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Abstract

Due to growing public awareness, governmental regulations and concerns, environmental sustainability initiatives have received increasing attention among industrial decision-makers and practitioners. Employing environmental management programs can significantly minimize the waste and preserve the environment. However, papers have not much focused on exploring the interactions and interdependencies among environmental sustainability innovation factors, particularly in the context of manufacturing sector of emerging economies. To address this issue, this paper proposes a criteria decision framework, with the target of investigating the interactions among environmental sustainability innovation criteria within an emerging economy nation manufacturing sector context using Z-based DEMATEL technique. According to the findings, "designing products for being reusable and energy efficient" is the most critical criterion and requires a considerable attention for successfully implementing environmental sustainability innovation. This paper significantly helps industrial managers and experts in emerging economies to better understand environmental sustainability innovation, employ environmental sustainability innovation practices in their supply chains and shift their industry towards sustainable development.

Keywords Sustainable supply chain management. Sustainable innovation. Environmental sustainability innovation. Z-DEMATEL. Z number

Introduction

A growing number of firms have started to employ sustainability initiatives in their operations and supply chains to attain their sustainability targets. Pressing adverse environmental impacts as well as harm to human life has caused through rapid industrialization (Gupta et al. 2020). Because of environmental issues, a growing number of stakeholders including decision-makers in policy and environmental activists advocate for a tough and difficult governmental rule (Luthra et al. 2017). Environmental problems such as usage of natural resources, air pollution, and increased hazardous materials utilization have become obstacles for the sustainable development of the economy and society.

Due to increased concern and knowledge of different agencies and governments globally, companies are required to consider environmentally friendly processes and products. Manufacturing companies are responsible for key environmental problems including environmental pollution, resources reduction and global warming. Non-governmental organizations as well as diverse governmental agencies emphasize the requirement to shift from traditional practices to innovative and green technologies during production process (Mousavi and Bossink 2020). Companies and supply chains can achieve their sustainability targets through employing sustainable innovation practices (Kusi-Sarpong et al. 2019). Firms should apply new solutions of manufacturing including improved production practices and product design and develop new ways to waste dispose without harming the environment (Silva et al. 2019). For responding to increasing pressures from clients, regulators and stakeholders, innovation is essential. As the main concern of clients and regulators are related to the environmental issues, hence, environmental sustainability innovation can be considered as an effective solution to dominate these concerns (Todeschini et al. 2020). Environmental sustainability innovation is considered as both product innovation and process innovation, and contains altering the status quo, modifying society norms, people mindset, and includes resistance from people, therefore contains a huge amount of risk (Tidd and Bessant 2018). An increasing number of papers have focused on environmental sustainability innovation from various categories (e.g., Mousavi and Bossink 2020). However, studies have not explored the interactions and interdependencies among environmental sustainability innovation factors, particularly in the context of emerging economies manufacturing sector.

The novelty of this research includes proposing a criteria decision framework for investigating the interrelationships and interactions among environmental sustainability innovation factors in an emerging economy manufacturing sector context using a new MCDM method (Z-DEMATEL). The objectives of this paper are listed as follows:

(i) To determine the environmental sustainability innovation criteria, with the target of proposing an environmental sustainability innovation evaluation framework within an emerging economy manufacturing sector context;

(ii) To identify the interdependencies and interactions among environmental sustainability innovation factors;

(iii) To determine the managerial and implications of the work;

To obtain the research objectives, initially a literature review is carried out and some potential environmental sustainability innovation criteria are identified. Then, several rounds of reviews are conducted by industry experts to propose a comprehensive environmental sustainability innovation criteria decision framework. Finally, Z-DEMATEL technique is utilized for evaluating the framework and identifying the interdependencies and interactions among criteria using several selected company managers within the manufacturing sector. This work consists of two major contributions. First, a criteria decision framework is developed to investigate environmental sustainability innovation within an emerging economy nation manufacturing sector context. Second, Z-DEMATEL, a new multiple criteria decision-making (MCDM) model, is applied for analyzing the interactions among environmental sustainability innovation factors.

Literature review

This section begins with a review of sustainable innovation. Second sub-section focuses on environmental sustainability innovation. Third sub-section presents existing works on environmental sustainability innovation. Last sub-section identifies the research gaps.

Sustainable innovation

Developing and implementing sustainability in organizational supply chains requires innovation to be occurred (Klewitz and Hansen 2014). Companies that try to attain sustainability in their supply chains must consider innovation for responding to adverse effects. Sustainable innovation can be described as implementing new or modified products or processes and techniques, with the target of minimizing negative social and environmental impacts (Kemp et al. 2001). Innovation should be distributed in the market (e.g. products) or implemented (e.g. processes) for obtaining economic impact. For diminishing adverse socio-environmental impacts, several factors need to be considered in organizational sustainable innovation including recycling, management of waste, and green design (Yew and Zhu 2019).

An increasing number of papers have addressed the significance as well as considerable role of

sustainable innovation in sustainable supply chain management implementation (de Vargas Mores et al. 2018). Silvestre and Ţîrcă (2019) argued that social problems including safety, poverty and human rights, as well as several pressing environmental issues have adverse impacts on supply chains and prevent companies from obtaining their sustainability targets and should be taken into account in organizational sustainable innovation. Vasilenko and Arbačiauskas (2013) deemed that building competitive advantage, R&D support, cost saving and requirement of clients, are firms motivation for attaining sustainable innovation. Iles and Martin (2013) considered that one of the key sustainable innovation aspects is risk management, and companies that do not take into consideration social factors, face more risk than other corporations. Tariq et al. (2017) argued that essential elements for promoting sustainable innovation include knowledge management and learning. In addition, organizational, social, cultural, and technological factors are other sustainability innovation attributes, which lead to market, economic and environmental performance outcome. Murphy and Gouldson (2000) concluded that innovation-friendly environmental policies have a positive influence on technological change and provide incentives that provoke environmental sustainability innovation factors in corporations.

Sustainable innovation plays a critical role in obtaining long-term sustainable development. Companies, supply chains and nations can attain their sustainability goals through implementing innovation factors. Sustainable innovation consists of innovative management approaches which lead to a company supply chain enhanced sustainability performance. Companies try to apply variety of innovation-based policies in their entire supply chain to obtain sustainable development. Social innovation, economic innovation, and environmental innovation are three dimensions of sustainable innovation. In this paper we focus on environmental aspect of sustainability innovation in an emerging economy manufacturing sector context, with the goal of increasing the understanding of this aspect.

Environmental sustainability innovation

According to Chen et al. (2006) environmental sustainability innovation can be defined as products and processes innovations which employ technologies for saving the energy, pollution prevention, recycling the waste and environmental management. These innovations promote green growth and meet the requirements of environmental protection. Environmental sustainability innovation has been taken into consideration as one of the main factors for improving the environmental, social, and financial results of corporations. A growing number of environmental sustainability initiatives are moving towards improving technological processes, obtaining competitive advantage, and reducing manufacturing cost (Varadarajan 2017).

According to Carlile (2002), achieving innovative solutions for environmental sustainability

needs improving and integrating practices in the entire organizational boundaries, also noted that environmental sustainability innovation needs a socio-technical transaction, which requires innovative technologies, as well as innovations in market logics. Iles and Martin (2013) argued that if companies mobilize their dynamic capabilities to address environmental sustainability issues and concern, they can easily bring new environmentally sustainable technologies and products to the market efficiently. Lin (2012) argued that the desire of firms for having resources and competencies from partners for obtaining environmental sustainability innovation is a key driver for creating cross-sector partnership.

In this sub-section environmental aspect of sustainable innovation was overviewed. Because of enhanced knowledge and concern of agencies and governments worldwide, firms are under pressure to utilize environmentally friendly processes and products. Utilizing environmental sustainability innovation standards can be an efficient innovative solution for overcoming environmental challenges and improving sustainability of organizational supply chains.

