An integrated approach to modeling the barriers in implementing green manufacturing practices in SMEs

Highlights

- Critical barriers of implementing green manufacturing practices in SMEs are identified, categorized and ranked.
- Indian SMEs are considered as the context of the study.
- A novel approach combining Delphi method, integrated MCDM framework using fuzzy DEMATEL, fuzzy ANP and fuzzy TOPSIS and sensitivity analysis is employed.
- Core barriers referring to the lack of internal abilities and strategies are found as the most critical barrier category for SMEs.

Abstract

Rapid environmental depletion and ever-increasing CO_2 emission have necessitated an environment-friendly manufacturing practice for industries across the globe. In this perspective, green manufacturing (GM) practices were conceptualized and practiced by large scale enterprises of developed countries. However, small and medium-sized enterprises (SMEs) in developing countries are struggling to adopt GM practices. There are many reasons for this struggle in a developing country like India. To shed light on this issue, this research work intends to identify, analyze and rank the predominant barriers, which restrict implementing of GM practices in Indian manufacturing small and medium-sized enterprises (SMEs). Based on a comprehensive literature review and experts' opinion by employing the Delphi method (DM), the study revealed 25 barriers, in three broad categories, of GM implementation in Indian SMEs. The identified barriers are ranked, and their interrelationships are explored using a novel integrated multi-criteria decision making (MCDM) framework, with a combination of Decision-Making Trial and Evaluation Laboratory Model (DEMATEL), Analytical Network Process (ANP), and Technique for Order Performance by Similarity to Ideal Solution (TOPSIS) in a fuzzy context. A sensitivity analysis is performed to check the consistency of the results. The results reveal that core category, which include several barriers related to lack of internal abilities and strategies, is the most critical category of barriers for manufacturing SMEs in India. In particular, the three most critical barriers are lack of research and development (R&D), failure in eco-design and lack of accreditation respectively. The study findings, which provide valuable insight for SME practitioners of Indian manufacturing SMEs, can be used to formulate appropriate strategies to overcome the barriers.

Keywords: Green manufacturing; Delphi method; Fuzzy MCDM; Sensitivity analysis.

1. Introduction

Owing to rapid industrialization and urbanization, available natural resources on the earth are getting depleted quickly. As a result, the global community is at a crucial juncture of facing acute resource shortage (Kothawade, 2017). In some cases, environmental problems have affected regional cooperation and have even prompted conflict (Tol, 2018). To nurture regional cooperation and to safeguard natural resources, green manufacturing (GM) practices have become common practice for all member of cooperation nations. GM refers to manufacturing methods that not only focus on the reduction of waste generation and natural resource depletion but also ensure the elimination of waste entering landfill (Cortellini, 2001). In general, GM is an environmentally conscious process that lowers the negative environmental impact. In a recent statement, the Intergovernmental Panel on Climate Change (IPCC) indicates that the average global temperature has increased by 0.85^0C (Porter et al., 2018). In connection with this, many companies across various countries have either implemented or demonstrated their interest in adopting GM strategies (Moldavska & Welo, 2017). For instance, the six 'R's (Reduce, Reuse, Recover, Redesign, Remanufacture, Recycle) practice, zero waste production and lean manufacturing practices have been adopted as GM strategies by many manufacturing firms (Cimatti et al., 2017). Such GM practices help the firms financially by ensuring the optimal use of resources and by obtaining value from waste (Rehman & Shrivastava, 2013).

While implementation of GM practices is equally important for both and large and smaller firms, SMEs are comparatively more reluctant to adopt GM practices (Tumpa et al., 2019). SMEs are defined by size, organizational structure, number of employees and sales volume (Mukherjee, 2018). The adoption of GM practices is crucial given the fact that the survival of SMEs in global competition has become difficult without these practices, and SMEs play an important role in the economic development of countries around the world. In this connection, there is an immediate need to explore the barriers of GM implementation in SMEs. Therefore, this study aims to explore and model the barriers in implementing such GM practices in SMEs. There could be many reasons, such as lack of data, technical expertise, infrastructure, and capital resources, for low implementation of GM practices by SMEs (Mittal et al., 2013). The condition is even worse in SMEs in emerging countries as there exists an inequality in the GM progress between developed and developing nations. With strict environmental regulations and policies in place, the developed nations (like US, EU, and Germany) have seen progress in GM implementation (Biju et al., 2015). However, the scenario is completely different in developing countries (Mittal et al., 2013). For example, a recent study on GM practices in India by Gandhi et al., (2018) revealed that the majority of manufacturing SMEs are not even aware of GM practices and hence lagging behind in implementation. Since SMEs are the most common type of business in developing countries (Chowdhury et al., 2019), their low implementation of GM practices impacts the environmental index of these countries. For instance, India ranks third in global CO_2 emission in 2017 (Global Carbon Project Report, 2017).

Considering the low implementation of GM practices by the SMEs in developing countries and limited research to answer the question why (Luo et al., 2018), the context for this study is precisely SMEs in a developing country like India. In the Indian context, the role of SMEs is crucial in terms of economic achievement and job generation; hence, SMEs are considered the backbone of the country's economic growth (Yadav et al., 2019). According to the *Confederation of Indian Industry (CII)*, SMEs' contribution to the nation's gross domestic product (GDP) is around 33.4% and is expected to rise by 10% in 2020 (https://www.cii.in/Sectors.aspx?enc=prvePUj2bdMtgTmvPwvisYH+5EnGjyGXO9hLECvTuNuXK6QP3tp4gPGuPr/xpT2f).With this expectation and with the aim of boosting SMEs, India conceived an ambitious program called *'Make in India'* (Singh & Jaiswal, 2018; Maheswari et al., 2018). As per this program, many foreign large-scale entrepreneurs are setting up a footprint in India with the expectation of Indian SMEs supplying low-cost finished or semi-finished products. As a result, it is hoped SMEs will grow rapidly and provide, directly and indirectly, new job opportunities.

However, to take full advantage of such opportunities, SMEs are compelled to adhere to strict environmental regulations and to implement GM practices. It is generally believed that the identification of barriers of GM implementation is a precondition for formulating appropriate strategies for enhancing GM practices (Ghosh et al., 2018). This study, therefore, can assist practitioners as it identifies the barriers of GM implementation, reveals their interrelationships, categorizes them and ranks them and their categories. A three-stage solution methodology i.e. DM, integrated fuzzy DEMATEL, ANP and TOPSIS, and sensitivity analysis is employed in this study to solve the problem. DM was used to scrutinize and finalize prominent barriers from a list of barriers as identified through a comprehensive literature review (Bouzon et al., 2016). DM considered the similarities and differences between the opinions of experts to arrive at a consensus on the prominent barriers. As many barriers restrict the implementation of GM practices, a novel integrated MCDM framework combining DEMATEL, ANP and TOPSIS in a fuzzy environment is used to reduce vagueness of results (Velasquez & Hester, 2013; Chowdhury & Paul, 2020). In this work, fuzzy DEMATEL was used to understand the relationships among different barriers of GM practices, fuzzy ANP was utilized to calculate the weight of barriers, and fuzzy TOPSIS was applied for prioritizing the barriers and their categories. In addition to this, sensitivity analysis is performed to measure the robustness of the results obtained using the adopted methods. The findings of this study can also assist policy makers in formulating campaigns, training and programs to foster the implementation of GM practices in industry. In so doing, the findings of this study enhance understanding of GM practices in several ways. First, they enhance knowledge on GM practices in SMEs which are scare at the stage (Luo et al., 2018). Although focused on Indian SMEs, the findings of this study can be considered as a reference for SMEs in all developing nations as they all share similar characteristics. Second, the study contributes to the literature on GM practices in developing nations (Majumdar and Sinha, 2019). Third, the study integrates three MCDM techniques with DM to identify and analyze the GM barriers. To our knowledge, no previous work has analyzed GM barriers by combining DM and fuzzy DEMATEL-ANP-TOPSIS. Finally, the investigation of the interrelationships among the barriers of implementing GM practices is a unique contribution of this study. More specifically, the study intends to answer the following research questions (RQs):

RQ 1: What are the various barriers in adopting GM practices in Indian SMEs?

RQ 2: What are the relationships among the different barriers of implementing GM practices?

RQ 3: What are the most critical barriers in implementing GM practices?

The rest of the paper is in six sections. Section 2 reviews the relevant literature. While Section 3 details the problem of the study, section 4 elaborates the application of the proposed method. In section 5, the results are discussed. Implications for managers are suggested in section 6. Finally, section 7 concludes by highlighting the main contributions and proposing scope for future research.

2. Literature survey

The literature review is presented in three sub-sections: (1) GM practices and the current state of Indian SMEs in implementing these practices, (2) barriers of GM practices, and (3) use of different MCDM methods in green initiatives.

2.1 Green manufacturing practices

In the late 1980s, with the intention of setting a benchmark for products to be exported globally, Germany proposed the concept of GM practices. In the meantime, the Brundtland Commission report (1987) on environment and development underscored the fact that natural resources were getting depleted at a faster rate in the interests of development. Adding weight to this report, rapid depletion of natural resources, rising energy demand, growing customer awareness of environment-friendly products and the need to comply with rigid environmental regulations urged the industrial community to adopt GM practices. This need from the industrial community motivated researchers to formulate a framework for GM practices (Daly, 1990). Many GM definitions given by researchers focus mainly on minimization of adverse environmental impacts from cradle to grave, i.e. from the design stage to the end of life stage. Mohanty and Deshmukh (1998) defined GM practices as the collection of all activities carried out with the intention of waste minimization. Atlas and Florida (1998) endorsed the same with the addition of resource reduction, recycling and usage of green energy as GM practices. Dornfeld (2014) explained GM practices as a manufacturing practice which meets the customer need and environmental norms. In other words, GM practices is referred to as a green design for manufacturing which aims at energy conservation and product development with less wastage (Paul et al., 2014).

Implementation of zero waste generation and elimination processes by industry with the intention of mitigating adverse environmental impacts is understood to be GM practice (Binnemans et al., 2015). Integration of green and lean manufacturing have been proposed as a solution for manufacturing industries in minimizing adverse environmental impact (Thanki et al., 2016; Dieste et al., 2019). While the above GM practices have evolved in the recent past, the situation is completely different in the SME sector in India. According to Redwood (2013), a GM practice framework is developed by industry in meeting corporate social responsibility (CSR). However, a case study carried by Vancheswaran and Gautam (2011) in 30 Indian SMEs revealed that while many SMEs view CSR as a marketing channel, for many others, the concept still appears to be vague. As a result, there is no consistent understanding of GM practices by Indian SMEs (Singh et al., 2018). On the other hand, the environmental initiative taken by SMEs is nevertheless equal to or greater than that of large entrepreneurs (Nair & Sodhi, 2012).

In India, many SMEs find the implementation of GM practices difficult due to lack of required skills and financial resources (Gandhi et al., 2018). From a survey of 198 Indian SMEs, it was identified that the majority are calculating their short-term qualitative and quantitative benefits by GM implementation rather than environmental conservation (Sangwan 2011). However, the study carried out by Sezen and Cankaya (2013) explained that the implementation of GM practices improves the social and environmental performance of a SME along with enhancement of economic performance in the long-run by reducing raw material and energy cost. Despite mass environmental awareness campaigns and rigid environmental norms, many Indian SMEs are reluctant to implement GM practices. As an emerging economy and major manufacturing hub, India is facing significant pressure from external stockholders, i.e., from investors, to adopt GM practice (Mohanty and Prakash, 2014). Therefore, it has become imperative for Indian SMEs to take proper initiatives to change the current low-level adoption of GM practices.

2.2 Key barriers to green manufacturing practices

Many researchers focus solely on the benefits of GM practices but very few have addressed the barriers that restrict their successful implementation. The adoption of green initiatives by firms demand changes in operational capabilities and resources used (Wang & Chan, 2013). This is mainly because the implementation of GM practices needs a production system that generates less environmental pollution, even though the system generally requires more operational costs and skills (Zhang et al., 2017). Ghazilla et al. (2015) explored the drivers and barriers of GM practices in Malaysian SMEs. Their work suggests rigid environmental norms, competitiveness, environmental awareness, and customers demand as drivers of GM practices while barriers like financial constraints, lack of technical support, lack of guidelines, poor R&D, and low-level commitment from top management as inhibitors. Lack of innovation in the manufacturing process is considered the kingpin of barriers in GM implementation as all secondary barriers are the result of failure in innovation (Rodriguez & Wiengarten, 2017). From a survey comprising 120 leading firms in south India, Govindan et al., (2015a) identified 12 common drivers of GM practices. Their study identified compliance with regulations as the primary driver, however, underlined that all 12 drivers might fail in the case of Indian SMEs as they are unaware of GM practices.

