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RESEARCH ARTICLE

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Structural model for analysis of key performance indicators for sustainable manufacturer–supplier collaboration: A grey-decision-making trial and evaluation laboratory-based approach

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Abstract

With growing competition in the market and dire need for sustainability, it has become imperative for companies to build long-term relationship with their supply chain partners through sustainable collaboration. Among these, the supplier–manufacturer relationship is crucial for improved organizational, business and sustainable performance. Sustainable collaboration with suppliers involves crucial decision-making processes such as continuous supplier monitoring and supplier development. Hence, a critical challenge that a company faces is to identify the key performance indicators (KPIs) for assessing the performance of a supplier for sustainable collaboration. In this regard, this study focuses on identification of KPIs for an Indian home appliance company through exhaustive discussions involving multiple decision-makers. Further, a grey-based decision-making trial and evaluation laboratory (DEMATEL) model is proposed in the study for analysing the importance levels among the fifteen KPIs based on multiple stakeholder perspectives. The results of the grey structural model indicate seven KPIs as influencing KPIs and eight KPIs as influenced KPIs. The KPI 'Information disclosure' has been identified as the most influential KPI for the evaluation of suppliers for sustainable collaboration. The implications drawn from the result analysis model can provide meaningful insights to managers for identifying strategies towards strengthening the supplier–manufacturer relationship and achieving organizational and market competence.

KEYWORDS
DEMATEL, grey theory, key performance indicators, supplier–manufacturer relationship, sustainable collaboration, relational view theory

1 | INTRODUCTION

Due the growing global competition, companies need to continuously analyse their supply chain (SC) performance and devise strategies for enhancing their performance level, thus creating need for adoption of an effective performance measurement system (PMS) (Deloitte, 2017). The aim of any PMS is to analyse the purpose of performance measurement, the measures that can be used for improvement of SC and the benefits that the entire process can yield (Neely, Gregory, & Platts, 1995). The PMS generally comprises key performance indicators (KPIs), which can be considered as the set of measures that represent the whole system. It can be observed that performance measurement for a system on a continuous basis is necessary in any company to identify underperforming areas and processes of SC so that appropriate and timely measures can be taken for the upgradation of each SC process (Govindan, Rajeev, Padhi, & Pati, 2020).

In recent years, it is apparent that more companies are moving towards networking and exchange; they deemphasize individualism and seek to adopt a collaborative strategic approach in their SC network in order to heighten their market's competitive advantage (Hofman, Blome, Schleper, & Subramanian, 2020). Because SC networks involve both upstream and downstream flows of goods, services, information and finances from suppliers to the buyers, success in today's competitive era requires the collaborative participation of each SC actor (Fattahi & Govindan, 2020; Melander, 2018; Naderi, Govindan, & Soleimani, 2020). Im, Rai and Lambert (2019) found that collaborative relationships create many benefits: higher profits, reduced costs, high customer satisfaction and a competitive advantage. These relationships do require continuous nurturing. With the underlying understanding that success of the company is dependent on the collaborative participation of SC partners and the relationships among others (Yen, 2018), the focus of the present study is on the supplier–manufacturer relationship. The supplier–manufacturer relationship plays an important role in the overall SC performance as improper coordination among the two may lead to poor quality of raw material, excessive delays, accumulation of inventories and eventual poor customer services, which can consequently result in increase in the SC cost and losing the competitive edge in the market (Bai, Kusi-Sarpong, Badri Ahmadi, & Sarkis, 2019). Thus, it becomes imperative for the manufacturing company to develop a strong relationship for better coordination and strengthen it by continuous performance evaluation of suppliers (Whipple, Wiedmer, Boyer, & K., 2015). This relationship can be strengthened by continuous monitoring and evaluation of suppliers and better communication between the two actors. However, it is not easy to maintain the relationship unless there is support and cooperation of the all the SC actors involved (Yen, 2018).

Further, with growing concerns over environmental and social issues such as pollution, climate change, health and safety, population growth, poverty and human rights, companies need to shift focus towards adopting newer strategies for enhancing their global and local SC performance and, in turn, their market image (Goodman, Korsunova, & Halme, 2017). Given these influences, companies are inclined towards supplier development and supplier collaboration (Melander, 2018). Sustainable supplier–manufacturer collaboration would be instrumental in fostering interorganizational learning, knowledge creation, reduce the negative environmental and social impacts of operations and other collaborative capabilities for execution of SC (Dangelico, Pujari, & Pontrandolfo, 2017). For example, Dell, Hewlett-Packard, IBM and Procter & Gamble have successfully incorporated collaborative relationships with their suppliers for enhancing the profit and achieving the competitive advantage in the market (Cao & Zhang, 2011). Thus, sustainable supplier–manufacturer collaboration requires the company to collaborate with those suppliers who meet its sustainable requirements (Amindoust, Ahmed, Saghafinia, & Bahreininejad, 2012). Prajogo, Chowdhury, Yeung and Cheng (2012) have proved in their study that the performance evaluation of the suppliers could be one of the approaches to create a collaborative relationship with the sustainable objectives of the manufacturer. Thus, to sustain in the highly competitive market, it has become imperative that suppliers are assessed through an effective PMS (Ahmed Khan, Kusi-Sarpong, Kow Arhin, & Kusi-Sarpong, 2018). The transformation of the supplier selection problem towards collaboration for achieving sustainable goals requires the manufacturer to periodically measure the sustainable performance of their suppliers. The systematic supplier evaluation process primarily involves two parts: (i) KPIs and (ii) evaluation method. The critical challenge faced by the purchasing managers in this context is the choice of the KPIs that can best measure the supplier's sustainable performance and can quantify the sustainable performance indicators in terms of sustainable supplier–manufacturer collaboration (Beske-Janssen, Johnson, & Schaltegger, 2015). Thus, this paper focuses on the identification and selection aspects of the KPIs' performance evaluation indicators.

Indeed, suitable KPI selection is important for the supplier selection problem, especially in the context of sustainable manufacturer–supplier collaboration. It is critical because the selection of KPIs determines the metrics on which suppliers are assessed and selected; those choices ultimately impact the firm's operations performance. Hence, the identification of KPIs is an important stage in the performance evaluation and supplier selection process, for suppliers in both global and local SCs (Lima-Junior & Carpinetti, 2016a). To embrace collaboration with global suppliers, it becomes imperative for companies to select appropriate KPIs regardless of the nature of the economy (developed or developing) or the size of the company (large, medium or small) (Soh, Jayaraman, Yen, & Kiumarsi, 2016). However, for supplier selection on a global scale, the chosen KPIs may also change with time depending on the political characteristics of the business (Awasthi, Govindan, & Gold, 2018). Additionally, these KPIs may vary based on the economic, social and environmental needs of the industry (Sagar & Singh, 2012; Kannan, Moazzeni, Mostafayi-Darmian, & Afrasiabi, 2021) and resilience metric (Fattahi, Govindan, & Maihami, 2020). Therefore, in actual implementation, the company's decision makers must choose the KPIs that are consistent with their business focus and managerial requirements. In the local context, the identification of KPIs must be done within a company-specific, industry-specific environment. That task requires assessment and evaluation at the managerial level. Undoubtedly, the appropriate selection of a set of sustainable KPIs through a structured assessment modelling technique is clearly a fundamental necessity for the buying company for a productive supplier–manufacturer collaboration. The aim of this research is to develop an integrated multicriteria model for an Indian home appliances company, which can aid in identifying KPIs for performance evaluation of suppliers and in determining the most influential KPIs for sustainable collaboration using grey-decision-making trial and evaluation laboratory (DEMATEL)-based approach.

This paper draws from relational view theory to develop relationships/cooperation among supply chain actors by combining the key competencies or capabilities to improve both manufacture and supplier's performance. Most of the previous studies explored the relational view with a sustainable focus in the context of enablers, barriers of SSCM collaboration (Touboulic & Walker, 2015); reverse supply chain (RSC) relationships (Pal, Sandberg, & Paras, 2019); green innovation adoption through sustainable capabilities (Aboelmaged & Hashem, 2019) the key performance indicators.

The novelty of this study lies in answering the following research questions:

1. Which KPIs are appropriate for evaluation and selection of suppliers for sustainable supplier manufacturer collaboration drawn from theoretical lens based on the relational view?
2. Which method is suitable for understanding the interrelationships between the selected KPIs and determining the importance of KPIs?
3. What are the interrelationships between the selected KPIs for selection of suppliers for sustainable supplier manufacturer collaboration?

The identification process of KPIs includes establishing the group decision-making team, an extensive literature survey and exhaustive group discussions. The grouping of the KPIs in the cause and effect group using grey DEMATEL would enable the company to assign importance levels to KPIs for the performance evaluation of suppliers. The use of grey theory ensures that the subjectivity and uncertainty in the decision-making environment are suitably handled.

Hence, the key contributions of this study are summarized as follows:

1. The performance evaluation indicators of suppliers under sustainability for achieving the goal of collaboration are identified through theoretical lens based on the relational view.
2. An analysis of KPIs is presented to understand the relationships between the KPIs and relative importance with other KPIs.
3. Grey theory is applied to handle the ambiguity of data and vagueness in linguistics expressions in the decision-making environment.
4. DEMATEL approach is utilized to determine the influential and influenced groups of KPIs and to understand their interrelationships with each other.
5. The proposed framework is validated by a real-life case study of an Indian home appliances company.

The remainder of the paper is outlined as follows: Section 2 presents literature review, which is further classified into three subsections: sustainable supplier collaboration in SCs, performance evaluation indicators for sustainable supplier collaboration and multicriteria decision-making (MCDM) techniques for evaluation of KPIs. In Section 3, the case problem is discussed. Theoretical background of the study is explained in Section 4. Section 5 describes a case illustration and the proposed framework. Results of the study are discussed in Section 6. Section 7 focuses on managerial implications, whereas Section 8 discusses theoretical contributions of the study. Section 9 concludes the work and explains the future scope.