Existing works on environmental sustainability innovation

Environmental sustainability innovation can be described as a firm's impact on the environment and completing company environmental goals and attaining profit through it (Wong et al. 2014). A growing number of researchers have investigated environmental sustainability innovation from various contexts and categories. Chiou et al. (2011) analyzed the environmental performance of firms through employing green supply chain and environmental sustainability innovation. Based on the research findings environmental performance and competitive position of a company is significantly affected by applying environmental innovation sustainability factors. Zhu et al. (2012) investigated environmental sustainability innovation diffusion and its relationship to organizational improvement using Chinese manufacturing companies. Findings reveal that organizational characteristics and managers' attitudes, force companies to adopt innovations. They also found that manufacturing firms can be classified as early adopters, followers, and laggards based on innovation diffusion and adoption. Klewitz and Hansen (2014) investigated sustainability-oriented innovation in the context of small and medium size enterprises and found that green innovation practices can be classified into three main areas including product innovation, process innovation, and organizational innovation. De Medeiros et al. (2014) investigated critical factors for product innovation. According to the findings, knowledge about government policies and market, learnings relevant to innovation and investments in research, are the key points for success of green product innovation. Todeschini et al. (2020) investigated stakeholder's collaboration factors in the context of fashion industry using two case studies, with the target of achieving environmental sustainability innovation. They found that the main drivers for

obtaining environmentally sustainable innovation are external and competitive environment pressures, search for competitive advantage and capabilities development. Mousavi and Bossink (2020) investigated partnership among a firm and nongovernmental organizations for achieving environmental sustainability innovation. They found that learning, coordination, and reconfiguration identify the partnership progress. Shahzad et al. (2020) explored the relation of environmental sustainability to corporate social responsibility and environmental sustainability innovation, in the context of Pakistani manufacturing sector. They found that CSR activities need to be included in the environmental strategies of organizations for attaining environmental sustainability innovation. Other environmental sustainability innovation criteria were determined according to the review of literature and can be found in **Table 1**.

Table 1 Environmental sustainability innovation criteria according to the literature

Criteria	References
Initiatives for reducing carbon	Kannan et al. (2014); Kusi-Sarpong et al. (2019)
Green production development and operational capabilities	Gupta et al. (2020); Silva et al. (2019)
Initiatives and commitment for environmental issues	Borsatto and Amui (2019); Shahzad et al. (2020)
Implementing environmental policy, market demands and incentives for manufacturing green products	Carter et al. (2019); Saeed and Kersten (2019)
Investment in environment and economic benefits	Govindan et al. (2019); Silvestre and Țîrcă (2019)
Availability of resources and green competencies	Yew and Zhu (2019); Gupta et al. (2020)
Collaboration with rivals, research institutes and environmental groups	Mousavi and Bossink (2020); Silva et al. (2019)
Designing products for being reusable and energy efficient	Saeed and Kersten (2019); Todeschini et al. (2020)
Planning and organizational factors	Kusi-Sarpong et al. (2019); Gupta et al. (2020)
Environmental rules and regulations	Toke and Kalpande (2019); Mousavi and Bossink (2020)
Carrying out environmental audits	Borsatto and Amui (2019); Todeschini et al. (2020)
Designing products for diminishing their environmental impact	Gupta et al. (2020); Govindan et al. (2019)
Development of green logistics capabilities	Borsatto and Amui (2019); Luthra and Mangla (2018)
Foreign direct investment	Carter et al. (2019); Saeed and Kersten (2019)
Strategies to employ sustainable factors in supply chains	Silvestre and Țîrcă (2019); Luthra and Mangla (2018)
Selecting suppliers based on environmental factors	Yew and Zhu (2019); Borsatto and Amui (2019)
Technical help for technology improvement	Carter et al. (2019); Govindan et al. (2019)

Second sub-section of the literature review presented a review of environmental sustainability innovation, and the third sub-section introduced several studies related to this aspect. Environmental management concerns are receiving much more attention between corporations globally. Several authors have completed studies related to environmental aspect of sustainability innovation. Authors have investigated environmental sustainability innovation from different aspects.

Research gaps

Porter and Van der Linde (1995) argued that due to enhanced pressures from clients, regulators, and other stakeholders, employing innovation factors in sustainable supply chains has received much more attention. However, few papers have focused on environmental sustainability innovation,

whereas most of them have been conducted in developed countries context (De Medeiros et al. 2016), a limited number of papers have focused on emerging economies (e.g., Yang et al. 2015). Up to now, no paper has focused on investigating the interrelationships and interdependencies among environmental sustainability innovation factors in the context of emerging economies manufacturing sector. To close this gap, this paper proposes a criteria decision framework for investigating the interdependencies and interrelationships among environmental sustainability innovation factors in the context of an emerging economy nation manufacturing sector.

Nowadays companies are to a greater extent inclined towards utilizing environmental management factors into their processes and supply chain operations. Strict rules from government and social groups have inspired firms to employ environmental sustainability standards which can be considered as an edge over their competitors.

Research methodology

An improved Z-DEMATEL technique is utilized in this paper for investigating the interdependencies and interactions among various environmental sustainability innovation factors. **Fig. 1** presents a brief flowchart of this study overall process.
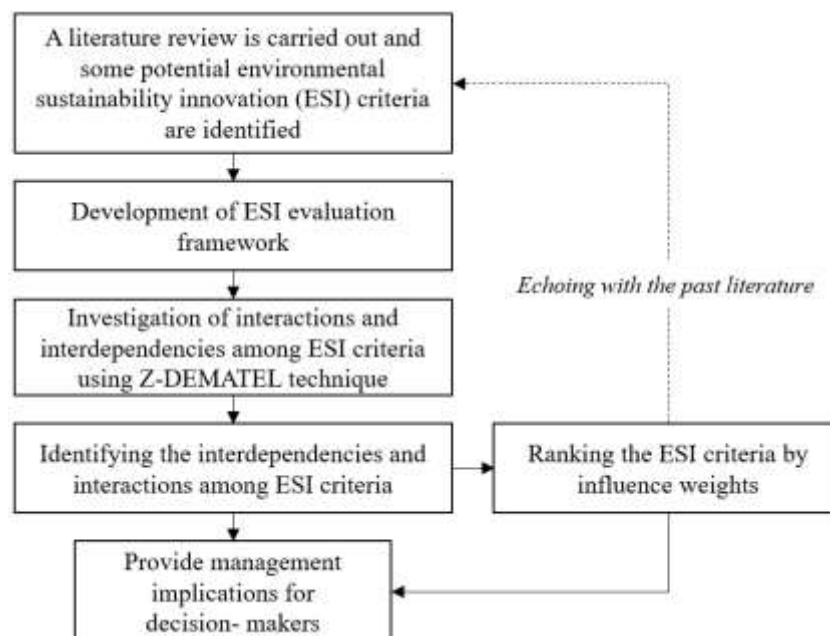

Fig. 1 A brief flowchart of the study overall process

The following content introduces the Z-DEMATEL technique. At first, Z-numbers concepts and the related computational processes are presented. Then, a complete set of evaluation scales for Z-

DEMATEL is formulated. This technique displays the Influential Network Relationship Map (INRM) to demonstrate interactions and interdependencies among factors. The detailed implementation steps of this model are described below.