To understand the attitude of the leather, cement, and textile sectors towards GM practices in Ethiopia, Wakeford et al., (2017) carried out a survey in 117 firms and the result revealed expensive technology, lack of financial support, and meager information as the barriers to GM practices. The findings also suggested increasing competition would act as the main driver of GM practices. Another case study, carried out in an automobile manufacturing company, identified eco-design, green image, top management commitment, and use of environment-friendly raw material as drivers of GM practices (Shen et al., 2013). Several studies also highlighted the importance of designing a formal model of implementing GM practices. For example, through a case study in Chongqing Machine Tool Works, Li et al., (2010) framed a five-layer model for planning and implementation of GM practices. Enterprise information systems, product design, enterprise operation objectives, strategic goals, and product life cycle form the five layers. The study indicates long-term commitment and a desire for continuous improvement from top management are needed for successful implementation of the model. Similarly, a four-stage GM implementation model is presented by Deif (2011), through a case study in a wood product manufacturing company. As discussed, several barriers of adopting GM practices are stated in previous studies. A comprehensive literature review revealed a total of 30 such barriers, which are summarized and presented in Table 1.

Table 1 Barriers to implement GM practices

Barriers	Significance	Supporting literature(s)
Lack of Research and Development (R & D)	Identification and development of new manufacturing process without adverse environmental impact	Ghazilla et al. (2015); Kuo et al., (2015); Govindan et al., (2015c); Wakeford et al., (2017); Luo et al., (2018)
Lack of capital investment	Modification of existing process for adoption of new green practice requires huge investment	Büyüközkan & Çifçi, (2012); Ghazilla et al. (2015); Wakeford et al., (2017); Zhang et al., (2017); Luo et al., (2018)
Lack of employee empowerment	Allows managers and decision makers to have vision	Ghazilla et al. (2015); Gandhi et al., (2018); Moktadir et al., (2018);
Inadequate training	Familiarization with the importance of green initiatives	Ghazilla et al. (2015); Gandhi et al., (2018); Moktadir et al., (2018); Luo et al., (2018)
Poor supply chain management	Utilization of recyclable material in manufacturing	Paul et al., 2014; Govindan et al., (2015c); Luo et al., (2018)
Lack of foreign direct investment (FDI)	Advance technology will be made readily available	Govindan et al., (2015c)
Failure in prime utility of resources	Make the most of the available resources	Zhang et al., (2017)
Failure in eco-design	Design processes with environmental safety as top priority	Shen et al., (2013); Govindan et al., (2015c)

Absence of a green disposal system	Ensure the wastes are treated before entering the environment	Li et al., (2010); Deif, (2011); Mohanty and Prakash (2014); Govindan et al., (2015c); Zhang et al., (2017)
Failure in implementation of green logistics	Enable seamless flow of product without adverse impact	Kannan et al., (2009); Mohanty and Prakash (2014)
Unawareness of green energy	Helps in lowering the dependence on conventional energy sources	Deif, (2011); Kuo et al., (2015); Wakeford et al., (2017); Zhang et al., (2017); Rodriguez & Wiengarten, (2017)
Lack of accreditation	Permission given by government for firms adhering with environmental norms	Govindan et al., (2015c); Moktadir et al., (2018)
Lack of recognition	Acknowledging efforts of firms in green initiatives	Luo et al., (2018)
Stringent levy policy	Tax exemption will aid in marketing green products	Govindan et al., (2015b); Rodriguez & Wiengarten, (2017)
Lack of cluster development	Establishment of industrial zones will ease waste management	Wakeford et al., (2017)
Poor export policy	Relaxation on constraints will enable larger volumes of export	Govindan et al., (2015b)
Lack of subsides	Financial support from government will encourage firms to adopt GM practice	Moktadir et al., (2018)
Poor market demand	Demand for green products will increase industries' production volume	Wakeford et al., (2017)
Lack of customer interest	Society's preference for environmentally aware products	Luo et al., (2018)
Lack of contenders	Motivate a firm to find new opportunities	Ghazilla et al., (2015); Govindan et al., (2015c); Wakeford et al., (2017); Gandhi et al., (2018); Moktadir et al., (2018); Luo et al., (2018)
Lack of venture capitalism	Collaboration between two or more firms will lessen the burden of capital investment	Govindan et al., (2015b)
Unavailability of patents	Prevents knowledge sharing	Fujii & Managi, (2019)
Unawareness of firms' reputation	Improve a company's public image as an environmentally concerned organization	Shen et al., (2013); Govindan et al., (2015c); Wakeford et al., (2017); Gandhi et al., (2018); Luo et al., (2018)
Insufficient marketing	Promotion of green products will expand the green market	Wang & Chan, (2013); Govindan et al., (2015b)
Absence of market diversification	Venturing into different fields of manufacturing to expand their business opportunities	Wakeford et al., (2017)
Scarcity of resources	May kindle interest in search of alternative renewable resources	Moktadir et al., (2018)
Lack of partnership between organizations	Enable sharing of knowledge among firms	Moktadir et al., (2018);
Poor work standardization	Enhances production rate and morale of workers	Gandhi et al., (2018)
Lack of guidelines	Non-availability of resource person in respective field for guidelines	Ghazilla et al. (2015)
Poor organizational structure	Unstructured organization may cause confusion in knowledge flow	Kuo et al., (2015); Ghazilla et al. (2015); Govindan et al., (2015c); Luo et al., (2018)

2.3 MCDM in green manufacturing initiatives

As problems with GM practices involve various factors, e.g., social, environmental and economic, a holistic approach to decision-making is required for finding a solution. Hence, the MCDM method appears to be appropriate. MCDM methods have been widely used in the supply chain literature to analyze and prioritize the decision alternatives. For example, Chen and Lin (2018) utilized DEMATEL-ANP (DANP) to analyse various determinants in the promotion of emerging technology. Grey DANP is used to establish the interactions between logistics and manufacturing industries (Jiang et al., 2018). Since decision making in multi-criteria is influenced by many factors, it leads to uncertainty. To overcome this limitation, fuzzy set theory is incorporated with MCDM methods. To estimate the wind power potential and the amount need to be invested in 15 locations, Mohsin et al., (2019) used fuzzy TOPSIS to prioritize the sites. In general, a large number of research studies in green initiative areas such as, green supply chain management, green logistics, green supplier selection, and green purchasing have been carried out using fuzzy MCDM methods, as shown in Table 2.

Table 2 Applications of fuzzy MCDM methods

Author(s)	Application area	Method used
Karaşan & Kahraman, (2019)	Selection of location for freight	Fuzzy DEMATEL-ANP-TOPSIS
Lin et al., (2018)	Sustainable supply chain management	Fuzzy DEMATEL
Luo et al., (2018)	Ranking of GM drivers	Fuzzy DEMATEL-fuzzy TOPSIS
Kuo et al., (2015)	Evaluating carbon performance of suppliers	Fuzzy ANP-fuzzy TOPSIS
Büyüközkan & Çifçi, (2012)	Selection of green supplier	Fuzzy DANP-fuzzy TOPSIS

3. Problem description and formulation

In developing countries, GM practices are still at the infant stage in most manufacturing sectors. Some industries are aware of the benefits of GM practices, but they are mainly concerned with marginal profit (Jayaraman et al., 2012). Although the interest in GM practices has been steadily increasing among industries, lack of investment and technical support remain as obstacles. Because of these issues, the enforcement of environmental regulation is a great challenge in many developing countries. Moreover, in some developing countries, the cost of implementing GM practices is greater than the amount of the fine for not complying with environmental norms (Zhang, 2005). However, the increasing demand for green products from customers urges the manufacturing sector to produce green products. With the intention of making *'Make in India'* a fruitful program, the government has advised the manufacturing sectors to use green energy and to develop green products with eco-concerned processes. Bearing this in mind, this paper intends to identify the phenomenal barriers of implementing GM practices in Indian SMEs by collecting the common barriers from the available literature and by employing the integrated DM, fuzzy DAMATEL, fuzzy ANP, and fuzzy TOPSIS. The problem is formulated and solved in three major phases, i.e., preparation, evaluation, and sensitivity analysis; Fig. 1 displays the framework of the study.

3.1 Preparation Phase

The study first designed the problem and research questions, as stated in the introduction. In line with the research problem, the barriers related to GM implementation were identified through literature surveys and filtered based on experts' opinions using DM. Generally, DM is used in research to obtain consistency in responses of the experts for finalizing issues or factors that are related to organizational decision making. For example, DM is used by Bouzon et al., (2016) to shortlist the critical factors of reverse logistics in the Brazilian context and by Ocampo et al., (2018) to identify the most influential indicators for establishing sustainable ecotourism in Philippines. In this study, the experts were either SME practitioners in the Indian leather industry or GM academics who have been researching the leather industry (Zhang et al., 2019). One of the main reasons for selecting the leather industry was that it is undergoing radical transformation due to pollution and discharge legislation. Hence the industry in India is under pressure to adopt environment-friendly processing techniques (Saravanabhavan et al., 2004). Moreover, the industry contributes substantially to generating employment and revenue in India (Sathish et al., 2016). The processed leather is supplied to renowned shoe manufacturers and to foreign countries. Thus, the industry needs to comply with environmental norms. A questionnaire consisting of collected barriers was given to the experts who responded on a five-point Likert scale. A five-point scale was preferred over seven and nine as it enables distinct rating of factors (Preston and Colman, 2000). Once the final list of barriers of implementing GM practices was approved, the barriers were categorized based on their common characteristics to be evaluated using fuzzy MCDM methods.

