gunasekaran 2017). In a complex, challenging and continually changing business environment, supply chain managers are faced with the dilemma of making informed decisions that require inputs about the Key Performance Indicators (KPIs) (Chai et al. 2013). From the supply chain perspective, it is imperative to determine the key performance indicators (KPIs) from the environmental, social and economic dimensions as well as the operational, strategic and tactical decision-making levels. Organisational performance and its measurement are vastly covered in the literature from the perspective of green supply chain and environmental management yet overlooking the need to address the trade-off as well as the impact of social dimensions on organisation's performance (Oyemomi et al. 2016; Olugu et al. 2011). Several researchers such as Deshmukh and Sunnapwar (2013) and Genovese et al. (2014) identified indicators for implementing environmental green supply chain and accordingly established its performance measurement framework. However, these researches are limited to providing guidance related to a specific aspect of the supply chain, e.g. supplier selection or green supply chain with a focus on academic literature only. Therefore, a holistic framework comprising of a set of KPIs of the triple bottom line and including three levels (strategic, operational and tactical) of decision-making is needed to manage the sustainability performance of a manufacturing supply chain.

The use of KPIs to determine the sustainability performance of the manufacturing supply chain requires the involvement of uncertainty related to human judgement in decision making. Multi-criteria decision-making (MCDM) techniques take into account of the uncertainty associated with expert opinion in an endeavour to simplify the decision context (Cheng and Liu 2007; Banasik et al. 2016). MCDM methods ensure the weighing of the expert judgement, allowing the balancing of different criteria and supporting the decision makers' judgements (Alexander et al. 2014; Belton and Stewart 2010). The application of MCDM to determine the weights of the KPIs for sustainability implementation in the supply chain presents a novelty (De Brucker et al. 2013; Allevi et al. 2018), as this approach requires the identification of the essential factors within the supply chain (Govindan et al. 2017). However, weighing the KPIs and their significance falls short in supporting the

managerial decision-making. This leads to the need of establishing a conceptual framework that aims to alleviate the subjectivity of the organisation's performance assessment criterion and establish possible ways for improving the organisation's sustainability performance.

Thus, the contribution of the paper is to (1) identify KPIs for the sustainable supply chain management (SSCM) through literature review, content analysis of industrial practices identified in the sustainability reports, experts opinions for validation of KPIs and obtaining their respective weights and significance levels; (2) propose a novel multi-attribute decision-making (MADM) based sustainability assessment framework, which integrates value focussed thinking (VFT), intuitionistic fuzzy (IF) Analytic Hierarchy Process (AHP) and IF Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) methods; (3) developing and employing intuitionistic fuzzy analytic hierarchy process (IFAHP) for determining the intuitionistic fuzzy weights associated with the KPIs and estimating the importance of each KPI for judging the performance of manufacturing organisation; (3) developing and applying Intuitionistic fuzzy TOPSIS in a novel manner to rank sustainability performance of different organisation on the basis of the KPIs; and (4) demonstrating the application of the sustainability assessment framework in the context of UK based organisations along with its validity through a robustness check. The research addresses the following interrelated research questions:

1. What are the KPIs essential for assessing the sustainability performance of the manufacturing supply chain?
2. How to determine the importance of each KPIs while ranking the sustainability performance of the organizations?
3. How the proposed sustainability assessment framework can be deployed for practical application in terms of helping the supply chain managers to make informed decisions?

The remainder of the paper is organised as follows. Section 2 presents a literature review related to the key areas of this research to identify existing research gaps. Section 3 presents a conceptual framework for sustainability assessment using the proposed MADM methods. Section 4 describes integrated intuitionistic methodologies. Section 5 presents the application of the proposed framework and methodologies. Section 6 concludes this paper highlighting the limitations of the study and proposing future research directions.

2 Literature review

This section is comprised of three parts. The first part reviews the literature in the domain of key performance indicators used in the context of sustainable supply chain management. The second part specifically reviews the research related to the application of intuitionistic fuzzy (IF) MCDM methods. Based on the literature review, the final part identifies research gaps in the current literature.

2.1 Key performance indicators

Performance evaluation of supply chains has been a managerial focus since the existence of supply chain management, and it is no different for supply chain managers concerned with sustainability. Initial works related to performance measurement have focused primarily on developing frameworks for estimating the organization's performance level while considering both qualitative and quantitative performance measures (Chan 2003).

Further efforts have been made to establish supply chain performance evaluation metrics and in particular, there are a number of works that aims to estimate the performance measurements of green supply chains (Olugu et al. 2011). Within the literature many of the benefits of incorporating performance measurement into supply chain have been identified (Taticchi et al. 2013; Oyemomi et al. 2016) with much of the focus being on internal performance. Whilst these measures are evidently of importance, there is arguably a need to consider key performance indicators on a more holistic level which consider a range of sustainable supply chain activities (Ahi and Searcy 2015). Additionally, there is a need to develop effective methods to benchmark, correlate and assess sustainability practices (Taticchi et al. 2013).

The impact of environmental performance on the adoption of SSCM by companies, both financially and competitively, has been thoroughly analysed in the literature (Chen et al. 2017). Dubey et al. (2015) identified that institutional pressures, operational practices, and organizational managers, are seldom observed collectively. Montabon et al. (2007) identified that there is a lack of proper evidence about measuring the organization's financial performance and its environmental performance together. Several research demonstrated that organization's commercial performance is positively correlated and directly proportional to environmental performance (Montabon et al. 2007; Iraldo et al. 2009). Thus, in accordance with the set parameters outlined by governments and regulatory authorities, organizations have adopted various metrics for assessing environmental performance (Dangelico and Pujari 2010). It is noteworthy that the limited volume of research that addresses the relationship between organizational competitiveness and environmental performance has been conducted solely from the perspective of organizational profitability (Fahimnia et al. 2015). According to dictionary definitions, "*metrics*" refers to a standard of measurement, while a "*Key Performance Indicator*" refers to a quantifiable measure utilized for evaluating organizational success in meeting outlined objectives (Reh 2016). In reviewing previous research, many issues, perspectives and criteria of SSCM as well as environmental impacts on organizations have been identified. Table 1 presents information of the key performance indicators in terms of their description and the literature sources from where the KPIs are obtained. After reviewing the literature, several KPIs and measures were recognized and collated in Table 1. It has been identified that future references refer to the subsequent references, and any overlaps were removed, with KPIs being primarily limited to their first initiating research. This also further shows the different perspectives from which SSCM has been evaluated.

After obtaining the KPIs from the abovementioned literature, it is also evident that there is a need of comprehensive set of key performance indicators along with their relative importance; at strategic, tactical and operational levels, reflecting a holistic view of SSCM performance. Most performance evaluation frameworks begin by identifying areas where performance should be measured, typically done by reviewing literature and it lacks consideration of specialist knowledge, whilst the approach considers multiple supply chain aspects taking into account of expert's knowledge. However, determining the relative importance of KPIs is a challenging task, given their conflicting nature and hence there is a need of rigorous approaches such as MCDM methods (Garg et al. 2014). Due to the inherent weakness of MCDM methods in addressing uncertainty and vagueness of decision makers while providing preferential judgement, many researchers have combined fuzzy sets with MCDM methods (Tooranloo and Iranpour 2017). However, due to the fact that fuzzy based MCDM methods only takes into account the degree of agreement of decision makers' opinions and neglect their disagreement, which is a natural way of human thought process. This limitation of the existing methodologies prompted the authors to develop

Table 1 Collated key performance indicators from literature

Source	Key performance indicator	Description and interpretation
Dubey et al. (2015), Li et al. (2018) and Asefi et al. (2019)	Waste management Reverse logistics Governmental regulations Management commitment Risk management Injury prevention Adoption of safety practices Labour equity Quality of employee life Operational costs Customer satisfaction rates Investment costs Return on investment Greenhouse gas emission rates Employment creation rates Training Rates Noise rates Environmental Quality management	Management of the waste Operations based on reusing products and materials Regulations imposed by governmental bodies Commitment of management to causes The management for risks Preventative precautions within facilities Safety practices implemented within organization Equality and diversity in employment Employee life-quality balance Costs of running operations Rates of customer satisfaction Costs of investment in sustainability Return on Investment (ROD) rates GHG emissions from facilities Rate of new job creation and hiring cycles Rate of employee developmental trainings Noise rates causing disturbance Managing quality with attention to environment
Hussain et al. (2016), Ghosh et al. (2018), Kara et al. (2018), Barbosa-Póvoa et al. (2018) and Chakraborty et al. (2019)		
Morali and Searcy (2013), Yawar and Seuring (2017), Chen et al. (2017) and Mathivathanan et al. (2018)		
Hofer et al. (2012) and Shaharudin et al. (2017)		

Table 1 (continued)

Source	Key performance indicator	Description and interpretation
Khidir and Zailami (2011), Want et al. (2017) and Ghosh et al. (2018)	Regulations	The regulations and their importance which are imposed upon the organization
	Customer pressures	The pressures customers put on the organization for sustainability implementation
	Supplier pressures	The pressures suppliers impose on the organization for sustainability implementation
	Competition	The competitive forces that cause organizations to implement SSCM
	Market demand	The demand presented from the market for sustainability in activities and products provided
	Community pressures	The pressures exerted by the community on the organization
	Social responsibility	The overarching perception of the organization's social responsibility
	Expected business benefits	The perceived business benefits to SSCM implementation
	Employee pressures	The pressures employees exert on the organization for sustainability implementation
	Inventory costs	Costs of inventory holding
	Production flexibility	Flexibility of production processes
	Logistics costs	Costs related to logistics and transportation
	Capacity utilization	The utilisation of the facilities' capacity
	Compliance to regulations	Organizational adherence to regulations
Labour efficiency	Efficiency of labour employment and production	

Gunasekaran and Kobu (2007), Balliaqih et al. (2016) and Maestrini et al. (2017)

Table 1 (continued)

Source	Key performance indicator	Description and interpretation
Gunasekaran et al. (2001), Shepherd and Günter (2010), Chardine-Baumann and Botta-Genoulaz (2014) and Maestrini et al. (2017)	Stakeholders involvement Product cost Product quality Speed of delivery Capacity utilization	Involvement of stakeholders within organization Overall costs involved in manufacturing the product The ability to maintain the quality of the product The impact on the speed with which the product is delivered to customers The ability to make the most of the capacity available within the organization
Beamon (1999), Sanititerakul et al. (2015) and Dev et al. (2016)	Production Efficiency Supplier selection costs Perceived value of product Planning and product design Customer retention Resource utilization Innovation and improvement	Efficiency of production rates Decisions relating to selection of suppliers The perceived value of the product Designing the products and planning their production Rate of customer retention and turnover The utilization of all resources Innovation and improvement of processes and products
Kaplan and Norton (1996), Isaksson et al. (2010) and Tan et al. (2015)		

intuitionistic fuzzy sets based MCDM methods, which overcome the issues of the degree of disagreement in the present context of sustainable supply chain management.

2.2 Intuitionistic multi criteria decision-making

To overcome the shortcomings of fuzzy MCDM methods attributed to taking into account of human judgement in evaluating criteria and alternatives, as mentioned above, several researchers have introduced the concept of combining intuitionistic fuzzy sets with MCDM methods to provide more efficient decision support frameworks Tooranloo and Iranpour (2017) and Govindan and Jepsen (2016). Interestingly, most of the work is limited to supplier selection problems in the wider area of supply chain. Chang (2017) proposed a novel supplier selection method based on integrating the intuitionistic fuzzy weighted averaging method and the soft set with imprecise data. Tooranloo and Iranpour (2017) developed a supplier selection group decision framework employing interval intuitionistic fuzzy AHP method. Similarly, some researchers have combined intuitionistic fuzzy set with outranking methods. For example, Govindan and Jepsen (2016) addressed a supplier selection problem by employing trapezoidal intuitionistic fuzzy numbers integrated with ELECTRE. Similarly, Shen et al. (2015) extended the intuitionistic fuzzy ELECTRE III method taking into account group decision techniques and developed an automatic approach to achieve group opinion satisfaction. Moreover, Cao et al. (2015) proposed an intuitionistic fuzzy numbers for conducting pairwise comparison of criteria for green supplier selection and then used TOPSIS combined with intuitionistic fuzzy set to determine the rank of green suppliers. Besides the application of intuitionistic fuzzy set (IFS) based MCDM methods in supplier selection, few attempts were made to use this approach in other areas of supply chain. Qu et al. (2017) proposed an evaluation formula of intuitionistic fuzzy Choquet integral correlation coefficient between an alternative and the ideal alternative. They employed the proposed model to assess the green supply chain choice. Dong et al. (2015) used trapezoidal intuitionistic fuzzy numbers (TIFNs) to develop TIFN prioritized score, average, AND and OR operators to solve MCDM priority problem as well as applied the same in a supply chain collaboration case. It is evident from the above that the application of intuitionistic MCDM is relatively new in the SCM context with most of the literatures addressing supplier selection, risk assessment and green supply chain issues.

2.3 Research gaps and contribution

The literature review highlights the research gaps and a need to identify KPIs of sustainable supply chain management, which are essential to supply chain managers from the performance assessment perspective. Furthermore, considering the concept and definition of sustainable supply chain management, there is a need for further clarity and consistency related to the KPIs of SSCM (Taticchi et al. 2013; Oyemomi et al. 2016). Past research has focussed on green supply chain management or various aspects of environmental sustainability and has failed to consider the societal aspects of sustainability (Montabon et al. 2007; Dubey et al. 2015). Besides, the Key Performance Indicators (KPIs) need to be identified by taking into account the expert judgements. Based on the above research gaps, this paper aims to identify the KPIs impacting manufacturing organization's sustainability performance. A 3-level hierarchical model, which categories the key performance indicators on the basis of economic, environmental and social aspects, is presented in this paper.

A framework is developed while considering the KPIs for assessing the sustainability performance of the manufacturing organizations. Intuitionistic Fuzzy AHP and intuitionistic fuzzy TOPSIS methodologies have been employed in different stages of the framework. It has been observed in the current literature that fuzzy AHP as MCDM method has its weakness in dealing with human judgement and consistency of preference relations. To deal with the current methodological shortcomings, a sustainability assessment framework is developed and incorporated with expert opinions coupled with intuitionistic fuzzy AHP based algorithm to improve the consistency of preference relations for determining the weights of the KPIs and their respective importance. Moreover, intuitionistic fuzzy TOPSIS is innovatively employed to rank different organisations on the basis of their performance on several essential KPIs.