Main concepts and Z-numbers computation

Zadeh (2011) proposed Z-numbers; it is a soft computation technique which can be applied for computation in not valid information environment. Evaluation value and its reliability are two types of Z-numbers fuzzy information. Recently, integrating Z-numbers with MCDM methods has been proposed by several authors, including the Z-AHP (Azadeh et al. 2013), Z-BWM (best worst method) (Aboutorab et al. 2018), Z-TOPSIS (Yaakob and Gegov 2016), Z-VIKOR (visekriterijumska optimizacija i kompromisno resenje) (Shen and Wang 2018). For further description, converting traditional fuzzy numbers into Z-numbers is described. Let's suppose a Z-number is written as $Z = \left(\tilde{F}, \tilde{R} \right)$, $\tilde{F}$ is the triangular fuzzy numbers of the assessment value. $\tilde{R}$ is $\tilde{F}$ reliability (degree of confidence), where $\tilde{F} = \left(f, \mu_{\tilde{F}} \right) \big| x \in [0, 1]$ and $\tilde{R} = \left(x, \mu_{\tilde{R}} \right) \big| x \in [0, 1]$ are both triangular membership functions. We can transform $\tilde{R}$ to a crisp value as displayed in Eq. (1).

$$\alpha = \frac{\int^x \mu_{\tilde{R}} \, dx}{\int^{\mu_{\tilde{R}}} dx} \tag{1}$$

Then, the reliability weight α is added to the assessment value $\tilde{F}$, and the weighted Z-numbers are displayed in Eq. (2).

$$Z^\alpha = \left\{ \left(x, \mu_{\tilde{F}^\alpha} \right) \big| \mu_{\tilde{F}^\alpha}(x) = \alpha \mu_{\tilde{F}}(x), \ x \in \sqrt{\alpha} x \right\} \tag{2}$$

Here, consider an assessment system has n factors/alternatives $c_i = \left(c_1, c_2, \ldots, c_n \right)$. Pairwise comparisons should be conducted to identify the mutual influence between factors/alternatives, it means, the influence degree of c_i on c_j. The assessment scale contains "No influence (N)", "Low influence (L)", "Medium influence (M)", "High influence (H)", and "Very high influence (VH)". These linguistic variables are then converted into the corresponding membership functions (fuzzy numbers). The conversion rules are shown in **Table 2**.

Table 2 DEMATEL's influence scales and membership functions (Liou et al. (2008))

Linguistic variable	Code	Membership function
No influence	N	(0, 0, 1)
Low influence	L	(0, 1, 2)
Medium influence	M	(1, 2, 3)
High influence	H	(2, 3, 4)
Very high influence	VH	(3, 4, 4)

The experts were requested to identify the confidence degree in the survey, which is the assessment reliability. The evaluation scale includes "Very low (VL)", "Low (L)", "Medium (M)", "High (H)", and "Very high (VH)". **Table 3** displays the reliability rating scale.

Table 3 Reliability scale and the membership functions (Aboutorab et al. (2018))

Linguistic variable	Code	Membership function
Very low	VL	(0, 0, 0.3)
Low	L	(0.1, 0.3, 0.5)
Medium	M	(0.3, 0.5, 0.7)
High	H	(0.5, 0.7, 0.9)
Very high	VH	(0.7, 1, 1)

According to **Table 2** and **Table 3**, generally 25 Z-numbers combinations can be attained. **Table 4** indicates Z-numbers linguistic variables as well as their membership functions.

Table 4 Z-numbers linguistic variables and their corresponding membership functions

	level of Influence				
Reliability	N	L	M	H	VH
VL	(0, 0, 0.316)	(0, 0.316, 0.632)	(0.316, 0.632, 0.949)	(0.632, 0.949, 1.265)	(0.949, 1.265, 1.265)
L	(0, 0, 0.548)	(0, 0.548, 1.096)	(0.548, 1.096, 1.644)	(1.096, 1.644, 2.192)	(1.644, 2.192, 2.192)
M	(0, 0, 0.707)	(0, 0.707, 1.414)	(0.707, 1.414, 2.121)	(1.414, 2.121, 2.828)	(2.121, 2.828, 2.828)
H	(0, 0, 0.837)	(0, 0.837, 1.673)	(0.837, 1.673, 2.510)	(1.673, 2.510, 3.347)	(2.510, 3.347, 3.347)
VH	(0, 0, 0.949)	(0, 0.949, 1.897)	(0.949, 1.897, 2.846)	(1.897, 2.846, 3.795)	(2.846, 3.795, 3.795)

Modified Z-DEMATEL technique

DEMATEL method determines the interdependencies and interrelationships among criteria, through a structural INRM that assists experts to understand which criteria affect other factors, and which factors are affected (Gabus and Fontela 1972). In an evaluation environment that contains complexity as well as uncertainty, it is challenging for decision-makers to employ crisp value to show their actual feelings. There are a large number of fuzzy theory methods, integrated with DEMATEL model to handle uncertainty issues. Unfortunately, these methods don't consider experts' confidence degree on the assessment value. This work integrates Z-numbers into DEMATEL technique. This novel model consists of two unique advantages. First, group decision-making reliability in the assessment can be identified, Second, the shape of triangular fuzzy numbers for calculations can be retained to avoid the information loss. Through the improvement of this research, Z- based DEMATEL technique can obtain a set of criteria influential weights. The modified Z-DEMATEL steps are explained below:

Step 1. Identifying a set of assessment criteria

A group of decision-makers are formed to determine a set of assessment criteria (c_i). In this study, we investigate the interdependencies among ten environmental sustainability innovation criteria,

$$c_i = \{c_1,\ c_2,\ldots,\ c_n\}.$$

Step 2. Identifying the direct relationship matrix

There are (*n*) criteria that should be assessed for their influence. Every manager judges the direct influence of the criteria i on the criteria j on the basis of the assessment scale of **Table 2** and also checks its confidence based on the **Table 3** reliability scale. The second step introduces the concept of Z-numbers into each DEMATEL questionnaire. In order to avoid the influence of some managers extreme opinions, causing the distortion of the assessment results, an optimization model is presented to acquire group judgment (Wu et al. 2016). The model is shown in Eq. (3).

$$\min\ z = \sum_{k=1}^{K}\left(l_{ij}-l_{ij}^{k}\right)^2 + \sum_{k=1}^{K}\left(m_{ij}-m_{ij}^{k}\right)^2 + \sum_{k=1}^{K}\left(u_{ij}-u_{ij}^{k}\right)^2$$

$$s.\,t. \begin{cases} \min_k\ l_{ij}^k \le l_{ij} \le \max_k\ l_{ij}^k, \\ \min_k\ m_{ij}^k \le m_{ij} \le \max_k\ m_{ij}^k, \\ \min_k\ u_{ij}^k \le u_{ij} \le \max_k\ u_{ij}^k, \\ \quad l_{ij} \le m_{ij} \le u_{ij}. \end{cases} \tag{3}$$

k indicates a decision-maker, *k* = 1, 2, ..., *K*. In addition, l_{ij}, m_{ij}, and u_{ij} shows the group judgement minimum, intermediate, and maximum values. Wu et al. (2016) proved that the model optimal solution can be acquired by computing partial differentiation of l_{ij}, as displayed in Eq. (4), same as for m_{ij} and

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u_{ij}.

$$\frac{\partial z}{\partial l_{ij}} = 2\sum\nolimits_{k=1}^{K}\left(l_{ij} - l_{ij}^{k}\right)\cdot 1 = 0$$

$$\Rightarrow l_{ij} = \frac{\sum\nolimits_{k=1}^{K} l_{ij}^{k}}{K} \tag{4}$$

All experts' opinions can be incorporated into a group direct relationship matrix $\otimes A$ using Eqs. (3–4), as shown in Eq. (5).

$$\otimes A = \left[\otimes a_{ij}\right]_{n\times n} = \begin{bmatrix} \otimes a_{11} & \otimes a_{12} & \cdots & \otimes a_{1j} & \cdots & \otimes a_{1n} \\ \otimes a_{21} & \otimes a_{22} & \cdots & \otimes a_{2j} & \cdots & \otimes a_{2n} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ \otimes a_{i1} & \otimes a_{i2} & \cdots & \otimes a_{ij} & \cdots & \otimes a_{in} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ \otimes a_{n1} & \otimes a_{n2} & \cdots & \otimes a_{nj} & \cdots & \otimes a_{nn} \end{bmatrix}_{n\times n}, i = j = 1,\ 2,\ldots,\ n. \tag{5}$$

where $\otimes a_{ij} = \left(a_{ij}^{L},\ a_{ij}^{M},\ a_{ij}^{U}\right)$. Here, DEMATEL requires that the diagonal factors in the matrix be 0, i.e.

$\otimes a_{ij} = 0$ (when $i = j$).