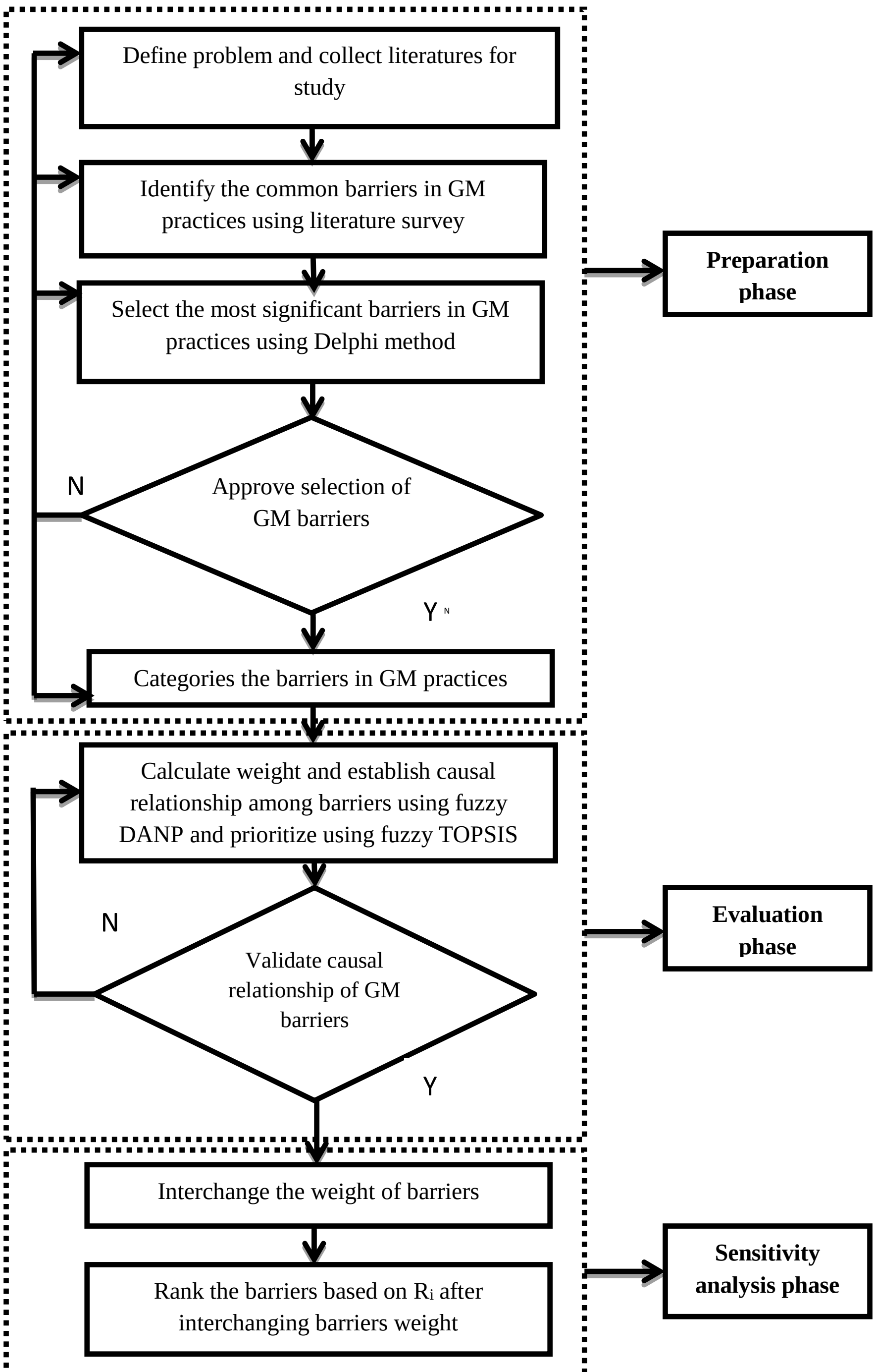

Fig.1 Framework for the study

3.2 Evaluation phase

The final list of barriers, derived from the literature survey and DM, were analyzed using a novel MCDM method consisting of fuzzy DEMATEL, fuzzy ANP, and fuzzy TOPSIS. Fuzzy DEMATEL was used to establish causal relationships. Fuzzy TOPSIS was used to prioritize the barriers, and fuzzy ANP, which work as a connector between fuzzy DEMATEL and fuzzy TOPSIS, was employed to compute the weight of the barriers. The steps involved in the proposed work are detailed below (Büyüközkan & Çifçi, 2012).

3.2.1 Formation of causal relation

Step 1: Obtain a fuzzy direct-relation matrix. A matrix $\tilde{K}$ containing $n \times n$ key factors is constructed and denoted $\tilde{a}_{ij} = (l_{ij}, m_{ij}, n_{ij})$ representing the degree of influences of factor *i* over factor *j* for experts. Experts were asked to make pair-wise comparisons of factors for matrix $\tilde{K}$ depending on the influence of one factor over others.

Step 2: Obtain a normalized fuzzy direct-relation matrix. The fuzzy direct-relation matrix $\tilde{K}$ obtained in step 1 is converted into a normalized fuzzy direct-relation matrix $\tilde{X}$. Using Eq. (1), the normalized fuzzy direct-relation matrix $\tilde{X}$ is calculated.

Consider $\tilde{a}_{ij} = (l_{ij}, m_{ij}, n_{ij})$ and $s = \frac{1}{\max_{1 \le i \le n} \sum_{j=1}^{n} u_{ij}}$, then

$$\tilde{X} = s \times \tilde{K} \tag{1}$$

Step 3: Obtain a fuzzy total-relation matrix. Total-relation matrix $\tilde{T}$, is obtained from the normalized fuzzy-relation matrix $\tilde{X}$ using the following equations where I – identity matrix.

Let $\tilde{X}_{ij} = (l_{ij}, m_{ij}, n_{ij})$ it defines the three crisp matrices whose elements are obtained from $\tilde{X}$.

$$X_1 = \begin{bmatrix} 0 & l_{12} & \cdots & l_{1n} \\ l_{21} & 0 & \cdots & l_{2n} \\ . & & & . \\ l_{n1} & l_{n2} & \cdots & 0 \end{bmatrix},\ X_2 = \begin{bmatrix} 0 & m_{12} & \cdots & m_{1n} \\ m_{21} & 0 & \cdots & m_{2n} \\ . & & & . \\ m_{n1} & m_{n2} & \cdots & 0 \end{bmatrix},\ X_3 = \begin{bmatrix} 0 & u_{12} & \cdots & u_{1n} \\ u_{21} & 0 & \cdots & u_{2n} \\ . & & & . \\ u_{n1} & u_{n2} & \cdots & 0 \end{bmatrix}$$

The total-relation fuzzy matrix $\tilde{T}$ is obtained using Eq. (2):

$$\tilde{T} = \tilde{X}(I - \tilde{X})^{-1} \tag{2}$$

$$\tilde{T} = \begin{bmatrix} \tilde{t}_{11} & \tilde{t}_{12} & \cdots & \tilde{t}_{1n} \\ . & & & . \\ . & & & . \\ \tilde{t}_{n1} & \tilde{t}_{n2} & \cdots & \tilde{t}_{nn} \end{bmatrix}$$

Step 4: Calculate the sum of rows and columns. Using Eqs. (3) and (4), the sums of rows and columns are calculated.

$$r = [r_i]_{nx1} = \left[\sum_{j=1}^{n} t_{ij}\right]_{nx1},\ s = [s_j]_{nx1} = \left[\sum_{i=1}^{n} t_{ij}\right] \tag{3}$$

$$T = \lfloor t_{ij} \rfloor,\ i, j = 1,2,\ldots n \tag{4}$$

Step 5: Set up a causal influence diagram.

With the obtained sum of rows and columns, the causal influence diagram is determined.

Step 6: Calculate the unweighted supermatrix ‘W’

Using Eq. (5), an unweighted supermatrix ‘W’ is obtained.

$$W = (T)^{'}.W \tag{5}$$

Step 7: Calculate the weighted supermatrix ‘W^{α}’

$$W^{\alpha} = T^{\alpha} \times W \tag{6}$$

Where W^{α} - normalized total-influence matrix

Step 8: Limit the weighted super matrix.

To obtain a stable super matrix, the power of the weighted super matrix is raised to a certain power. $\lim_{h\to\infty}(W^{\alpha})^{h}$ where *h* represents any number of powers.

3.2.2 Ranking the barriers

Step 1: Construct the fuzzy decision matrix with *m* alternatives and *n* criteria as follows:

$$\tilde{E} = \begin{array}{c} \\ A_1 \\ A_2 \\ A_3 \\ A_4 \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \cdots & C_n \end{array} \\ \begin{bmatrix} \tilde{X}_{11} & \tilde{X}_{12} & \cdots & \tilde{X}_{1n} \\ \vdots & \ddots & & \\ \vdots & & \ddots & \\ \tilde{X}_{m1} & \tilde{X}_{m2} & & \tilde{X}_{mn} \end{bmatrix} \end{array}$$

where $\tilde{E}$ represents the fuzzy decision matrix.

Step 2: A normalized decision matrix $\tilde{Z}$ is calculated as:

$$\tilde{Z} = \left[\tilde{z}_{ij}\right]_{m*n} \quad i = 1,2,..m; \; j = 1,2,...n$$

$$\tilde{z}_{ij} = \left(\frac{a_{ij}}{C_j^+}, \frac{b_{ij}}{C_j^+}, \frac{c_{ij}}{C_j^+}\right), \tag{7}$$

Step 3: Construct the weighted decision matrix. Using Eq. (10) the weighted decision matrix is computed.

$$\tilde{v}_{ij} = \tilde{z}_{ij} \otimes \tilde{w}_{ij} \tag{8}$$

Where $\tilde{w}_{ij}$ - weight for the criteria *j*

Step 4: Estimate the distance from the positive and negative ideal points.

$$A^{+} = \left\{\tilde{v}_1^{+}, \tilde{v}_2^{+}, ...\tilde{v}_n^{+}\right\}, \; A^{-} = \left\{\tilde{v}_1^{-}, \tilde{v}_2^{-}, ...\tilde{v}_n^{-}\right\} \quad (9)$$

Where $\tilde{v}_1^{+} = \{1,1,1\}$ $\tilde{v}_2^{-} = \{0,0,0\}$

$$s_i^{+} = \sum_{j=1}^{n} d\left(\tilde{v}_{ij}, \tilde{v}_j^{+}\right), \; i = 1,2,...,m; \; j = 1,2,..n. \quad (10)$$

$$s_i^{-} = \sum_{j=1}^{n} d\left(\tilde{v}_{ij}, \tilde{v}_j^{-}\right), \; i = 1,2,....,m: \; j = 1,2,..n. \quad (11)$$

$$s\left(\tilde{A}, \tilde{B}\right) = \sqrt{\frac{1}{3}\left[(a_1 - b_1)^2 + (a_2 - b_2)^2 + (a_3 - b_3)^2\right]} \quad (12)$$

Step 5: Calculate relative closeness.

$$R^{*}_{j} = \frac{D_j}{D_j^{*} + D_j}, \quad j = 1,2,..n. \quad (13)$$

Step 6: Rank the preference order.

3.3 Sensitivity analysis phase

The output obtained using fuzzy TOPSIS was solely influenced by the inputs from the expert team. As the judgment of the expert team was highly sensitive to change, a sensitivity analysis was carried out. Sensitivity analysis is performed to examine the impact of barriers weight on the ranking. This analysis gives the solution to the question: how sensitive is the overall ranking of barriers to small change in individual weights? (Ahmed et al., 2019). In this work, the sensitivity analysis was carried out to evaluate the influence of most prominent barrier in the implementation of GM by interchanging the weights. Similar sensitivity analysis was carried in earlier studies (Önüt & Soner, 2008; Yadav et al., 2018; Solangi et al., 2019; Çalık et al., 2019).

4. Confirmation and Evaluation of GM barriers

Phase 1: Identification of key barriers of GM implementation

In the first phase of the research, a questionnaire (Appendix 1) consisting of all 30 barriers, summarized in Table 1, was framed to collect the data from the experts to finalize the list of barriers of implementing GM practices in the manufacturing SME sector of India. The questionnaire (Appendix 1) was sent to ten experts to scrutinize the predominant barriers in GM implementation. Among the ten experts, eight responded to the questionnaire through Delphi analysis. In a Delphi study, there is no clear cut rule regarding the size of the expert panel (Keeney, Hasson and McKenna, 2001). Rather, it mostly depends on the purpose of the project; hence, a comparison was made with the similar types of projects. The panel size of DM was deemed acceptable when compared with previous studies, i.e., (Rezaei et al., 2016 (6 experts); Gandhi et al., 2018 (9 experts); Zavadskas et al., 2018 (7 experts); Malek & Desai, 2019 (5 experts); Intharathirat & Salam, 2020 (5 experts); Rostamabadi et al., 2020 (5 experts)). Moreover, complete anonymity among the experts was maintained to ensure that each respondent provides data completely, truthfully and without any kind of pressure from other experts (Keeney, Hasson and McKenna, 2001). In addition, the expert panel comprises of persons from different background like academic, industrial sector to get various inputs and to ensure group dynamics.The basic profile of the experts who responded is shown in Table 3.

Table 3 Experts profile

Experts	Designation	Department/ Area of expertise	Experience (years)
1	Proprietor	Supply chain unit	12
2	Academician	Green manufacturing	8
3	Supervisor	Production department	20
4	Director	Management	25
5	Safety engineer	Production department	12
6	Engineer	Energy department	8
7	Manager	Production unit	10
8	Manager	Logistic department	9

Respondents were requested to select '5' for the most critical barriers and '1' for the least critical barriers. Based on the experts' responses, 25 most predominant barriers in GM implementation in manufacturing SMEs in India were segregated and are listed in Table 4. Barriers which received maximum iterated responses from the experts were selected and barriers with minimum iteration were rejected (Abdullah et al., 2016). A closure looks into the 25 barriers reveal that seven (7) of the them linked to regulatory policy, ten (10) of them related to internal core abilities and strategies of the SMEs and the remaining eight (8) are associated to external barriers. As such, the 25 selected barriers were classified into three categories namely regulatory, core and external based on the similarities among the barriers. Such a classification clearly represents the areas where the Indian SMEs are struggling. This study identifies that SMEs are struggling to apprehend with government regulatory norms, enhance its internal abilities and facing external challenges (Bhoganadam et al., 2017).