3 Framework for sustainability assessment

This section provides a framework for identifying, assessing and prioritising the key performance indicators within sustainable supply chain management. Figure 1 presents the proposed conceptual framework associated with the overall process for the evaluation and assessment of

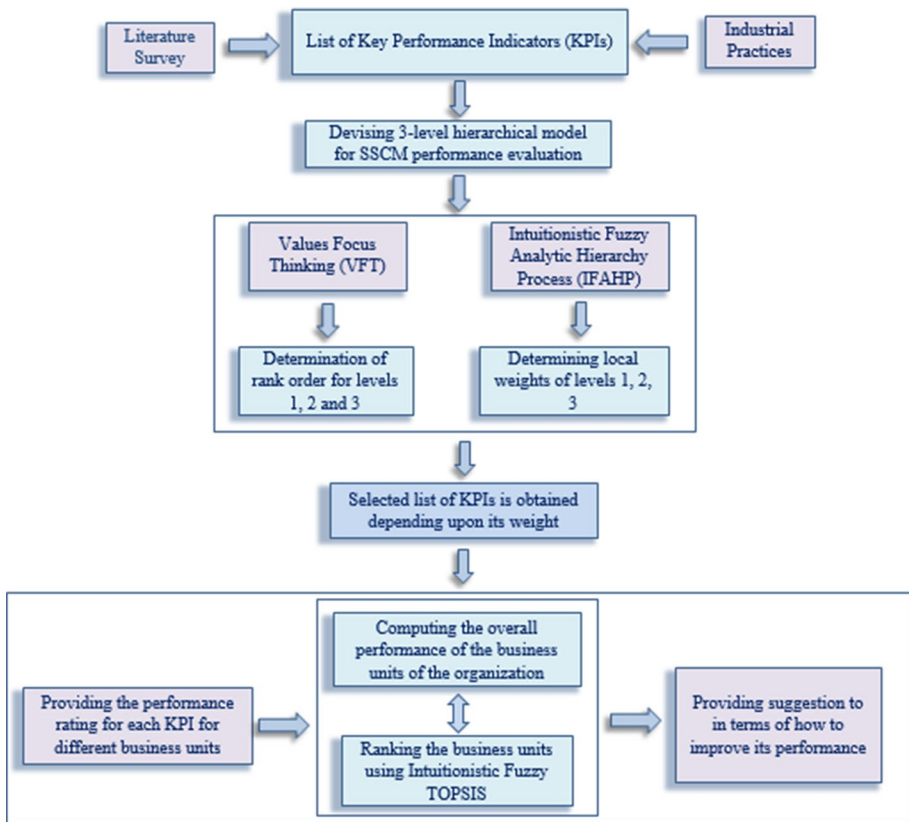


Fig. 1 Framework for assessing the sustainability performance of the organizations

KPIs for sustainable supply chain management. This framework outlines the methodologies used at each stage which begins with the identification of KPIs. Based on this, a three-level hierarchical model is developed, which categorises the KPIs on the basis of Triple Bottom Line (TBL) and organisational decision-making levels. Table 2 presents the detailed list of the KPIs considering the three-level hierarchical model. Moreover, Table 2 helps to categorize the obtained KPIs into first level criteria of triple bottom line related to economic, environmental and social. Table 2 also helps to categorize the KPIs into second level criteria associated with organizational decision level such as operational decisions, strategic decisions and tactical decisions. Third level Criteria of Table 2 are the Key Performance Indicators which are selected by performing a thorough literature survey, content analysis of sustainability reports from a cross-section of manufacturing firms in the FTSE 500 list and experts opinion.

After obtaining the KPIs in the third level criteria, Values Focus Thinking (VFT) is conducted for ranking each of the levels based on the preferences of the experts. Values Focus Thinking (VFT), a widely used method is applied to rank the Key Performance Indicators (KPIs) based on the initial opinions accumulated from the decision makers (Keeney 1996). Values-Focused thinking is conducted in a focus-group meeting with a pool of industry experts from the field who are attendees of the UK Forum for Supply Chain Sustainability and identified as per specific criteria including (1) experts should belong to a manufacturing organisation, (2) experts should have a track record of credentials in implementing sustainability in supply chain (3) experts should have a decision making role in their organisations. It is imperative to note that the respondents are asked to give a ranking score of importance of 1–5 on a Likert scale for each KPI presented within the survey, where 1 is the most important and 5 is the least important. The results obtained from VFT approach need a further ratification of the choices and “decisions” made.

As discussed earlier, intuitionistic fuzzy analytic hierarchy process (IFAHP) is the most widely used approach to deal with the ambiguity and complexity of the decision-making process, especially over several hierarchical levels of decisions. Intuitionistic fuzzy analytic hierarchy process (IFAHP) is employed to determine the weights of the KPIs and based on the relative weights a selected group of KPIs are identified. Intuitionistic fuzzy analytic hierarchy process is used to compute the local weights for hierarchical levels 1, 2 and 3. Based on the local weights for the 3rd level KPIs, the importance of each KPIs are obtained. Revised list of KPIs is determined comprises of the KPIs whose importance value is more than a certain threshold limit. The revised list of KPIs obtained is used for the performance evaluation framework.

The data associated with the performance ratings for the selected list of KPIs are obtained for several organisations, and accordingly, the overall performance of the organization is determined. The organization’s performance is determined by considering the combined performance level of the selected group of KPIs. The organisations are ranked using intuitionistic fuzzy TOPSIS based on their performance on different KPIs. Several suggestions are provided to the organisations regarding the possible scope of improvement from the perspective of the performance of the KPIs. The next section illustrates about the intuitionistic fuzzy analytic hierarchy process which is used to obtain the weight for each KPIs.

Table 2 Detailed list of the key performance indicators (KPIs)

Goal	1st level criteria (TBL)	2nd level criteria (organizational decision level)	3rd level criteria (KPIs)	Descriptions
Performance evaluation for SSCM	Economic	<i>Operational</i>	Operational costs	Cost of running operations
			Customer satisfaction rates	Rates of customer satisfaction
			Production efficiency	Efficiency of production rates
		<i>Strategic</i>	Inventory costs	Costs of inventory holding
			Production flexibility	Flexibility of production processes
			Investment costs	Costs of investment in sustainability
		<i>Tactical</i>	Supplier selection costs	Decisions related to selection of suppliers
			Logistics costs	Costs associated with logistics and transportation
			Return on investment	Return on investment (ROI) rates
	Environmental	<i>Operational</i>	Capacity utilization	Utilization of the facilities capacity
			Perceived value of product	Perceived value of the product
			Greenhouse gas emission rates	GHG emissions from facilities
		<i>Strategic</i>	Noise rates	Noise rates causing disturbances
			Waste management	Management of the waste products
			Innovation and improvement	Innovation and improvement of processes and products
	<i>Tactical</i>	Planning and product design	Designing the products and planning their production	
		Compliance to regulations	Organizational adherence to regulations	
		Environmental Quality management	Managing quality with attention to environment	
		Management commitment	Commitment of management to causes	
		Governmental regulations	Regulations imposed by governmental bodies	
		Resource utilization	Optimum utilization of resources	
		Risk management	Management of risks	
		Reverse logistics	Operations based on reusing products	

Table 2 (continued)

Goal	1st level criteria (TBL)	2nd level criteria (organizational decision level)	3rd level criteria (KPIs)	Descriptions
Social	<i>Operational</i>	Labour efficiency	Labour efficiency	Efficiency of labour employment and product
		Injury prevention	Injury prevention	Preventative precautions within facilities
		Stakeholders involvement	Stakeholders involvement	Involvement of stakeholders within organization
	<i>Strategic</i>	Employment creation rates	Employment creation rates	Rate of new job creation and hiring cycles
		Training rates	Training rates	Rate of employee developmental trainings
	<i>Tactical</i>	Adoption of safety practices	Adoption of safety practices	Safety practices implemented within organization
		Customer retention	Customer retention	Rate of customer retention and turnover
		Labour equity	Labour equity	Equality and diversity in employment
			Quality of employee life	Employee life-quality balance

4 Intuitionistic fuzzy set combined with MCDM techniques

Atanassov (1999) introduced the concept of intuitionistic fuzzy set, which contains the information related to membership, non-membership and hesitancy function. The intuitionistic fuzzy set has shown definite advantages in handling vagueness and uncertainty associated with human judgement (Xu and Liao 2014). Given that the preferences are essentially judgements of humans which are based on perceptions, therefore it is essential to employ intuitionistic fuzzy set theory combined with analytical hierarchy process which addresses the vagueness associated with human judgement (Xu and Liao 2014). Intuitionistic fuzzy set is characterized by a membership function, a non-membership function and a hesitancy function (Xu and Liao 2014). Let Y be a crisp set which is assumed to be fixed and suppose $b \subset Y$ is a fixed set. Therefore, an intuitionistic fuzzy set (IFS) \tilde{b} can be represented in the following way,

$$\tilde{b} = \{ (y, \alpha_b(y), \beta_b(y)) | y \in Y \} \quad (1)$$

The function $\alpha_b : E \rightarrow [0, 1]$ is the degree of membership and $\beta_b : E \rightarrow [0, 1]$ is defined as the degree of non-membership function of the element $y \in Y$. Moreover, for each $y \in Y$, the following relationship $0 \leq \alpha_b + \beta_b \leq 1$ holds true. For each intuitionistic fuzzy set \tilde{b} in the crisp set Y , the degree of non-determinacy (uncertainty) associated with the membership of the element $y \in Y$ can be expressed in the following way,

$$\eta_b(y) = 1 - \alpha_b(y) - \beta_b(y) \quad (2)$$

For ordinary fuzzy sets such triangular or trapezoidal fuzzy sets, the degree of non-determinacy is zero for all the element $y \in Y$ or $\eta_b(y) = 0$ for $\forall y \in Y$. $\eta_b(y)$ is the hesitance degree of y and $\eta_b(y)$ should be considered while computing the distance between two intuitionistic fuzzy sets. It should be noted that the value of $\eta_b(y)$ lies with the range $[0, 1]$ or $\eta_b(y) \in [0, 1]$ for $\forall y \in Y$. An intuitionistic fuzzy value comprises of the following $\rho = (\alpha_\rho, \beta_\rho, \eta_\rho)$, where $\alpha_\rho \in [0, 1]$, $\beta_\rho \in [0, 1]$, $\eta_\rho \in [0, 1]$ and $\alpha_\rho + \beta_\rho \leq 1$.

4.1 Intuitionistic preference relation

An intuitionistic preference relation v related to the set $Y = \{y_1, y_2, \dots, y_m\}$ can be expressed

in the following way, $v = (v_{pq})_{m \times m} = \begin{bmatrix} \alpha_{11}, \beta_{11} & \alpha_{12}, \beta_{12} & \cdots & \alpha_{1m}, \beta_{1m} \\ \alpha_{21}, \beta_{21} & \alpha_{22}, \beta_{22} & \cdots & \alpha_{2m}, \beta_{2m} \\ \vdots & \vdots & \vdots & \vdots \\ \alpha_{m1}, \beta_{m1} & \alpha_{m2}, \beta_{m2} & \cdots & \alpha_{mm}, \beta_{mm} \end{bmatrix}$. Here, $v_{pq} = (\alpha_{pq}, \beta_{pq})$

and α_{pq} provides the degree up to which y_p is preferred over y_p and β_{pq} denotes the degree up to which y_p is not preferred over y_p . Indeterminacy degree or hesitancy degree can be computed using the following relationship,

$$\eta(y_p, y_q) = 1 - \alpha(y_p, y_q) - \beta(y_p, y_q) \quad (3)$$

The following conditions need to be satisfied for determining hesitancy degree using Eq. (3),

$$\left. \begin{array}{l} \alpha_{pq}, \beta_{pq} \in [0, 1], \alpha_{pq} + \beta_{pq} \leq 1, \alpha_{pq} = \beta_{qp}, \beta_{pq} = \alpha_{qp} \\ \alpha_{pp} = \beta_{pp} = 0.5, \eta_{pq} = 1 - \alpha_{pq} - \beta_{pq} \end{array} \right\} p, q = 1, 2, \dots, n \quad (4)$$

The consistency associated with the intuitionistic preference relation need to be checked and repaired if certain inconsistency is observed. Maintain the appropriate consistency is essential within preference relations as the lack of consistency may lead to misleading solutions. The consistency is validated by adopting a property called multiplicative consistency proposed by Xu et al. (2014). An intuitionistic preference relation $v = (v_{pq})_{m \times m}$, where $v_{pq} = (\alpha_{pq}, \beta_{pq})$ and $p, q = 1, 2, \dots, n$, becomes a multiplicative consistent by satisfying the following conditions.

$$\alpha_{pq} = \left\{ \begin{array}{ll} 0, & \text{if } (\alpha_{pr}, \alpha_{rq}) \in \{(0, 1), (1, 0)\} \\ \frac{\alpha_{pr}\alpha_{rq}}{\alpha_{pr}\alpha_{rq} + (1-\alpha_{pr})(1-\alpha_{rq})}, & \text{otherwise} \end{array} \right\} \quad \text{for all } p \leq r \leq q \quad (5)$$

$$\beta_{pq} = \left\{ \begin{array}{ll} 0, & \text{if } (\beta_{pr}, \beta_{rq}) \in \{(0, 1), (1, 0)\} \\ \frac{\beta_{pr}\beta_{rq}}{\beta_{pr}\beta_{rq} + (1-\beta_{pr})(1-\beta_{rq})}, & \text{otherwise} \end{array} \right\} \quad \text{for all } p \leq r \leq q \quad (6)$$

When $(\alpha_{pr}, \alpha_{rq}) \in \{(0, 1), (1, 0)\}$, that means $(\alpha_{pr}, \alpha_{rq}) = (0, 1)$ or $(\alpha_{pr}, \alpha_{rq}) = (1, 0)$ or both hold true, then the denomination of Eq. (5) will be zero or $\alpha_{pr}\alpha_{rq} + (1-\alpha_{pr})(1-\alpha_{rq}) = 0$. Thus, $\alpha_{pq} = 0$ and $\beta_{pq} = 0$, when $(\alpha_{pr}, \alpha_{rq}) \in \{(0, 1), (1, 0)\}$ and $(\beta_{pr}, \beta_{rq}) \in \{(0, 1), (1, 0)\}$ respectively.

4.2 Procedure of intuitionistic fuzzy analytic hierarchy process (IFAHP)

The procedure of IFAHP as given in Xu and Liao (2014) can be described in the following steps,

Step 1 Obtain the intuitionistic preference relation $v = (v_{pq})_{m \times m}$ for all the criteria from the decision makers. Here, $v_{pq} = (\alpha_{pq}, \beta_{pq})$, where α_{pq} is the degree of preferring criteria y_p over criteria y_q and β_{pq} is the degree of not preferring criteria y_p over criteria y_q .

Determining the intuitionistic preference relations via the pairwise comparison between each criterion and sub-criteria. Moreover, the alternatives are compared under each criteria or sub-criteria, and then, the intuitionistic preference relations are constructed (Xu and Liao (2014)).

Step 2 Determining the perfect multiplicative consistent intuitionistic preference relation,

$$\bar{v} = (\bar{v}_{pq})_{m \times m} = \begin{bmatrix} \bar{\alpha}_{11}, \bar{\beta}_{11} & \bar{\alpha}_{12}, \bar{\beta}_{12} & \dots & \bar{\alpha}_{1m}, \bar{\beta}_{1m} \\ \bar{\alpha}_{21}, \bar{\beta}_{21} & \bar{\alpha}_{22}, \bar{\beta}_{22} & \dots & \bar{\alpha}_{2m}, \bar{\beta}_{2m} \\ \vdots & \vdots & \vdots & \vdots \\ \bar{\alpha}_{m1}, \bar{\beta}_{m1} & \bar{\alpha}_{m2}, \bar{\beta}_{m2} & \dots & \bar{\alpha}_{mm}, \bar{\beta}_{mm} \end{bmatrix} \quad \text{using Eqs. (7) and (8). For } \forall q \text{ and } \forall p,$$

if $q > p + 1$, then $\bar{v}_{pq} = (\bar{\alpha}_{pq}, \bar{\beta}_{pq})$ where $\bar{\alpha}_{pq}$ and $\bar{\beta}_{pq}$ can be computed using the following expressions,

$$\bar{\alpha}_{pq} = \frac{(\alpha_{pr})^{q-1} \sqrt{\prod_{r=p+1}^{q-1} \alpha_{pr} \alpha_{rq}}}{(\alpha_{pr})^{q-1} \sqrt{\prod_{r=p+1}^{q-1} \alpha_{pr} \alpha_{rq}} + (\alpha_{rq})^{q-1} \sqrt{\prod_{r=p+1}^{q-1} (1-\alpha_{pr})(1-\alpha_{rq})}} \quad (7)$$

$$\bar{\beta}_{pq} = \frac{\sqrt[q-p-1]{\prod_{r=p+1}^{q-1} \beta_{pr} \beta_{rq}}}{\sqrt[q-p-1]{\prod_{r=p+1}^{q-1} \beta_{pr} \beta_{rq}} + \sqrt[q-p-1]{\prod_{r=p+1}^{q-1} (1 - \beta_{pr})(1 - \beta_{rq})}} \tag{8}$$

When $p > q + 1$, then $\bar{\alpha}_{pq} = \bar{\beta}_{qp}$ and $\bar{\beta}_{pq} = \bar{\alpha}_{qp}$. For rest of the scenarios, $\bar{\alpha}_{pq} = \alpha_{pq}$ and $\bar{\beta}_{pq} = \beta_{pq}$.