Step 3. Construction of normalized direct relationship matrix

Because the range of $\otimes a_{ij}$ value is from 0 to 4, we can convert this assessment value to 0 to 1 using normalization, as shown in Eqs. (6–7).

$$\otimes X = \left[\otimes x_{ij}\right]_{n\times n} = \begin{bmatrix} \varepsilon\cdot\otimes a_{11} & \varepsilon\cdot\otimes a_{12} & \cdots & \varepsilon\cdot\otimes a_{1j} & \cdots & \varepsilon\cdot\otimes a_{1n} \\ \varepsilon\cdot\otimes a_{21} & \varepsilon\cdot\otimes a_{22} & \cdots & \varepsilon\cdot\otimes a_{2j} & \cdots & \varepsilon\cdot\otimes a_{2n} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ \varepsilon\cdot\otimes a_{i1} & \varepsilon\cdot\otimes a_{i2} & \cdots & \varepsilon\cdot\otimes a_{ij} & \cdots & \varepsilon\cdot\otimes a_{in} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ \varepsilon\cdot\otimes a_{n1} & \varepsilon\cdot\otimes a_{n2} & \cdots & \varepsilon\cdot\otimes a_{nj} & \cdots & \varepsilon\cdot\otimes a_{nn} \end{bmatrix}_{n\times n}, i = j = 1,\ 2,\ldots,\ n. $$

$$\tag{6}$$

where $\otimes x_{ij} = \left(x_{ij}^{L},\ x_{ij}^{M},\ x_{ij}^{U}\right)$.

$$\varepsilon = \min\left\{\frac{1}{\max_{i}\sum_{j=1}^{n} a_{ij}^{U}}, \frac{1}{\max_{j}\sum_{i=1}^{n} a_{ij}^{U}}\right\} \tag{7}$$

Step 4. Obtaining the total influence matrix

Using Eqs. (9–10), the $\otimes X$ (Eq. 8) is integrated into a total influence matrix. A faster solution formula is attained from Eq. (10), as the Eq. (9) operation procedure is cumbersome.

$$\otimes T = \left[\otimes t_{ij}\right]_{n \times n} = \begin{bmatrix} \otimes t_{11} & \otimes t_{12} & \cdots & \otimes t_{1j} & \cdots & \otimes t_{1n} \\ \otimes t_{21} & \otimes t_{22} & \cdots & \otimes t_{2j} & \cdots & \otimes t_{2n} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ \otimes t_{i1} & \otimes t_{i2} & \cdots & \otimes t_{ij} & \cdots & \otimes t_{in} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ \otimes t_{n1} & \otimes t_{n2} & \cdots & \otimes t_{nj} & \cdots & \otimes t_{nn} \end{bmatrix}_{n \times n}, i = j = 1,\ 2,\ldots,\ n. \tag{8}$$

where $\otimes t_{ij} = \left(t_{ij}^L,\ t_{ij}^M,\ t_{ij}^U\right)$.

$$\otimes T = \otimes X + \otimes X^2 + \cdots + \otimes X^\infty \tag{9}$$

$$\otimes T = \otimes X + \otimes X^2 + \cdots + \otimes X^\infty = \otimes X\left(I + \otimes X + \otimes X^2 + \cdots + \otimes X^{\infty-1}\right)$$
$$= \otimes X\left(I - \otimes X^\infty\right)\left(I - \otimes X\right)^{-1} = \otimes X\left(I - \otimes X\right)^{-1} \tag{10}$$

where $\otimes X^\infty = \left[0\right]_{n \times n}$ and I are identity matrices.

Step 5. Constructing INRM to determine the mutual influence of the environmental sustainability innovation criteria

As in Eqs. (11–12), $\otimes r$ is gained by adding up each column of the total influence matrix $\otimes T$. Similarly, as in Eqs. (13–14), $\otimes s$ is obtained by adding up each row.

$$\otimes r = \left[\otimes r_i\right]_{n \times 1} = \left(\otimes r_1,\ \otimes r_2,\ldots,\ \otimes r_i,\ldots,\ \otimes r_n\right) \tag{11}$$

$$\left[\otimes r_i\right]_{n \times 1} = \left[\sum\nolimits_{j=1}^{n} \otimes t_{ij}\right]_{n \times 1} \tag{12}$$

$$\otimes s = \left[\otimes s_j\right]_{1 \times n} = \left(\otimes s_1,\ \otimes s_2,\ldots,\ \otimes s_j,\ldots,\ \otimes s_n\right)^T \tag{13}$$

$$\left[\otimes s_j\right]_{1 \times n} = \left[\sum\nolimits_{i=1}^{n} \otimes t_{ij}\right]_{1 \times n} = \left[\otimes s_i\right]_{n \times 1}^T \tag{14}$$

where symbol "superscript T" denotes for matrix transpose. In addition, $\otimes r_i = \left(r_i^L,\ r_i^M,\ r_i^U\right)$ and

$\otimes s_i = \left(s_i^L,\ s_i^M,\ s_i^U\right)$. $\otimes r_i + \otimes s_i$ represents the strength of influences given and received. And,

$\otimes r_i - \otimes s_i$ is the index of the net influence. Here, we can use $\otimes r_i - \otimes s_i$ to measure whether the

criterion is a causal factor or an affected factor. If $\otimes r_i - \otimes s_i$ is a positive value, it means that criterion

i has a significant effect on other criteria, which is called a causal factor; otherwise, if $\otimes r_i - \otimes s_i$ is a

negative value, it means that criterion i is affected by other factors, which is called an affected factor.

The average method is used to de-fuzzy the fuzzy value (for example, $\otimes \varphi = \left(\varphi^L, \varphi^M, \varphi^U \right)$) to obtain

the crisp value (φ), as shown in Eq. (15).

$$\varphi = \frac{1}{3}\left(\varphi^L + \varphi^M + \varphi^U \right) \tag{15}$$

After $\otimes r_i$ and $\otimes s_i$ are put through the de-fuzzy procedure of Eq. (15), r_i and s_i can be

obtained, respectively. Using $r_i + s_i$ as the horizontal axis and $r_i - s_i$ as the vertical axis, the

relative coordinate position of each project can be clearly marked. The total influence matrix $\otimes T$
is used to identify the influence among criteria, and an arrow (indicating the direction of influence)
is drawn to generate a systematic INRM.

Step 6. Determination of influential weight of the criteria

Criteria total influence on the assessment system is determined, so the influential weight of the
criteria can be identified through Eq. (16). Sum of weights needed here equals to 1 (Lo et al. 2020).

$$w_i = \frac{\left(r_i + s_i \right)}{\sum_{i=1}^{n} \left(r_i + s_i \right)} \tag{16}$$

Results and analysis

This Section begins with an introduction of a real case example. Next sub-sections focus on
evaluation framework development process, and the application of Z-DEMATEL methodology to the
case.

Real case example

The case country of this work is Iran, which is in Southwest part of Asia. According to Bai et al.
(2019) sustainability initiatives as well as manufacturing practices in Iran are immature and require
much more focus. To attain the research objectives of this paper, seven managers from seven different
Iranian manufacturing firms were chosen. The managers have different profiles, at least ten years of
working experience, and were selected from diverse companies. They are expert and knowledgeable
in their specific fields. Moreover, for obtaining homogeneity they were purposely chosen from various

backgrounds to be sure that the outcomes are more generalizable for the industry and to another industrial context. Detailed information of managers can be found in **Table 5.**

Table 5 Profile of managers involved in this study

Manager	Firm	Expertise	Experience (years)
Manager 1	Automotive corporation	Supply chain manager	14
Manager 2	Steel corporation	Financial manager	12
Manager 3	Electronic corporation	Marketing manager	11
Manager 4	Tile corporation	Purchasing manager	15
Manager 5	Plastic corporation	Assistant supply manager	17
Manager 6	Automobile corporation	General manager	13
Manager 7	Motorcycle corporation	Production manager	10

The process of framework development

This sub-section explains the development process of the evaluation framework of this work. After reviewing the literature, several environmental sustainability innovation criteria were identified (**Table 1)**. Then, a survey with the mentioned criteria was designed and sent to each of seven managers for their review and consideration at different times. They were asked to vote for each criterion and identify which of the criteria are more relevant to their corporation supply chains by displaying (Yes) as approved, and (No) as not approved. Moreover, they were requested to add any more related environmental sustainability innovation criteria based on their experience and expertise. The authors confirmed with the managers that those criteria that would be approved by at least five managers would be selected for the next round of review. One additional criterion (*Technical experience availability and investment in R&D for green practices-ESI 2*) was suggested by one of the managers. Generally, three rounds of interviews were conducted for refining the set of criteria. Finally, 10 criteria were selected, and took into consideration in the final list, as shown in **Table 6**.