2 | LITERATURE REVIEW

With regard to the focus of the study, which is on sustainable manufacturer–supplier collaboration in SC, the literature analysis is presented in this section. The literature review section is divided into four sections: Section 2.1 discusses sustainable supplier collaboration in SCs; Section 2.2 demonstrates relational view and performance evaluation indicators for sustainable supplier collaboration; Section 2.3 discusses MCDM techniques for evaluation of KPIs; and Section 2.4 highlights the research gap and provides the significant contribution of the present study.

2.1 | Sustainable supplier collaboration in SC

Most researchers define collaboration in SC in terms of cooperation, mutual objectives and coordination among SC partners (Josserand, Kaine, & Nikolova, 2018; Reim, Parida, & Örtqvist, 2015). Chen et al. (2017) insist that collaboration with SC actors is a necessary and critical step when the aim is to enhance simultaneous economic, environmental and social performance. Because the overall performance of companies is largely affected by the practices taken towards upstream SC members (Luzzini, Brandon-Jones, Brandon-Jones, & Spina, 2015), sustainable collaboration of the company with its suppliers and customers can be truly beneficial for solving environmental problems and providing solutions jointly (Dangelico & Pontrandolfo, 2015). Hence, research in this area emphasizes that support and the participation of suppliers are vital for sustainable SC performance (Luo, Chong, Ngai, & Liu, 2015), and collaboration with sustainable suppliers can reap long-term sustainable benefits for the company (Lee, Cho, & Paik, 2016; Yu, Chavez, & Feng, 2017). Based on these several findings, the importance of sustainable supplier collaboration in SC network is clearly highlighted. Although extensive work has been done on sustainable performance evaluations of suppliers, performance measurement of suppliers for the long-term purpose of sustainable collaboration has not been studied in depth, which is the primary focus of the present research.

2.2 | Relational view and performance evaluation indicators for sustainable supplier collaboration

Drawing from the relational view (Dyer & Singh, 1998; Kamalaldin et al., 2020), it is important to improve both manufacture and supplier's sustainability performance through collaboration. One has first to define the indicators which directly measure the performance. So, defining performance indicators is an important step in the performance evaluation process; it has major impact on the overall SC performance (Kannan & Tan, 2002). Most of the previous studies have focused only on the traditional indicators such as price, quality, delivery, technical capability or financial position for supplier evaluation and selection (Chen, Lin, & Huang, 2006). In the study by Ho, Xu and Dey (2010), the authors assert that delivery, cost and price are the most used economic criteria for evaluating supplier performance. Fazlollahtabar, Mahdavi, TalebiAshoori, Kaviani and Mahdavi-Amiri (2011) have emphasized service, delivery, quality and innovation in addition to cost for evaluating the suppliers. Further, inclusion of environmental criteria in the supplier evaluation problem has been within the focus of many researchers in the last decade. Some of these include pollution treatment cost (Yeh & Chuang, 2011), gasoline consumption during transportation (Zhang et al., 2013), carbon dioxide emission level of suppliers (Theißen & Spinler, 2014) and reuse and recycle rate (Yazdani, Chatterjee, Zavadskas, & Zolfani, 2017). In the field of sustainable supplier selection, social responsibility dimensions are also being considered in the supplier evaluation criteria. Bai and Sarkis (2010) classified social dimensions into two main criteria for supplier selection decision: internal social indicators (such as employment practices and safety factors) and external social indicators (such as local communities influence, contractual stakeholders' influence and other stakeholders' influence). The social indicators considered in some recent studies pertain to sustainable supplier selection problems, which may include stakeholder engagement (Sarkis, Meade, & Presley, 2012), job opportunities (Dai & Blackhurst, 2012), employment practices influence (Govindan, Khodaverdi, & Jafarian, 2013), the interest and rights of employees (Kannan, Govindan, & Rajendran, 2015), employees' rights and welfare (Song, Xu, & Liu, 2017), occupational injury and illness (Vahidi, Torabi, & Ramezankhani, 2018), brand image (Chen, Wang, Yao, Li, & Yang, 2018), child labour (Memari, Dargi, Jokar, Ahmad, & Rahim, 2019) or ethical issues and legal compliance (Abdel-Baset, Chang, Gamal, & Smarandache, 2019). Whereas many studies in the literature have researched critical KPIs to be considered for sustainable performance evaluation of suppliers (Rashidi, Noorizadeh, Kannan, & Cullinane, 2020), research with regard to identification and selection of KPIs from the relational view theoretical perspective of sustainable supplier collaboration is very limited. That research gap is addressed in this study.

2.3 | MCDM techniques for evaluation of KPIs

Most of the studies in the current literature emphasize the MCDM approach as an effective tool for sustainable KPI evaluation for supplier selection (Lima-Junior & Carpinetti, 2016b; Pomerol & Barba-Romero, 2012). For evaluation of environmental KPIs, different MCDM techniques have been used by researchers: analytical network process (ANP) to deal with the interdependencies of green KPIs (Hashemi, Karimi, & Tavana, 2015), best–worst method (BWM) to assign weight to green KPIs (Lo, Liou, Wang, & Tsai, 2018), to assign weights to sustainable procurement drivers (Kannan, 2021), quality function deployment (QFD) for identifying the degree of relationship between green supplier selection KPIs (Yazdani et al., 2017) and analytical hierarchy process (AHP) to derive global importance weights of traditional and green KPIs based on the company's strategy (Hamdan & Cheaitou, 2017). The inclusion of social KPIs poses more challenges in terms of conflicting opinions; hence, integrated MCDM techniques have become more popular because of their combined efficiencies. These include AHP and entropy weight method approach (Freeman, & Chen, 2015); strengths, weaknesses, opportunities, and threats (SWOT) analysis and QFD methodology (Vahidi et al., 2018); and DEMATEL and ANP (Govindan, Shankar, & Kannan, 2018). Further, uncertainty in information and biases in the decision-making environment has been effectively handled by researchers by integrating grey set theory with MCDM techniques (Bai & Sarkis, 2013; Memon, Lee, & Mari, 2015). Some of the recent studies utilizing grey-based MCDM approaches for KPI evaluation include grey BWM (Bai et al., 2019), grey AHP methodology (Bakhat & Rajaa, 2019) and grey DEMATEL (Parkouhi, Ghadikolaei, & Lajimi, 2019). The above-mentioned studies have effectively used integrated MCDM techniques for selection of KPIs for supplier evaluation, but the KPIs are not prioritized with the focus on manufacturer–supplier collaboration with integration of sustainability. Hence, in this study, a novel structural model based on grey DEMATEL is developed for selection of the dominant KPIs, which would be influential in supplier selection decisions for a successful supplier–manufacturer collaboration.

2.4 | Research gap

In this section, the gap that exists in the research area of supplier performance evaluation modelling and the significant research contribution of the study are presented. Table 1 highlights the gap and contribution through a summary of recent studies on supplier performance evaluation problems discussed in Sections 2.1–2.3. It categorizes these studies based on sustainability aspects, collaboration as the goal of study, evaluation of supplier's performance indicators and grey-based MCDM approach.

It is clear from an analysis of Table 1 that there is no previous research work that addresses the evaluation process of KPIs considering sustainability dimensions integrated with supplier collaboration through relational view. The above literature review on supplier performance evaluation and selection problems clearly shows that the focus is more on the evaluation of supplier performance indicators for sustainable supplier selection rather than on a comprehensive perspective towards supplier collaboration under sustainability. It can be seen that Ho et al. (2010) and Lima-Junior and Carpinetti (2016a) have focused only on traditional performance indicators of suppliers whereas Song et al. (2017), Vahidi et al. (2018), Govindan et al. (2018) and Abdel-Baset et al. (2019) carried out an evaluation of supplier performance indicators under sustainable environments. Moreover, only Theißen and Spinler (2014) and Yu et al. (2017) have addressed the importance of supplier collaboration in the area of supplier performance evaluation. No study has focused on how the evaluation of suppliers should be done based on collaboration. This fact proves that only a few papers have addressed this concern in literature. Hence, to bridge the literature concern, this study attempts to identify sustainable KPIs for suppliers' performance evaluation and their selection under consideration of sustainable collaboration.

As this study provides an analysis of a broad set of sustainable KPIs, various challenges were faced regarding the inherent ambiguity

TABLE 1 Recent literature on supplier performance evaluation

Author	Sustainability	Goal (collaboration)	Performance indicators evaluation	Grey-based MCDM
Ho et al. (2010)			✓	
Theißen and Spinler (2014)		✓	✓	
Lima-Junior and Carpinetti (2016a, 2016b)			✓	
Song et al. (2017)	✓		✓	
Yu et al. (2017)	✓	✓		
Vahidi et al. (2018)	✓		✓	
Govindan et al. (2018)	✓		✓	
Parkouhi et al. (2019)	✓		✓	✓
Bai et al. (2019)	✓		✓	✓
Abdel-Baset et al. (2019)	✓		✓	
Our study	✓	✓	✓	✓

Abbreviation: MCDM, multicriteria decision-making.

in the decision-making process of evaluation of KPIs. Ambiguity occurs due to the non-availability of complete information and conflicts in opinions among the decision makers. Hence, the reason for using the grey-DEMATEL model is to provide meaningful results without significantly influencing the quality of the result. This kind of integrated method for analysis of KPIs for manufacturer–supplier collaboration has rarely been utilized in the supplier selection modelling. Grey theory is a strong mathematical-based theory that is very effective in managing issues arising out of uncertainty and incomplete information in the discrete data collected for evaluation and in managing a heterogeneous group of DMs (Singh, Thakkar, & Jenamani, 2019: Bouzon, Govindan, & Taboada Rodriguez, 2020). For the purpose of analysis of KPIs, it is necessary to understand the interrelationships and interdependencies between the criteria, which is very effectively achieved through the DEMATEL approach (Govindan, Mina, Esmaeili, & Gholami-Zanjani, 2020). The technique is particularly powerful in converting cause and effect relations between the KPIs into a structural model. The integrated model results in a grey causal diagram, which visually depicts the contextual relations between the KPIs, along with a numeral signifying the strength of influence, a useful tool for the analysis of KPIs.