Step 3 Determining the distance measure between the given intuitionistic preference relation $v = (v_{pq})_{m \times m}$ and its corresponding perfect multiplicative consistent intuitionistic preference relation $\bar{v} = (\bar{v}_{pq})_{m \times m}$. The distance measure can be computed using the following equation,

$$Dist(\bar{v}, v) = \frac{1}{2(m-1)(m-2)} \sum_{p=1}^m \sum_{q=1}^m \left(\left| \bar{\alpha}_{pq} - \alpha_{pq} \right| + \left| \bar{\beta}_{pq} + \beta_{pq} \right| + \left| \bar{\eta}_{pq} - \eta_{pq} \right| \right) \tag{9}$$

here m is the number of criteria and η_{pq} is the hesitance degree. η_{pq} is determined using the relationship, $\eta_{pq} = 1 - \alpha_{pq} - \beta_{pq}$ and the value of η_{pq} lies with $(0,1)$.

Step 4 Suppose K is the maximum number of iteration. So, considering $k < K$, where k is the current iteration. At first, the distance measure between V and \bar{V} computed using Eq. (9) is checked. If $Dist(\bar{v}, v) > \lambda$ (here, λ is the consistency threshold), it means the intuitionistic preference relation is within unacceptable consistency and the algorithm moves on to step 5 (Xu and Liao 2014). Otherwise (when $Dist(\bar{v}, v) < \lambda$ or distance measure is less than the consistency threshold or the intuitionistic preference relation is within the acceptable consistency (Xu et al. 2014)), stop the iteration and move on to step 7 and consider v as the output.

Step 5 Repair the inconsistent intuitionistic preference relations as mentioned in Xu and Liao (2014). IFAHP presented a novel way to ensure the consistency by automatically repairing the inconsistent intuitionistic preference relation, which do not need much participation from the decision maker (Xu and Liao 2014). For performing the repair mechanism, construct the fused intuitionistic preference relation

$$\tilde{s} = (\tilde{s}_{pq})_{m \times m} = \begin{bmatrix} \tilde{x}_{11}, \tilde{z}_{11} & \tilde{x}_{12}, \tilde{z}_{12} & \dots & \tilde{x}_{1m}, \tilde{z}_{1m} \\ \tilde{x}_{21}, \tilde{z}_{21} & \tilde{x}_{22}, \tilde{z}_{22} & \dots & \tilde{x}_{2m}, \tilde{z}_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{x}_{m1}, \tilde{z}_{m1} & \tilde{x}_{m2}, \tilde{z}_{m2} & \dots & \tilde{x}_{mm}, \tilde{z}_{mm} \end{bmatrix} \text{ using the following equations,}$$

$$\tilde{x}_{pq} = \frac{(\alpha_{pq})^{(1-\delta)} (\bar{\alpha}_{pq})^\delta}{(\alpha_{pq})^{(1-\delta)} (\bar{\alpha}_{pq})^\delta + (1 - \alpha_{pq})^{(1-\delta)} (1 - \bar{\alpha}_{pq})^\delta} \tag{10}$$

$$\tilde{z}_{pq} = \frac{(\beta_{pq})^{(1-\delta)} (\bar{\beta}_{pq})^\delta}{(\beta_{pq})^{(1-\delta)} (\bar{\beta}_{pq})^\delta + (1 - \beta_{pq})^{(1-\delta)} (1 - \bar{\beta}_{pq})^\delta} \tag{11}$$

where $\tilde{s}_{pq} = (\bar{x}_{pq}, \bar{z}_{pq})$ for $p, q = 1, 2, \dots, n$ and δ is the controlling parameter and for smaller value of δ , the fused intuitionistic preference relation of k^{th} iteration, $\tilde{s}^k = (\tilde{s}_{pq}^k)_{m \times m}$ is more closer to the v^k . Here, $v^{k+1} = \tilde{s}^k$ or $\alpha_{pq}^{k+1} = \tilde{x}_{pq}^k$ and $\beta_{pq}^{k+1} = \tilde{z}_{pq}^k$.

The repair mechanism approach presented by Xu and Liao (2014) is adopted over here for ensuring the consistency of intuitionistic preference relation and moreover improving the consistency automatically.

Step 6 Now, compute the distance measure between the infused intuitionistic preference relation v^{k+1} (which is the \tilde{s}^k determined in step 5) and perfect multiplicative consistent intuitionistic preference relation \bar{v} . Move to step 4 for comparing the distance measure with the consistency threshold.

Step 7 Based on the operational laws of intervals, a new normalizing rank summation method is given by Xu and Liao (2014) to derive the priority weights. Now, determining the priority weights $w_i = (w_1, w_2, \dots, w_m)$ for the intuitionistic preference relation $v = (v_{pq})_{m \times m}$, $v_{pq} = (\alpha_{pq}, \beta_{pq})$ using the following equations,

$$w_i = \left(\frac{\sum_{q=1}^m \alpha_{pq}}{\sum_{p=1}^m \sum_{q=1}^m (1 - \beta_{pq})}, 1 - \frac{\sum_{q=1}^m (1 - \beta_{pq})}{\sum_{p=1}^m \sum_{q=1}^m \alpha_{pq}} \right) \quad (12)$$

Figure 2 presents the pseudo-code associated with the algorithm for intuitionistic fuzzy analytic process. Section 4.3 presents an example of determining the weights using intuitionistic fuzzy analytic hierarchy process (IFAHP) for the KPIs associated with environmental-strategic.

4.3 Intuitionistic fuzzy TOPSIS

The methodology adopted in this paper combines intuitionistic fuzzy AHP with intuitionistic fuzzy TOPSIS which are adopted from the research work of Xu and Liao (2014), Yue (2014) and Cheng et al. (2017). Intuitionistic fuzzy AHP presented in Sect. 4.2 aims to perform the pair wise comparison of criteria for determining the criteria weights while employing the novel repair mechanism for correcting multiplicative consistency of decision matrices. The intuitionistic fuzzy TOPSIS presented in this section aims to obtain the rank for the alternatives while considering the specific set of criteria. Intuitionistic fuzzy AHP and intuitionistic fuzzy TOPSIS have been used separately in the literature, although there no such research which presents an integrated strategy of combining intuitionistic fuzzy AHP with intuitionistic fuzzy TOPSIS. The procedure of intuitionistic fuzzy TOPSIS presented in Cheng et al. (2017) can be briefly described using the following steps,

Step 1 Obtaining the intuitionistic preference matrix from M decision makers (t_1, t_2, \dots, t_m) considering S alternatives (a_1, a_2, \dots, a_s) and R criteria (b_1, b_2, \dots, b_r) and the decision matrix obtained can be represented as $(x_{sr}^m)_{S \times R} = (\tau_{sr}^m, \theta_{sr}^m)_{S \times R}$. The weights associated with each of the criteria for each of the decision makers can be represented in the following way, $w_r^m = (w_1^m, w_2^m, \dots, w_R^m)$. The intuitionistic fuzzy matrix is obtained by using the criteria weights.

Procedure: Intuitionistic Fuzzy AHP

1. Assign values for the parameters λ , δ and K (Maximum number of iterations)
2. Provide the intuitionistic preference relation $v = (v_{pq})_{m \times m}$
3. Determine the size of v , $[p, q] = \text{size}(v)$
4. for $p=1$ to number of rows of matrix
5. for $q=1$ to number of column of matrix
6. if $q > p+1$
7. Determine $\bar{\alpha}_{pq}$ and $\bar{\beta}_{pq}$ using equations (7) and (8) respectively
8. elseif $p > q+1$
9. Determine $\bar{\alpha}_{pq}$ and $\bar{\beta}_{pq}$ using the relationships, $\bar{\alpha}_{pq} = \bar{\beta}_{qp}$ and $\bar{\beta}_{pq} = \bar{\alpha}_{qp}$
10. else
11. Determine $\bar{\alpha}_{pq}$ and $\bar{\beta}_{pq}$ using the equations, $\bar{\alpha}_{pq} = \alpha_{pq}$ and $\bar{\beta}_{pq} = \beta_{pq}$
12. end
13. end
14. end
15. Compute the distance measure between v and \bar{v} , $\text{Dist}(\bar{v}, v)$ using equation (9)
16. for $k=1$ to K (Maximum number of iterations)
17. if distance measure is more than the consistency threshold (or, $\text{Dist}(\bar{v}, v) > \lambda$)
18. for $p=1$ to number of rows of matrix
19. for $q=1$ to number of column of matrix
20. Determine fused intuitionistic preference relation \tilde{s} using equations (10) and (11)
21. end
22. end
23. Consider \tilde{s} as the new intuitionistic preference relation or $v^{k+1} = \tilde{s}^k$
24. Estimate the distance measure between v^{k+1} and \bar{v} , $\text{Dist}(\bar{v}, v^{k+1})$ using equation (9)
25. Move on to the next iteration, $k = k + 1$
26. else
27. Stop the iteration and consider v^{k+1} as the output
28. end
29. end
30. Determine priority weights related to the output v^{k+1} using the equation (12)

Fig. 2 Algorithm related to the intuitionistic fuzzy analytic process

$$(x_{sr}^m)_{S \times R} = (\tau_{sr}^m, \theta_{sr}^m)_{S \times R} = \begin{matrix} a_1 \\ a_2 \\ \vdots \\ a_S \end{matrix} \begin{bmatrix} \tau_{11}^m, \theta_{11}^m & \tau_{12}^m, \theta_{12}^m & \cdots & \tau_{1R}^m, \theta_{1R}^m \\ \tau_{21}^m, \theta_{21}^m & \tau_{22}^m, \theta_{22}^m & \cdots & \tau_{2R}^m, \theta_{2R}^m \\ \vdots & \vdots & \vdots & \vdots \\ \tau_{S1}^m, \theta_{S1}^m & \tau_{S2}^m, \theta_{S2}^m & \cdots & \tau_{SR}^m, \theta_{SR}^m \end{bmatrix}_{(S \times R)} \quad (13)$$

$$X^m = (w_r^m x_{sr}^m)_{S \times R} = (\bar{\tau}_{sr}^m, \bar{\theta}_{sr}^m)_{S \times R} = \begin{matrix} a_1 \\ a_2 \\ \vdots \\ a_S \end{matrix} \begin{bmatrix} \bar{\tau}_{11}^m, \bar{\theta}_{11}^m & \bar{\tau}_{12}^m, \bar{\theta}_{12}^m & \cdots & \bar{\tau}_{1R}^m, \bar{\theta}_{1R}^m \\ \bar{\tau}_{21}^m, \bar{\theta}_{21}^m & \bar{\tau}_{22}^m, \bar{\theta}_{22}^m & \cdots & \bar{\tau}_{2R}^m, \bar{\theta}_{2R}^m \\ \vdots & \vdots & \vdots & \vdots \\ \bar{\tau}_{S1}^m, \bar{\theta}_{S1}^m & \bar{\tau}_{S2}^m, \bar{\theta}_{S2}^m & \cdots & \bar{\tau}_{SR}^m, \bar{\theta}_{SR}^m \end{bmatrix}_{(S \times R)} \quad (14)$$

Equation (13) represents the intuitionistic fuzzy matrix obtained from M decision makers and Eq. (14) presents the weighted intuitionistic fuzzy matrix obtained using the fol-

lowing relationships, $\bar{\tau}_{sr}^m = 1 - (1 - \tau_{sr}^m)^{w_r^m}$ and $\bar{\theta}_{sr}^m = (\theta_{sr}^m)^{w_r^m}$ which is adopted from the research work of Cheng et al. (2017).

Step 2 Determining the positive ideal decision matrix X^* , negative ideal decision matrix X_c^* , left individual negative ideal decision matrix X_u^- and right individual negative ideal decision matrix X_v^- in the following way,

$$X^* = (x_{sr}^*)_{S \times R} = (\tilde{\tau}_{sr}^*, \tilde{\theta}_{sr}^*)_{S \times R} = \begin{matrix} a_1 \\ a_2 \\ \vdots \\ a_S \end{matrix} \begin{bmatrix} \tilde{\tau}_{11}^*, \tilde{\theta}_{11}^* & \tilde{\tau}_{12}^*, \tilde{\theta}_{12}^* & \cdots & \tilde{\tau}_{1R}^*, \tilde{\theta}_{1R}^* \\ \tilde{\tau}_{21}^*, \tilde{\theta}_{21}^* & \tilde{\tau}_{22}^*, \tilde{\theta}_{22}^* & \cdots & \tilde{\tau}_{2R}^*, \tilde{\theta}_{2R}^* \\ \vdots & \vdots & \vdots & \vdots \\ \tilde{\tau}_{S1}^*, \tilde{\theta}_{S1}^* & \tilde{\tau}_{S2}^*, \tilde{\theta}_{S2}^* & \cdots & \tilde{\tau}_{SR}^*, \tilde{\theta}_{SR}^* \end{bmatrix}_{(S \times R)} \quad (15)$$

where $\tilde{\tau}_{sr}^* = 1 - \prod_{m=1}^M (1 - \tau_{sr}^m)^M$ and $\tilde{\theta}_{sr}^* = 1 - \prod_{m=1}^M (1 - \theta_{sr}^m)^M$.

$$X_c^* = ((x_{sr}^*)^c)_{S \times R} = (\tilde{\theta}_{sr}^*, \tilde{\tau}_{sr}^*)_{S \times R} = \begin{matrix} a_1 \\ a_2 \\ \vdots \\ a_S \end{matrix} \begin{bmatrix} \tilde{\theta}_{11}^*, \tilde{\tau}_{11}^* & \tilde{\theta}_{12}^*, \tilde{\tau}_{12}^* & \cdots & \tilde{\theta}_{1R}^*, \tilde{\tau}_{1R}^* \\ \tilde{\theta}_{21}^*, \tilde{\tau}_{21}^* & \tilde{\theta}_{22}^*, \tilde{\tau}_{22}^* & \cdots & \tilde{\theta}_{2R}^*, \tilde{\tau}_{2R}^* \\ \vdots & \vdots & \vdots & \vdots \\ \tilde{\theta}_{S1}^*, \tilde{\tau}_{S1}^* & \tilde{\theta}_{S2}^*, \tilde{\tau}_{S2}^* & \cdots & \tilde{\theta}_{SR}^*, \tilde{\tau}_{SR}^* \end{bmatrix}_{(S \times R)} \quad (16)$$

$(x_{sr}^*)^c$ is the compliment of $x_{sr}^* = (\tilde{\tau}_{sr}^*, \tilde{\theta}_{sr}^*)$, or $(x_{sr}^*)^c$ can be represented as $(x_{sr}^*)^c = (\tilde{\theta}_{sr}^*, \tilde{\tau}_{sr}^*)$.