Table 6 Environmental sustainability innovation criteria decision framework

Criteria	Description
Collaboration with rivals, research institutes and environmental groups (ESI 1)	Collaboration among different units, aiming to manufacture green products
Technical experience availability and investment in R&D for green practices (ESI 2)	Accessibility of technical skills for attaining sustainable practices
Green production development and operational capabilities (ESI 3)	Employing green practices for manufacturing environmentally- friendly products
Designing products for diminishing their environmental impact (ESI 4)	Designing products with the target of reducing their adverse effect on environment
Initiatives and commitment for environmental issues (ESI 5)	Employing diverse environmental standards in companies
Implementing environmental policy, market demands and incentives for manufacturing green products (ESI 6)	Applying different environmental management initiatives and policy to produce environmentally sustainable products
Investment in environment and economic benefits (ESI 7)	It refers to the environmental investments and potential economic profits that can be achieved
Designing products for being reusable and energy efficient (ESI 8)	Considering environmental management standards while designing products, such as being reusable and being energy efficient
Carrying out environmental audits (ESI 9)	Performing audits in firms
Availability of resources and green competencies (ESI 10)	Employing efficient strategies for having resources available and green competencies

Application of Z-DEMATEL methodology to the case

Seven managers separately evaluated the degree of influence among the criteria. They answered the content of the Z-DEMATEL questionnaire based on the linguistic variables given in **Table 1** and **Table 2**. **Table 7** presents the evaluation results of the first manager. Then, according to **Table 3**, we convert the linguistic variables into Z-numbers to obtain **Table 8**. For example, evaluation of ES1 and ES2 by first manager is (M, VH), and the corresponding Z-number is (0.949, 1.897, 2.846). A complete Z-DEMATEL questionnaire can form a 10×10 matrix, and the diagonal elements of the matrix should be (0, 0, 0) (which means there is no self-dependence).

Table 7 Initial evaluation matrix of the first manager (linguistic variables)

	ESI 1	ESI 2	ESI 3	ESI 4	ESI 5	ESI 6	ESI 7	ESI 8	ESI 9	ESI 10
ESI 1	-	M, VH	H, VH	H, VH	M, H	H, H	M, H	M, H	H, H	M, VH
ESI 2	M, H	-	VH, VH	M, VH	M, H	M, VH	H, H	H, VH	VH, VH	VH, VH
ESI 3	H, H	H, VH	-	VH, H	H, VH	VH, H	VH, H	H, H	H, H	VH, H
ESI 4	L, VH	L, H	M, H	-	M, H	H, H	VH, VH	VH, VH	H, H	H, H
ESI 5	VH, VH	H, H	H, H	M, VH	-	H, H	H, H	M, H	H, H	M, VH
ESI 6	H, VH	H, H	H, VH	VH, VH	L, VH	-	H, VH	M, VH	M, H	M, H
ESI 7	H, H	H, H	VH, H	M, VH	H, VH	M, H	-	L, VH	M, H	H, VH
ESI 8	H, VH	M, VH	M, H	VH, VH	H, VH	M, VH	M, H	-	VH, VH	H, H
ESI 9	N, H	H, VH	H, H	H, H	M, VH	VH, H	M, H	H, VH	-	H, VH
ESI 10	H, VH	M, H	L, VH	H, VH	VH, H	M, H	M, VH	H, H	VH, VH	-

Table 8 Initial evaluation matrix of the first expert (Z numbers)

	ESI 1	ESI 2	ESI 3	ESI 4	ESI 5	ESI 6	ESI 7	ESI 8	ESI 9	ESI 10
ESI 1	(0, 0, 0)	(0.949, 1.897, 2.846)	(1.897, 2.846, 3.795)	(1.897, 2.846, 3.795)	(0.837, 1.673, 2.510)	(1.673, 2.510, 3.347)	(0.837, 1.673, 2.510)	(0.837, 1.673, 2.510)	(1.673, 2.510, 3.347)	(0.949, 1.897, 2.846)
ESI 2	(0.837, 1.673, 2.510)	(0, 0, 0)	(2.846, 3.795, 3.795)	(0.949, 1.897, 2.846)	(0.837, 1.673, 2.510)	(0.949, 1.897, 2.846)	(1.673, 2.510, 3.347)	(1.897, 2.846, 3.795)	(2.846, 3.795, 3.795)	(2.846, 3.795, 3.795)
ESI 3	(1.673, 2.510, 3.347)	(1.897, 2.846, 3.795)	(0, 0, 0)	(2.510, 3.347, 3.347)	(1.897, 2.846, 3.795)	(2.510, 3.347, 3.347)	(2.510, 3.347, 3.347)	(1.673, 2.510, 3.347)	(1.673, 2.510, 3.347)	(2.510, 3.347, 3.347)
ESI 4	(0.000, 0.949, 1.897)	(0.000, 0.837, 1.673)	(0.837, 1.673, 2.510)	(0, 0, 0)	(0.837, 1.673, 2.510)	(1.673, 2.510, 3.347)	(2.846, 3.795, 3.795)	(2.846, 3.795, 3.795)	(1.673, 2.510, 3.347)	(1.673, 2.510, 3.347)
ESI 5	(2.846, 3.795, 3.795)	(1.673, 2.510, 3.347)	(1.673, 2.510, 3.347)	(0.949, 1.897, 2.846)	(0, 0, 0)	(1.673, 2.510, 3.347)	(1.673, 2.510, 3.347)	(0.837, 1.673, 2.510)	(1.673, 2.510, 3.347)	(0.949, 1.897, 2.846)
ESI 6	(1.897, 2.846, 3.795)	(1.673, 2.510, 3.347)	(1.897, 2.846, 3.795)	(2.846, 3.795, 3.795)	(0.000, 0.949, 1.897)	(0, 0, 0)	(1.897, 2.846, 3.795)	(0.949, 1.897, 2.846)	(0.837, 1.673, 2.510)	(0.837, 1.673, 2.510)
ESI 7	(1.673, 2.510, 3.347)	(1.673, 2.510, 3.347)	(2.510, 3.347, 3.347)	(0.949, 1.897, 2.846)	(1.897, 2.846, 3.795)	(0.837, 1.673, 2.510)	(0, 0, 0)	(0.000, 0.949, 1.897)	(0.837, 1.673, 2.510)	(1.897, 2.846, 3.795)
ESI 8	(1.897, 2.846, 3.795)	(0.949, 1.897, 2.846)	(0.837, 1.673, 2.510)	(2.846, 3.795, 3.795)	(1.897, 2.846, 3.795)	(0.949, 1.897, 2.846)	(0.837, 1.673, 2.510)	(0, 0, 0)	(2.846, 3.795, 3.795)	(1.673, 2.510, 3.347)
ESI 9	(0.000, 0.000, 0.837)	(1.897, 2.846, 3.795)	(1.673, 2.510, 3.347)	(1.673, 2.510, 3.347)	(0.949, 1.897, 2.846)	(2.510, 3.347, 3.347)	(0.837, 1.673, 2.510)	(1.897, 2.846, 3.795)	(0, 0, 0)	(1.897, 2.846, 3.795)
ESI 10	(1.897, 2.846, 3.795)	(0.837, 1.673, 2.510)	(0.000, 0.949, 1.897)	(1.897, 2.846, 3.795)	(2.510, 3.347, 3.347)	(0.837, 1.673, 2.510)	(0.949, 1.897, 2.846)	(1.673, 2.510, 3.347)	(2.846, 3.795, 3.795)	(0, 0, 0)

Using Eqs. (3–4) to integrate the assessment data of seven managers to construct an average evaluation matrix (Eq. 5), as shown in **Table 9**. According to Eqs. (6–10), the total influence matrix (**Table 10**) can be constructed, which considers the direct and indirect impacts of all criteria.