Table 4 Barriers to implement GM practices in Indian SMEs

Categories	Barriers
Regulatory (A1)	Lack of accreditation (A11)
	Lack of recognition (A12)
	Stringent levy policy (A13)
	Lack of cluster development (A14)
	Lack of foreign direct investment (FDI) (A15)
	Poor export policy (A16)
	Lack of subsides (A17)
Core (A2)	Lack of research and development (R & D) (A21)
	Lack of capital investment (A22)
	Lack of employee empowerment (A23)
	Inadequate training (A24)
	Poor supply chain management (A25)
	Failure in prime utility of resources (A26)
	Failure in eco-design (A27)
	Absence of green disposal system (A28)
	Failure in implementation of green logistics (A29)
	Lack of awareness of green energy (A20)
External (A3)	Poor market demand (A31)
	Lack of customer interest (A32)
	Lack of contenders (A33)
	Lack of venture capitalism (A34)
	Unavailability of patents (A35)
	Lack of awareness of firm's reputation (A36)
	Insufficient marketing (A37)
	Absence of market diversification (A38)

Phase 2: Analysis of GM barriers using the proposed methodology

For evaluating the GM barriers, the following steps, as mentioned in the solution methodology, are to be carried out.

(a) Establish initial relationship matrix 'K'

In the second phase, using the fuzzy five-point scale given in Table 5 (Wang & Wu, 2016), the same eight experts were asked to rate the severity of the selected barriers of the implementation of GM practices through a questionnaire (Appendix 2 (a)). Similarly, for categories, the experts are asked to respond using a questionnaire (Appendix 2 (b)). Both the questionnaires in the second phase, Appendix 2 (a) and (b), were carried out at the same time. A fuzzy five-point scale was used as it enables quick and exact assessment of barriers and categories. Based on the experts' ratings, the initial relationship matrix was formed for barriers and categories as shown in Table 6 and 7. Table 6 and 7 show the average of the obtained responses. This paper details the steps taken to evaluate the barriers; the same procedure was used to evaluate categories.

Table 5 Fuzzy Linguistic scale

Linguistic Terms	Five-point scale for preference ratings	Corresponding Triangular Fuzzy Numbers (TFNs)
No influence (NO)	0	(0, 0, 0.25)
Very low influence (VL)	1	(0, 0.25, 0.5)
Low influence (L)	2	(0.25, 0.5, 0.75)
High influence (H)	3	(0.5, 0.75, 1)
Very high influence (VH)	4	(0.75, 1, 1)

(b) Calculate the normalized direction-relationship matrix 'X'

Using Eq. (1), the initial relationship matrix is normalized and given in Appendix 2 (c).

(c) Establish Total-Influence matrix 'T'

Appendix 2 (d) shows the total influence matrix 'T' obtained through Eq. (2).

(d) Calculate the sums of rows and columns

Using Eq. (3) and (4), the sums of rows and columns of categories and barriers are calculated and shown in Table 8 and 9. The sums of rows and columns are mentioned as 'row_i' and 'col_i'

(e) Set up causal influence diagram

Based on the values of the sums of rows and columns, $row_i + col_i$ and $row_i - col_i$ a causal influence diagram is drawn with $row_i + col_i$ as x-axis and $row_i - col_i$ as the y-axis. The barriers at the top of the graph are the causal barriers, while barriers at the bottom are effect barriers as shown in Fig. 2.

(f) Develop an unweighted super matrix

Using Eq. (5), an unweighted super matrix 'W' is obtained and given in Appendix 2 (e).

(g) Develop a weighted super matrix

Weighted super matrix 'W^{α}' is obtained using Eq. (6) and given in Appendix 2 (f).

(h) Limit the weighted super matrix

The limited super matrix is given in Appendix 2 (g) and termed $\lim_{h\to\infty}(W^{\alpha})^{h}$.

Table 6 Initial relationship matrix of barriers

	A11	A12	A13	A14	A15	A16	A17	A21	A22	A23	A24	A25	A26	A27	A28	A29	A20	A31	A32	A33	A34	A35	A36	A37	A38
A11	0	2	1	2	2	2	2	4	1	1	0	1	1	2	2	0	2	1	2	2	2	1	3	1	1
A12	4	0	2	3	3	2	4	3	2	0	0	1	2	3	4	2	2	0	0	2	2	1	3	1	0
A13	0	1	0	0	3	4	3	0	1	0	0	1	0	0	0	2	2	2	0	1	4	0	0	0	3
A14	4	2	1	0	2	3	0	2	3	0	0	3	1	3	2	3	2	0	0	3	3	1	0	1	1
A15	2	2	3	3	0	4	3	4	3	1	1	2	0	0	0	2	0	1	2	1	3	3	3	2	3
A16	4	2	3	2	3	0	2	1	1	0	0	2	1	0	0	3	0	3	0	1	2	2	3	2	3
A17	2	0	2	1	0	2	0	0	4	0	0	1	2	2	3	1	3	0	0	0	1	1	0	3	2
A21	4	3	0	0	3	2	0	0	1	2	3	3	4	4	4	3	3	3	2	4	3	3	2	4	3
A22	3	1	3	2	3	2	3	4	0	3	3	2	3	2	2	2	3	2	0	2	2	1	4	3	3
A23	2	0	1	0	2	1	0	2	0	0	2	3	3	2	3	1	2	3	2	3	2	2	0	0	1
A24	1	0	1	2	0	0	0	2	0	4	0	2	1	2	2	1	3	1	0	2	1	0	3	0	0
A25	3	1	2	4	1	3	1	1	0	1	3	0	3	4	2	1	2	4	3	3	2	2	0	3	4
A26	4	4	3	3	3	2	1	3	2	3	3	3	0	2	3	3	1	0	0	4	2	1	3	3	0
A27	4	4	2	3	3	2	1	4	1	3	4	3	3	0	3	2	3	0	2	3	3	2	3	3	1
A28	4	4	2	3	2	2	1	3	2	3	3	3	3	3	0	2	2	0	1	4	1	2	3	3	0
A29	1	1	3	3	2	3	1	3	1	1	1	2	2	1	1	0	1	3	2	3	1	0	3	2	4
A20	4	4	3	3	2	3	1	3	3	3	4	2	3	3	2	1	0	4	1	4	2	2	2	1	0
A31	3	0	2	1	1	3	3	1	0	3	1	3	1	2	1	3	1	0	2	3	1	0	1	1	4
A32	4	3	3	3	3	2	1	1	3	3	4	3	3	2	2	3	2	3	0	4	2	3	3	3	3
A33	2	1	1	2	2	1	0	2	1	2	2	1	1	1	0	1	0	4	1	0	0	1	0	1	1
A34	3	0	2	2	1	1	1	3	3	4	4	3	2	2	1	3	1	1	0	3	0	3	1	2	4
A35	4	0	1	3	2	1	0	1	2	2	1	1	0	0	0	2	0	2	3	1	1	0	3	3	1
A36	3	1	1	3	1	1	0	3	4	3	3	2	2	2	1	2	1	0	2	3	1	3	0	2	1
A37	1	0	1	2	2	0	0	1	0	3	3	4	1	0	1	2	1	2	3	4	1	3	2	0	3
A38	2	1	4	2	3	4	3	2	2	3	3	1	1	2	2	3	1	3	1	4	3	2	2	3	0

Table 7 Initial relationship matrix of categories

	A1	A2	A3
A1	0	1	2
A2	4	0	3
A3	2	1	0

Step 3: Prioritizing categories by fuzzy TOPSIS

(a) Construct a normalized matrix

Using Eq. (7), a normalized matrix is constructed and given in Appendix 2 (h).

(b) Construct a weighted matrix

Appendix 2 (i) shows a weighted matrix constructed using Eqs. (8) and (12).

(c) Calculate relative closeness (R_i)

Table 10 displays the relative closeness calculated using Eq. (13).

Phase 3: Sensitivity Analysis

Sensitivity analysis was carried out in 24 different conditions. The different conditions followed and the results of the sensitivity analysis are provided in Appendix 2 (j) and Table 11.

5. Findings and Discussions

The findings displayed in Table 8 show that the following barriers are in the effect group: 'lack of accreditation' (A11), 'stringent levy policy' (A13), 'lack of cluster development' (A14), 'lack of foreign direct investment (FDI)' (A15), 'poor export policy' (A16), 'lack of employee empowerment' (A23), 'inadequate training' (A24), 'failure in implementation of green logistics' (A29), 'poor market demand' (A31), 'lack of contenders' (A33), 'unavailability of patents' (A35), 'unawareness of firms reputation' (A36), and 'insufficient marketing' (A37). They are in the 'effect' group because they are easily influenced by other barriers as their (row_i-col_i) value is negative. On the other hand, the following barriers are in the 'cause' group because they may greatly influence other barriers as their (row_i-col_i) value is positive: 'lack of recognition' (A12), 'lack of subsides' (A17), 'lack of research and development (R&D)' (A21), 'lack of capital investment' (A22), 'poor supply chain management' (A25), 'failure in prime utility of resources' (A26), 'failure in eco-design' (A27), 'absence of green disposal system' (A28), 'unawareness of green energy' (A20), 'lack of customer interest' (A32), 'lack of venture capitalist' (A34), and 'absence of market diversification' (A38).

Table 8 Sum of influence given and received on barriers

Barriers	row_i	col_i	row_i+col_i	Rank	row_i-col_i	Cause/Effect
A11	2.10688011	3.39070761	5.497587719	3	-1.283827	Effect
A12	2.506176229	2.02044088	4.526617114	21	0.485735	Cause
A13	1.61528973	2.44618594	4.06147567	23	-0.830896	Effect
A14	2.269470498	2.77394243	5.043412929	12	-0.504472	Effect
A15	2.562922581	2.63467626	5.197598842	7	-0.071754	Effect
A16	2.153637883	2.63445271	4.788090589	17	-0.480815	Effect
A17	1.813995016	1.76384382	3.577838832	25	0.050151	Cause
A21	3.311415971	2.80674718	6.118163154	1	0.504669	Cause
A22	3.032895867	2.12497074	5.157866611	8	0.907925	Cause
A23	2.117300591	2.5739147	4.691215295	18	-0.456614	Effect
A24	1.669101369	2.5548952	4.223996567	22	-0.885794	Effect
A25	2.763692413	2.73166016	5.495352573	4	0.032032	Cause
A26	2.908344107	2.28932428	5.197668383	6	0.619020	Cause
A27	3.22571367	2.38904509	5.614758758	2	0.836669	Cause
A28	2.921797768	2.20863528	5.13043305	10	0.713162	Cause
A29	2.391254413	2.54261179	4.933866201	15	-0.151357	Effect
A20	3.055205841	2.07774184	5.132947678	9	0.977464	Cause
A31	2.182829137	2.34468752	4.527516656	20	-0.161858	Effect
A32	3.366617714	1.75330913	5.119926842	11	1.613309	Cause
A33	1.55163602	3.27630513	4.827941154	16	-1.724669	Effect
A34	2.597780739	2.41323696	5.011017701	13	0.184544	Cause
A35	1.890098436	2.14976632	4.039864753	24	-0.259668	Effect
A36	2.411149922	2.55584667	4.966996595	14	-0.144697	Effect
A37	2.141998993	2.49077331	4.632772298	19	-0.348774	Effect
A38	2.849423015	2.46890709	5.318330104	5	0.380516	Cause

Among the three broad categories, the results (Table 9) show that core (A2) and external (A3) categories are in the cause group while the regulatory category (A1) is in the effect group.

Table 9 Sum of influence given and received on categories

Categories	row_i	col_i	row_i+col_i	Rank	row_i-col_i	Cause/Effect
A1	0.8270349	2.9375	3.764534884	3	-2.110465116	Effect
A2	2.8502907	2.09157	4.941860465	1	0.75872093	Cause
A3	2.9898256	1.638081	4.627906977	2	1.351744186	Cause

The causal relationships among the barriers is displayed in Fig. 2. The 'cause' barriers need immediate attention and should be removed. The positive value of (row_i-col_i) indicates that the influential impact (row_i) is higher than that of being influenced (col_i). Categories and barriers with high prominence (row_i+col_i) value will greatly influence and get influenced by other categories and barriers. These categories and barriers need to be addressed without further delay as they are the central barriers of GM implementation. Similarly, the causal relationships among categories is shown in Fig. 3.