3 | PROBLEM DESCRIPTION

The problem under consideration is of Company ABC, India's leading major home appliances company (the name is omitted for confidentiality reasons). The company has three manufacturer bases at Pune, Faridabad and Pondicherry. It manufactures refrigerators, washing machines, air conditioners and microwave ovens. It has 2,500 employees, and a robust manufacturing and research and development (R&D) infrastructure. Specifically, the case problem considered is that of a product line of washing machines. The focus of this research is on its SC network performance. The schematic view of SC network of the company is shown in Figure 1. The schematic representation has been made in discussion with the decision makers of the company. It consists of a set of suppliers, manufacturing plants, distribution centers, retail stores and customers.

Raw materials/components are supplied by the suppliers to the manufacturing plants. In the manufacturing plants, mainly two processes are performed for manufacturing the washing machine: assembly and mounting. The company produces different models of washing machines, which are either fully automatic or semi-automatic with front loading or top loading options. The final product is moved to the distribution centres by carrying and forwarding agents (CFAs). Then it is shipped to the retail stores and finally to the end customers.

The intense competition in the market necessitates that washing machines manufactured by the company are of high quality, available at a reasonable cost and delivered to customers on time. To ensure the aforementioned, the company needs to ensure that all the processes involved in the SC from the initial procurement process to the end delivery to the customer are effectively carried out with maximum efficiency and that areas that need improvement are identified.

The performance of the SC is satisfactory to a certain extent, but it is revealed that sustainable performance needs to be improved. Therefore, the penalties that would be incurred by the company for not meeting the targets of sustainability have been carefully assessed. This forms the base of the research problem considered in this study. At the initial stage, through deliberations and discussions, management has determined that there is no sustainable variant of washing machine to offer to the customers. Thus, company is losing its image as one that promotes sustainability to its environmentally conscious customers. Hence, the company needs to respond more quickly to the frequently changing demands of customers. To capture the market of environmentally friendly customers, the company has decided to launch a new green variant. This new variant of the washing machine is more energy efficient and uses less water as compared with existing models. This strategy can not only capture the green market share,

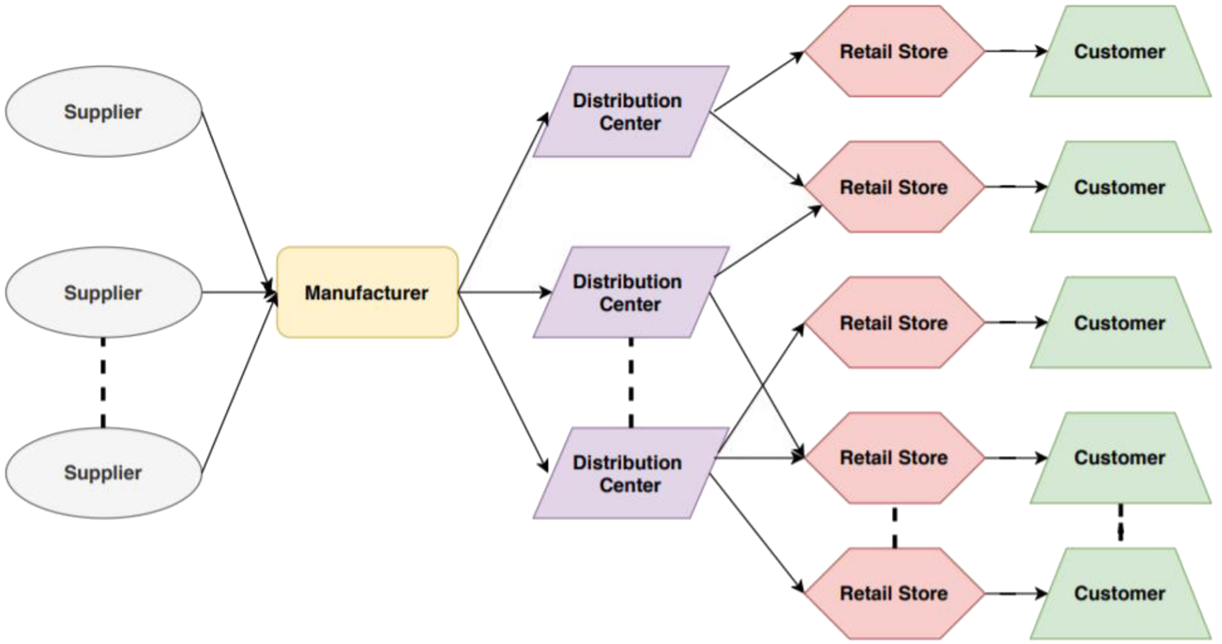

FIGURE 1 The schematic view of supply chain network of company [Colour figure can be viewed at wileyonlinelibrary.com]

which will derive economic benefits, but also, more importantly, will suffice in lowering the overall carbon footprint of the product. Because most of the components are outsourced from the suppliers, the sustainable performance of company is majorly dependent on their suppliers' environmental and social performance.

Hence, appropriate selection of suppliers and green procurement are identified as essential processes for improving the company's sustainable performance. However, only the selection of a sustainable supplier is not enough. It has been reasoned that the company can benefit from a collaborative participation of environmentally and socially responsible suppliers, which, in turn, would aid in supplier development and in enhancing the performance levels of the procurement process. Existing and new suppliers who can supply raw materials/components for the green variant are to be evaluated. Accordingly, sustainable KPIs need to be identified by the company. Due to this, the identification and selection of KPIs are fundamentally important decisions for sustainable collaboration with suppliers.

The fundamental focus of the study is to assess sustainable KPIs on which supplier can be examined for collaborative performance through relational view. For achieving this goal, a framework has been designed, which includes three stages. The first stage of framework starts with the selection of appropriate decision-making team members to provide seamless and unbiased judgements. The selected team members are proficient in making strategic, tactical and operational decisions for the company; all members have more than 10 years of experience in their respective fields. Next, the KPIs are identified with the help of literature review and the decision-making team so the collaboration between supplier and manufacturer can be enhanced. In the final step, the identified KPIs are analysed to manage risk and benefits for long-term relationships and to improve the company's overall performance.

4 | SOLUTION METHODOLOGY

4.1 | Grey system theory

Due to incomplete information and human decisions in real-life situations, some biases and vagueness are found in the obtained results. Grey system theory, a mathematical approach, can help in solving and modelling uncertainty problems with limited and incomplete information (Julong, 1989). It helps in generating satisfactory results with less data (Tseng, 2009). A brief summary of the concepts of the grey system theory used in the study is discussed below:

A grey number $\otimes b$ represents the number with incomplete and insufficient information.

$$\otimes b = [b^-, b^+] = \{x \in \otimes b | b^- \leq x \leq b^+\},$$

where b^- = the lower bound of the interval and b^+ = the upper bound of the interval.

The arithmetic operations of grey number are given in the following equations (Tseng, 2009):

Let $\otimes b_1 = [b_1^-, b_1^+]$ and $\otimes b_2 = [b_2^-, b_2^+]$ be two grey numbers.

- Addition

$$\otimes b_1 + \otimes b_2 = [b_1^-, b_1^+] + [b_2^-, b_2^+] = [b_1^- + b_2^-, b_1^+ + b_2^+]. \quad (1)$$

- Subtraction

$$\otimes b_1 - \otimes b_2 = [b_1^-, b_1^+] - [b_2^-, b_2^+] = [b_1^- - b_2^-, b_1^+ - b_2^+]. \quad (2)$$

- Multiplication

$$\otimes b_1 \times \otimes b_2 = [\{b_1^- b_2^-, b_1^- b_2^+, b_1^+ b_2^-, b_1^+ b_2^+\}, max\{b_1^- b_2^-, b_1^- b_2^+, b_1^+ b_2^-, b_1^+ b_2^+\}. \quad (3)$$

- Division

$$\frac{\otimes b_1}{c} = \left[\frac{b_1^-}{c}, \frac{b_1^+}{c}\right], \quad \frac{c}{\otimes b_1} = \left[\frac{c}{b_1^-}, \frac{c}{b_1^+}\right], \quad (4)$$

where $b_1^- > 0, b_2^- > 0, b_1^+ > 0, b_2^+ > 0, c > 0$ are real numbers.

4.2 | Grey DEMATEL

In this section, a hybrid approach, which is a combination of grey system theory and DEMATEL method, has been discussed. This hybrid approach is used to deal with vagueness and incomplete information due to subjective decision-making. The steps of this approach are as follows:

Step 1: Define linguistic scale for representation of judgments of decision makers.

The KPIs are identified using the extant literature and through detailed discussions with the decision makers of the company. A grey linguistic scale is used for the evaluation of KPIs; it is described in Table 2.

TABLE 2 Linguistic scale for evaluation of KPIs

Linguistic term	Grey number
No influence	(0,0)
Very low influence	(0,1)
Low influence	(1,2)
High influence	(2,3)
Very high influence	(3,4)

Abbreviation: KPIs, key performance indicators.

Step 2: Develop the direct relation matrix.