Table 9 Average initial evaluation matrix

	ESI 1	ESI 2	ESI 3	ESI 4	ESI 5	ESI 6	ESI 7	ESI 8	ESI 9	ESI 10
ESI 1	(0, 0, 0)	(0.733, 1.482, 2.231)	(1.124, 1.992, 2.861)	(0.781, 1.546, 2.431)	(0.988, 1.841, 2.694)	(1.227, 2.080, 2.933)	(1.140, 1.889, 2.758)	(0.988, 1.721, 2.574)	(1.124, 1.737, 2.487)	(1.092, 1.825, 2.678)
ESI 2	(0.972, 1.825, 2.678)	(0, 0, 0)	(1.307, 2.088, 2.854)	(0.781, 1.666, 2.550)	(0.733, 1.602, 2.470)	(0.765, 1.682, 2.598)	(0.919, 1.599, 2.415)	(1.124, 2.008, 2.893)	(1.156, 1.921, 2.670)	(1.618, 2.487, 2.981)
ESI 3	(1.275, 2.176, 3.077)	(0.917, 1.682, 2.431)	(0, 0, 0)	(0.749, 1.514, 2.279)	(1.034, 1.916, 2.798)	(1.156, 2.056, 2.702)	(0.837, 1.554, 2.287)	(1.124, 2.008, 2.893)	(0.972, 1.806, 2.641)	(1.379, 2.263, 3.029)
ESI 4	(0.646, 1.546, 2.447)	(1.052, 1.833, 2.750)	(0.970, 1.820, 2.670)	(0, 0, 0)	(1.140, 1.889, 2.638)	(0.765, 1.411, 2.328)	(1.020, 1.769, 2.503)	(1.677, 2.524, 3.136)	(0.988, 1.737, 2.487)	(1.108, 1.857, 2.742)
ESI 5	(1.291, 2.038, 2.514)	(1.140, 1.785, 2.532)	(0.917, 1.307, 2.073)	(1.310, 2.160, 2.891)	(0, 0, 0)	(1.315, 1.912, 2.662)	(0.869, 1.618, 2.503)	(1.227, 2.080, 2.933)	(1.108, 1.992, 2.758)	(0.988, 1.737, 2.588)
ESI 6	(1.379, 2.008, 2.774)	(0.885, 1.753, 2.622)	(1.156, 2.056, 2.957)	(1.259, 2.128, 2.861)	(1.052, 1.969, 2.886)	(0, 0, 0)	(1.020, 1.801, 2.599)	(1.411, 2.192, 2.989)	(0.630, 1.395, 2.279)	(1.363, 2.112, 2.877)
ESI 7	(0.733, 1.602, 2.470)	(1.108, 1.976, 2.726)	(1.937, 2.838, 3.348)	(1.140, 1.921, 2.702)	(0.749, 1.602, 2.454)	(0.494, 1.227, 2.080)	(0, 0, 0)	(1.243, 2.144, 2.806)	(0.869, 1.618, 2.367)	(1.562, 2.447, 3.061)
ESI 8	(1.897, 2.846, 3.659)	(1.445, 2.311, 3.058)	(1.140, 1.889, 2.774)	(1.666, 2.431, 2.822)	(2.088, 3.005, 3.667)	(0.781, 1.698, 2.614)	(1.039, 1.753, 2.468)	(0, 0, 0)	(1.985, 2.902, 3.412)	(1.036, 1.870, 2.603)
ESI 9	(0.848, 1.594, 2.460)	(1.172, 1.817, 2.718)	(1.172, 1.953, 2.870)	(0.956, 1.790, 2.505)	(0.885, 1.666, 2.583)	(0.956, 1.671, 2.266)	(0.595, 1.071, 1.902)	(0.781, 1.647, 2.513)	(0, 0, 0)	(0.749, 1.602, 2.454)
ESI 10	(1.124, 2.008, 2.893)	(0.901, 1.666, 2.567)	(0.000, 0.779, 1.693)	(1.052, 1.833, 2.750)	(1.071, 1.937, 2.683)	(0.781, 1.427, 2.344)	(1.004, 1.769, 2.535)	(1.243, 2.128, 2.893)	(1.153, 1.916, 2.663)	(0, 0, 0)

Table 10 Total influence matrix

	ESI 1	ESI 2	ESI 3	ESI 4	ESI 5	ESI 6	ESI 7	ESI 8	ESI 9	ESI 10
ESI 1	(0.021, 0.108, 0.725)	(0.046, 0.151, 0.764)	(0.060, 0.170, 0.793)	(0.048, 0.158, 0.775)	(0.056, 0.170, 0.813)	(0.061, 0.156, 0.758)	(0.058, 0.156, 0.737)	(0.058, 0.171, 0.827)	(0.061, 0.164, 0.778)	(0.061, 0.173, 0.814)
ESI 2	(0.056, 0.175, 0.829)	(0.020, 0.104, 0.701)	(0.066, 0.176, 0.805)	(0.049, 0.166, 0.791)	(0.047, 0.167, 0.820)	(0.045, 0.151, 0.760)	(0.051, 0.151, 0.737)	(0.062, 0.185, 0.850)	(0.063, 0.175, 0.796)	(0.080, 0.199, 0.836)
ESI 3	(0.067, 0.188, 0.842)	(0.053, 0.163, 0.783)	(0.020, 0.105, 0.710)	(0.048, 0.162, 0.783)	(0.058, 0.178, 0.830)	(0.059, 0.150, 0.764)	(0.048, 0.150, 0.734)	(0.063, 0.186, 0.851)	(0.056, 0.172, 0.796)	(0.072, 0.192, 0.837)
ESI 4	(0.046, 0.164, 0.811)	(0.058, 0.165, 0.783)	(0.055, 0.166, 0.790)	(0.021, 0.106, 0.695)	(0.062, 0.175, 0.814)	(0.045, 0.154, 0.742)	(0.055, 0.154, 0.731)	(0.082, 0.199, 0.847)	(0.058, 0.168, 0.781)	(0.062, 0.176, 0.818)
ESI 5	(0.069, 0.181, 0.805)	(0.062, 0.164, 0.769)	(0.055, 0.150, 0.764)	(0.069, 0.181, 0.784)	(0.023, 0.110, 0.718)	(0.066, 0.150, 0.745)	(0.051, 0.150, 0.724)	(0.068, 0.186, 0.833)	(0.063, 0.176, 0.781)	(0.060, 0.173, 0.805)
ESI 6	(0.072, 0.185, 0.853)	(0.053, 0.168, 0.809)	(0.063, 0.179, 0.829)	(0.067, 0.185, 0.821)	(0.061, 0.183, 0.853)	(0.019, 0.161, 0.691)	(0.056, 0.161, 0.762)	(0.075, 0.195, 0.875)	(0.047, 0.162, 0.804)	(0.073, 0.191, 0.854)
ESI 7	(0.049, 0.172, 0.820)	(0.060, 0.175, 0.789)	(0.088, 0.204, 0.818)	(0.062, 0.177, 0.793)	(0.049, 0.170, 0.816)	(0.037, 0.098, 0.741)	(0.019, 0.098, 0.653)	(0.068, 0.193, 0.845)	(0.054, 0.169, 0.784)	(0.079, 0.201, 0.836)
ESI 8	(0.095, 0.231, 0.938)	(0.078, 0.204, 0.878)	(0.069, 0.192, 0.880)	(0.086, 0.212, 0.876)	(0.101, 0.234, 0.935)	(0.053, 0.175, 0.833)	(0.062, 0.175, 0.810)	(0.031, 0.140, 0.835)	(0.099, 0.229, 0.895)	(0.068, 0.202, 0.904)
ESI 9	(0.049, 0.155, 0.770)	(0.059, 0.155, 0.742)	(0.059, 0.160, 0.756)	(0.052, 0.157, 0.740)	(0.050, 0.156, 0.771)	(0.050, 0.122, 0.702)	(0.037, 0.122, 0.675)	(0.048, 0.160, 0.786)	(0.018, 0.096, 0.657)	(0.047, 0.157, 0.768)
ESI 10	(0.059, 0.172, 0.804)	(0.050, 0.154, 0.758)	(0.020, 0.126, 0.741)	(0.056, 0.163, 0.768)	(0.057, 0.169, 0.795)	(0.044, 0.149, 0.724)	(0.052, 0.149, 0.714)	(0.064, 0.180, 0.819)	(0.061, 0.167, 0.767)	(0.020, 0.105, 0.705)