$$X_u^- = (x_{sr}^{u-})_{S \times R} = (\tilde{\tau}_{sr}^{u-}, \tilde{\theta}_{sr}^{u-})_{S \times R} = \begin{matrix} a_1 \\ a_2 \\ \vdots \\ a_S \end{matrix} \begin{bmatrix} \tilde{\tau}_{11}^{u-}, \tilde{\theta}_{11}^{u-} & \tilde{\tau}_{12}^{u-}, \tilde{\theta}_{12}^{u-} & \cdots & \tilde{\tau}_{1R}^{u-}, \tilde{\theta}_{1R}^{u-} \\ \tilde{\tau}_{21}^{u-}, \tilde{\theta}_{21}^{u-} & \tilde{\tau}_{22}^{u-}, \tilde{\theta}_{22}^{u-} & \cdots & \tilde{\tau}_{2R}^{u-}, \tilde{\theta}_{2R}^{u-} \\ \vdots & \vdots & \vdots & \vdots \\ \tilde{\tau}_{S1}^{u-}, \tilde{\theta}_{S1}^{u-} & \tilde{\tau}_{S2}^{u-}, \tilde{\theta}_{S2}^{u-} & \cdots & \tilde{\tau}_{SR}^{u-}, \tilde{\theta}_{SR}^{u-} \end{bmatrix}_{(S \times R)} \quad (17)$$

here $\tilde{\tau}_{sr}^{u-} = \min_m \{\tau_{sr}^m\}$ and $\tilde{\theta}_{sr}^{u-} = \max_m \{\theta_{sr}^m\}$. X_u^- is the left maximum separation from the individual positive ideal decision matrix.

$$X_v^- = (x_{sr}^{v-})_{S \times R} = (\tilde{\tau}_{sr}^{v-}, \tilde{\theta}_{sr}^{v-})_{S \times R} = \begin{matrix} a_1 \\ a_2 \\ \vdots \\ a_S \end{matrix} \begin{bmatrix} \tilde{\tau}_{11}^{v-}, \tilde{\theta}_{11}^{v-} & \tilde{\tau}_{12}^{v-}, \tilde{\theta}_{12}^{v-} & \cdots & \tilde{\tau}_{1R}^{v-}, \tilde{\theta}_{1R}^{v-} \\ \tilde{\tau}_{21}^{v-}, \tilde{\theta}_{21}^{v-} & \tilde{\tau}_{22}^{v-}, \tilde{\theta}_{22}^{v-} & \cdots & \tilde{\tau}_{2R}^{v-}, \tilde{\theta}_{2R}^{v-} \\ \vdots & \vdots & \vdots & \vdots \\ \tilde{\tau}_{S1}^{v-}, \tilde{\theta}_{S1}^{v-} & \tilde{\tau}_{S2}^{v-}, \tilde{\theta}_{S2}^{v-} & \cdots & \tilde{\tau}_{SR}^{v-}, \tilde{\theta}_{SR}^{v-} \end{bmatrix}_{(S \times R)} \quad (18)$$

here $\tilde{\tau}_{sr}^{v-} = \max_m \{\tau_{sr}^m\}$ and $\tilde{\theta}_{sr}^{v-} = \min_m \{\theta_{sr}^m\}$. X_v^- is the right maximum separation from the individual positive ideal decision matrix.

Step 3 Hamming distance is determined in this step to analyse the properties of the ideal decision matrixes (Cheng et al. 2017). Computing the hamming distance D_m^* between intuitionistic fuzzy matrix X^m and individual positive ideal decision matrix X^* , hamming distance D_m^c between X^m and individual negative ideal decision matrix X_c^* , hamming distance D_m^u between X^m and left individual negative ideal decision matrix X_u^- and hamming distance D_m^v between X^m and right individual negative decision matrix X_v^- .

$$D_m^* = \frac{\sum_{s=1}^S \sum_{r=1}^R \left(|\bar{\tau}_{sr}^m - \tilde{\tau}_{sr}^*| + |\bar{\theta}_{sr}^m - \tilde{\theta}_{sr}^*| + |\varphi_{sr}^m - \varphi_{sr}^*| \right)}{2SR} \tag{19}$$

$$D_m^c = \frac{\sum_{s=1}^S \sum_{r=1}^R \left(|\bar{\tau}_{sr}^m - \tilde{\theta}_{sr}^*| + |\bar{\theta}_{sr}^m - \tilde{\tau}_{sr}^*| + |\varphi_{sr}^m - (\varphi_{sr}^*)^c| \right)}{2SR} \tag{20}$$

$$D_m^u = \frac{\sum_{s=1}^S \sum_{r=1}^R \left(|\bar{\tau}_{sr}^m - \tilde{\tau}_{sr}^{u-}| + |\bar{\theta}_{sr}^m - \tilde{\theta}_{sr}^{u-}| + |\varphi_{sr}^m - \varphi_{sr}^{u-}| \right)}{2SR} \tag{21}$$

$$D_m^v = \frac{\sum_{s=1}^S \sum_{r=1}^R \left(|\bar{\tau}_{sr}^m - \tilde{\tau}_{sr}^{v-}| + |\bar{\theta}_{sr}^m - \tilde{\theta}_{sr}^{v-}| + |\varphi_{sr}^m - \varphi_{sr}^{v-}| \right)}{2SR} \tag{22}$$

where $\varphi_{sr}^m = 1 - \bar{\tau}_{sr}^m - \bar{\theta}_{sr}^m$, $\varphi_{sr}^* = 1 - \tilde{\tau}_{sr}^* - \tilde{\theta}_{sr}^*$, $(\varphi_{sr}^*)^c = 1 - \tilde{\theta}_{sr}^* - \tilde{\tau}_{sr}^*$, $\varphi_{sr}^{u-} = 1 - \tilde{\tau}_{sr}^{u-} - \tilde{\theta}_{sr}^{u-}$ and $\varphi_{sr}^{v-} = 1 - \tilde{\tau}_{sr}^{v-} - \tilde{\theta}_{sr}^{v-}$.

Step 4 Determining the relative closeness of intuitionistic fuzzy decision matrix for the alternatives, X^m with X^* , X_c^* , X_u^- and X_v^- using the following relationship,

$$C^m = \frac{D_m^c + D_m^u + D_m^v}{D_m^* + D_m^c + D_m^u + D_m^v} \tag{23}$$

Using the value of the relative closeness, C^m computing the weights associated with different decision makers by employing the following Eq. (24). Existed results in the literature show that the final preference order of alternatives is more accurate when the weights of Decision Makers are employed in decision making (Cheng et al. 2017).

$$\xi^m = \frac{C^m}{\sum_{m=1}^M C^m}, \text{ where } \xi^m \geq 0 \text{ and } \sum_{m=1}^M \xi^m = 1 \tag{24}$$

Step 5 Determining the weighted intuitionistic fuzzy decision matrix for all the decision makers in the following way,

$$P^m = \xi^m X^m = (\sigma_{sr}^m, \rho_{sr}^m)_{S \times R} = \begin{matrix} a_1 \\ a_2 \\ \vdots \\ a_S \end{matrix} \begin{bmatrix} \sigma_{11}^m, \rho_{11}^m & \sigma_{12}^m, \rho_{12}^m & \dots & \sigma_{1R}^m, \rho_{1R}^m \\ \sigma_{21}^m, \rho_{21}^m & \sigma_{22}^m, \rho_{22}^m & \dots & \sigma_{2R}^m, \rho_{2R}^m \\ \vdots & \vdots & \ddots & \vdots \\ \sigma_{S1}^m, \rho_{S1}^m & \sigma_{S2}^m, \rho_{S2}^m & \dots & \sigma_{SR}^m, \rho_{SR}^m \end{bmatrix}_{(S \times R)} \tag{25}$$

where σ_{sr}^m and ρ_{sr}^m are computed using equations, $\sigma_{sr}^m = 1 - (1 - \bar{\tau}_{sr}^m)^{\xi^m}$ and $\rho_{sr}^m = (\bar{\theta}_{sr}^m)^{\xi^m}$.

Step 6 The weighted intuitionistic fuzzy decision matrix can be represented in the following way with respect to the alternatives,

$$Q_s = (\sigma_{sr}^m, \rho_{sr}^m)_{M \times R} = \begin{matrix} t_1 \\ t_2 \\ \vdots \\ t_M \end{matrix} \begin{bmatrix} \sigma_{s1}^1, \rho_{s1}^1 & \sigma_{s2}^1, \rho_{s2}^1 & \cdots & \sigma_{sR}^1, \rho_{sR}^1 \\ \sigma_{s1}^2, \rho_{s1}^2 & \sigma_{s2}^2, \rho_{s2}^2 & \cdots & \sigma_{sR}^2, \rho_{sR}^2 \\ \vdots & \vdots & \vdots & \vdots \\ \sigma_{s1}^M, \rho_{s1}^M & \sigma_{s2}^M, \rho_{s2}^M & \cdots & \sigma_{sR}^M, \rho_{sR}^M \end{bmatrix}_{(M \times R)} \quad (26)$$

Step 7 Using the weighted intuitionistic decision matrix to determine the positive ideal solutions, Q^+ which is also referred to as the best decision matrix. Two negative ideal solutions Q_c^- and Q^- are also computed—the first one representing the complement of the positive ideal solution and the second one is the worst decision matrix considering all the weighted intuitionistic decision matrix with respect to the alternatives.

$$Q^+ = (\sigma_r^{m+}, \rho_r^{m+})_{M \times R} = \begin{matrix} t_1 \\ t_2 \\ \vdots \\ t_M \end{matrix} \begin{bmatrix} \sigma_1^{1+}, \rho_1^{1+} & \sigma_2^{1+}, \rho_2^{1+} & \cdots & \sigma_R^{1+}, \rho_R^{1+} \\ \sigma_1^{2+}, \rho_1^{2+} & \sigma_2^{2+}, \rho_2^{2+} & \cdots & \sigma_R^{2+}, \rho_R^{2+} \\ \vdots & \vdots & \vdots & \vdots \\ \sigma_1^{M+}, \rho_1^{M+} & \sigma_2^{M+}, \rho_2^{M+} & \cdots & \sigma_R^{M+}, \rho_R^{M+} \end{bmatrix}_{(M \times R)} \quad (27)$$

where $\sigma_r^{m+} = \max_s \{\sigma_{sr}^m\}$ and $\rho_r^{m+} = \min_s \{\rho_{sr}^m\}$.

$$Q_c^- = (\rho_r^{m+}, \sigma_r^{m+})_{M \times R} = \begin{matrix} t_1 \\ t_2 \\ \vdots \\ t_M \end{matrix} \begin{bmatrix} \rho_1^{1+}, \sigma_1^{1+} & \rho_2^{1+}, \sigma_2^{1+} & \cdots & \rho_R^{1+}, \sigma_R^{1+} \\ \rho_1^{2+}, \sigma_1^{2+} & \rho_2^{2+}, \sigma_2^{2+} & \cdots & \rho_R^{2+}, \sigma_R^{2+} \\ \vdots & \vdots & \vdots & \vdots \\ \rho_1^{M+}, \sigma_1^{M+} & \rho_2^{M+}, \sigma_2^{M+} & \cdots & \rho_R^{M+}, \sigma_R^{M+} \end{bmatrix}_{(M \times R)} \quad (28)$$

Q_c^- is the compliment of $Q^+ = (\sigma_r^{m+}, \rho_r^{m+})_{M \times R}$, or Q_c^- can be represented as $Q_c^- = (\rho_r^{m+}, \sigma_r^{m+})_{M \times R}$

$$Q^- = (\sigma_r^{m-}, \rho_r^{m-})_{M \times R} = \begin{matrix} t_1 \\ t_2 \\ \vdots \\ t_M \end{matrix} \begin{bmatrix} \sigma_1^{1-}, \rho_1^{1-} & \sigma_2^{1-}, \rho_2^{1-} & \cdots & \sigma_R^{1-}, \rho_R^{1-} \\ \sigma_1^{2-}, \rho_1^{2-} & \sigma_2^{2-}, \rho_2^{2-} & \cdots & \sigma_R^{2-}, \rho_R^{2-} \\ \vdots & \vdots & \vdots & \vdots \\ \sigma_1^{M-}, \rho_1^{M-} & \sigma_2^{M-}, \rho_2^{M-} & \cdots & \sigma_R^{M-}, \rho_R^{M-} \end{bmatrix}_{(M \times R)} \quad (29)$$

here $\sigma_r^{m-} = \min_s \{\sigma_{sr}^m\}$ and $\rho_r^{m-} = \max_s \{\rho_{sr}^m\}$.

Step 8 Determining the separation of the weight intuitionistic decision matrix Q_s from the positive ideal solution Q^+ and two negative ideal solutions Q_c^- and Q^- . D_s^+ , D_s^c and D_s^- represents the separation of Q_s from Q^+ , Q_c^- and Q^- respectively and it can be computed in the following way,

$$D_s^+ = \frac{\sum_{r=1}^R \sum_{m=1}^M (|\sigma_{sr}^m - \sigma_r^{m+}| + |\rho_{sr}^m - \rho_r^{m+}| + |\varepsilon_{sr}^m - \varepsilon_r^{m+}|)}{2RM} \quad (30)$$

$$D_s^c = \frac{\sum_{r=1}^R \sum_{m=1}^M (|\sigma_{sr}^m - \rho_r^{m+}| + |\rho_{sr}^m - \sigma_r^{m+}| + |\varepsilon_{sr}^m - (\varepsilon_r^{m+})^c|)}{2RM} \quad (31)$$

$$D_s^- = \frac{\sum_{r=1}^R \sum_{m=1}^M (|\sigma_{sr}^m - \sigma_r^{m-}| + |\rho_{sr}^m - \rho_r^{m-}| + |\varepsilon_{sr}^m - \varepsilon_r^{m-}|)}{2RM} \tag{32}$$

here $\varepsilon_{sr}^m = 1 - \sigma_{sr}^m - \rho_{sr}^m$, $\varepsilon_r^{m+} = 1 - \sigma_r^{m+} - \rho_r^{m+}$, $(\varepsilon_r^{m+})^c = 1 - \rho_r^{m+} - \sigma_r^{m+}$ and $\varepsilon_r^{m-} = 1 - \sigma_r^{m-} - \rho_r^{m-}$.

Step 9 Determining the relative closeness for each alternative using the following equation,

$$C^s = \frac{D_s^c + D_s^-}{D_s^+ + D_s^c + D_s^-} \tag{33}$$

Alternative, a_1 is better than a_2 only if C^{a_1} is greater than C^{a_2} .

5 Application of methodologies and results obtained

In this section, the results obtained by using intuitionistic fuzzy AHP for determining the rank of the KPIs are presented. In the first sub-section, a numerical illustration associated with KPIs related to environmental combined with strategic is presented. This presentation illustrates the application of intuitionistic fuzzy AHP. The second sub-section presents the ranking provided by VFT for the KPIs under different categories obtained by classifying the KPIs into environmental, social and economic criteria. This sub-section also presents the intuitionistic fuzzy weight obtained for each of the KPIs and the importance of every KPI. The third sub-section presents a case study, which aims to determine the performance of the various organisation and provides appropriate suggestions regarding the KPIs which require necessary improvement. The last sub-section presents the application of IF-TOPSIS to rank all the organisations based on their performance on different KPIs.