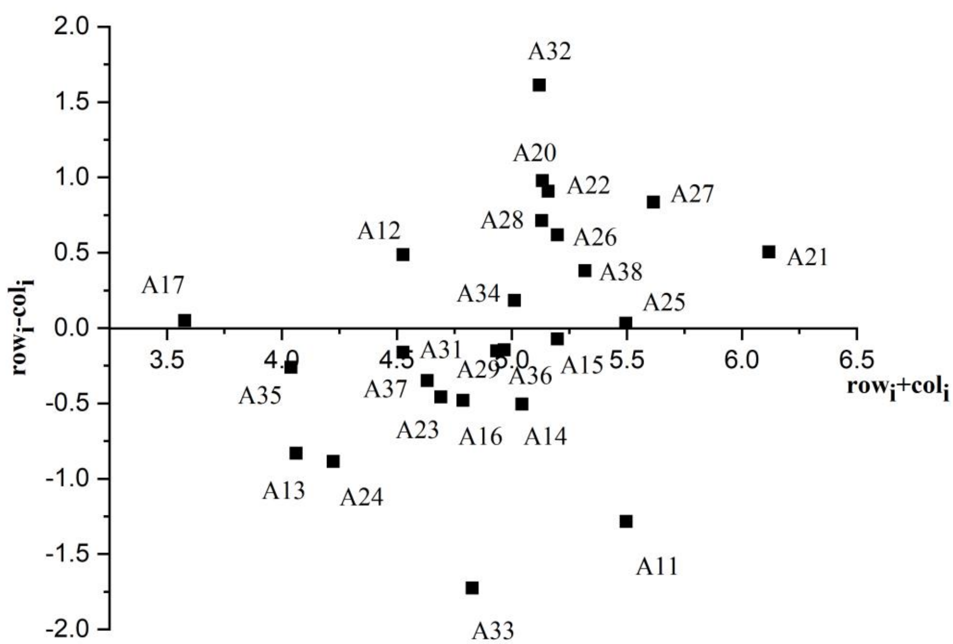

Fig. 2 Causes and effect diagram (barriers)

The results from fuzzy TOPSIS show that among the three categories of barriers of GM implementation in Indian SMEs, core category (A2) is the most critical category followed by external category (A3). In contrast, the regulatory category (A1) was found as the least critical category in the context of Indian SMEs.

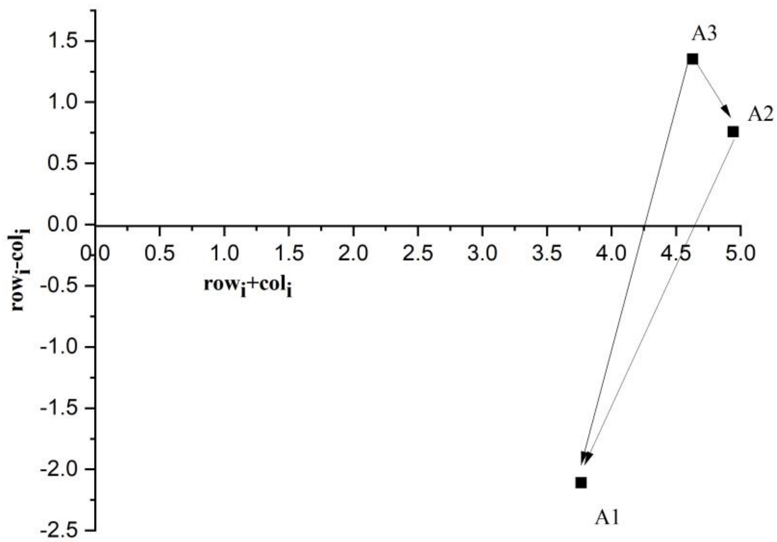

Fig. 3. Cause and effect diagram (categories)

Table 10 Ranking of Categories by TOPSIS

	S_i+	S_i-	R_i	Rank
A1	0.0295	0.0111	0.2730	3
A2	0.0145	0.0271	0.6505	1
A3	0.0224	0.0207	0.4812	2

Sensitivity analysis carried out under the mentioned 24 conditions also confirms that core (A2) and external (A3) categories are the major cause of problems. Sensitivity analysis confirms the rank of categories obtained using fuzzy TOPSIS. The ranking of categories from sensitivity analysis is shown in Fig. 4.

Table 11 Ranking by Sensitivity Analysis

Conditions	R_i			Ranking
	A1	A2	A3	
Main	0.273	0.651	0.481	A2>A3>A1
1	0.273	0.651	0.481	A2>A3>A1

2	0.273	0.651	0.481	A2>A3>A1
3	0.273	0.651	0.481	A2>A3>A1
4	0.273	0.651	0.481	A2>A3>A1
5	0.273	0.651	0.481	A2>A3>A1
6	0.274	0.650	0.481	A2>A3>A1
7	0.331	0.601	0.510	A2>A3>A1
8	0.332	0.600	0.510	A2>A3>A1
9	0.332	0.601	0.510	A2>A3>A1
10	0.332	0.600	0.510	A2>A3>A1
11	0.332	0.600	0.510	A2>A3>A1
12	0.332	0.601	0.510	A2>A3>A1
13	0.332	0.601	0.510	A2>A3>A1
14	0.332	0.601	0.510	A2>A3>A1
15	0.333	0.601	0.509	A2>A3>A1
16	0.332	0.601	0.509	A2>A3>A1
17	0.280	0.642	0.523	A2>A3>A1
18	0.280	0.642	0.523	A2>A3>A1
19	0.280	0.642	0.523	A2>A3>A1
20	0.280	0.642	0.523	A2>A3>A1
21	0.280	0.642	0.523	A2>A3>A1
22	0.281	0.642	0.523	A2>A3>A1
23	0.280	0.642	0.523	A2>A3>A1
24	0.279	0.643	0.523	A2>A3>A1

Lack of research and development (R&D) (A21) has the highest ($row_{i}+col_{i}$) value and hence this barrier has the highest relation with other barriers. Consistent with the findings of Rodriguez and Wiengarten (2017), the result suggests that R&D in Indian SMEs is slow (Ghosh et al., 2018; Kannan et al., 2009) and should be prioritized. When R&D in Indian SMEs is strengthened, it will assist in overcoming many related barriers. For example, advancement in R&D may help in overcoming failure in eco-design (A27) and lack of accreditation (A11) which received 2nd and 3rd ranks, respectively, in terms of relationship with other barriers. Poor supply chain management (A25) has the fourth highest relation to other barriers. This result is not surprising since this vital component of manufacturing is used by industry practitioners to exchange products and information. However, as mentioned by Queiroz and Wamba, (2019), supply chain management in Indian SMEs is still in its infancy and needs substantial improvement for implementing GM practices. As a result, Indian manufacturing SMEs are unable to enter a new market and hence absence of market diversification (A38) remains a major challenge.

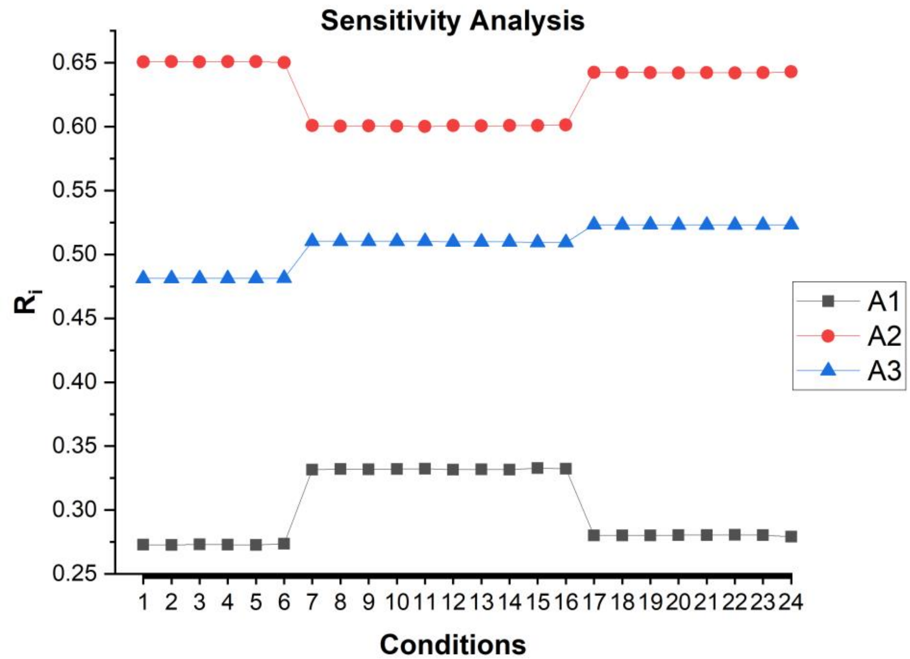

Fig. 4. Sensitivity analysis

Next, failure in prime utility of resources (A26) has been a hindrance to industrial progress towards GM practices. The results suggest that most Indian SMEs are not aware of the adaptation of 6R practice (Arora et al., 2019). Lack of customer interest (A32) is one of the most powerful barriers to GM practices as it is the driving force that motivates manufacturing firms to make green products. When compared with European countries, customer awareness about green products and their importance is very low in India (Saha et al., 2019). Lack of accreditation (A11) and poor market demand (A31) are the consequences of the lack of research and development (R&D) (A21) and lack of customer interest (A32). As mentioned, with advancement in R&D, it is possible for manufacturing sectors to develop eco-design and streamline their operations. By developing eco-design, it is possible for industries to overcome accreditation related problems. Similarly, when customers act on a preference for green products, the demand for green products will increase in the market. This market demand will encourage manufacturers to develop and market green products by adopting GM practices. From this study, it is clear that regulatory category (A1) is the consequence of core (A2) and external categories (A3).

It is worth to mention that some of the barriers identified in this study may be applied to large-scale industries too. However, this study only considers manufacturing SMEs; therefore, the findings such as ranking of the barriers and their categories are only applicable to SMEs. For example, the study confirmed that among the three categories of barriers, core category is the most critical for SMEs. With huge capital investment and advanced technology, large-scale firms may not rate this category as critical as SMEs do. Rather, they may consider external or regulatory categories are more critical since their supply chain generally comprises of global suppliers, customers, third-party logistics firms, and more than one regulatory body are involved in the operations (Govindan et al., 2014). Moreover, large-firms may not face many of the identified barriers in implementing GM. For instance, lack of capital investment and lack of training are not the influential barriers for large-scale firms (Tumpa et al., 2019). In fact, barriers like lack of resources (technology, skilled labor, finance, and market access), and inability to contend alongside large firms in terms of R&D expenditure and innovation (product, process, and organization) marginalize SMEs from large scale organization in global competition (Yoshino & Taghizadeh Hesary. 2016). Hence, we emphasize that the identified barriers, their causal relationships and ranking are only confined to SMEs.

6. Managerial Implication

The results of our research work have substantial implications for SME managers involved in the implementation of GM practices. This research will help SME practitioners identify the most critical barriers of GM practices. Considering the fact that adoption of GM practices is a must for the survival of manufacturing firms (Tumpa et al., 2019), SME practitioners should carefully check the barriers in implementing of these practices. By considering the relative importance of the categories and barriers, they should formulate proper strategies to overcome the problem. Practitioners should take prompt action to remove the barriers having high prominence (row_i+col_i) value. For example, this research has found that a lack of research and development (R&D) (A21) is the main reason for setbacks in the adoption of GM practices. Hence there is an immense need to give importance to R&D to curb all associated problems. It is recommended that the managers of SMEs commit resources to R&D so that they can successfully implement GM practices. With the vision of creating awareness about green initiatives and educating the manufacturers on developing green products, the Indian government has announced a programme called the *Green Skill Development Programme* (GSDP) (http://www.gsdp-envis.gov.in/). It is suggested that relevant SMEs practitioners should make use of this programme.