The direct relation matrix is developed for measuring the relationship between KPIs denoted as $\{KPI_i, i = 1,2,\ldots,p\}$, and these relationships are examined by each of the k decision makers. Each decision maker fills a pairwise comparison matrix for using linguistic scale given in Table 2 for establishing the relationship between the KPIs. The direct relation matrix Q^k as evaluated by the kth decision maker is as follows:

$$Q^k = \left[0 \otimes Q_{12}^k \cdots \otimes Q_{1p}^k \ \otimes Q_{21}^k \ 0 \cdots \otimes Q_{2p}^k \ \otimes Q_{31}^k \vdots \otimes Q_{p1}^k \ \otimes Q_{32}^k \vdots \ \otimes Q_{p2}^k \cdots \vdots \cdots \ \otimes Q_{3p}^k \vdots 0 \ \right], \quad (5)$$

where $\otimes Q_{ij}^k = \left[\underline{\otimes} Q_{ij}^k, \overline{\otimes} Q_{ij}^k\right]$ are grey numbers for $i = 1,2,\ldots,p$ and $j = 1,2,\ldots,p$.

Step 3: Evaluate overall grey relation matrix.

The overall grey relation matrix is computed by taking the average of all the grey direct relation matrices. Using Equation 6, the overall grey relation matrix Q is obtained.

$$Q = \frac{\left(\sum_{K=1}^{k} Q^k\right)}{k}. \quad (6)$$

Step 4: Evaluate the normalized direct relation grey matrix.

The normalized direct relation grey matrix is obtained by transforming the overall grey relation matrix. The procedure of transformation is carried out using Equations 7 and 8:

$$\sum_{j=1}^{p} \otimes Q_{ij} = \left[\sum_{j=1}^{p} \underline{\otimes} Q_{ij}, \sum_{j=1}^{p} \underline{\otimes} Q_{ij}\right], \quad (7)$$

$$r = \sum_{j=1}^{p} \underline{\otimes} Q_{ij}. \quad (8)$$

The normalized direct grey relation matrix N is obtained by using Equation 9

$$N = r^{-1} \times Q, \quad (9)$$

and $N = [0 \otimes N_{12} \cdots \otimes N_{1p} \ \otimes N_{21} \ 0 \cdots \otimes N_{2p} \ \otimes N_{31} \vdots \otimes N_{p1} \ \otimes N_{32} \vdots \ \otimes N_{p2} \cdots \vdots \cdots \ \otimes N_{3p} \vdots 0 \ ]$,

where $\otimes N_{ij} = \frac{\otimes Q_{ij}}{r} = \left[\frac{\underline{\otimes} Q_{ij}}{r}, \frac{\overline{\otimes} Q_{ij}}{r}\right]$.

Step 5: Evaluate the grey total relation matrix.

After establishing the normalized direct relation grey matrix, the total relation matrix R is computed by using the following equations:

$$R = N(I - N)^{-1}, \quad (10)$$

where $\boldsymbol{I}$ is the identity matrix.

$$R = \left[\otimes R_{11} \otimes R_{12} \cdots \otimes R_{1p} \ \otimes R_{21}\, 0 \cdots \otimes R_{2p} \ \otimes R_{31} \vdots \otimes R_{p1} \ \otimes R_{32} \vdots \otimes R_{p2} \cdots \vdots \cdots \ \otimes R_{3p} \vdots \otimes R_{pp}\right],$$

and $\otimes R_{ij} = \left[\underline{\otimes} R_{ij}, \underline{\otimes} R_{ij}\right]$.

$$Matrix\left[\underline{\otimes} R_{ij}\right] = \underline{\otimes} N\left(I - \underline{\otimes} N\right)^{-1}, \quad (11)$$

$$Matrix\left[\underline{\otimes} R_{ij}\right] = \underline{\otimes} N\left(I - \underline{\otimes} N\right)^{-1}. \quad (12)$$

Step 6: Whiten the grey total relation matrix.

Further, the grey total relation matrix R is whitened. For converting the grey numbers into crisp values, Converting Fuzzy data into Crisp Score (CFCS) process is used (Opricovic & Tzeng, 2004). This process is performed in three steps described as below:

i. Normalization

$$\underline{\otimes R_{ij}} = \left(\underline{\otimes} R_{ij} - \underline{\otimes}\, R_{ij}\right) / \triangle_{min}^{max}, \quad (13)$$

$$\underline{\otimes R_{ij}} = \left(\underline{\otimes} R_{ij} - \underline{\otimes}\, R_{ij}\right) / \triangle_{min}^{max}, \quad (14)$$

where

$$\triangle_{min}^{max} = \underline{\otimes}\, R_{ij} - \underline{\otimes}\, R_{ij}. \quad (15)$$

ii. Computation of total normalized crisp value

$$V_{ij} = \frac{\underline{\otimes R_{ij}}\left(1 - \underline{\otimes R_{ij}}\right) + \underline{\otimes R_{ij}} \times \underline{\otimes R_{ij}}}{1 - \underline{\otimes R_{ij}} + \underline{\otimes R_{ij}}}. \quad (16)$$

iii. Determination of final crisp values

$$W_{ij} = \underline{\otimes}\, R_{ij} + V_{ij} \triangle_{min}^{max}. \quad (17)$$

The whitened total relation matrix $W = [W_{ij}]$ is obtained using above-mentioned (Equations 13–17).

Step 7: Calculate the causal parameters.

The causal parameters are obtained by calculating the sum of rows and columns of matrix W.

$$D_i = \sum\nolimits_{j=1}^{p} W_{ij}, \ \forall i, \quad (18)$$

$$C_i = \sum\nolimits_{i=1}^{p} W_{ij}, \ \forall j. \quad (19)$$

Step 8: Determine prominence and the net effect of the KPIs.

The prominence (E_i) and net effect (F_i) of the KPIs are determined by using Equations 20 and 21.

$$E_i = \{D_i + C_i | i = j\}, \quad (20)$$

$$F_i = \{D_i - C_i | i = j\}. \quad (21)$$

Step 9: Analyse and plot the causal–prominence graph

The prominence (E_i) indicates the importance of KPIs. The positive value of F_i represents the net effect of the KPI on the other KPIs, and the negative value of F_i shows the net effect received on KPI by the other KPIs. $E_i$and F_i are the horizontal axis and vertical axis of the causal–prominence graph, respectively.

5 | CASE ILLUSTRATION AND THE PROPOSED FRAMEWORK

In the present study, a framework is designed for identifying and analysing the KPIs to increase the efficiency of procurement process of the company and evaluate suppliers for collaborative partnership. The proposed framework is divided into three stages as follows:

The first stage involves five steps for forming the decision body. In the next stage, two steps are performed for identification and finalization of KPIs. The last stage involves application of grey-based DEMATEL methodology for analysing the KPIs and providing the structural model of KPIs. The schematic representation of proposed framework is shown in Figure 2.

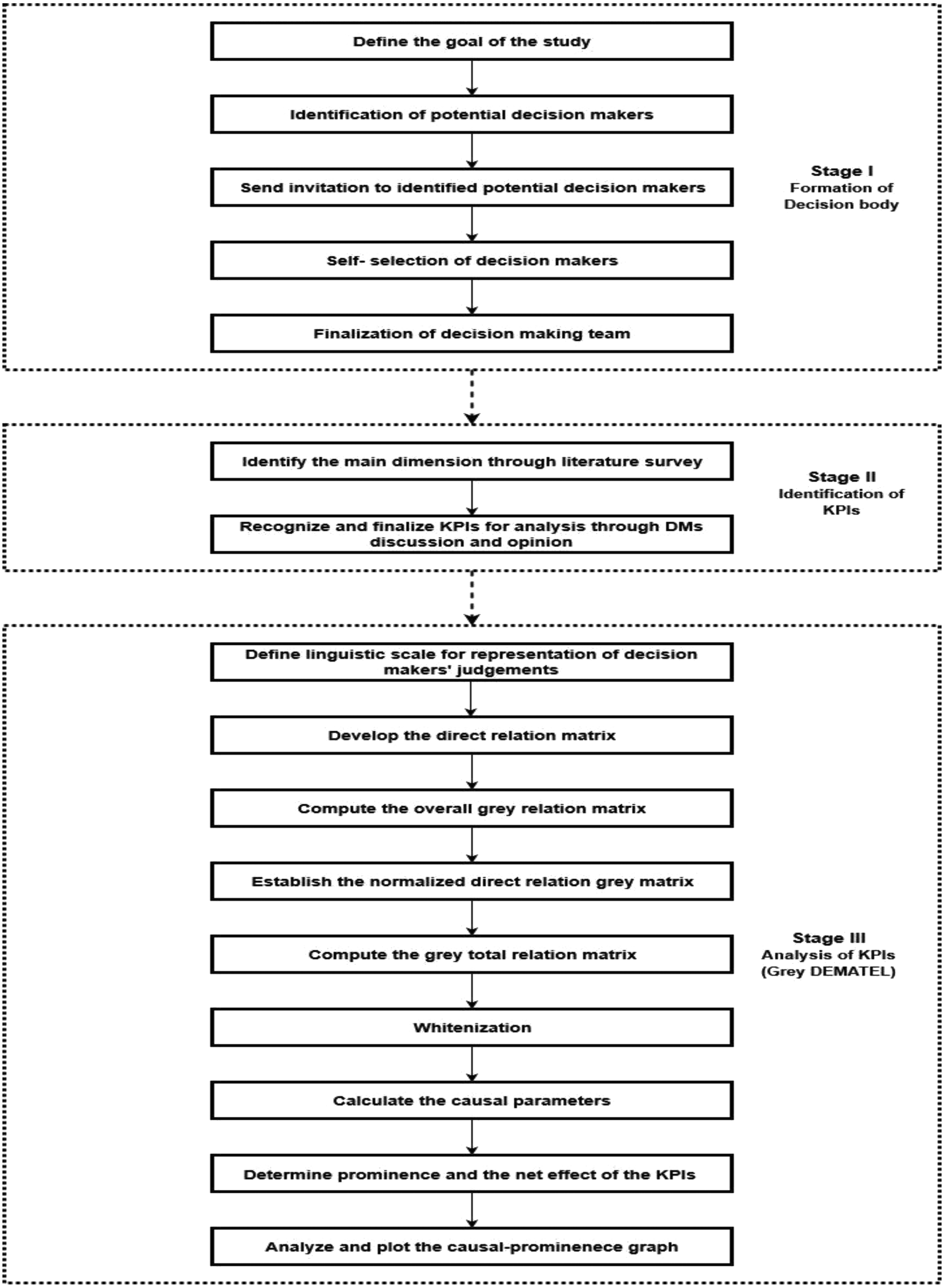

FIGURE 2 Schematic representation of proposed approach

5.1 | Stage I: Formation of decision body

For this study, 16 potential decision makers are identified. They are invited to evaluate the sustainable collaborative performance of suppliers. Eleven of the makers accepted the invitation and readily participated in this study; five rejected the invitation. The decision-making team is formed with 11 members, and each member is currently working and has more than 10 years of work experience. The roles and work experience of members are shown in Table 3. This team includes a Strategic planning manager, Production manager,