5.1 A case application

In order to determine the relative importance of KPIs and their respective weights, a panel of three experts were asked to give their opinion. The experts have more than 15 years of working experience in senior supply chain roles within the organisations in the UK. A pair wise comparison is carried out by the experts using linguistic term. These comparisons are then transformed into intuitionistic fuzzy values and used as input to the IFAHP method for the computation of KPIs weights. The decision-maker provides his/her preference information for the KPIs related to environmental combined with strategic – innovation & improvement, planning and product design, compliance to regulations, environmental quality management, management commitment and governmental regulations. Thus, v is the intuitionistic preference relation obtained from the decision-maker.

$$v = (v_{pq})_{m \times m} = (\alpha_{pq}, \beta_{pq})_{m \times m} = \begin{bmatrix} (0.5, 0.5) & (0.2, 0.6) & (0.3, 0.9) & (0.4, 0.7) & (0.8, 0.3) & (0.2, 0.8) \\ (0.6, 0.2) & (0.5, 0.5) & (0.6, 0.1) & (0.3, 0.5) & (0.7, 0.4) & (0.8, 0.3) \\ (0.9, 0.3) & (0.1, 0.6) & (0.5, 0.5) & (0.9, 0.2) & (0.3, 0.6) & (0.8, 0.4) \\ (0.7, 0.4) & (0.5, 0.3) & (0.2, 0.9) & (0.5, 0.5) & (0.2, 0.7) & (0.6, 0.2) \\ (0.3, 0.8) & (0.4, 0.7) & (0.6, 0.3) & (0.7, 0.2) & (0.5, 0.5) & (0.8, 0.1) \\ (0.8, 0.2) & (0.3, 0.8) & (0.4, 0.8) & (0.2, 0.6) & (0.8, 0.1) & (0.5, 0.5) \end{bmatrix}$$

From step 1 of the procedure of IFAHP, the intuitionistic preference relation for all the criteria is obtained from the decision-maker. Now, determining the perfect multiplicative consistent intuitionistic preference relation using Eqs. (7) and (8) given in step 2.

$$\bar{v} = (\bar{v}_{pq})_{m \times m} = \left(\bar{\alpha}_{pq}, \bar{\beta}_{pq} \right)_{m \times m}$$

$$= \begin{bmatrix} (0.5, 0.5) & (0.2, 0.6) & (0.27, 0.14) & (0.39, 0.64) & (0.20, 0.80) & (0.69, 0.36) \\ (0.6, 0.2) & (0.5, 0.5) & (0.6, 0.1) & (0.93, 0.02) & (0.20, 0.38) & (0.76, 0.1) \\ (0.14, 0.27) & (0.1, 0.6) & (0.5, 0.5) & (0.9, 0.2) & (0.69, 0.36) & (0.82, 0.09) \\ (0.64, 0.39) & (0.02, 0.93) & (0.2, 0.9) & (0.5, 0.5) & (0.2, 0.7) & (0.5, 0.20) \\ (0.80, 0.20) & (0.38, 0.20) & (0.36, 0.69) & (0.7, 0.2) & (0.5, 0.5) & (0.8, 0.1) \\ (0.36, 0.69) & (0.1, 0.76) & (0.09, 0.82) & (0.20, 0.5) & (0.1, 0.8) & (0.5, 0.5) \end{bmatrix}$$

Now according to step 3, computing the distance measure between the intuitionistic preference relation $v = (v_{pq})_{m \times m}$ and perfect multiplicative consistent intuitionistic preference relation $\bar{v} = (\bar{v}_{pq})_{m \times m}$, $Dist(\bar{v}, v) = 0.4105$. In step 4, the distance measure is compared with the consistency threshold λ (assuming the value of λ as 0.1 as given in Xu and Liao (2014)). As, $Dist(\bar{v}, v) = 0.4105 > \lambda (= 0.1)$, therefore move on to step 5 for computing the fused intuitionistic preference relation \tilde{s} .

$$\tilde{s} = (\tilde{s}_{pq})_{m \times m} = \left(\tilde{x}_{pq}, \tilde{z}_{pq} \right)$$

$$= \begin{bmatrix} (0.5, 0.5) & (0.2, 0.6) & (0.27, 0.27) & (0.39, 0.65) & (0.31, 0.72) & (0.59, 0.45) \\ (0.6, 0.2) & (0.5, 0.5) & (0.6, 0.1) & (0.87, 0.05) & (0.28, 0.38) & (0.77, 0.12) \\ (0.27, 0.27) & (0.1, 0.6) & (0.5, 0.5) & (0.9, 0.2) & (0.61, 0.41) & (0.82, 0.12) \\ (0.65, 0.39) & (0.05, 0.87) & (0.2, 0.9) & (0.5, 0.5) & (0.2, 0.7) & (0.52, 0.20) \\ (0.72, 0.31) & (0.38, 0.28) & (0.41, 0.61) & (0.7, 0.2) & (0.5, 0.5) & (0.8, 0.1) \\ (0.45, 0.59) & (0.12, 0.77) & (0.12, 0.82) & (0.20, 0.52) & (0.1, 0.8) & (0.5, 0.5) \end{bmatrix}$$

Now the distance measure between the fused intuitionistic preference relation and perfect multiplicative consistent intuitionistic preference relation is computed as given in step 6. So, the distance measure is, $Dist(\bar{v}, \tilde{s}) = 0.065$ which is compared with the consistency threshold λ in step 4 and found that the distance measure is less than λ or $Dist(\bar{v}, \tilde{s}) = 0.065 < \lambda (= 0.1)$. Now, the fused intuitionistic preference relation \tilde{s} is obtained as the output and using Eq. (12) given in step 7, the intuitionistic fuzzy weight for each of the KPIs is obtained. Intuitionistic fuzzy weights are given as follows, $KPI_{(Innovation \& \text{improvement})} = (0.11, 0.82)$, $KPI_{(Planning \text{ and } \text{product design})} = (0.18, 0.71)$, $KPI_{(Compliance \text{ to } \text{regulations})} = (0.16, 0.76)$, $KPI_{(Environment \text{ quality } \text{management})} = (0.10, 0.85)$, $KPI_{(Management \text{ commitment})} = (0.17, 0.75)$ and $KPI_{(Government \text{ regulations})} = (0.07, 0.87)$. The next section provides the results obtained using IFAHP for all the KPIs and also presents the case study for validating the performance of the organizations.

Table 3 IFAHP weight and VFT rank for 3-level hierarchy and different KPIs

1st level criteria (TBL)	IFAHP weight	VFT rank	2nd level criteria (organizational decision level)	IFAHP weight	VFT rank	3rd level criteria (KPIs)	VFT rank	IFAHP weight	Importance of KPIs	Revised list of KPIs
Economic	(0.19, 0.61)	3	<i>Eco-operational</i>	(0.37, 0.67)	1	Operational costs	3	(0.31, 0.71)	0.303	Operational costs
						Customer satisfaction rates	1	(0.26, 0.76)	0.254	Customer satisfaction rates
						Production Efficiency	2	(0.19, 0.85)	0.182	-
						Inventory costs	4	(0.17, 0.84)	0.168	-
						Production flexibility	5	(0.14, 0.91)	0.133	-
			<i>Eco-strategic</i>	(0.46, 0.59)	3	Investment costs	1	(0.54, 0.65)	0.453	Investment costs
						Supplier Selection Costs	3	(0.27, 0.81)	0.250	Supplier selection costs
			<i>Eco-tactical</i>	(0.26, 0.83)	2	Logistics Costs	2	(0.41, 0.71)	0.366	Logistics costs
						Return on investment	1	(0.37, 0.81)	0.313	Return on investment
						Capacity utilization	2	(0.52, 0.61)	0.460	Capacity utilization
						Perceived value of product	3	(0.34, 0.75)	0.311	Perceived value of product

Table 3 (continued)

1st level criteria (TBL)	IFAHP weight	VFT rank	2nd level criteria (organizational decision level)	IFAHP weight	VFT rank	3rd level criteria (KPIs)	VFT rank	IFAHP weight	Importance of KPIs	Revised list of KPIs
Environmental	(0.31, 0.51)	1	<i>Env-operational</i>	(0.49, 0.60)	1	Greenhouse gas emission rates	1	(0.39, 0.65)	0.375	Greenhouse gas emission rates
						Noise rates	3	(0.24, 0.75)	0.242	Noise rates
						Waste Management	2	(0.36, 0.59)	0.378	Waste management
			<i>Env-strategic</i>	(0.24, 0.83)	3	Innovation & improvement	6	(0.11, 0.82)	0.118	–
						Planning and Product Design	5	(0.18, 0.71)	0.202	Planning and product design
						Compliance to regulations	1	(0.16, 0.76)	0.173	–
						Environmental Quality management	4	(0.10, 0.85)	0.105	–
						Management commitment	3	(0.17, 0.75)	0.184	–
						Governmental Regulations	2	(0.07, 0.87)	0.074	–
			<i>Env-tactical</i>	(0.45, 0.71)	2	Resource Utilization	2	(0.31, 0.86)	0.265	Resource utilization
						Risk Management	1	(0.43, 0.74)	0.367	Risk management
						Reverse Logistics	3	(0.17, 0.83)	0.170	–

Table 3 (continued)

1st level criteria (TBL)	IFAHP weight	VFT rank	2nd level criteria (organizational decision level)	IFAHP weight	VFT rank	3rd level criteria (KPIs)	VFT rank	IFAHP weight	Importance of KPIs	Revised list of KPIs
Social	(0.25, 0.56)	2	<i>Soc-operational</i>	(0.45, 0.49)	1	Labour efficiency	2	(0.57, 0.63)	0.475	Labour efficiency
						Injury prevention	3	(0.40, 0.68)	0.370	Injury prevention
						Stakeholders involvement	1	(0.55, 0.58)	0.486	Stakeholders involvement
			<i>Soc-strategic</i>	(0.17, 0.79)	3	Employment creation rates	3	(0.47, 0.48)	0.494	Employment creation rates
						Training Rates	2	(0.28, 0.70)	0.285	Training Rates
						Adoption of Safety Practices	1	(0.21, 0.79)	0.210	Adoption of safety practices
			<i>Soc-tactical</i>	(0.30, 0.63)	2	Customer Retention	1	(0.30, 0.52)	0.365	Customer retention
						Labour Equity	3	(0.20, 0.70)	0.222	Labour equity
						Quality of employee life	2	(0.31, 0.56)	0.356	Quality of employee life

5.2 Results obtained using VFT and IFAHP

The results obtained from the VFT approach is presented in Table 3 and it can be assessed from Table 3 that the most important VFT choices of the experts are customer retention, rate of adoption of safety practices, stakeholders involvement, risk management, compliance with regulations, investment costs, greenhouse gas (GHG) emission rates, return on investments and customer satisfaction rates. It is evident from the above list that an organisation's customers, stakeholders and financial standing are all perceived to have the highest values of importance for the implementation of sustainability within organisations. Although, it is essential to compare the result obtained using VFT with that of intuitionistic Fuzzy analytic hierarchy process for dealing with the ambiguity and complexity of the decision making process. Table 3 presents the IFAHP weight and VFT ranking for three different levels. From the Table 3, the following KPIs are identified as the most important as per the VFT choices of experts; Customer Retention, Rate of Adoption of Safety Practices, Stakeholders Involvement, Risk Management, Compliance to Regulations, Investment Costs, Greenhouse Gas (GHG) Emission Rate, Return on Investments, Customer Satisfaction Rates. The perceived importance as per the VFT is Environmental KPIs > Social KPIs > Economic KPIs. Table 3 also provides the importance associated with each of the KPIs. The following equation given by Tooranloo and sadat Ayatollah (2016) is used to estimate the importance of each KPI.

$$\omega_n = \left(\frac{\alpha_n + \eta_n \left(\frac{\alpha_n}{\alpha_n + \beta_n} \right)}{\sum_{n=1}^N \left(\alpha_n + \eta_n \left(\frac{\alpha_n}{\alpha_n + \beta_n} \right) \right)} \right), \text{ where } \sum_{n=1}^N \omega_n = 1 \quad (34)$$

here n represents the KPI and total number of KPIs is given by N . ω_n is the importance given to each KPI n . Intuitionistic fuzzy weight obtained for each KPI can be represented in the following way, $w_n = (\alpha_n, \beta_n)$. Here, α_n is the degree of the membership and β_n is the degree of non-membership. Using the values of α_n and β_n , the degree of hesitancy can be computed or $\eta_n = 1 - \alpha_n - \beta_n$. So, employing the Eq. (13), the importance associated with the KPIs is determined and presented in Table 3. However, it is noteworthy that the list of KPIs is quite a large list, which could be problematic for the further incorporation within the subsequent stages and hence, it is imperative for the list to be reduced to a more practical quantity. Therefore, KPI with less than 0.20 importance is omitted and the rest of the KPIs having more than 0.20 values are considered for the case study.

Table 3 provides a detailed information about the intuitionistic fuzzy weights obtained for each of the KPIs using intuitionistic fuzzy AHP. The importance of each KPI is obtained from the intuitionistic fuzzy weight using Eq. (3) provided by Tooranloo and sadat Ayatollah (2016). Moreover, Table 4 also presents the importance of each KPIs, which are used to determine the revised list of KPIs after comparing with the threshold limit of 0.20. Figure 3 presents the importance of all the KPIs and compares it with the threshold limit of 0.20. Moreover, it gives a visual illustration of the comparative importance of the KPIs.

Table 4 Performance ratings for different KPIs obtained for different organizations

S. no.	KPI	Organization						Average
		A	B	C	D	E	F	
1	Customer satisfaction rates	4	3	3	4	4	2	3.33
2	Operational costs	3	4	5	3	2	4	3.50
3	Investment cost	4	4	4	2	1	3	3.00
4	Return on investment	4	3	5	1	2	3	3.00
5	GHG emission rates	3	1	4	2	2	4	2.66
6	Logistic cost	2	2	3	3	4	2	2.66
7	Supplier selection costs	5	4	3	5	1	5	3.83
8	Perceived value of product	4	3	1	4	5	2	3.16
9	Noise rates	3	2	5	5	3	4	3.66
10	Planning and product design	1	5	2	2	2	3	2.50
11	Stakeholders involvement	3	2	4	1	4	2	2.66
12	Employment creation rates	2	2	4	3	2	4	2.83
13	Capacity utilisation	2	3	3	4	4	3	3.16
14	Labour efficiency	3	5	3	3	4	4	3.66
15	Waste management	4	2	2	2	3	1	2.33
16	Injury prevention	5	3	2	3	5	2	3.33
17	Resource utilization	3	3	4	3	2	3	3.00
18	Training rates	4	1	2	1	4	4	2.66
19	Risk management	3	2	4	3	3	4	3.16
20	Adoption of safety practices	4	4	3	3	4	2	3.33
21	Customer retention	5	3	4	4	4	2	3.66
22	Labour equity	4	3	2	2	1	1	2.16
23	Quality of employee life	3	4	3	2	4	2	3.00
Total score		78	68	75	65	70	66	
Mean score		3.391	2.956	3.260	2.826	3.043	2.869	

5.3 A case study

The sustainability performance of various organisations can be judged based on the most influential KPIs and their respective importance. Depending on the initial results of importance presented in *r*, the identified KPIs can be used for the computational purpose; wherein each organisation can identify which Key Performance Indicators (KPIs) need to be focused on to further assess, manage and improve these KPIs. Among all the research methodologies identified across the supply chain and sustainability research domains, a case study approach was deemed most appropriate due to its structured approach and in-depth analysis. For the case study purpose, performance ratings related to selected list of KPIs are obtained from six manufacturing organisations of UK origin operating in different part of United Kingdom. For confidentiality purposes, the organisations have requested to remain anonymous for this research. A panel of three experts from each organisation is selected to rate the sustainability performance of the organisations based on the KPIs identified using IFAHP method. Table 4 presents the consolidated performance ratings of six organisations provided by the experts based on the scale of 1 to 5, where 1 is poor