The execution process of Z-DEMATEL maintains the fuzzy numbers form. Through Eqs. (11–14), the fuzzy total and net influences of each criterion ($\otimes r_i + \otimes s_i$ and $\otimes r_i - \otimes s_i$) can be found in **Table 11**. When the values in the fuzzy net influence are all negative, it means that the criterion is

significantly affected by other criteria. Next, obtain the crisp values of each element through the defuzzification (**Eq. 15**), and further calculate the influence weights of the criteria. The analysis results of Z-DEMATEL and the ranking of criteria are shown in **Table 12**.

Table 11 The total influence and net influence (Z numbers)

	$\otimes r_i$	$\otimes s_i$	$\otimes r_i + \otimes s_i$	$\otimes r_i - \otimes s_i$
ESI 1	(0.530, 1.585, 7.784)	(0.586, 1.731, 8.198)	(1.116, 3.316, 15.982)	(-0.056, -0.146, -0.413)
ESI 2	(0.539, 1.653, 7.924)	(0.540, 1.603, 7.777)	(1.078, 3.256, 15.701)	(-0.001, 0.050, 0.148)
ESI 3	(0.544, 1.663, 7.930)	(0.555, 1.628, 7.886)	(1.099, 3.291, 15.817)	(-0.011, 0.036, 0.044)
ESI 4	(0.544, 1.618, 7.812)	(0.559, 1.666, 7.825)	(1.103, 3.284, 15.637)	(-0.014, -0.048, -0.013)
ESI 5	(0.585, 1.633, 7.729)	(0.564, 1.712, 8.167)	(1.149, 3.345, 15.896)	(0.021, -0.079, -0.438)
ESI 6	(0.586, 1.709, 8.152)	(0.478, 1.500, 7.459)	(1.064, 3.209, 15.611)	(0.108, 0.209, 0.693)
ESI 7	(0.565, 1.702, 7.894)	(0.489, 1.465, 7.278)	(1.054, 3.168, 15.173)	(0.077, 0.237, 0.616)
ESI 8	(0.742, 1.994, 8.785)	(0.619, 1.796, 8.369)	(1.361, 3.791, 17.154)	(0.123, 0.198, 0.416)
ESI 9	(0.469, 1.463, 7.366)	(0.578, 1.677, 7.839)	(1.047, 3.140, 15.206)	(-0.109, -0.214, -0.473)
ESI 10	(0.484, 1.526, 7.596)	(0.622, 1.769, 8.176)	(1.106, 3.295, 15.771)	(-0.138, -0.243, -0.580)

Table 12 The Z-DEMATEL results

	r_i	s_i	$r_i + s_i$	$r_i - s_i$	Influential weight	Rank
ESI 1	3.300	3.505	6.805	-0.205	0.101	2
ESI 2	3.372	3.306	6.678	0.066	0.099	6
ESI 3	3.379	3.356	6.736	0.023	0.100	4
ESI 4	3.325	3.350	6.675	-0.025	0.099	7
ESI 5	3.316	3.481	6.797	-0.165	0.101	3
ESI 6	3.482	3.146	6.628	0.337	0.098	8
ESI 7	3.387	3.077	6.465	0.310	0.096	9
ESI 8	3.840	3.595	7.435	0.246	0.110	1
ESI 9	3.100	3.365	6.464	-0.265	0.096	10
ESI 10	3.202	3.522	6.724	-0.320	0.100	5

ESI 8 and ESI 9 have the largest and smallest total influences, respectively. However, in terms of net influence, ESI 6 has a maximum value of 0.337, but it is not the criterion for the maximum total influence. This result shows that ESI 6 has only a slight strength of influence received. The influence weights of the criteria can be obtained by Eq. (16). The top three ranked criteria are ESI 8, ESI 1, and ESI 5. Although the results of our analysis can determine the priority of the criteria, in fact, their

difference of the weights are not too large, because the influence relationship among them is close. Therefore, the next step is to determine the influence network of the criteria through INRM.

Fig. 1 clearly depicts the relative position of each criterion. The criterion with the greater total influence will approach the right, and the criterion with the greater net influence will approach the top. The criterion at the end of the arrow indicates that it is affected. ESI 8 is a criterion that mainly affects others, while ESI 10 is deeply influenced by multiple criteria.
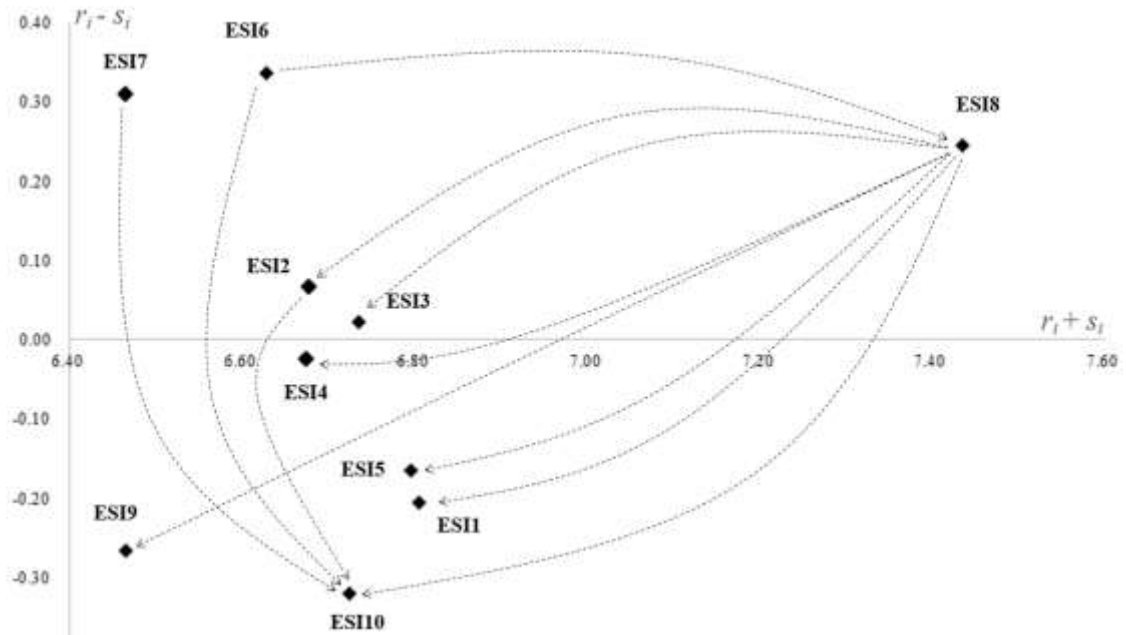
Fig. 1 INRM of environmental sustainability innovation factors

Discussion

The sustainability debate is gaining momentum due to focus of various nations to achieve sustainability development goals in next decade. The findings from Table 12 and Figure 1 indicate that "Designing products for being reusable and energy efficient (ESI 8)" is the most important criteria for environment sustainability innovation as per the prominence ranking and INRM. Past studies show that companies need to develop facilities so that various environmental standards are considered while designing the products such that these products are easily reusable and recyclable. The organizations also need to adopt energy efficient materials while designing the products so that overall energy wastage can be minimized (Toke and Kalpande 2019). This is in line with our findings from Z-DEMATEL analysis which indicates that "designing products for being reusable and energy efficient" has the highest prominence to achieve environmental sustainability innovation. Designing reusable and energy efficient products further motivates the organizations to collaborate with research institutes,

investing in research and design for sustainable practices, enhancing green production development capabilities, designing products with lesser environmental impacts and also motivates management to commit more towards green initiatives. Reusable products have a significant impact on sustainability initiatives as they significantly reduce the resource requirements and make resources available for future consumption and also have lesser environmental impact.