TABLE 3 List of the decision makers from the company

Decision maker	Role	Experience
Strategic planning manager	Responsibility of evaluating and developing the strategies	15 years
Production manager	Responsibility of examining and managing the different areas of production	20 years
Sourcing manager	Responsibility of managing and measuring the sourcing contacts	22 years
Product development manager	Responsibility of understanding and managing the product development related activities (idea generation, idea screening, concept development and screening, business analysis, beta testing and marketing testing, technical implementation, product launch, new product pricing and post launch review)	26 years
Research and development (R&D) manager	Responsibility of managing the research and development related activities	17 years
Purchasing manager	Responsibility for implementing purchasing programme and training	18 years
IT manager	Responsibility for implementing information technology programs and evaluating them	10 years
Scrum master	Responsibility of evaluating processes and working on process improvement, team development and product quality	11 years
General manager	Responsibility of managing the firm's marketing and sales functions as well as the daily business operations	13 years
Logistic and delivery manager	To plan, disseminate, implement and continuously monitor the product import and export processes	11 years
Finance manager	To create financial strategies to meet the needs of the organization's short- and long-term goals.	23 years

Sourcing manager, Product development manager, R&D manager, Purchasing manager, IT manager, Scrum master, General manager, Logistics and delivery manager and Finance manager.

5.2 | Stage II: Identification of KPIs

After formation of decision-making body, the questionnaires are given to the decision-making team regarding the KPIs. Through the questionnaires, the feedback of each decision maker is obtained with regard to the KPIs. The final list of KPIs based on relational view perspective is shown in Table 4.

5.3 | Stage III: Analysis of KPIs

A comprehensive evaluation framework is provided for analysing the KPIs. This framework includes a decision-making model (grey DEMATEL), which is implemented in this case. The decision makers are accustomed to the grey-DEMATEL approach, and their response is recorded in the form of direct relationship matrix on the linguistic scale. The grey direct relation matrices for sustainable KPIs for supplier collaboration are filled by all team members. Then, the overall grey relation matrix (**Q**) is determined using Equation 6 and is shown in Table 5.

Further, the normalized direct relation grey matrix (**N**) is obtained using Equations 7–9 by converting this overall grey relation matrix (**Q**). After that, the grey total relation matrix (**R**) is developed using Equations 10–12. The whitened total relation matrix (**W**) is obtained by applying CFCS process on the grey total relation matrix (**R**) using Equations 13–17. The whitened total relation matrix (**W**) is shown in Table 6. Further, the causal parameters D_i and C_i are calculated by using Equations 18 and 19, respectively and shown in Table 7.

The prominence (E_i) and net effect (F_i) of each KPI are determined by using Equations 20 and 21, respectively. The cause and effect of KPI is dependent on the sign of F_i. If it is positive, the corresponding KPI is the net effect of the KPI on the other KPIs. If it is negative, the corresponding KPI is the net effect received on KPI by the other KPIs. According to the value of F_i, the cause and effect of the KPI are decided and are presented in Table 7. The causal–prominence graph is plotted using the values of prominence (D_i+C_i), and net effect (D_i − C_i) is shown in Figure 3. The diagraphs drawn in Figure 3 represent interrelationships among each couple of KPIs under consideration of sustainable supplier–manufacturer collaboration. To reduce the effects of KPIs, which are comparably insignificant, a threshold value () of 0.07 is chosen by decision-making team. In the causal–prominence graph,

TABLE 4 Identified key performance indicators (KPIs) from a relational view perspective

KPI	Notation	Definition	References
Pollution prevention	KPI_1^S	Mutual practices that reduce, eliminate or prevent pollution at the source through cost-effective changes in production, operation and raw materials use.	Humphreys et al. (2006); Hashemi et al. (2015)
Environmental management system	KPI_2^S	Joint planning of processes and practices that enable supplier's and manufacturer's company to reduce their environmental impacts and increase their operating efficiency	Kuo, Wang and Tien (2010); Mafakheri, Breton and Ghoniem (2011); Tseng and Chiu (2013)
Pollution controls	KPI_3^S	Synchronization of rules for controlling the amount of pollution releases to the environment by the supplier and the manufacturer	Lee, Kang, Hsu and Hung (2009); Govindan et al. (2013)
Returns handling capabilities	KPI_4^S	Collective efforts for handling returns	Humphreys et al. (2006); Chiou, Hsu and Hwang (2008)
Waste material treatment capability	KPI_5^S	Collective efforts for managing the waste material	Yu and Tsai (2008); Fatimah, Govindan, Murniningsih and Setiawan (2020)
Green image	KPI_6^S	Collaborative approach for creating green image in the competitive environment	Mafakheri et al. (2011)
Environmental competencies	KPI_7^S	Synchronization of competencies related to the environment enabling the whole network to better manage risk while sharing benefits	Mafakheri et al. (2011)
Recycling	KPI_8^S	Allied planning for recycling of the used products, components and materials	Yeh and Chuang (2011); Kannan et al., (2020)
Environmental costs	KPI_9^S	The mutually shared value of risk posed on society by the environmental effects of the activities of supplier and manufacturer activities	Mafakheri et al. (2011); Yeh and Chuang (2011)
Information disclosure	KPI_{10}^S	Level of sharing information about the martial being used during the manufacturing process and carbon emission	Luthra, Govindan, Kannan, Mangla and Garg (2017)
Training education and community influence	KPI_{11}^S	Collective planning for transferring and impact of knowledge from employer to its employees and the community within which they operate	Ahmadi et al. (2017)
Employment practices	KPI_{12}^S	Joint planning to incorporate employment practices like working hours, child labour, career development, employment compensation and equity labour sources	Bai et al. (2019)
Occupational health and safety management system	KPI_{13}^S	Collaborative actions for health, safety and welfare of workers at workplace.	Ahmadi et al. (2017)
Interests and rights of employees	KPI_{14}^S	Joint efforts that promote employee concerns related to sustainable employment issues	Luthra et al. (2017)
Work health and safety	KPI_{15}^S	Synchronization of rules for their operation health and safety practices by the supplier and the manufacturer	Ahmadi et al. (2017); Govindan, Shaw, and Majumdar (2021)

only those relationships are mapped that are above the chosen threshold value. Also, all the mapped relationships in Figure 3 that meet or exceed the value of are highlighted using red highlighter in Table 6.

6 | RESULT AND DISCUSSION

The grey-DEMATEL approach provides influential (cause) and influenced (effect) groupings of KPIs and their order of importance. It

TABLE 5 The overall grey relation matrix

	KPI_1^S	KPI_2^S	KPI_3^S	KPI_4^S	KPI_5^S	KPI_6^S	KPI_7^S	KPI_8^S	KPI_9^S	KPI_{10}^S	KPI_{11}^S	KPI_{12}^S	KPI_{13}^S	KPI_{14}^S	KPI_{15}^S
KPI_1^S	(0,0)	(0,0)	(1.5,2.5)	(0,0)	(0,0)	(3,4)	(0,0)	(0,0)	(2.5,3.5)	(0,0)	(0,0)	(0,0)	(0,0)	(0,0)	(0.5,1.5)
KPI_2^S	(2.5,3.5)	(0,0)	(3,4)	(0,0)	(2,3)	(3,4)	(2,3)	(1,2)	(2.5,3.5)	(0,0)	(0,0)	(0,0)	(0,0)	(0,0)	(0.5,1.5)
KPI_3^S	(2,3)	(0,0)	(0,0)	(0,0)	(1.5,2.5)	(3,4)	(1.5,2.5)	(2,3)	(0.5,1.5)	(0,0)	(0,0)	(0,0)	(0,0)	(0,0)	(0,0)
KPI_4^S	(0,0)	(0,0)	(0,0)	(0,0)	(1,2)	(2,3)	(0,0)	(0,1)	(2,3)	(0,0)	(0,0)	(0,0)	(0,0)	(0,0)	(0,0)
KPI_5^S	(1.5,2.5)	(0,0)	(0,0)	(0,0)	(0,0)	(3,4)	(0,0)	(3,4)	(2,3)	(0,0)	(0,0)	(0,0)	(0,0)	(0,0)	(0,0)
KPI_6^S	(0,0)	(0,0)	(0,0)	(0,0)	(0,0)	(0,0)	(0,0)	(0,0)	(0,0)	(0,0)	(3,4)	(0,0)	(0,0)	(0,0)	(0,0)
KPI_7^S	(1,2)	(2.5,3.5)	(1,2)	(2,3)	(2,3)	(3,4)	(0,0)	(1,2)	(0,1)	(0,0)	(0,0)	(0,0)	(0,0)	(0,0)	(0,0)
KPI_8^S	(2,3)	(0,0)	(1,2)	(3,4)	(3,4)	(2.5,3.5)	(0,0)	(0,0)	(2.5,3.5)	(0,0)	(0,0)	(0,0)	(0,0)	(0,0)	(0,0)
KPI_9^S	(0,0.5)	(0,0.5)	(0,0)	(0.5,1)	(0,0)	(0,0)	(0,0)	(0,0)	(0,0)	(0.5,1)	(0,0)	(0,0)	(0,0)	(0,0)	(0,0)
KPI_{10}^S	(1,2)	(2,3)	(3,4)	(2,3)	(3,4)	(1,2)	(2,3)	(1,2)	(0,0.5)	(0,0)	(1,2)	(0,1)	(2,3)	(2,3)	(3,4)
KPI_{11}^S	(0,1)	(0,0)	(1,2)	(1,2)	(0,1)	(0,0)	(0,0)	(2,3)	(0,0)	(0,0)	(0,0)	(3,4)	(2,3)	(0,0)	(2,3)
KPI_{12}^S	(0,0)	(0,0)	(0,0)	(0,0)	(0,0)	(0,0)	(0,0)	(0,0)	(0,0)	(0,0)	(2,3)	(0,0)	(3,4)	(1,2)	(2,3)
KPI_{13}^S	(0,0)	(2,3)	(0,0)	(0,0)	(0,0)	(0,0)	(0,0)	(0,0)	(0,0)	(0,0)	(0,0)	(3,4)	(0,0)	(2,3)	(2,3)
KPI_{14}^S	(0,0)	(0,0)	(0,0)	(0,0)	(0,0)	(0,0)	(0,0)	(0,0)	(0,0)	(0,0)	(1,2)	(2,3)	(3,4)	(0,0)	(2,3)
KPI_{15}^S	(0,0)	(0,0)	(0,0)	(0,0)	(0,0)	(0,0)	(0,0)	(0,0)	(0,0)	(0,0)	(2,3)	(3,4)	(2,3)	(0,1)	(0,0)