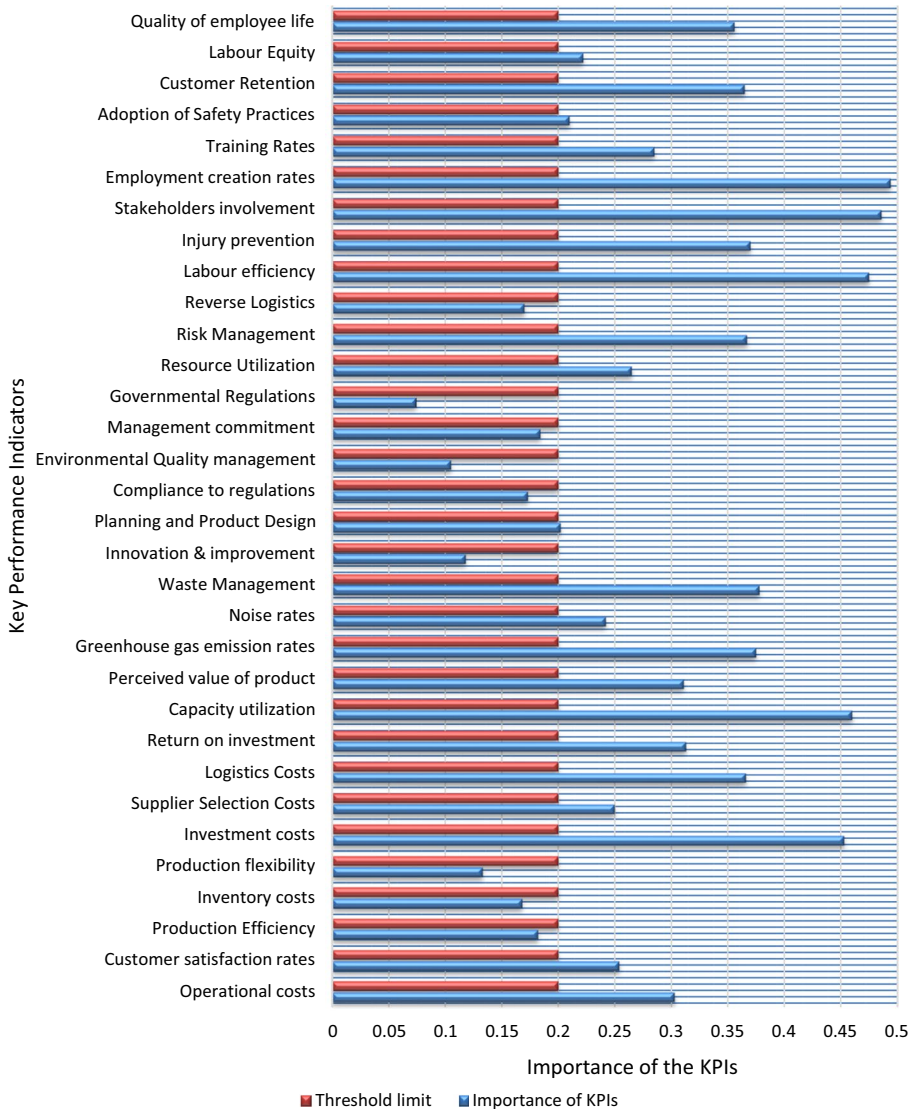


Fig. 3 Importance of the KPIs and the threshold limit

performance, and 5 is an excellent performance. This reflects the performance of each organisation with respect to each of the KPIs. However, this method does not provide an overall ranking of each organisation to evaluate their relative sustainability performance.

The importance of the KPI given in Table 3 and the performance rating of each organization for every KPI are considered for determining the overall performance of the organization. For a certain KPI, the performance rating of 1, 2, 3, 4 or 5 ensures a rating score of 0.2, 0.4, 0.6, 0.8 and 1 respectively. Figure 4 presents the pseudo-code of the logic employed for determining the performance score of the organization and also provides the information regarding the performance of the KPIs in the organization. The importance

Fig. 4 Pseudo-code for determining the performance of the organization based on the importance of the KPIs

Procedure: Determining the organization's performance

1. Store the rating of each KPI of the organization in A
2. Store the importance value of each KPI in K
3. $Total\ Score = \sum_{i=1}^{Total\ number\ of\ KPIs} A_i$
4. $Mean = \frac{Total\ Score}{Total\ number\ of\ KPIs}$
5. for $i = 1$ to $Total\ number\ of\ KPIs$
6. if $A_i = 1$
7. $KPI_i^{score} = 0.2 \times K_i$
8. elseif $A_i = 2$
9. $KPI_i^{score} = 0.4 \times K_i$
10. elseif $A_i = 3$
11. $KPI_i^{score} = 0.6 \times K_i$
12. elseif $A_i = 4$
13. $KPI_i^{score} = 0.8 \times K_i$
14. elseif $A_i = 5$
15. $KPI_i^{score} = 1 \times K_i$
16. end
17. if $K_i \geq 0.250$ and $A_i \geq 3$
18. $KPI_i^{suggestion} = "KPI\ is\ performing\ well"$
19. elseif $K_i \geq 0.250$ and $A_i < 3$
20. $KPI_i^{suggestion} = "KPI\ is\ not\ performing\ well"$
21. elseif $K_i < 0.250$ and $A_i \geq 3$
22. $KPI_i^{suggestion} = "KPI\ is\ performing\ well"$
23. elseif $K_i < 0.250$ and $A_i < 3$
24. $KPI_i^{suggestion} = "KPI\ is\ not\ performing\ well"$
25. end
26. end
27. $Overall\ performance\ score = \sum_{i=1}^{Total\ number\ of\ KPIs} KPI_i^{score}$

values of the KPIs are utilized to identify the KPIs performing well for the organization. For organization A, the overall performance score is 5.215 and the organization needs to pay further attention of the following KPIs—logistic cost, planning and product design, employment creation rates and capacity utilisation. The performance score of organization B is 4.535 and some of the KPIs which need thorough improvement are GHG emission rates, logistic cost, noise rates, stakeholder's involvement, employment creation rates, waste management, training rates and risk management. Pseudo-code presented in Fig. 4 helps in computing the performance score for the organizations and also provides recommendation regarding which KPI requires improvement.

It is apparent from Table 5 that some of the KPIs such as customer satisfaction rates, operational cost, supplier selection costs, noise rates, labour efficiency, injury prevention, adoption of safety practices and customer retention are given high preference by most of the organisations. Certain KPIs have a high degree of variations regarding preference within different organisations such as return on investment and perceived value of the product. The development of the methodology and its pilot-testing with the organisations

Table 5 Organization performance score

S. no.	KPI	Importance	Organizations (Org.) performance scores					
			Org. A	Org. B	Org. C	Org. D	Org. E	Org. F
1	Customer satisfaction rates	0.254	0.203	0.152	0.152	0.203	0.203	0.101
2	Operational costs	0.303	0.181	0.242	0.303	0.181	0.121	0.242
3	Investment cost	0.453	0.362	0.362	0.364	0.181	0.090	0.271
4	Return on investment	0.313	0.250	0.187	0.313	0.062	0.125	0.187
5	GHG emission rates	0.375	0.225	0.075	0.300	0.150	0.150	0.300
6	Logistic cost	0.366	0.146	0.146	0.219	0.219	0.292	0.146
7	Supplier selection costs	0.250	0.250	0.200	0.150	0.250	0.050	0.250
8	Perceived value of product	0.311	0.248	0.186	0.062	0.248	0.311	0.124
9	Noise rates	0.242	0.145	0.096	0.242	0.242	0.145	0.193
10	Planning and product design	0.202	0.040	0.202	0.080	0.080	0.080	0.121
11	Stakeholders involvement	0.486	0.291	0.194	0.388	0.097	0.388	0.194
12	Employment creation rates	0.494	0.197	0.197	0.395	0.296	0.197	0.395
13	Capacity utilisation	0.460	0.184	0.276	0.276	0.368	0.368	0.276
14	Labour efficiency	0.475	0.285	0.475	0.285	0.285	0.380	0.380
15	Waste management	0.378	0.302	0.151	0.151	0.151	0.226	0.075
16	Injury prevention	0.370	0.370	0.222	0.148	0.222	0.370	0.148
17	Resource utilization	0.265	0.159	0.159	0.212	0.159	0.106	0.159
18	Training rates	0.285	0.228	0.057	0.114	0.057	0.228	0.228
19	Risk management	0.367	0.220	0.146	0.293	0.220	0.220	0.293
20	Adoption of safety practices	0.210	0.168	0.168	0.126	0.126	0.168	0.084
21	Customer retention	0.365	0.365	0.219	0.292	0.292	0.292	0.146
22	Labour equity	0.222	0.177	0.133	0.088	0.088	0.044	0.044
23	Quality of employee life	0.356	0.213	0.284	0.213	0.142	0.284	0.142
Total score			5.215	4.535	5.169	4.325	4.844	4.505

facilitates the identification of the key organisational KPIs, which play a significant role in the implementation of SSCM. Furthermore, this knowledge could act as a foundation for further developing policies which could facilitate and drive the implementation of SSCM. As can be seen in Fig. 5, there is a range of different performance levels across the KPIs, and it is quite visible that organisational performance across the different KPIs varies significantly. Customer Retention, labour efficiency and logistic cost have a high degree of variance between the organisations. This could be due to the various priorities of each of the organisation such as certain organisations gives more priority in retaining its customer and thereby gives more values to customer feedback and customer services, and some of the organisations give less priority to customer retention. Organisational performance on resource utilisation, risk management, GHG emission and waste management have a low threshold across the different organisations. These points need further critical analysis and evaluation for enhancing the performance of the organisation. It is also interesting to note that stakeholder's involvement and employment creation rates have moderate to high-performance levels across the organisations.

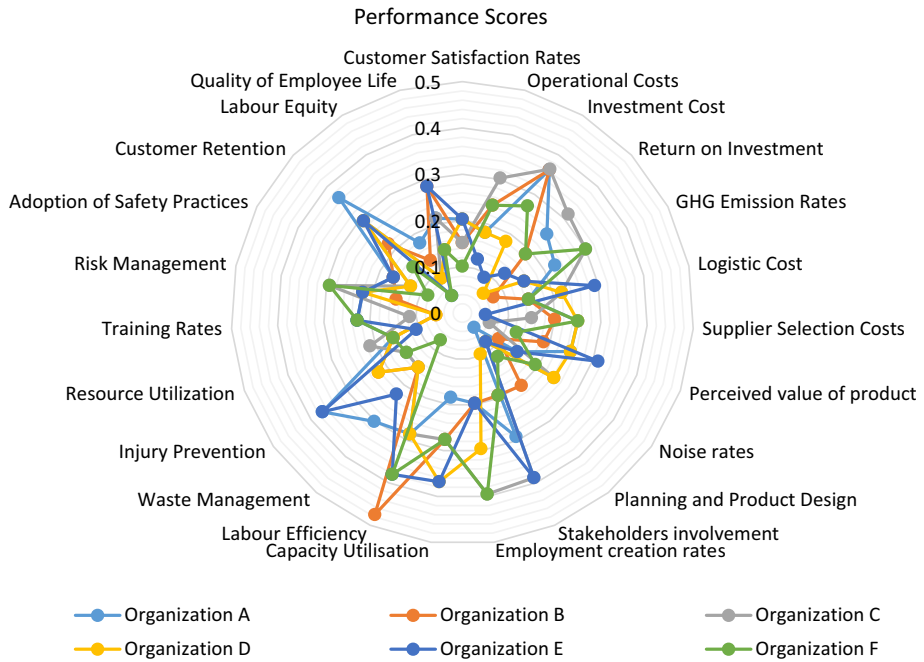


Fig. 5 Radar diagram of performance scores of six organisations on different KPIs

5.4 Application of intuitionistic fuzzy TOPSIS

The same panel of three experts is asked to provide their opinion on the performance of the organizations based on linguistic terms. These terms are then transformed into intuitionistic fuzzy data and then used by IF-TOPSIS system to determine the ranking of organizations based on their sustainability performance. Three decision makers provided their respective intuitionistic fuzzy data for the evaluation of different organizations with respect to various KPIs. The linguistic preference relation for each of the decision makers 1, 2 and 3 are presented in Table 6(a–c) respectively. The weighted intuitionistic preference matrix X^m for all the decision makers is obtained by multiplying with the normalized weight for respective KPIs. Table 7 presents the crisp weight of each KPI and also the weighted intuitionistic preference relation for decision maker 1. The crisp weight presented in Table 7 is obtained by normalizing the importance value of all the KPIs. The weighted intuitionistic preference relation for each of the decision maker is computed using the Eq. (14). The positive ideal solution matrix X^* , negative ideal decision matrix X_c^* , left individual negative ideal decision matrix X_u^- and right individual negative ideal decision matrix X_v^- are constructed using Eqs. (15), (16), (17) and (18). The hamming distances with respect to positive and negative ideal decision matrices D_m^* , D_m^c , D_m^u and D_m^v are estimated from the Eqs. (19), (20), (21) and (22). The relative closeness of each decision maker C^m and its respective weight ξ^m are computed using Eqs. (23) and (24) and their value are presented in Table 8.

The weighted intuitionistic fuzzy decision matrix P^m for all the decision makers are obtained using Eq. (25) where the decision makers weight ξ^m is multiplied with the respective decision matrix X^m . Now, the weighted intuitionistic fuzzy decision matrix with

Table 6 Intuitionistic evaluation given by (a) decision maker 1, (b) decision maker 2, (c) decision maker 3 for organizations with respect to various KPIs

	KPI 1	KPI 2	KPI 3	KPI 4	KPI 5	KPI 6	KPI 7	KPI 8	KPI 9	KPI 10	KPI 11	KPI 12
(a)												
Organization A	(0.40, 0.30)	(0.50, 0.30)	(0.10, 0.70)	(0.70, 0.20)	(0.80, 0.10)	(0.40, 0.50)	(0.60, 0.20)	(0.70, 0.30)	(0.10, 0.90)	(0.90, 0.10)	(0.30, 0.60)	(0.50, 0.40)
Organization B	(0.30, 0.60)	(0.50, 0.40)	(0.30, 0.60)	(0.90, 0.10)	(0.40, 0.60)	(0.50, 0.50)	(0.90, 0.10)	(0.10, 0.80)	(0.80, 0.10)	(0.10, 0.70)	(0.80, 0.20)	(0.20, 0.60)
Organization C	(0.20, 0.60)	(0.70, 0.20)	(0.50, 0.40)	(0.50, 0.30)	(0.10, 0.70)	(0.40, 0.60)	(0.20, 0.70)	(0.30, 0.50)	(0.70, 0.10)	(0.50, 0.40)	(0.40, 0.60)	(0.30, 0.50)
Organization D	(0.20, 0.70)	(0.70, 0.30)	(0.60, 0.20)	(0.30, 0.50)	(0.30, 0.60)	(0.90, 0.10)	(0.70, 0.20)	(0.20, 0.80)	(0.10, 0.70)	(0.40, 0.50)	(0.10, 0.80)	(0.60, 0.30)
Organization E	(0.40, 0.50)	(0.60, 0.30)	(0.40, 0.60)	(0.10, 0.90)	(0.20, 0.70)	(0.50, 0.40)	(0.30, 0.70)	(0.70, 0.20)	(0.60, 0.30)	(0.50, 0.40)	(0.20, 0.80)	(0.10, 0.70)
Organization F	(0.10, 0.90)	(0.10, 0.80)	(0.80, 0.20)	(0.60, 0.30)	(0.30, 0.60)	(0.90, 0.10)	(0.70, 0.20)	(0.80, 0.10)	(0.40, 0.50)	(0.80, 0.10)	(0.70, 0.20)	(0.70, 0.30)
	KPI 13	KPI 14	KPI 15	KPI 16	KPI 17	KPI 18	KPI 19	KPI 20	KPI 21	KPI 22	KPI 23	
Organization A	(0.20, 0.60)	(0.10, 0.90)	(0.60, 0.30)	(0.20, 0.60)	(0.80, 0.10)	(0.20, 0.70)	(0.30, 0.60)	(0.50, 0.30)	(0.20, 0.80)	(0.30, 0.60)	(0.20, 0.70)	
Organization B	(0.90, 0.10)	(0.60, 0.30)	(0.70, 0.20)	(0.10, 0.80)	(0.30, 0.70)	(0.60, 0.40)	(0.10, 0.80)	(0.60, 0.30)	(0.10, 0.80)	(0.80, 0.10)	(0.10, 0.90)	
Organization C	(0.30, 0.70)	(0.70, 0.20)	(0.60, 0.30)	(0.60, 0.40)	(0.70, 0.20)	(0.50, 0.40)	(0.90, 0.10)	(0.50, 0.30)	(0.10, 0.80)	(0.60, 0.30)	(0.70, 0.20)	
Organization D	(0.70, 0.10)	(0.50, 0.30)	(0.90, 0.10)	(0.40, 0.50)	(0.40, 0.60)	(0.50, 0.30)	(0.60, 0.30)	(0.70, 0.20)	(0.10, 0.90)	(0.80, 0.10)	(0.10, 0.90)	
Organization E	(0.20, 0.80)	(0.40, 0.50)	(0.20, 0.70)	(0.50, 0.40)	(0.80, 0.10)	(0.90, 0.10)	(0.50, 0.40)	(0.50, 0.30)	(0.40, 0.50)	(0.90, 0.10)	(0.50, 0.30)	
Organization F	(0.30, 0.60)	(0.60, 0.40)	(0.70, 0.10)	(0.70, 0.30)	(0.80, 0.20)	(0.30, 0.50)	(0.60, 0.20)	(0.90, 0.10)	(0.40, 0.60)	(0.90, 0.10)	(0.50, 0.40)	