Like R&D, SME practitioners should consider other critical barriers of GM implementation and take proper action to remove them. They should increase their eco-design efforts and take proper accreditation, such as ISO14001, so that customers consider green initiatives along with cost and quality in selecting suppliers. The findings also suggest that awareness also must be created among people about the importance of using green products in day-to-day life. A study by Reddy (2018) suggested that awareness about green products and their benefits should be raised through mass media. By creating awareness about green products, customers may give preference to green products and thus the market scope may widen. As indicated in earlier studies (Dieste et al., 2019; Gandhi et al., 2018), Indian leather manufacturing SMEs must volunteer themselves in adopting lean practice as it may greatly help in overcoming the absence of a green disposal system (A28), found to be a critical barrier of GM implementation. Effective implementation of such GM practice will establish a firm's image as an environmentally friendly organization and helps in meeting financial and environmental needs in Indian SMEs (Kek & Kandasamy, 2018).

7. Conclusions and future work

Generally, GM practices have been considered a sustainable solution as they bring many benefits for all types of manufacturing firms including SMEs (Sangwan & Choudhary, 2018). Hence, this research work identifies, evaluates and ranks the barriers in implementing GM practices in Indian SMEs. Based on the literature review and experts' opinion, the study identified 25 barriers of GM implementation, which were then broadly categorized as regulatory (A1), core (A2) and external (A3). Then, using a novel integrated MCDM framework, and a combination of fuzzy DEMATEL, fuzzy ANP and fuzzy TOPSIS, the study ranked the categories and barriers and revealed their causal relationships. The results show that among the barriers of implementing GM practices in Indian SMEs, the five most critical barriers are lack of research and development (R&D) (A21), failure in eco-design (A27), lack of accreditation (A11), poor supply chain management (A25) and absence of market diversification (A38). Out of these five barriers, three falls under the core category, one under the regulatory category and one under the external category. Ranking of the categories also clearly shows that core category (A2) is the most critical category among the three categories of barriers. Hence, as evident in the ranking of categories, SMEs need to pay more attention to barriers coming under the core category. In connection with this, suggestions are made for SME practitioners to overcome the barriers of GM practices.

This research makes unique contributions. Firstly, this study enhances the knowledge of green initiatives in the context of both SMEs and developing countries. There is very little research in operations management in SMEs in developing countries (Chowdhury et al., 2019). Secondly, we combined DM with a novel integrated MCDM framework using fuzzy DEMATEL, fuzzy ANP and fuzzy TOPSIS. Such an integration of DM with several MCDM methods has not been used previously and provides a comprehensive understanding of the topic of the study. Finally, this work has considered and evaluated the role of the regulatory sector in implementing GM practices by analyzing the barriers coming under regulatory category, an issue not addressed in earlier studies.

While the study contributes substantially to the literature, it also has several limitations. For example, the research is confined to Indian SMEs in the leather industry. Therefore, caution should be exercised in applying the findings to other Indian manufacturing industries or to the leather industry in other developing countries. A future study could be undertaken to compare the findings in the context of other industries or other countries with a different environmental situation to that in India. Moreover, the cause-effect relationship among barriers was only studied using the responses of eight experts and fuzzy MCDM techniques. Also, the representation of an expert from the government sector is missed out. Therefore, the findings of the study lack generalizability. A future study with an expert from governmental sector using a large-scale survey could be undertaken to test and establish the generalizability of these findings.

Conflict of Interest

None

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Appendix 1

This work analyses the various barriers of implementing GM practices. To select the vital few barriers, we ask you to rate the barriers using the given five-point Likert scale (e.g. 1 = extremely insignificant, 5 = extremely significant).

Sl. No	Barriers of the implementation of GM practices	Likert scale (1-extremely insignificant, 5-extremely significant)
1.	Lack of accreditation	
2.	Lack of recognition	
3.	Stringent levy policy	
4.	Lack of cluster development	
5.	Lack of foreign direct investment (FDI)	
6.	Poor export policy	

7.	Lack of subsides	
8.	Lack of research and development (R & D)	
9.	Lack of capital Investment	
10.	Lack of employee empowerment	
11.	Inadequate training	
12.	Poor supply chain management	
13.	Failure in prime utility of resources	
14.	Failure in Eco-design	
15.	Absence of green disposal system	
16.	Failure in implementation of green logistics	
17.	Unawareness of green Energy	
18.	Poor market Demand	
19.	Lack of customers interest	
20.	Lack of contenders	
21.	Lack of venture capitalist	
22.	Unavailability of patents	
23.	Unawareness of firms reputation	
24.	Insufficient marketing	
25.	Absence of market Diversification	
26.	Scarcity of resource	
27.	Lack of partnership between organizations	
28.	Poor work standardization	
29.	Lack of guidelines	
30.	Poor organizational structure	

Expert detail

Position/Designation: ………………..

Field of expertise: …………………………..

Experience (in years): …….

Thank you for showing interest in our research work and for spending time answering the questionnaire.

Appendix 2 (a): Questionnaire given to experts to rate the severity of barriers of GM practices using a fuzzy five-point scale given below.

Table A Fuzzy Linguistic scale

Linguistic Terms	Five-point scale for preference ratings	Corresponding Triangular Fuzzy Numbers (TFNs)
No influence (NO)	0	(0, 0, 0.25)
Very low influence (VL)	1	(0, 0.25, 0.5)
Low influence (L)	2	(0.25, 0.5, 0.75)
High influence (H)	3	(0.5, 0.75, 1)
Very high influence (VH)	4	(0.75, 1, 1)

Using Table-A, the experts are requested to rate the severity of barriers of GM practices.

Name: Department: Experience (in years):

Barriers	Linguistic scale of rating																								
	A11	A12	A13	A14	A15	A16	A17	A21	A22	A23	A24	A25	A26	A27	A28	A29	A20	A31	A32	A33	A34	A35	A36	A37	A38
A11																									
A12																									
A13																									
A14																									
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A36																									
A37																									

A38																									

Appendix 2 (b): Questionnaire given to experts to rate the severity of categories of barriers of GM adoption using fuzzy five-point scale given in Table A.

Categories	A1	A2	A3
A1			
A2			
A3			

Appendix 2 (c) Normalized influence matrix (X) of barriers

	A11	A12	A13	A14	A15	A16	A17	A21	A22	A23	A24	A25	A26	A27	A28	A29	A20	A31	A32	A33	A34	A35	A36	A37	A38
A11	0.01	0.03	0.02	0.03	0.03	0.03	0.03	0.06	0.02	0.02	0.01	0.02	0.02	0.03	0.03	0.01	0.03	0.02	0.03	0.03	0.03	0.02	0.05	0.02	0.02
A12	0.06	0.01	0.03	0.05	0.05	0.03	0.06	0.05	0.03	0.01	0.01	0.02	0.03	0.05	0.06	0.03	0.03	0.01	0.01	0.03	0.03	0.02	0.05	0.02	0.01
A13	0.01	0.02	0.01	0.01	0.05	0.06	0.05	0.01	0.02	0.01	0.01	0.02	0.01	0.01	0.01	0.03	0.03	0.03	0.01	0.02	0.06	0.01	0.01	0.01	0.05
A14	0.06	0.03	0.02	0.01	0.03	0.05	0.01	0.03	0.05	0.01	0.01	0.05	0.02	0.05	0.03	0.05	0.03	0.01	0.01	0.05	0.05	0.02	0.01	0.02	0.02
A15	0.03	0.03	0.05	0.05	0.01	0.06	0.05	0.06	0.05	0.02	0.02	0.03	0.01	0.01	0.01	0.03	0.01	0.02	0.03	0.02	0.05	0.05	0.05	0.03	0.05
A16	0.06	0.03	0.05	0.03	0.05	0.01	0.03	0.02	0.02	0.01	0.01	0.03	0.02	0.01	0.01	0.05	0.01	0.05	0.01	0.02	0.03	0.03	0.05	0.03	0.05
A17	0.03	0.01	0.03	0.02	0.01	0.03	0.01	0.01	0.06	0.01	0.01	0.02	0.03	0.03	0.05	0.02	0.05	0.01	0.01	0.01	0.02	0.02	0.01	0.05	0.03
A21	0.06	0.05	0.01	0.01	0.05	0.03	0.01	0.01	0.02	0.03	0.05	0.05	0.06	0.06	0.06	0.05	0.05	0.05	0.03	0.06	0.05	0.05	0.03	0.06	0.05
A22	0.05	0.02	0.05	0.03	0.05	0.03	0.05	0.06	0.01	0.05	0.05	0.03	0.05	0.03	0.03	0.03	0.05	0.03	0.01	0.03	0.03	0.02	0.06	0.05	0.05
A23	0.03	0.01	0.02	0.01	0.03	0.02	0.01	0.03	0.01	0.01	0.03	0.05	0.05	0.03	0.05	0.02	0.03	0.05	0.03	0.05	0.03	0.03	0.01	0.01	0.02
A24	0.02	0.01	0.02	0.03	0.01	0.01	0.01	0.03	0.01	0.06	0.01	0.03	0.02	0.03	0.03	0.02	0.05	0.02	0.01	0.03	0.02	0.01	0.05	0.01	0.01

A25	0.05	0.02	0.03	0.06	0.02	0.05	0.02	0.02	0.01	0.02	0.05	0.01	0.05	0.06	0.03	0.02	0.03	0.06	0.05	0.05	0.03	0.03	0.01	0.05	0.06
A26	0.06	0.06	0.05	0.05	0.05	0.03	0.02	0.05	0.03	0.05	0.05	0.05	0.01	0.03	0.05	0.05	0.02	0.01	0.01	0.06	0.03	0.02	0.05	0.05	0.01
A27	0.06	0.06	0.03	0.05	0.05	0.03	0.02	0.06	0.02	0.05	0.06	0.05	0.05	0.01	0.05	0.03	0.05	0.01	0.03	0.05	0.05	0.03	0.05	0.05	0.02
A28	0.06	0.06	0.03	0.05	0.03	0.03	0.02	0.05	0.03	0.05	0.05	0.05	0.05	0.05	0.01	0.03	0.03	0.01	0.02	0.06	0.02	0.03	0.05	0.05	0.01
A29	0.02	0.02	0.05	0.05	0.03	0.05	0.02	0.05	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.01	0.02	0.05	0.03	0.05	0.02	0.01	0.05	0.03	0.06
A20	0.06	0.06	0.05	0.05	0.03	0.05	0.02	0.05	0.05	0.05	0.06	0.03	0.05	0.05	0.03	0.02	0.01	0.06	0.02	0.06	0.03	0.03	0.03	0.02	0.01
A31	0.05	0.01	0.03	0.02	0.02	0.05	0.05	0.02	0.01	0.05	0.02	0.05	0.02	0.03	0.02	0.05	0.02	0.01	0.03	0.05	0.02	0.01	0.02	0.02	0.06
A32	0.06	0.05	0.05	0.05	0.05	0.03	0.02	0.02	0.05	0.05	0.06	0.05	0.05	0.03	0.03	0.05	0.03	0.05	0.01	0.06	0.03	0.05	0.05	0.05	0.05
A33	0.03	0.02	0.02	0.03	0.03	0.02	0.01	0.03	0.02	0.03	0.03	0.02	0.02	0.02	0.01	0.02	0.01	0.06	0.02	0.01	0.01	0.02	0.01	0.02	0.02
A34	0.05	0.01	0.03	0.03	0.02	0.02	0.02	0.05	0.05	0.06	0.06	0.05	0.03	0.03	0.02	0.05	0.02	0.02	0.01	0.05	0.01	0.05	0.02	0.03	0.06
A35	0.06	0.01	0.02	0.05	0.03	0.02	0.01	0.02	0.03	0.03	0.02	0.02	0.01	0.01	0.01	0.03	0.01	0.03	0.05	0.02	0.02	0.01	0.05	0.05	0.02
A36	0.05	0.02	0.02	0.05	0.02	0.02	0.01	0.05	0.06	0.05	0.05	0.03	0.03	0.03	0.02	0.03	0.02	0.01	0.03	0.05	0.02	0.05	0.01	0.03	0.02
A37	0.02	0.01	0.02	0.03	0.03	0.01	0.01	0.02	0.01	0.05	0.05	0.06	0.02	0.01	0.02	0.03	0.02	0.03	0.05	0.06	0.02	0.05	0.03	0.01	0.05
A38	0.03	0.02	0.06	0.03	0.05	0.06	0.05	0.03	0.03	0.05	0.05	0.02	0.02	0.03	0.03	0.05	0.02	0.05	0.02	0.06	0.05	0.03	0.03	0.05	0.01