TABLE 6 The whitened total relation matrix

	KPI^S_1	KPI^S_2	KPI^S_3	KPI^S_4	KPI^S_5	KPI^S_6	KPI^S_7	KPI^S_8	KPI^S_9	KPI^S_{10}	KPI^S_{11}	KPI^S_{12}	KPI^S_{13}	KPI^S_{14}	KPI^S_{15}
KPI^S_1	0.00291	0.000255	0.054461	0.001609	0.002324	0.111929	0.00181	0.003178	0.00181	0.000953	0.008963	0.002138	0.001584	0.000187	0.022406
KPI^S_2	0.107769	0.00442	0.11303	0.009226	0.087368	0.153499	0.072444	0.05687	0.072444	0.001127	0.011388	0.002437	0.001807	0.000216	0.023395
KPI^S_3	0.084063	0.003114	0.007146	0.009198	0.067081	0.138693	0.052481	0.080759	0.052481	0.000357	0.009275	0.000888	0.000655	7.76E-05	0.001642
KPI^S_4	0.001971	8.14E-05	0.000424	0.001553	0.042796	0.083802	5.98E-05	0.011609	5.98E-05	0.000805	0.005375	0.000471	0.000381	7.55E-05	0.000412
KPI^S_5	0.063274	0.00011	0.00522	0.008909	0.008122	0.124344	0.00024	0.104419	0.00024	0.000906	0.008553	0.000816	0.000634	0.000104	0.001347
KPI^S_6	0.00064	0.000317	0.002741	0.002976	0.000795	0.000886	0.00012	0.005272	0.00012	8.07E-06	0.106202	0.008658	0.006465	0.000543	0.005963
KPI^S_7	0.058176	0.083227	0.051343	0.075481	0.08893	0.150653	0.005817	0.055062	0.005817	0.000242	0.009917	0.000993	0.000724	7.74E-05	0.002458
KPI^S_8	0.082662	0.000212	0.042871	0.106187	0.112568	0.126018	0.001409	0.011412	0.001409	0.001171	0.008299	0.000807	0.000641	0.000118	0.001589
KPI^S_9	0.00626	0.005332	0.001739	0.023681	0.002296	0.003121	0.000916	0.000876	0.000916	0.02073	0.000647	0.000279	0.000978	0.00081	0.001495
KPI^S_{10}	0.073165	0.082771	0.127769	0.08712	0.139466	0.108987	0.080933	0.074318	0.080933	0.000284	0.063658	0.038977	0.107856	0.079123	0.132632
KPI^S_{11}	0.015791	0.004145	0.043289	0.046198	0.018001	0.014648	0.001549	0.079259	0.001549	9.82E-05	0.012042	0.126904	0.101267	0.007869	0.090495
KPI^S_{12}	0.000918	0.00566	0.002512	0.002211	0.000949	0.001255	0.000384	0.004116	0.000384	1.14E-05	0.082193	0.026501	0.135835	0.048592	0.093888
KPI^S_{13}	0.00513	0.071385	0.005879	0.000833	0.004199	0.007147	0.003524	0.003246	0.003524	6.37E-05	0.013651	0.125843	0.023117	0.078702	0.092736
KPI^S_{14}	0.000727	0.005698	0.001687	0.001317	0.000711	0.000991	0.000355	0.002529	0.000355	9.09E-06	0.051995	0.102041	0.13663	0.009027	0.093871
KPI^S_{15}	0.000788	0.004064	0.002375	0.002208	0.000843	0.001082	0.000297	0.004061	0.000297	9.81E-06	0.082287	0.128781	0.103884	0.016089	0.016855

TABLE 7 Cause and effect of KPIs

KPI	*D* + *C*	*D* − *C*	Cause/effect
KPI_1^S	0.720759	**−0.28773**	Effect
KPI_2^S	0.988228	0.446648	Cause
KPI_3^S	0.970397	0.045423	Cause
KPI_4^S	0.528584	**−0.22883**	Effect
KPI_5^S	0.903688	**−0.24921**	Effect
KPI_6^S	1.168761	**−0.88535**	Effect
KPI_7^S	0.811257	0.366577	Cause
KPI_8^S	0.994357	0.000388	Cause
KPI_9^S	0.292418	**−0.15226**	Effect
KPI_{10}^S	1.304768	1.251217	Cause
KPI_{11}^S	1.037549	0.088657	Cause
KPI_{12}^S	0.971943	**−0.16112**	Effect
KPI_{13}^S	1.061437	**−0.18348**	Effect
KPI_{14}^S	0.649552	0.166332	Cause
KPI_{15}^S	0.945104	**−0.21726**	Effect

Abbreviation: KPIs, key performance indicators.

should be noted that the company cannot focus on working towards only one or two KPIs because there are interrelationships among KPIs (Govindan, Rajendran, Sarkis, & Murugesan, 2015). Therefore, there is a need to classify them into cause and effect groups; working over the cause group KPIs will lead to improved effect group KPIs. The cause and effect groups are obtained based on the (*D* − *C*) scores generated from the application of grey-DEMATEL model. The scores are tabulated in Table 7, and the clustering of the groups is shown in Figure 3. Seven KPIs are identified as influential KPIs in cause group, and thus, they are significantly important. The first focus should be on these influential KPIs because their enhancement (influential KPIs) boosts enhancement in the influenced KPIs. The company must devote particular attention to these KPIs. The seven cause group KPIs are arranged in increasing order of their strength of influence as follows: 'Information disclosure' (KPI_{10}^S), 'Environmental management system' (KPI_2^S), 'Environmental competencies' (KPI_7^S), 'Interests and rights of employees' (KPI_{14}^S), 'Training education and community influence' (KPI_{11}^S), 'Pollution controls' (KPI_3^S) and 'Recycling' (KPI_8^S).

Effect group KPIs do not have direct impact on process; yet, they still make a substantive contribution and cannot be totally neglected. Of all the eight effect group KPIs, 'Green image' (KPI_6^S) obtains the least (*D* − *C*) score of −0.88535, which implies that this KPI obtains the highest impact. The remaining influenced KPIs, arranged in the decreasing order of (*D* − *C*) scores, are as follows: 'Pollution prevention' (KPI_1^S) with a score of −0.28773, 'Waste material treatment capabilities' (KPI_5^S) with a score of −0.24921, 'Return handling capabilities' (KPI_4^S) with a score of −0.22883, 'Work health and safety' (KPI_{15}^S), with a score of −0.21726, 'Occupational health and safety' (KPI_{13}^S) with a score of −0.18348, 'Employment practices' (KPI_{12}^S) with a score of −0.16112 and 'Environmental cost' (KPI_9^S) with a score of −0.15226. Effect group KPIs can be improved by improving the cause group KPIs because effect group KPIs have dependent relationship with the causal group KPIs.

As presented in Table 7, within the cause and effect groups, the KPIs are arranged with their (*D* + *C*) score in increasing order of