Table 6 (continued)

	KPI 1	KPI 2	KPI 3	KPI 4	KPI 5	KPI 6	KPI 7	KPI 8	KPI 9	KPI 10	KPI 11	KPI 12
(b)												
Organization A	(0.90, 0.10)	(0.30, 0.60)	(0.20, 0.70)	(0.70, 0.30)	(0.30, 0.60)	(0.80, 0.10)	(0.80, 0.20)	(0.80, 0.10)	(0.60, 0.30)	(0.80, 0.20)	(0.70, 0.20)	(0.80, 0.20)
Organization B	(0.50, 0.30)	(0.10, 0.80)	(0.40, 0.50)	(0.70, 0.20)	(0.20, 0.80)	(0.40, 0.50)	(0.90, 0.10)	(0.20, 0.70)	(0.20, 0.80)	(0.30, 0.60)	(0.50, 0.30)	(0.60, 0.20)
Organization C	(0.40, 0.50)	(0.60, 0.20)	(0.70, 0.30)	(0.40, 0.50)	(0.80, 0.10)	(0.80, 0.20)	(0.30, 0.70)	(0.90, 0.10)	(0.20, 0.70)	(0.50, 0.30)	(0.40, 0.60)	(0.30, 0.50)
Organization D	(0.70, 0.20)	(0.30, 0.60)	(0.40, 0.50)	(0.10, 0.90)	(0.40, 0.60)	(0.70, 0.20)	(0.70, 0.30)	(0.90, 0.10)	(0.40, 0.50)	(0.10, 0.80)	(0.50, 0.40)	(0.70, 0.20)
Organization E	(0.70, 0.20)	(0.10, 0.80)	(0.70, 0.30)	(0.30, 0.50)	(0.90, 0.10)	(0.40, 0.60)	(0.40, 0.50)	(0.50, 0.30)	(0.70, 0.20)	(0.10, 0.80)	(0.10, 0.90)	(0.60, 0.30)
Organization F	(0.50, 0.40)	(0.70, 0.20)	(0.30, 0.70)	(0.40, 0.50)	(0.30, 0.70)	(0.20, 0.80)	(0.80, 0.10)	(0.90, 0.10)	(0.80, 0.20)	(0.10, 0.70)	(0.10, 0.90)	(0.80, 0.10)
	KPI 13	KPI 14	KPI 15	KPI 16	KPI 17	KPI 18	KPI 19	KPI 20	KPI 21	KPI 22	KPI 23	
Organization A	(0.90, 0.10)	(0.50, 0.40)	(0.60, 0.30)	(0.10, 0.80)	(0.80, 0.20)	(0.90, 0.10)	(0.10, 0.80)	(0.10, 0.70)	(0.30, 0.60)	(0.10, 0.70)	(0.60, 0.30)	
Organization B	(0.90, 0.10)	(0.50, 0.40)	(0.80, 0.10)	(0.60, 0.30)	(0.60, 0.20)	(0.50, 0.40)	(0.60, 0.30)	(0.20, 0.80)	(0.50, 0.30)	(0.50, 0.40)	(0.60, 0.30)	
Organization C	(0.10, 0.80)	(0.80, 0.20)	(0.70, 0.10)	(0.60, 0.30)	(0.90, 0.10)	(0.80, 0.10)	(0.40, 0.60)	(0.10, 0.80)	(0.70, 0.10)	(0.80, 0.10)	(0.40, 0.60)	
Organization D	(0.90, 0.10)	(0.20, 0.80)	(0.60, 0.30)	(0.70, 0.20)	(0.60, 0.40)	(0.20, 0.70)	(0.10, 0.80)	(0.20, 0.70)	(0.50, 0.40)	(0.90, 0.10)	(0.20, 0.80)	
Organization E	(0.60, 0.20)	(0.50, 0.40)	(0.20, 0.80)	(0.90, 0.10)	(0.10, 0.80)	(0.50, 0.40)	(0.40, 0.60)	(0.10, 0.80)	(0.50, 0.40)	(0.30, 0.70)	(0.90, 0.10)	
Organization F	(0.90, 0.10)	(0.90, 0.10)	(0.60, 0.40)	(0.90, 0.10)	(0.10, 0.70)	(0.60, 0.30)	(0.20, 0.70)	(0.60, 0.40)	(0.40, 0.50)	(0.20, 0.70)	(0.10, 0.80)	

Table 6 (continued)

	KPI 1	KPI 2	KPI 3	KPI 4	KPI 5	KPI 6	KPI 7	KPI 8	KPI 9	KPI 10	KPI 11	KPI 12
(c)												
Organization A	(0.10, 0.80)	(0.90, 0.10)	(0.90, 0.10)	(0.10, 0.70)	(0.40, 0.60)	(0.30, 0.60)	(0.80, 0.20)	(0.20, 0.70)	(0.10, 0.70)	(0.20, 0.60)	(0.70, 0.20)	(0.10, 0.80)
Organization B	(0.10, 0.80)	(0.70, 0.20)	(0.80, 0.10)	(0.10, 0.90)	(0.60, 0.30)	(0.40, 0.50)	(0.10, 0.80)	(0.40, 0.60)	(0.30, 0.60)	(0.90, 0.10)	(0.70, 0.20)	(0.30, 0.60)
Organization C	(0.10, 0.80)	(0.70, 0.20)	(0.80, 0.10)	(0.90, 0.10)	(0.10, 0.80)	(0.10, 0.70)	(0.90, 0.10)	(0.50, 0.40)	(0.10, 0.80)	(0.60, 0.30)	(0.50, 0.40)	(0.80, 0.20)
Organization D	(0.60, 0.20)	(0.10, 0.80)	(0.50, 0.40)	(0.30, 0.60)	(0.80, 0.20)	(0.10, 0.80)	(0.50, 0.40)	(0.70, 0.20)	(0.50, 0.40)	(0.40, 0.50)	(0.20, 0.70)	(0.10, 0.80)
Organization E	(0.50, 0.40)	(0.90, 0.10)	(0.10, 0.80)	(0.30, 0.60)	(0.50, 0.40)	(0.60, 0.30)	(0.70, 0.20)	(0.80, 0.10)	(0.30, 0.60)	(0.90, 0.10)	(0.60, 0.30)	(0.20, 0.70)
Organization F	(0.10, 0.80)	(0.90, 0.10)	(0.40, 0.50)	(0.30, 0.60)	(0.80, 0.10)	(0.30, 0.60)	(0.90, 0.10)	(0.10, 0.90)	(0.20, 0.80)	(0.10, 0.90)	(0.30, 0.60)	(0.10, 0.80)
	KPI 13	KPI 14	KPI 15	KPI 16	KPI 17	KPI 18	KPI 19	KPI 20	KPI 21	KPI 22	KPI 23	
Organization A	(0.40, 0.50)	(0.40, 0.60)	(0.20, 0.70)	(0.10, 0.80)	(0.30, 0.60)	(0.60, 0.30)	(0.60, 0.20)	(0.60, 0.40)	(0.80, 0.20)	(0.70, 0.10)	(0.10, 0.80)	
Organization B	(0.10, 0.80)	(0.10, 0.70)	(0.20, 0.80)	(0.70, 0.20)	(0.30, 0.60)	(0.50, 0.40)	(0.50, 0.30)	(0.70, 0.20)	(0.80, 0.10)	(0.90, 0.10)	(0.60, 0.30)	
Organization C	(0.90, 0.10)	(0.90, 0.10)	(0.50, 0.40)	(0.90, 0.10)	(0.70, 0.10)	(0.70, 0.20)	(0.30, 0.60)	(0.10, 0.70)	(0.70, 0.20)	(0.60, 0.30)	(0.30, 0.50)	
Organization D	(0.20, 0.70)	(0.30, 0.60)	(0.70, 0.20)	(0.50, 0.40)	(0.10, 0.80)	(0.70, 0.20)	(0.10, 0.80)	(0.10, 0.70)	(0.20, 0.80)	(0.10, 0.90)	(0.60, 0.20)	
Organization E	(0.10, 0.80)	(0.30, 0.60)	(0.60, 0.40)	(0.10, 0.80)	(0.10, 0.90)	(0.80, 0.10)	(0.70, 0.20)	(0.50, 0.40)	(0.10, 0.80)	(0.70, 0.20)	(0.70, 0.30)	
Organization F	(0.30, 0.70)	(0.10, 0.80)	(0.10, 0.70)	(0.80, 0.20)	(0.60, 0.40)	(0.20, 0.70)	(0.30, 0.60)	(0.40, 0.50)	(0.10, 0.80)	(0.10, 0.90)	(0.50, 0.40)	

Table 7 Weighted intuitionistic preference matrix for decision maker 1 and crisp weight for all the KPIs

	Crisp weight	Organization A	Organization B	Organization C	Organization D	Organization E	Organization F
KPI 1	0.0326	(0.0165, 0.9615)	(0.0116, 0.9835)	(0.0072, 0.9835)	(0.0072, 0.9884)	(0.0165, 0.9777)	(0.0034, 0.9966)
KPI 2	0.0388	(0.0265, 0.9544)	(0.0265, 0.9651)	(0.0456, 0.9395)	(0.0456, 0.9544)	(0.0349, 0.9544)	(0.0041, 0.9914)
KPI 3	0.0581	(0.0061, 0.9795)	(0.0205, 0.9708)	(0.0395, 0.9482)	(0.0518, 0.9107)	(0.0292, 0.9708)	(0.0893, 0.9107)
KPI 4	0.0401	(0.0471, 0.9375)	(0.0882, 0.9118)	(0.0274, 0.9528)	(0.0142, 0.9725)	(0.0042, 0.9957)	(0.0361, 0.9528)
KPI 5	0.0481	(0.0744, 0.8951)	(0.0242, 0.9757)	(0.0050, 0.9829)	(0.0170, 0.9757)	(0.0106, 0.9829)	(0.0170, 0.9757)
KPI 6	0.0469	(0.0236, 0.9680)	(0.0319, 0.9680)	(0.0236, 0.9763)	(0.1023, 0.8976)	(0.0319, 0.9579)	(0.1023, 0.8976)
KPI 7	0.0320	(0.0288, 0.9498)	(0.0710, 0.9289)	(0.0071, 0.9886)	(0.0377, 0.9498)	(0.0113, 0.9886)	(0.0377, 0.9498)
KPI 8	0.0399	(0.0469, 0.9530)	(0.0041, 0.9911)	(0.0141, 0.9727)	(0.0088, 0.9911)	(0.0469, 0.9378)	(0.0621, 0.9122)
KPI 9	0.0310	(0.0109, 0.9842)	(0.0486, 0.9311)	(0.0366, 0.9311)	(0.0032, 0.9890)	(0.0280, 0.9633)	(0.0157, 0.9787)
KPI 10	0.0259	(0.0578, 0.9421)	(0.0027, 0.9908)	(0.0177, 0.9765)	(0.0131, 0.9822)	(0.0177, 0.9765)	(0.0408, 0.9421)
KPI 11	0.0623	(0.0219, 0.9686)	(0.0954, 0.9045)	(0.0313, 0.9686)	(0.0065, 0.9861)	(0.0138, 0.9861)	(0.0722, 0.9045)
KPI 12	0.0633	(0.0429, 0.9436)	(0.0140, 0.9681)	(0.0223, 0.9570)	(0.0563, 0.9266)	(0.0066, 0.9776)	(0.0733, 0.9266)
KPI 13	0.0590	(0.0130, 0.9703)	(0.1270, 0.8729)	(0.0208, 0.9791)	(0.0685, 0.8729)	(0.0130, 0.9869)	(0.0208, 0.9703)
KPI 14	0.0609	(0.0063, 0.9936)	(0.0542, 0.9293)	(0.0706, 0.9066)	(0.0413, 0.9293)	(0.0306, 0.9586)	(0.0542, 0.9457)
KPI 15	0.0484	(0.0433, 0.9433)	(0.0566, 0.9250)	(0.0433, 0.9433)	(0.1054, 0.8945)	(0.0107, 0.9828)	(0.0566, 0.8945)
KPI 16	0.0474	(0.0105, 0.9760)	(0.0049, 0.9894)	(0.0425, 0.9574)	(0.0239, 0.9676)	(0.0323, 0.9574)	(0.0554, 0.9445)
KPI 17	0.0340	(0.0532, 0.9246)	(0.0120, 0.9879)	(0.0401, 0.9467)	(0.0172, 0.9827)	(0.0532, 0.9246)	(0.0532, 0.9467)
KPI 18	0.0365	(0.0081, 0.9870)	(0.0328, 0.9671)	(0.0249, 0.9671)	(0.0249, 0.9570)	(0.0806, 0.9193)	(0.0129, 0.9750)
KPI 19	0.0470	(0.0166, 0.9762)	(0.0049, 0.9895)	(0.1025, 0.8974)	(0.0421, 0.9449)	(0.0320, 0.9578)	(0.0421, 0.9271)
KPI 20	0.0269	(0.0184, 0.9681)	(0.0243, 0.9681)	(0.0184, 0.9681)	(0.0318, 0.9576)	(0.0184, 0.9681)	(0.0601, 0.9399)
KPI 21	0.0468	(0.0103, 0.9896)	(0.0049, 0.9896)	(0.0049, 0.9896)	(0.0049, 0.9950)	(0.0236, 0.9680)	(0.0236, 0.9763)
KPI 22	0.0285	(0.0101, 0.9855)	(0.0448, 0.9364)	(0.0257, 0.9662)	(0.0448, 0.9364)	(0.0635, 0.9364)	(0.0635, 0.9364)
KPI 23	0.0456	(0.0101, 0.9838)	(0.0047, 0.9952)	(0.0534, 0.9292)	(0.0047, 0.9952)	(0.0311, 0.9465)	(0.0311, 0.9590)

Table 8 Relative closeness of three decision makers and their respective weights

Decision maker	Relative closeness	Weight
Decision maker 1, t_1	$C^{t_1}=0.9764$	$\xi^{t_1}=0.3337$
Decision maker 2, t_2	$C^{t_2}=0.9738$	$\xi^{t_2}=0.3328$
Decision maker 3, t_3	$C^{t_3}=0.9754$	$\xi^{t_3}=0.3334$

respect to each alternative Q_s is constructed using Eq. (26). The positive ideal solution Q^+ and two negative ideal solutions Q_c^- and Q^- are constructed considering the weighted intuitionistic decision matrix with respect to the alternatives and using Eqs. (27), (28) and (29). The positive and negative ideal decision matrices Q^+ , Q_c^- and Q^- are presented in Table 9. The separation measures D_s^+ , D_s^c and D_s^- representing the separation of Q_s from the positive ideal solution Q^+ and two negative ideal solutions Q_c^- and Q^- respectively. The separation measures D_s^+ , D_s^c and D_s^- are determined using Eqs. (30), (31) and (32) respectively and presented in Table 10. Relative closeness associated with all the alternatives C^s are computed using Eq. (33). Table 10 also provides the related closeness for different alternatives (organizations) and their corresponding ranking.