Appendix 2 (d) Total influence matrix (T) of barriers

	A11	A12	A13	A14	A15	A16	A17	A21	A22	A23	A24	A25	A26	A27	A28	A29	A20	A31	A32	A33	A34	A35	A36	A37	A38
A11	0.09	0.08	0.07	0.10	0.10	0.09	0.07	0.12	0.07	0.08	0.07	0.08	0.07	0.09	0.09	0.07	0.08	0.07	0.07	0.11	0.09	0.07	0.11	0.08	0.08
A12	0.15	0.07	0.10	0.13	0.12	0.11	0.11	0.13	0.09	0.08	0.08	0.09	0.10	0.12	0.12	0.10	0.09	0.07	0.06	0.12	0.10	0.08	0.12	0.09	0.08
A13	0.07	0.05	0.05	0.06	0.09	0.11	0.08	0.06	0.06	0.05	0.05	0.07	0.05	0.05	0.04	0.08	0.07	0.08	0.04	0.07	0.10	0.05	0.05	0.05	0.10
A14	0.15	0.09	0.08	0.08	0.10	0.12	0.05	0.11	0.10	0.07	0.07	0.12	0.08	0.11	0.09	0.11	0.08	0.07	0.05	0.13	0.11	0.07	0.07	0.08	0.08
A15	0.13	0.09	0.12	0.13	0.08	0.13	0.10	0.14	0.11	0.09	0.09	0.11	0.07	0.08	0.07	0.11	0.07	0.09	0.08	0.11	0.12	0.11	0.12	0.11	0.12
A16	0.14	0.08	0.11	0.10	0.11	0.07	0.08	0.09	0.07	0.07	0.07	0.10	0.07	0.06	0.06	0.11	0.06	0.10	0.05	0.10	0.09	0.08	0.11	0.09	0.11
A17	0.10	0.05	0.08	0.07	0.06	0.09	0.04	0.07	0.10	0.06	0.06	0.07	0.08	0.08	0.09	0.07	0.09	0.05	0.04	0.08	0.07	0.06	0.06	0.10	0.08
A21	0.19	0.12	0.10	0.12	0.15	0.13	0.07	0.12	0.10	0.13	0.15	0.15	0.14	0.15	0.14	0.14	0.12	0.14	0.10	0.18	0.14	0.13	0.13	0.15	0.14
A22	0.16	0.09	0.13	0.13	0.14	0.12	0.11	0.15	0.08	0.14	0.14	0.13	0.13	0.11	0.11	0.12	0.12	0.11	0.07	0.15	0.12	0.09	0.14	0.13	0.13
A23	0.11	0.06	0.08	0.07	0.09	0.08	0.05	0.10	0.06	0.07	0.09	0.11	0.10	0.09	0.10	0.08	0.08	0.10	0.07	0.13	0.09	0.08	0.07	0.07	0.08

A24	0.08	0.05	0.06	0.08	0.06	0.06	0.04	0.09	0.05	0.11	0.06	0.08	0.06	0.08	0.07	0.06	0.09	0.06	0.04	0.10	0.06	0.05	0.09	0.05	0.05
A25	0.15	0.08	0.11	0.14	0.10	0.13	0.07	0.10	0.07	0.10	0.13	0.09	0.12	0.13	0.10	0.10	0.10	0.13	0.10	0.15	0.11	0.10	0.09	0.12	0.13
A26	0.17	0.12	0.12	0.14	0.13	0.12	0.07	0.14	0.10	0.13	0.13	0.14	0.08	0.11	0.12	0.13	0.09	0.08	0.07	0.16	0.11	0.09	0.13	0.13	0.09
A27	0.18	0.13	0.12	0.15	0.14	0.13	0.08	0.16	0.10	0.14	0.15	0.15	0.13	0.10	0.13	0.12	0.12	0.09	0.10	0.17	0.14	0.11	0.14	0.14	0.11
A28	0.17	0.12	0.11	0.14	0.12	0.12	0.07	0.14	0.10	0.13	0.13	0.14	0.12	0.13	0.08	0.11	0.10	0.08	0.08	0.17	0.10	0.10	0.13	0.13	0.09
A29	0.11	0.07	0.11	0.12	0.10	0.12	0.07	0.12	0.07	0.09	0.09	0.11	0.09	0.08	0.08	0.08	0.07	0.11	0.08	0.14	0.08	0.07	0.11	0.10	0.13
A20	0.18	0.13	0.13	0.14	0.12	0.14	0.08	0.15	0.12	0.14	0.14	0.13	0.13	0.13	0.11	0.11	0.08	0.14	0.08	0.17	0.12	0.10	0.12	0.10	0.09
A31	0.13	0.06	0.09	0.08	0.08	0.11	0.09	0.08	0.06	0.11	0.08	0.11	0.07	0.09	0.07	0.11	0.07	0.07	0.07	0.13	0.08	0.06	0.08	0.08	0.12
A32	0.19	0.12	0.14	0.15	0.15	0.13	0.09	0.13	0.13	0.15	0.15	0.15	0.13	0.12	0.12	0.14	0.11	0.14	0.07	0.18	0.12	0.13	0.14	0.14	0.14
A33	0.09	0.05	0.06	0.08	0.08	0.06	0.04	0.08	0.05	0.08	0.07	0.07	0.06	0.06	0.05	0.06	0.04	0.10	0.05	0.06	0.05	0.05	0.05	0.06	0.06
A34	0.14	0.06	0.10	0.11	0.09	0.09	0.07	0.13	0.11	0.13	0.13	0.13	0.10	0.10	0.08	0.12	0.08	0.09	0.06	0.14	0.08	0.11	0.09	0.11	0.13
A35	0.13	0.05	0.07	0.11	0.09	0.07	0.04	0.08	0.08	0.09	0.07	0.08	0.05	0.06	0.05	0.09	0.05	0.08	0.09	0.09	0.07	0.05	0.10	0.10	0.07
A36	0.14	0.07	0.08	0.12	0.09	0.09	0.05	0.12	0.11	0.12	0.12	0.11	0.10	0.10	0.08	0.10	0.07	0.07	0.08	0.14	0.08	0.10	0.08	0.10	0.08
A37	0.10	0.05	0.08	0.10	0.09	0.07	0.05	0.08	0.06	0.11	0.11	0.12	0.07	0.06	0.07	0.09	0.07	0.09	0.09	0.14	0.07	0.10	0.09	0.07	0.11
A38	0.09	0.08	0.07	0.10	0.10	0.09	0.07	0.12	0.07	0.08	0.07	0.08	0.07	0.09	0.09	0.07	0.08	0.07	0.07	0.11	0.09	0.07	0.11	0.08	0.08

Appendix 2 (e) The unweighted super matrix

	A11	A12	A13	A14	A15	A16	A17	A21	A22	A23	A24	A25	A26	A27	A28	A29	A20	A31	A32	A33	A34	A35	A36	A37	A38
A11	0.027	0.046	0.020	0.043	0.039	0.040	0.030	0.055	0.048	0.034	0.024	0.045	0.050	0.054	0.050	0.032	0.052	0.038	0.055	0.027	0.043	0.038	0.041	0.029	0.041
A12	0.041	0.033	0.025	0.042	0.043	0.038	0.025	0.061	0.043	0.028	0.023	0.040	0.061	0.065	0.062	0.035	0.063	0.028	0.060	0.025	0.032	0.024	0.036	0.026	0.039
A13	0.030	0.041	0.022	0.033	0.048	0.044	0.034	0.041	0.053	0.031	0.025	0.045	0.051	0.049	0.045	0.046	0.053	0.038	0.057	0.024	0.042	0.028	0.033	0.031	0.055
A14	0.035	0.045	0.020	0.029	0.045	0.036	0.027	0.042	0.046	0.027	0.030	0.052	0.050	0.054	0.050	0.043	0.051	0.031	0.056	0.028	0.041	0.038	0.044	0.036	0.043
A15	0.036	0.046	0.036	0.038	0.032	0.042	0.024	0.056	0.052	0.036	0.021	0.038	0.051	0.054	0.046	0.040	0.047	0.031	0.056	0.029	0.036	0.033	0.034	0.036	0.050
A16	0.036	0.041	0.040	0.044	0.051	0.028	0.033	0.049	0.047	0.031	0.021	0.049	0.045	0.048	0.045	0.046	0.052	0.043	0.051	0.024	0.036	0.028	0.033	0.027	0.054
A17	0.041	0.060	0.046	0.030	0.056	0.044	0.025	0.041	0.060	0.027	0.021	0.041	0.042	0.045	0.041	0.037	0.045	0.051	0.048	0.022	0.038	0.025	0.030	0.027	0.059
A21	0.044	0.046	0.020	0.038	0.048	0.030	0.023	0.041	0.055	0.035	0.031	0.037	0.051	0.058	0.051	0.043	0.052	0.030	0.045	0.029	0.046	0.027	0.044	0.030	0.043
A22	0.033	0.045	0.027	0.047	0.052	0.033	0.047	0.045	0.038	0.026	0.022	0.034	0.047	0.045	0.047	0.035	0.056	0.027	0.060	0.024	0.050	0.036	0.053	0.027	0.047
A23	0.030	0.030	0.020	0.028	0.035	0.026	0.024	0.051	0.053	0.027	0.041	0.039	0.050	0.055	0.051	0.033	0.053	0.042	0.057	0.030	0.052	0.034	0.046	0.043	0.050
A24	0.027	0.031	0.020	0.029	0.035	0.026	0.024	0.057	0.053	0.037	0.022	0.050	0.051	0.059	0.051	0.034	0.056	0.031	0.060	0.029	0.052	0.028	0.046	0.043	0.050

A25	0.030	0.035	0.024	0.043	0.040	0.035	0.027	0.055	0.046	0.041	0.031	0.034	0.050	0.054	0.050	0.039	0.047	0.041	0.055	0.024	0.046	0.028	0.039	0.045	0.039
A26	0.032	0.043	0.020	0.034	0.032	0.030	0.035	0.062	0.055	0.044	0.027	0.051	0.036	0.057	0.054	0.040	0.055	0.032	0.058	0.024	0.043	0.024	0.042	0.031	0.039
A27	0.038	0.048	0.020	0.045	0.032	0.027	0.034	0.061	0.048	0.038	0.033	0.055	0.047	0.040	0.053	0.034	0.055	0.038	0.051	0.024	0.043	0.024	0.041	0.027	0.044
A28	0.039	0.054	0.020	0.040	0.032	0.026	0.041	0.063	0.049	0.045	0.034	0.045	0.054	0.058	0.037	0.034	0.050	0.032	0.052	0.021	0.037	0.024	0.035	0.031	0.045
A29	0.027	0.041	0.031	0.044	0.042	0.043	0.027	0.056	0.047	0.031	0.025	0.039	0.051	0.049	0.045	0.031	0.041	0.043	0.056	0.024	0.047	0.034	0.040	0.036	0.051
A20	0.039	0.044	0.032	0.041	0.032	0.027	0.043	0.059	0.057	0.039	0.041	0.046	0.042	0.059	0.049	0.034	0.039	0.033	0.053	0.021	0.038	0.024	0.036	0.031	0.040
A31	0.031	0.030	0.032	0.029	0.037	0.044	0.023	0.058	0.048	0.044	0.026	0.056	0.036	0.040	0.036	0.048	0.058	0.029	0.058	0.042	0.038	0.035	0.031	0.039	0.053
A32	0.042	0.032	0.021	0.030	0.047	0.029	0.024	0.057	0.039	0.042	0.023	0.058	0.037	0.055	0.043	0.045	0.044	0.043	0.042	0.027	0.034	0.049	0.046	0.052	0.042
A33	0.034	0.038	0.023	0.040	0.034	0.029	0.023	0.056	0.045	0.039	0.029	0.046	0.050	0.052	0.051	0.042	0.052	0.039	0.056	0.020	0.044	0.027	0.042	0.042	0.049
A34	0.037	0.042	0.042	0.045	0.049	0.038	0.029	0.056	0.048	0.037	0.026	0.045	0.046	0.056	0.040	0.035	0.048	0.032	0.051	0.020	0.032	0.028	0.034	0.031	0.051
A35	0.033	0.037	0.021	0.034	0.051	0.039	0.028	0.060	0.043	0.039	0.022	0.046	0.041	0.052	0.048	0.031	0.049	0.028	0.059	0.025	0.051	0.025	0.049	0.046	0.047
A36	0.042	0.047	0.021	0.029	0.047	0.042	0.024	0.051	0.056	0.027	0.036	0.034	0.051	0.055	0.052	0.045	0.047	0.031	0.057	0.020	0.036	0.040	0.030	0.036	0.044
A37	0.031	0.036	0.021	0.033	0.043	0.037	0.040	0.061	0.053	0.027	0.021	0.050	0.051	0.055	0.051	0.040	0.041	0.031	0.056	0.024	0.042	0.040	0.040	0.027	0.050
A38	0.031	0.031	0.039	0.033	0.050	0.045	0.033	0.056	0.053	0.031	0.020	0.054	0.036	0.043	0.035	0.051	0.037	0.048	0.057	0.025	0.052	0.029	0.034	0.043	0.036