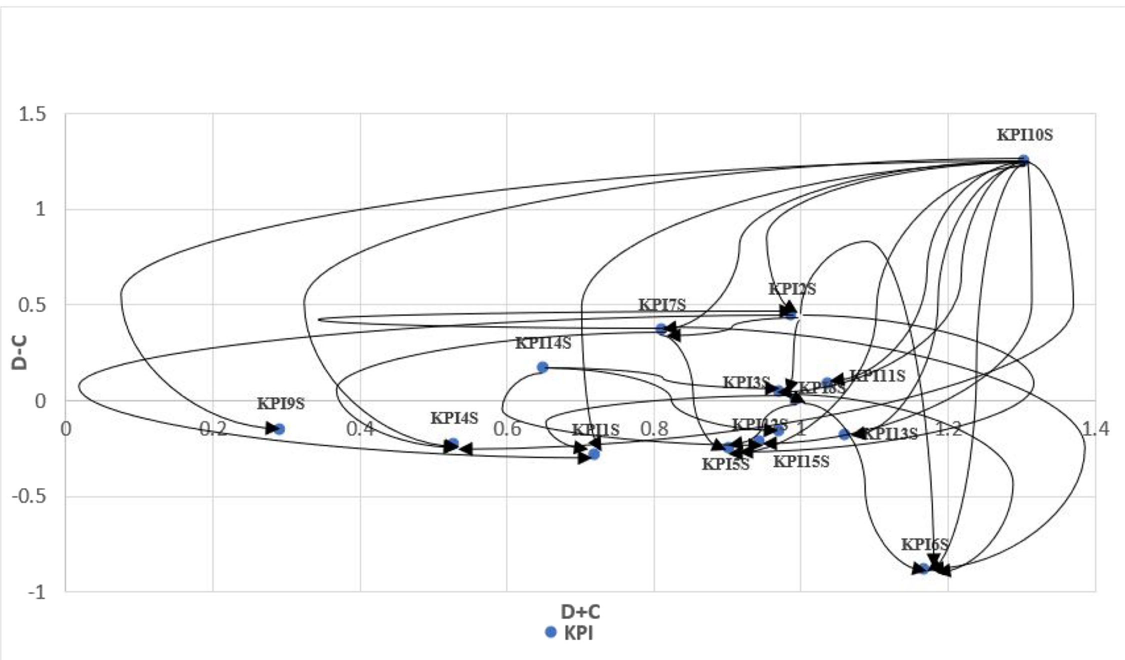

FIGURE 3 Diagraph showing overall grey decision-making trial and evaluation laboratory (DEMATEL) prominence–causal relationship among key performance indicators (KPIs) [Colour figure can be viewed at wileyonlinelibrary.com]

importance based on the prominence value as follows: KPI_{10}^S with a score of 1.304768, KPI_6^S with a score of 1.168761, KPI_{13}^S with a score of 1.061437, KPI_{11}^S with a score of 1.037549, KPI_8^S with a score of 0.994357, KPI_2^S with a score of 0.988228, KPI_{12}^S with a score of 0.971943, KPI_3^S with a score of 0.970397, KPI_{15}^S with a score of 0.945104, KPI_5^S with a score of 0.903688, KPI_7^S with a score of 0.811257, KPI_1^S with a score of 0.720759, KPI_{14}^S with a score of 0.649552, KPI_4^S with a score of 0.528584 and KPI_9^S with a score of 0.292418.

The (*D*+*C*) score represents 'total cause and effect' impact, and hence, the highest value of (*D* + *C*) indicates the greatest overall prominence of KPI over other KPIs. The net effect (*D* – *C*) represents 'relation or influence.' The ranking based on (*D* + *C*) shows the importance of the KPI, and ranking based on (*D* – *C*) indicates the net effect order of the KPIs. All the KPIs in the cause group and the effect group are characterized now by two parameters: that is, their strength of influence (*D* – *C* score) and their prominence in terms of importance (*D* + *C* score). Based on the values obtained for each KPI based on these two parameters, the impact of the KPI in the cause group on the effect group KPIs is discussed in detail.

In this study, 'Information disclosure (KPI_{10}^S)' (1.251217, 1.304768) being regarded as the most influential and important KPI based on its (*D* – *C*) score and (*D* + *C*) score, respectively; these scores are not confounding. The necessity of information disclosure for collaboration with suppliers has been addressed in many studies (Kim, Choi, & Skilton, 2015; Parker, 2000; Rönnberg-Sjödin, 2013; Wang, 2011). It is considered as a key KPI for performance benefits such as better responsiveness, increased profit and improved service performance (Wu, Chuang, & Hsu, 2014). It builds trust, transparency and long-term commitment between collaboration partners and strengthens the perception of sustainable collaboration (Parker, 2000). However, there are some risks such as information leakage that can be harmful for the status of the company so there should be contracts between partners to ensure information security. Also, it helps to understand the environmental competencies of each other and establish an environmentally friendly image in the market (Ramanathan & Gunasekaran, 2014). The right amount of information disclosure augments the decision-making process and helps to better understand the areas that may need improvement (Whang, 2000). It can strengthen environment management systems by collaborative efforts of manufacturer and suppliers and positively influence the green image of the company (Wong, 2013). Figure 4 depicts that this KPI initiates the effect of many other KPIs such as KPI_1^S, KPI_2^S, KPI_3^S, KPI_4^S, KPI_5^S, KPI_6^S, KPI_7^S, KPI_8^S, KPI_9^S, KPI_{13}^S, KPI_{14}^S and KPI_{15}^S. The results

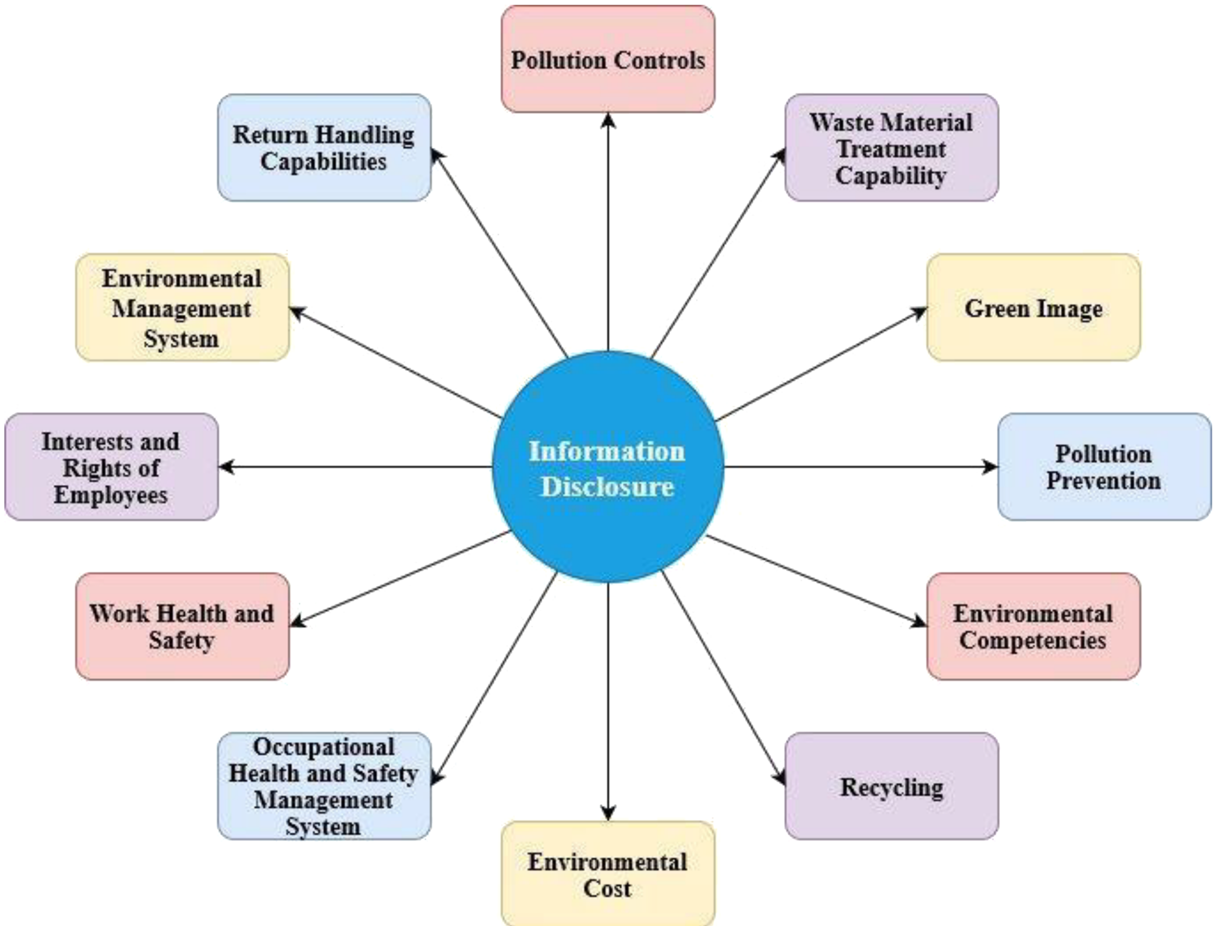

FIGURE 4 The prominence–causal relationship structural model for information disclosure [Colour figure can be viewed at wileyonlinelibrary.com]

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clearly exemplify the need of KPI^S_{10} in sustainable supplier–manufacturer collaboration.

'Environmental management system $\left(KPI^S_2\right)$' (0.446648, 0.988228) secures second place in strength of influence and sixth place in prominence ranking. It is justifiable as its importance in collaboration context has been pointed out in numerous studies (Jiang, Hu, Yen, & Tsao, 2018; Vachon & Klassen, 2008). It has been proven that sustainable collaboration with suppliers is positively affected by environmental management, and it leads to competitive advantage in the market (Yang, Lin, Chan, & Sheu, 2010). Moreover, KPI^S_2 is a non-negotiable KPI because the operations efficiency of supplier and manufacturer, as well as planning of processes and practices for reducing negative environmental impacts on the society, is dependent on it. It is evident from Table 6 and Figure 5 that non-negotiability of this KPI is proven because an improvement in KPI^S_2 leads to improvement in other factors such as KPI^S_1, KPI^S_3, KPI^S_5, KPI^S_6, KPI^S_7 and KPI^S_{12}.

'Environmental competencies (KPI^S_7)' (0.366577, 0.811257) has obtained the third influential and 11th most important KPI in the study. There are numerous studies that have considered this KPI as a crucial driver for evaluating the sustainable supplier (Akman & Pışkın, 2013; Kannan, Rajendran, Sarkis, & Murugesan, 2013; Theißen and Spinler, 2013). It includes assessment of the supplier's ability to decrease pollution effects, to utilize environmentally friendly materials and to exert clean technology (Humphreys, McCloskey, McIvor, Maguire, & Glackin, 2006). For better management of risk, sharing benefits and improvement in sustainable KPIs like KPI^S_2, KPI^S_4, KPI^S_5 and KPI^S_6, a synchronization of environmental related competencies between supplier and manufacturer is needed.