5.5 Sensitivity analysis for robustness check

Sensitivity analysis is performed for ensuring the robustness and feasibility of the proposed framework comprising of different methodologies including IF-AHP and IF-TOPSIS. The analysis aims to investigate about the impact of changing in the criteria weights on the priority results of the alternatives. It basically means that the sensitivity analysis is conducted by varying the crisp weights of the key performance indicators (KPIs) and accordingly studying their impact on the ranking of the alternatives. Decision maker's linguistic responses are used to derive the intuitionistic weights of the KPIs and which in turn are employed for obtaining the crisp weight of the KPIs. Moreover, linguistic responses of the decision makers might be subject to error due to the involvement of human judgement, therefore it is imperative to perform a sensitivity analysis to check the robustness and feasibility of the proposed system. For conducting the sensitivity analysis, certain experiments are created by interchanging the crisp weight of a particular KPI with another KPI and accordingly the ranking of the alternatives are obtained (Önüt et al. 2010; Zyoud et al. 2016)).

Based on the kind of sensitivity analysis suggested in the work of Önüt et al. (2010) and Zyoud et al. (2016), 12 combinations are generated by exchanging one criteria's weight with another. Three priority vectors pertaining to each of the decision makers containing intuitionistic fuzzy information associated with the KPIs are generated for performing the sensitivity analysis. Each experiment is denoted in a certain way to make it clear in understanding about which crisp weights of the KPIs are interchanged. For example—C15 means that crisp weight of KPI 1 is exchanged with the crisp weight of KPI 5. Table 11 presents the results associated with the sensitivity analysis. The relative closeness coefficient for each of the alternatives are represented as CCA1, CCA2, CCA3, CCA4, CCA5 and CCA6. The value of the closeness coefficient and the ranking of the alternative are presented on Table 11. It is interesting to note that for all the 12 experiments, the alternatives A4 and A3 consistently changes the position among themselves as the first two ranked alternatives. Although, the ranking position of A1, A6, A5 and A2 remains same and their ranking order stays unchanged throughout the experiments. The internal coherence of the

Table 9 Positive and negative ideal matrices obtained considering all the alternatives

	KPI 1	KPI 2	KPI 3	KPI 4	KPI 5	KPI 6	KPI 7	KPI 8	KPI 9	KPI 10	KPI 11	KPI 12
Q^+												
Decision maker 1	(0.01, 0.98)	(0.01, 0.97)	(0.03, 0.96)	(0.03, 0.96)	(0.02, 0.96)	(0.03, 0.96)	(0.02, 0.97)	(0.02, 0.96)	(0.01, 0.97)	(0.01, 0.98)	(0.03, 0.96)	(0.02, 0.97)
Decision maker 2	(0.02, 0.97)	(0.01, 0.97)	(0.02, 0.97)	(0.01, 0.97)	(0.03, 0.96)	(0.02, 0.96)	(0.02, 0.97)	(0.03, 0.96)	(0.01, 0.98)	(0.01, 0.98)	(0.02, 0.96)	(0.04, 0.95)
Decision maker 3	(0.01, 0.98)	(0.02, 0.97)	(0.04, 0.95)	(0.03, 0.96)	(0.02, 0.96)	(0.01, 0.98)	(0.02, 0.97)	(0.02, 0.96)	(0.00, 0.99)	(0.01, 0.98)	(0.02, 0.96)	(0.03, 0.96)
Q^-												
Decision maker 1	(0.04, 0.95)	(0.02, 0.96)	(0.03, 0.96)	(0.01, 0.98)	(0.01, 0.97)	(0.02, 0.97)	(0.03, 0.96)	(0.02, 0.97)	(0.01, 0.98)	(0.02, 0.97)	(0.01, 0.97)	(0.01, 0.97)
Decision maker 2	(0.04, 0.95)	(0.04, 0.95)	(0.02, 0.96)	(0.03, 0.96)	(0.02, 0.97)	(0.02, 0.97)	(0.01, 0.98)	(0.00, 0.99)	(0.02, 0.96)	(0.02, 0.97)	(0.03, 0.96)	(0.03, 0.96)
Decision maker 3	(0.04, 0.95)	(0.04, 0.95)	(0.01, 0.97)	(0.03, 0.96)	(0.01, 0.97)	(0.01, 0.97)	(0.01, 0.97)	(0.02, 0.98)	(0.02, 0.96)	(0.02, 0.97)	(0.01, 0.97)	(0.01, 0.97)
Q^c												
Decision maker 1	(0.98, 0.01)	(0.97, 0.01)	(0.96, 0.03)	(0.96, 0.03)	(0.96, 0.02)	(0.96, 0.03)	(0.97, 0.02)	(0.96, 0.02)	(0.97, 0.01)	(0.98, 0.01)	(0.96, 0.03)	(0.97, 0.02)
Decision maker 2	(0.97, 0.02)	(0.97, 0.01)	(0.97, 0.02)	(0.97, 0.01)	(0.96, 0.03)	(0.96, 0.02)	(0.97, 0.02)	(0.96, 0.03)	(0.98, 0.01)	(0.98, 0.01)	(0.96, 0.02)	(0.95, 0.04)
Decision maker 3	(0.98, 0.01)	(0.97, 0.02)	(0.95, 0.04)	(0.96, 0.03)	(0.96, 0.02)	(0.98, 0.01)	(0.97, 0.02)	(0.96, 0.02)	(0.99, 0.00)	(0.98, 0.01)	(0.96, 0.02)	(0.96, 0.03)
Decision maker 1	(0.95, 0.04)	(0.96, 0.02)	(0.95, 0.03)	(0.98, 0.01)	(0.97, 0.01)	(0.97, 0.02)	(0.96, 0.03)	(0.97, 0.02)	(0.98, 0.01)	(0.97, 0.02)	(0.97, 0.01)	(0.97, 0.02)
Decision maker 2	(0.95, 0.04)	(0.95, 0.04)	(0.96, 0.02)	(0.96, 0.03)	(0.97, 0.02)	(0.97, 0.02)	(0.98, 0.01)	(0.99, 0.00)	(0.96, 0.02)	(0.97, 0.02)	(0.96, 0.02)	(0.96, 0.03)

Table 9 (continued)

	KPI 13	KPI 14	KPI 15	KPI 16	KPI 17	KPI 18	KPI 19	KPI 20	KPI 21	KPI 22	KPI 23	
Decision maker 3	(0.95, 0.04)	(0.95, 0.04)	(0.97, 0.01)	(0.96, 0.03)	(0.97, 0.01)	(0.97, 0.01)	(0.97, 0.01)	(0.98, 0.02)	(0.96, 0.02)	(0.97, 0.02)	(0.97, 0.01)	
Q^-	KPI 1	KPI 2	KPI 3	KPI 4	KPI 5	KPI 6	KPI 7	KPI 8	KPI 9	KPI 10	KPI 11	KPI 12
Decision maker 1	(0.0011, 0.9989)	(0.0014, 0.9971)	(0.0020, 0.9931)	(0.0014, 0.9986)	(0.0017, 0.9943)	(0.0080, 0.9920)	(0.0024, 0.9962)	(0.0014, 0.9970)	(0.0011, 0.9963)	(0.0009, 0.9969)	(0.0022, 0.9954)	(0.0022, 0.9925)
Decision maker 2	(0.0055, 0.9925)	(0.0014, 0.9971)	(0.0043, 0.9931)	(0.0014, 0.9986)	(0.0036, 0.9964)	(0.0035, 0.9965)	(0.0038, 0.9962)	(0.0030, 0.9953)	(0.0023, 0.9977)	(0.0009, 0.9981)	(0.0022, 0.9978)	(0.0191, 0.9750)
Decision maker 3	(0.0011, 0.9976)	(0.0014, 0.9971)	(0.0020, 0.9971)	(0.0014, 0.9986)	(0.0017, 0.9964)	(0.0016, 0.9965)	(0.0011, 0.9976)	(0.0014, 0.9986)	(0.0011, 0.9977)	(0.0009, 0.9991)	(0.0046, 0.9926)	(0.0022, 0.9953)
	KPI 13	KPI 14	KPI 15	KPI 16	KPI 17	KPI 18	KPI 19	KPI 20	KPI 21	KPI 22	KPI 23	
Decision maker 1	(0.0044, 0.9956)	(0.0021, 0.9979)	(0.0036, 0.9943)	(0.0017, 0.9965)	(0.0040, 0.9960)	(0.0027, 0.9957)	(0.0017, 0.9965)	(0.0062, 0.9892)	(0.0016, 0.9984)	(0.0034, 0.9952)	(0.0016, 0.9984)	
Decision maker 2	(0.0021, 0.9956)	(0.0045, 0.9955)	(0.0036, 0.9964)	(0.0017, 0.9965)	(0.0012, 0.9975)	(0.0027, 0.9957)	(0.0016, 0.9965)	(0.0009, 0.9980)	(0.0055, 0.9921)	(0.0009, 0.9966)	(0.0016, 0.9966)	
Decision maker 3	(0.0021, 0.9956)	(0.0021, 0.9955)	(0.0017, 0.9964)	(0.0017, 0.9965)	(0.0012, 0.9988)	(0.0027, 0.9957)	(0.0016, 0.9965)	(0.0009, 0.9968)	(0.0016, 0.9965)	(0.0010, 0.9990)	(0.0016, 0.9966)	

Table 10 Separation measures, relative closeness and ranking of the alternatives

Organizations	Separation measures			Relative closeness of each alternative C^s	Ranking
	D_s^+	D_s^c	D_s^-		
Organization A	0.0152	0.9624	0.0109	0.9846	4
Organization B	0.0147	0.9620	0.0112	0.9851	3
Organization C	0.0118	0.9591	0.0142	0.9880	1
Organization D	0.0164	0.9637	0.0098	0.9834	6
Organization E	0.0159	0.9632	0.0098	0.9839	5
Organization F	0.0146	0.9619	0.0114	0.9852	2

Table 11 Sensitivity analysis for validation of the proposed system

Experiment number	Relative closeness of each alternative						Ranking order of the alternative
	CCA1	CCA2	CCA3	CCA4	CCA5	CCA6	
1—C15	0.9760	0.9735	0.9823	0.9833	0.9753	0.9758	A4 > A3 > A1 > A6 > A5 > A2
2—C17	0.9764	0.9613	0.9846	0.9855	0.9705	0.9743	A4 > A3 > A1 > A6 > A5 > A2
3—C25	0.9788	0.9651	0.9838	0.9882	0.9689	0.9731	A4 > A3 > A1 > A6 > A5 > A2
4—C27	0.9823	0.9734	0.9834	0.9863	0.9759	0.9793	A4 > A3 > A1 > A6 > A5 > A2
5—C35	0.9765	0.9657	0.9820	0.9814	0.9692	0.9714	A3 > A4 > A1 > A6 > A5 > A2
6—C37	0.9806	0.9753	0.9879	0.9843	0.9787	0.9794	A3 > A4 > A1 > A6 > A5 > A2
7—C45	0.9774	0.9671	0.9889	0.9819	0.9738	0.9747	A3 > A4 > A1 > A6 > A5 > A2
8—C47	0.9764	0.9669	0.9804	0.9787	0.9747	0.9756	A3 > A4 > A1 > A6 > A5 > A2
9—C55	0.9866	0.9611	0.9874	0.9896	0.9710	0.9719	A4 > A3 > A1 > A6 > A5 > A2
10—C57	0.9701	0.9630	0.9804	0.9839	0.9641	0.9679	A4 > A3 > A1 > A6 > A5 > A2
11—C65	0.9815	0.9632	0.9834	0.9826	0.9748	0.9796	A3 > A4 > A1 > A6 > A5 > A2
12—C67	0.9810	0.9609	0.9871	0.9867	0.9659	0.9700	A3 > A4 > A1 > A6 > A5 > A2

proposed system is validated by performing this sensitivity analysis which highlights the fact that the ranking of the alternative remain same.

5.6 Implications

From Table 10, it can be interpreted that organization C of the organization possesses the highest rank followed by organizations F and B. The relative closeness coefficient of organizations F and B are nearly same with a different of 0.0001 in magnitude. Considering Tables 5 and 10, it must be noted that the organization B performs well in both the cases. Although, organization D occupies the last position in terms of ranking (from Table 10) and the total performance score of organization D is the lowest (from Table 5) when compared with other organizations. Therefore, more emphasis should be given in the development of organization D by improving certain aspects such as return on investment, stakeholder's involvement, labour efficiency, training rates and quality of employee life.

The research work performed in this paper contributes to the area of operations management by proposing a novel multi criteria decision making method by integrating

intuitionistic fuzzy AHP and intuitionistic Fuzzy TOPSIS. To the best of author's knowledge, none of the multi-criteria decision-making techniques proposed in the literature combined IF-AHP and IF-TOPSIS which is proposed in this paper. The proposed methodology estimates the importance of the Key Performance Indicators and determines the performance of different organizations. The application of methodology is new to the field of sustainable development and it provides several opportunities to apply this proposed method in other context pertaining to closed loop supply chain management or supply chain resilience. This research also possesses teaching implication by giving awareness of this novel method to business, engineering and operations management students.

6 Conclusion

The proposed research contributes to bridging the research gap between literature and industrial practice in identifying the KPIs explicitly applicable to sustainable supply chain management for assessing the performance of the organizations. Several researchers in the past focused on performance assessment of green supply chain management (Fahimnia et al. 2015), supplier sustainability assessment Govindan et al. (2013) and others focussed specifically on environmental or economic aspects separately Dubey et al. (2015) and Barbosa-Póvoa et al. (2018). However, the proposed research addressed the research gaps by holistically considering all three dimensions of sustainability and identifying a set of KPIs for environmental, economic and social dimensions by performing a rigorous mixed method approach including literature survey and analysis of industrial practices. Moreover, a novel sustainability assessment framework using integrated intuitionistic fuzzy-based methodologies for assessing organizations performance is proposed. Intuitionistic fuzzy methodologies are employed to address another research gap in the literature, which suggest a lack of appropriate research considering the human judgement aspect within decision making.

The first part of the sustainability assessment framework obtains a revised list of KPIs from the initial set of KPIs by considering the expert judgements while performing Values Focus Thinking (VFT) and adopting a robust methodology named intuitionistic fuzzy analytic hierarchy process (IFAHP) for obtaining the weights of the identified KPIs. In the second part, these intuitionistic fuzzy weights of the KPIs are subsequently utilized in the proposed sustainability assessment framework for evaluating the performance of the KPIs for different organizations. The sustainability performance of various organizations is ranked using identified KPIs and intuitionistic fuzzy TOPSIS method.

The feasibility of the proposed framework is illustrated through its application to UK based firms. The data is collected in linguistic variables from the experts belonging to the UK manufacturing organizations. Moreover, the proposed sustainability framework has facilitated the identification of KPIs, their weighting and utilization to aid supply chain managers in evaluating and improving their organization's sustainability performance. Several insights and recommendations are provided regarding the improvement of the performance of the organizations on specific KPIs. The proposed decision-making framework for sustainability is convenient for the supply chain managers as the input can be provided in linguistic data and complex model of the decision support framework provides robust and appropriate results as shown in the sensitivity analysis. It is thus imperative for the organizations to adopt the concepts brought forth through this research work for continually evaluating and improving their supply chain sustainability.

In future, the research can be extended by employing other robust MCDM methodologies combined with the intuitionistic fuzzy set for determining the weights of the KPIs. Furthermore, there is potential for the development of a decision support system based on the proposed sustainability assessment framework which could assess, identify hot spots, improve and provide managerial decision-making support to the supply chain managers.

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