Appendix 2 (f) The weighted super matrix

	A11	A12	A13	A14	A15	A16	A17	A21	A22	A23	A24	A25	A26	A27	A28	A29	A20	A31	A32	A33	A34	A35	A36	A37	A38
A11	0.005	0.014	0.006	0.008	0.012	0.012	0.006	0.017	0.014	0.006	0.008	0.014	0.009	0.017	0.015	0.006	0.016	0.011	0.010	0.008	0.013	0.007	0.013	0.009	0.008
A12	0.008	0.011	0.008	0.008	0.014	0.012	0.005	0.019	0.013	0.005	0.007	0.012	0.012	0.020	0.019	0.007	0.020	0.008	0.012	0.008	0.010	0.005	0.011	0.008	0.007
A13	0.006	0.013	0.007	0.006	0.015	0.013	0.007	0.013	0.016	0.006	0.008	0.013	0.010	0.015	0.014	0.009	0.017	0.012	0.011	0.008	0.013	0.005	0.011	0.009	0.011
A14	0.007	0.014	0.006	0.006	0.014	0.011	0.005	0.013	0.014	0.005	0.010	0.016	0.010	0.016	0.015	0.008	0.016	0.009	0.011	0.009	0.012	0.007	0.014	0.011	0.008
A15	0.007	0.015	0.011	0.007	0.010	0.013	0.005	0.017	0.016	0.007	0.007	0.012	0.010	0.017	0.014	0.008	0.015	0.009	0.011	0.009	0.011	0.006	0.011	0.011	0.009
A16	0.007	0.013	0.012	0.008	0.016	0.008	0.006	0.016	0.014	0.006	0.007	0.015	0.009	0.015	0.013	0.009	0.016	0.013	0.010	0.008	0.011	0.005	0.010	0.008	0.010
A17	0.008	0.019	0.014	0.006	0.018	0.013	0.005	0.013	0.018	0.005	0.006	0.012	0.008	0.014	0.013	0.007	0.014	0.015	0.009	0.007	0.011	0.005	0.009	0.008	0.011
A21	0.023	0.017	0.010	0.020	0.018	0.015	0.012	0.015	0.028	0.018	0.011	0.019	0.026	0.021	0.026	0.022	0.019	0.015	0.023	0.011	0.023	0.014	0.016	0.015	0.022
A22	0.017	0.017	0.014	0.024	0.019	0.016	0.024	0.017	0.019	0.014	0.008	0.017	0.025	0.017	0.024	0.018	0.021	0.014	0.031	0.009	0.025	0.019	0.020	0.014	0.024
A23	0.016	0.011	0.010	0.015	0.013	0.013	0.012	0.019	0.027	0.014	0.015	0.020	0.026	0.020	0.026	0.017	0.019	0.021	0.029	0.011	0.026	0.017	0.017	0.022	0.026

A24	0.014	0.011	0.010	0.015	0.013	0.013	0.012	0.021	0.027	0.019	0.008	0.025	0.026	0.022	0.026	0.017	0.021	0.016	0.031	0.011	0.026	0.014	0.017	0.022	0.026
A25	0.016	0.013	0.012	0.022	0.015	0.018	0.014	0.020	0.023	0.021	0.011	0.017	0.026	0.020	0.025	0.020	0.017	0.021	0.029	0.009	0.023	0.015	0.015	0.023	0.020
A26	0.017	0.016	0.010	0.017	0.012	0.015	0.018	0.023	0.028	0.023	0.010	0.026	0.019	0.021	0.027	0.021	0.020	0.016	0.030	0.009	0.022	0.012	0.015	0.016	0.020
A27	0.020	0.018	0.010	0.024	0.012	0.013	0.017	0.023	0.024	0.020	0.012	0.028	0.024	0.015	0.027	0.018	0.020	0.019	0.027	0.009	0.022	0.012	0.015	0.014	0.023
A28	0.020	0.020	0.010	0.021	0.012	0.013	0.021	0.023	0.025	0.023	0.012	0.023	0.028	0.022	0.019	0.018	0.018	0.016	0.027	0.008	0.019	0.012	0.013	0.016	0.024
A29	0.014	0.015	0.016	0.023	0.016	0.022	0.014	0.021	0.024	0.016	0.009	0.020	0.026	0.018	0.023	0.016	0.015	0.022	0.029	0.009	0.024	0.018	0.015	0.018	0.026
A20	0.020	0.016	0.016	0.021	0.012	0.013	0.022	0.022	0.029	0.020	0.015	0.023	0.022	0.022	0.025	0.018	0.014	0.016	0.028	0.008	0.019	0.013	0.013	0.016	0.021
A31	0.009	0.009	0.006	0.008	0.012	0.009	0.007	0.018	0.009	0.013	0.008	0.011	0.010	0.012	0.007	0.014	0.018	0.006	0.017	0.013	0.007	0.010	0.010	0.008	0.015
A32	0.012	0.010	0.004	0.009	0.015	0.006	0.007	0.018	0.007	0.012	0.007	0.011	0.011	0.017	0.008	0.013	0.014	0.008	0.012	0.009	0.007	0.014	0.014	0.010	0.012
A33	0.010	0.012	0.004	0.012	0.011	0.006	0.007	0.018	0.009	0.011	0.009	0.009	0.015	0.016	0.010	0.012	0.016	0.008	0.016	0.006	0.009	0.008	0.013	0.008	0.014
A34	0.011	0.013	0.008	0.013	0.015	0.007	0.008	0.018	0.009	0.011	0.008	0.009	0.013	0.018	0.008	0.010	0.015	0.006	0.015	0.006	0.006	0.008	0.011	0.006	0.015
A35	0.009	0.012	0.004	0.010	0.016	0.008	0.008	0.019	0.008	0.011	0.007	0.009	0.012	0.016	0.009	0.009	0.015	0.005	0.017	0.008	0.010	0.007	0.015	0.009	0.014
A36	0.012	0.015	0.004	0.008	0.015	0.008	0.007	0.016	0.011	0.008	0.011	0.007	0.015	0.017	0.010	0.013	0.015	0.006	0.016	0.006	0.007	0.011	0.010	0.007	0.013
A37	0.009	0.011	0.004	0.010	0.013	0.007	0.011	0.019	0.010	0.008	0.007	0.010	0.015	0.017	0.010	0.012	0.013	0.006	0.016	0.007	0.008	0.011	0.013	0.005	0.015
A38	0.009	0.010	0.007	0.010	0.016	0.009	0.010	0.018	0.010	0.009	0.006	0.010	0.010	0.013	0.007	0.015	0.012	0.009	0.017	0.008	0.010	0.008	0.011	0.008	0.011

Appendix 2 (g) Limit the super matrix

	A11	A12	A13	A14	A15	A16	A17	A21	A22	A23	A24	A25	A26	A27	A28	A29	A20	A31	A32	A33	A34	A35	A36	A37	A38
A11	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011
A12	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011
A13	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011
A14	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011
A15	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011
A16	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011
A17	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011
A21	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019
A22	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019

A23	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019
A24	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019
A25	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019
A26	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019
A27	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019
A28	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019
A29	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019
A20	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019
A31	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011
A32	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011
A33	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011
A34	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011
A35	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011
A36	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011
A37	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011
A38	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010

Appendix 2 (h) Normalized matrix of categories by TOPSIS

	A11	A12	A13	A14	A15	A16	A17	A21	A22	A23	A24	A25	A26	A27	A28	A29	A20	A31	A32	A33	A34	A35	A36	A37	A38
A1	0.267	0.694	0.426	0.577	0.640	0.640	0.302	0.254	0.267	0.408	0.577	0.333	0.302	0.660	0.728	0.302	0.577	0.229	0.189	0.092	0.229	0.485	0.070	0.485	0.389
A2	0.802	0.694	0.640	0.577	0.426	0.640	0.905	0.933	0.802	0.816	0.577	0.667	0.905	0.660	0.485	0.302	0.577	0.688	0.694	0.552	0.688	0.485	0.632	0.485	0.583
A3	0.535	0.189	0.640	0.577	0.640	0.426	0.302	0.254	0.535	0.408	0.577	0.667	0.302	0.360	0.485	0.905	0.577	0.688	0.694	0.829	0.688	0.728	0.772	0.728	0.713
W	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.010

Appendix 2 (i) Weighted matrix of TOPSIS

	A11	A12	A13	A14	A15	A16	A17	A21	A22	A23	A24	A25	A26	A27	A28	A29	A20	A31	A32	A33	A34	A35	A36	A37	A38
A1	0.003	0.007	0.005	0.006	0.007	0.007	0.003	0.005	0.005	0.008	0.011	0.006	0.006	0.012	0.013	0.006	0.011	0.002	0.002	0.001	0.002	0.005	0.001	0.005	0.004
A2	0.009	0.007	0.007	0.006	0.005	0.007	0.010	0.017	0.015	0.015	0.011	0.012	0.017	0.012	0.009	0.006	0.011	0.007	0.007	0.006	0.007	0.005	0.007	0.005	0.006

A3	0.006	0.002	0.007	0.006	0.007	0.005	0.003	0.005	0.010	0.008	0.011	0.012	0.006	0.007	0.009	0.017	0.011	0.007	0.007	0.009	0.007	0.008	0.008	0.008	0.007
V+	0.003	0.007	0.007	0.006	0.007	0.007	0.010	0.017	0.015	0.015	0.011	0.012	0.017	0.012	0.013	0.017	0.011	0.007	0.007	0.009	0.007	0.008	0.008	0.008	0.007
V-	0.009	0.002	0.005	0.006	0.005	0.005	0.003	0.005	0.005	0.008	0.011	0.006	0.006	0.007	0.009	0.006	0.011	0.002	0.002	0.001	0.002	0.005	0.001	0.005	0.004

Appendix 2 (j) Conditions for Sensitivity Analysis

Conditions	Weights																								
	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15	W16	W17	W18	W19	W20	W21	W22	W23	W24	W25
Main	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.010
1	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.010
2	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.010
3	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.010
4	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.010
5	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.010
6	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.010
7	0.019	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.010
8	0.019	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.010
9	0.019	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.010
10	0.019	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.010
11	0.019	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.010
12	0.019	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.010
13	0.019	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.010
14	0.019	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.010
15	0.019	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.010
16	0.019	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.010
17	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.011	0.011	0.011	0.011	0.011	0.011	0.010
18	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.011	0.011	0.011	0.011	0.011	0.011	0.010
19	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.011	0.011	0.011	0.011	0.011	0.011	0.010
20	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.011	0.011	0.011	0.011	0.011	0.011	0.010
21	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.011	0.011	0.011	0.011	0.011	0.011	0.010
22	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.011	0.011	0.011	0.011	0.011	0.011	0.010
23	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.011	0.011	0.011	0.011	0.011	0.011	0.010
24	0.010	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.011	0.011	0.011	0.011	0.011	0.011	0.011