'Interests and rights of employees (KPI^S_{14})' (0.166332, 0.649552) is found a

s the fourth causal and 13th prominence KPI. It considers issues like human rights, labour relations and interests of employee. For achieving success and sustainable effectiveness in long run, company needs to focus on these issues (Muduli & Barve, 2013). Further, the compliance of companies towards corporate social responsibility can be significantly improved by respecting and taking care of their supplier's interests (Chen et al., 2018). Thus, joint efforts for the promotion of employee concerns and related sustainable employment issues are considered as key elements for sustainable collaboration and are instrumental in improving the other interrelated KPIs as well.

The fifth most influential and fourth most important KPI is 'Training education and community influence (KPI^S_{11})' (0.088657, 1.034768). In procurement process and supplier selection, many studies consider this to be a critical KPI for achieving social sustainability (Azadnia, Saman, & Wong, 2015; Ahmadi et al., 2017). As discussed earlier, supplier selection by itself is not enough for sustainability in this competitive environment. Instead, joint planning of manufacturer and suppliers in terms of transfer and impact of knowledge from employer to employees and the community within which they operate is desirable. Hence, training education and community influence can motivate other KPIs and drive them to collaborate with suppliers and enhance the sustainable performance of company.

The sixth influential and eighth prominence KPI among the identified KPIs is 'Pollution controls (KPI^S_3)' (0.045423, 0.970397). Due to growing environmental concerns, companies are bound by certain regulations for effective functioning of procurement process. Pollution control is one such necessary and effective way to tackle this concern, and it can be best done through collaborative efforts of company and the suppliers (Gurel, Acar, Onden, & Gumus, 2015; Vachon & Klassen, 2008). Due to this reason, KPI^S_3 is a driver for other KPIs to exceed the sustainability standards of manufacturer as well as supplier.

'Recycling $\left(KPI^S_8\right)$' (0.000388, 0.994357) occupies seventh place in strength of influence and fourth place in prominence ranking, indicating that supplier and manufacturer definitely need to together trigger recycling activities to enhance the overall performance. It has been reported in the literature that companies are lagging behind in achieving sustainable environments due to the inadequacy of recycling activities (Ji, Yuan, Feng, & Wang, 2020).

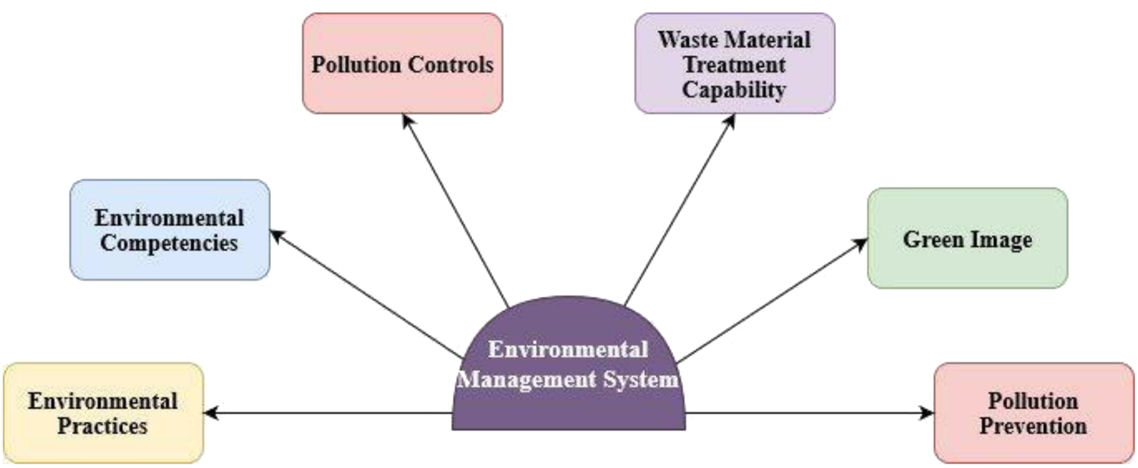

FIGURE 5 The prominence–causal relationship structural model for environmental management system [Colour figure can be viewed at wileyonlinelibrary.com]

7 | MANAGERIAL IMPLICATIONS

For improving the performance levels of the procurement process of the home appliances manufacturing company, the collaborative participation of environmentally and socially responsible suppliers is essential. The results presented in this study offer several implications for the company and researchers. These results may help managers in achieving sustainable collaboration with the suppliers. The KPIs identified in this study through relational view can serve as the checklist that comprehensively covers possible performance indicators associated with sustainable collaboration. Due to limited resources and time constraint, managers involved in strategizing towards sustainable collaboration between supplier and company cannot focus on all KPIs simultaneously. Thus, they need to primarily focus on the highly influential KPIs. After that, low influential KPIs are generally addressed with much less effort. The proposed causal relationships among KPIs can support the company in their decision-making process of sustainable collaboration with suppliers. This study motivates the practitioners who are keen to become involved and take initiatives towards implementing a collaborative environment between company and their suppliers for enhancing their sustainable performance. This research also gives the direction to the practitioners in how to identify and evaluate the KPIs for sustainable collaboration with their partners. A few key points that are beneficial for the managers through this study are as follows:

1. **Encourage supplier and manufacturer for information disclosure:** On the basis of the results of the research, managers are encouraged to consider information disclosure as a top priority for evaluation suppliers for achieving sustainable collaboration. This assists in building trust, transparency and long-term commitment between collaborative partners; improves the decision-making process; enhances the efficiency of the maximum number of sustainable collaborative KPIs; and leads to improved sustainable performance of the company.
2. **Empower environmental management systems jointly:** Managers should focus on the environmental management systems' capability of the supplier. It can be improved by the joint planning of supplier and manufacturer for processes and practices to reduce environmental impact and increase operating efficiency. This work also indicates that waste material treatment capabilities of suppliers are important to create a green image in the market for the company.
3. **Focus on effect group of KPIs:** The effect group KPIs will be taken care by cause group KPIs. Hence, managers should focus on cause group KPIs such as information disclosure, environmental management systems and environmental competencies.

8 | THEORETICAL CONTRIBUTIONS

Over the years, the process of KPI selection has emerged as the most important stage in the supplier evaluation and selection problems. Differently from what is illustrated in the literature in this particular research area, this study contributes theoretically in the following ways:

1. This study provides a structural model that is generalizable for evaluation for suppliers for sustainable manufacturer collaboration through the theoretical lens of the relational view. It helps to extend the collaboration among SC partners' stream of research (Elia, Margherita, & Petti, 2020) by reinforcing the fact that the boundaries of manufacturer's firm should be unlocked for suppliers for sustainable supplier–manufacturer collaboration.
2. In the performance evaluation of the many SC partners and, moreover, in the area of supplier selection, limited emphasis has been given to the detailing on KPIs (Lima-Junior & Carpinetti, 2016a). There is complete lack of supplier selection problems embracing the aspect of sustainable collaboration. Hence, most studies in literature have neglected the consideration of sustainability aspect for identification of KPIs in the context of manufacturer–supplier collaboration in a relational view theoretical lens. Hence, the novelty of the current research is in the inclusion of supplier evaluation KPIs in terms of sustainable collaboration based on relational view. Additionally, KPIs such as information disclosure, environmental system management, environmental competencies, interests and rights of employees and so forth have uniquely been considered in the current research.
3. In the present study, a mathematical modelling framework based on grey-DEMATEL methodology has been proposed for tackling the KPI evaluation and selection problem with the goal of sustainable collaboration. The implications drawn from the grey-DEMATEL structural model can serve as a strong base model for researchers to understand the influence of the KPIs and their interrelationships. The model successfully addresses the issues arising due to uncertainty in decision-making with regard to an analysis of KPIs. Therefore, the model can be suitably modified to deal with ambiguity in real-life group decision-making scenarios.

9 | CONCLUSION

Sustainable supplier manufacturer collaboration is a key to survive in the highly competitive market. Because of the importance of this objective, this study attempts to address and understand how to measure the performance of supplier for sustainable supplier–manufacturer collaboration. In terms of conceptual development, the present work is an effort to identify and evaluate the KPIs for sustainable collaboration with suppliers in an SC context using relational view theoretical lens. Notably, 15 KPIs are shortlisted through literature and DM's opinions. The grey-DEMATEL methodology is further used to analyse the KPIs to identify their causal–effect relations. According to the results, 'information disclosure,' 'environmental management system,' 'environmental competencies,' 'interests and rights of employees,' 'training education and community influence,' 'pollution controls' and 'recycling' comprise the cause group and need to be focused primarily to achieve the desired goal. The remaining eight KPIs, 'environmental costs,' 'employment practices,' 'occupational health and safety management system,' 'work health and safety,' 'return handling capabilities,' 'waste material treatment capability,' 'pollution prevention' and 'green image' comprise the effect group. Cause group KPIs have direct effect on the system so they are demonstrated as having high priority. Therefore, the focus should be largely on the cause group to improve all KPIs (cause and effect group). Effect group KPIs are significantly driven by constructing efforts upon cause KPIs to extract positive outcomes in terms of the effect group. The current research also presents a case problem example of a home appliances company in India to understand the usefulness of the proposed approach.

There are few limitations in this study as well that can be considered as opportunities for future research. These are as follows:

- In this study, 15 KPIs are selected for evaluating the performance of supplier for sustainable collaboration for single case problem and for procurement of material for a specific product. For future research work, the identification of KPIs for sustainable collaboration with multiple suppliers for multiple products may pose different challenges. In such cases, the process of identification of KPIs may require a more detailed and structured methodology.
- The identification and evaluation study of KPIs is specifically done in the Indian context. As home appliances companies in India are venturing into the domain of sustainable SC, some KPIs that gained high influential strength for companies may become peripheral in future, and some KPIs that have less influential power may become top priority later. Hence, the findings of the KPI analysis need to be suitably modified for different country scenarios.
- The criteria considered and the methodology used are specific to the home appliances manufacturing industry. For application of the methodology to a wider range of industries, more criteria can be considered, the scope of data collection can be broadened, and findings may be compared in future studies.

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