Other important criteria as per prominence ranking emerged out to be "Collaboration with rivals, research institutes and environmental groups (ESI 1)", past studies showed that many companies are resource constrained especially in the current uncertain time when economy is plunging in most of the nations. It is difficult for companies to meet sustainability targets in standalone mode, there is growing need to coexist and collaborate for resource sharing. Firms can be greatly benefited to achieve sustainability by collaborating and sharing resources with their rivals as with research institutes who already have expertise and resources to achieve environmental sustainability (Saeed and Kersten 2019). The results are in line with our finding that "collaboration with rivals, research institutes and environmental groups" are necessary for environment sustainability innovations. Similarly, "Investment in environment and economic benefits (ESI 7)" and "technical experience availability and investment in R&D for green practices (ESI 2)" have influencing power over other criteria and ensure availability of resources and green competencies for carrying out environmental sustainability innovations.

"Initiatives and commitment for environmental issues (ESI 5)" is another important innovation criterion, Shahzad et al. (2020) found that management commitment is the quintessential for organizations sustainability development initiatives. Management goals should match with the overall sustainability development goals set by regulatory bodies. Management commitment involves adopting and implementing a diverse category of environmental standards and practices across the organization. These initiatives include adopting environmental regulations and standards set by government, skill development programs related to sustainability practices and motivating employees through rewards and incentives for green initiatives (Shahzad et al. 2020). Our results corroborate with this finding that "initiatives and commitment for environmental issues" are prominent for environmental sustainability innovations.

Further, INRM analysis results indicate that apart from ESI8, "Implementing environmental policy, market demands and incentives for manufacturing green products (ESI 6)" has a high influencing power over other criteria and is important for environment sustainability innovation. Implementing environmental management policies and initiatives influences organizations for designing reusable and energy efficient products which in turn has influence on other criteria. Effective

and stringent environmental policies create an atmosphere in organization to produce sustainable products having lesser impact on environment and lesser resource utilization. Environmental management initiatives and policies also influences resource availability and enhances green competencies of the workforce of organization. Environmental policies and regulations by regulatory bodies also indicate that developing skill set for green and sustainable practices is essential to meet sustainability goals, thus organizations are also inclined to take initiatives to provide training for their employees to enhance their green competencies (Toke and Kalpande 2019). Investments made in environmental initiatives influences the availability of the availability of resources and this investment makes providing training related to sustainability practices easier for the organizations, thus enhancing competencies of workforce (Mathiyazhagan et al. 2013).

INRM analysis also indicate the influencing relationship of "investment in environment and economic benefits (ESI 7)" over other criteria. Past studies also show that organizations having few managers that have technical skill set related to green practices can help train other employees and enhance their green competencies through regular in-house training programs. These influential factors have great impact on achieving overall environmental sustainability innovation in an organization and thus meet their sustainability goals, "technical experience availability and investment in R&D for green practices (ESI 2)" in this study also emerged as in an important influencing criterion for other environmental sustainability innovation criteria.

Conclusion

Environmental management and environmental sustainability innovation factors can significantly help companies to minimize the waste, preserve the environment, and achieve sustainable development. Based on the Z-DEMATEL results, the top three ranked criteria are "Designing products for being reusable and energy efficient-ESI 8 ($r_8 + s_8 = 7.435$ and $w_8 = 0.110$)", "Collaboration with rivals, research institutes and environmental groups-ESI 1 ($r_1 + s_1 = 6.805$ and $w_1 = 0.101$)", and "Initiatives and commitment for environmental issues-ESI 5 ($r_5 + s_5 = 6.797$ and $w_5 = 0.101$)". In general, except for ESI 8, the influence weights of the other criteria are not much different. This phenomenon indicates that the criteria we have summarized are all sufficient to represent environmentally sustainable development factors.

On the other hand, in terms of net influence, "implementing environmental policy, market demands and incentives for manufacturing green products-ESI 6" has a maximum value of 0.337 ($r_6 - s_6 = 0.337$), but it is not the criterion for the maximum total influence. This result shows that ESI 6 has only a slight strength of influence received. Furthermore, the mutual influence of criteria can be

identified through INRM. "Designing products for being reusable and energy efficient-ESI 8" is the most important factor and requires a considerable attention for obtaining environmental sustainability innovation. In INRM, ESI 8 is in the upper right corner of the map, and according to the direction of the arrow, it can be known that it affects the criteria ESI 1, ESI 2, ESI 3, ESI 4, ESI 5, ESI 9, and ESI 10. If this criterion can be implemented well, there will be hope for the development of other criteria.

This study is the first research paper that develops a criteria decision framework for investigating the interactions among environmental sustainability innovation criteria in the manufacturing sector using a new MCDM model (Z-DEMATEL), which highlights the novelty of this research. In addition, the novel model consists of several advantages. First, the reliability/confidence of the decision-makers in the assessment can be identified. Secondly, the shape of triangular fuzzy numbers for calculations can be retained to avoid the information loss. Thirdly, the influence relationships of the criteria are clearly determined, and their influence weights can also be generated. This paper provides the complete linguistic variables and the corresponding fuzzy numbers, which can assist various industries to solve related decision-making issues. A sample of seven industrial managers from manufacturing sector was employed in the assessment process. Developing a framework for investigating the environmental aspect of sustainable innovation and utilizing Z-DEMATEL for analyzing the proposed framework and exploring the interactions among the criteria are the academic contributions of this work. as part of the academic contribution of the research, the results of this study have a significant implication to environmental sustainability innovation theory and contribute to developing efficient strategies and innovative solutions for achieving environmental sustainability innovation in emerging economies. Now industrial experts in emerging economies have a means to focus and invest on the most significant environmental sustainability innovation factors, make effective decisions, and achieve environmental sustainability innovation, which identifies the practical contribution of this research. The results of the study provide various recommendations and implications for management, policy makers and researchers as follows:

(i)   Managers can focus on better designing and research facilities at their end so that products being designed are reusable and recyclable for future use. They also need to focus on using more energy efficient materials for manufacturing.

(ii) Managers can develop collaborations with research institutes and potential competitors to share technologies and other resources available.

(iii) The developed framework and prioritization of criteria can assist the managers to identify and adopt critical criteria for achieving environmental sustainability innovation.

(iv) Policy makers can use this study to formulate policies that incentivize activities for reuse and

recycling facilities.

(v) Government and regulatory bodies can set up more institutes that work with industry to find innovative solutions and achieve environmental sustainability.

This paper suffers from few limitations. Limitations can provide additional room for more and deeper investigation in this area. One limitation of this work is that few experts from Iran manufacturing sector participated in the evaluation process and completed data collection. We suggest future studies apply our framework in other emerging economy manufacturing sectors and compare the outcome of their work with this work results. Another limitation of this paper is that it only focused on environmental sustainability innovation. Future works could extend our criteria decision framework and include additional economic and social dimensions of sustainable innovation and investigate the interrelationships among different sustainable innovation factors. This paper integrated Z numbers with DEMATEL method to handle uncertainty issues and investigated interdependencies among criteria. We suggest future authors try to combine fuzzy or rough numbers with DEMATEL and compare their findings with this paper results. Moreover, possible future works can utilize ISM-hesitant fuzzy-MICMAC instead of DEMATEL. Potential future papers can focus on the most critical environmental sustainability innovation criteria obtained in this study and develop some efficient strategies to help managers better understand and implement those factors in their organizational supply chains and shift their industry towards sustainable development.

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