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Selecting green suppliers based on GSCM practices: Using fuzzy TOPSIS applied to a Brazilian electronics company



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ABSTRACT

Due to an increased awareness and significant environmental pressures from various stakeholders, companies have begun to realize the significance of incorporating green practices into their daily activities. This paper proposes a framework using Fuzzy TOPSIS to select green suppliers for a Brazilian electronics company; our framework is built on the criteria of green supply chain management (GSCM) practices. An empirical analysis is made, and the data are collected from a set of 12 available suppliers. We use a fuzzy TOPSIS approach to rank the suppliers, and the results of the proposed framework are compared with the ranks obtained by both the geometric mean and the graded mean methods of fuzzy TOPSIS methodology. Then a Spearman rank correlation coefficient is used to find the statistical difference between the ranks obtained by the three methods. Finally, a sensitivity analysis has been performed to examine the influence of the preferences given by the decision makers for the chosen GSCM practices on the selection of green suppliers. Results indicate that the four dominant criteria are Commitment of senior management to GSCM; Product designs that reduce, reuse, recycle, or reclaim materials, components, or energy; Compliance with legal environmental requirements and auditing programs; and Product designs that avoid or reduce toxic or hazardous material use.

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1. Introduction

Environmental issues are no longer a concern only for environmental experts; environmental awareness affects almost all parts of our society and it is a special concern for our industrial sectors (Sarkis, 1998; Hart & Dowell, 2011). Companies and their decision makers must consider environmental issues in all of their administrative activities (Marcus & Fremeth, 2009), including the role of the supply chain (Linton, Klassen, & Jayaraman, 2007) and the firms' selection of suppliers (Genovese, Lenny Koh, Bruno, & Esposito, 2013). One of the most important and difficult decisions in supplier selection process is the commitment to environmental causes (Dekker, Bloemhof, & Mallidis, 2012). Thus, the process for supplier selection creates a new research area known as green supplier selection, and this area has many research gaps still to be explored (Kumar, Jain, & Kumar, 2014). Green supplier selection should be considered important when companies are looking for greener supply chain management, including, for example, remanufacturing targets (Xiong, Zhou, Li, & Chan, 2013).

Several environmental criteria may be emphasized when selecting the most environmentally friendly suppliers (Dekker et al.,

2012). For example, several studies have suggested that the supplier selection can be based on the criteria related to environmental practices (Humphreys, Wong, & Chan, 2003) or to hazardous material management (Hsu & Hu, 2009). Other studies address social, economic, and environmental sustainability practices as the criteria for the supplier selection (Govindan, Khodaverdi, & Jafarian, 2013) in the context of more sustainable supply chains (Seuring, 2013). However, the best manner by which a firm might select suppliers based on their GSCM reputation is still a missing link in the literature.

Hence, studies that propose supplier selection based on the supplier's adoption of Green Supply Chain Management (GSCM) practices, a modern environmental sustainability concept, is still to be done. GSCM offers an expanded perspective on environmental management that considers practices adopted both inside and outside the company (Ageron, Gunasekaran, & Spalanzani, 2012), and this approach can generate more business opportunities for firms (Wang & Chan, 2013). In addition, although studies on supplier selection based on environmental criteria in many national contexts are available (Baskaran, Nachiappan, & Rahman, 2012; Large & Thomsen, 2011), proposals that consider the realities of the developing countries – mainly the BRICS countries – are still scarce and deserve more attention from researchers. For example, in 2010, Brazil formulated new environmental legislation called the National Solid Waste Policy. This new legislation requires firms

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¹ This paper was completed while the first author visited UNESP, Bauru, Brazil as a research assistant.

Table 1a

Top 10 cited works in green supply chain management.

Author(s)	Purpose/findings
Srivastava (2007)	Classified the available literature on GSCM into categories such as problem context; methodology/approach; and tools and techniques. Supplied a comprehensive review of the literature on green supply chain
Zhu and Sarkis (2004)	Used empirical results from more than 180 respondents on GSCM practices in Chinese manufacturing firms to examine the relationships between GSCM practices and environmental and economic performance
Sarkis (2003)	Presented a decision framework that considers green management factors, designed to facilitate improvements in green supply chain management decision making
Seuring and Müller (2008)	Reviewed and classified the literature on sustainable supply chain management, including green issues, and presented an overview of state of the art literature
Rao and Holt (2005)	Tested linkages between green supply chain management as an initiative for environmental enhancement, economic performance and competitiveness among a sample of ISO 14001-certified companies in Southeast Asia. They found positive relationships in the studied model
Kleindorfer et al. (2005)	Reviewed various themes on sustainability (including green supply chain management). Covered Production and Operations Management journal. They highlighted future research challenges in sustainable operations management
Linton et al. (2007)	Presented a special issue on sustainable supply chain management. Reinforced the argument that the focus on environmental management and operations has now moved from local optimization of environmental factors to consideration of the entire supply chain
Zhu et al. (2005)	Based on 314 complete questionnaires, authors concluded that more awareness on environmental issues has not yet been translated into strong GSCM practice adoption
Vachon and Klassen (2006)	Conceptualized and empirically tested green supply chain practices, and considered both upstream and downstream interactions in chain
Sheu et al. (2005)	Presented an optimization-based model to deal with integrated logistics operational problems of green-supply chain management

and municipalities to adopt proactive green management values and practices, and companies are feeling pressured to enact these environmentally sensitive practices in a timely manner (Jabbour, Jabbour, Sarkis, & Govindan, 2013a).

Suppliers that adopt GSCM practices may encourage improved environmental performance throughout the entire supply chain (Genovese et al., 2013; Kumar et al., 2014). Advances in creating novel supplier selection approaches as part of applying GSCM may help companies to address continuing challenges in the green supplier selection process and thus to improve their environmental performance (Handfield, Walton, Sroufe, & Melnyk, 2002). Clearly, a company's environmental management performance level is highly correlated with its adoption of green supplier selection practices (Jabbour & Jabbour, 2009). In this context, many quantitative approaches have been proposed to facilitate the green supplier selection process more efficiently. For example, researchers have proposed the application of Green Data Envelopment Analysis (Kumar et al., 2014), hierarchical fuzzy TOPSIS approach (Wang & Chan, 2013), and other methodologies, such as life cycle assessment, multi-criteria decision making, and analytical hierarchy process (Seuring, 2013).

No current research discusses how companies might use GSCM practices as criteria by which to select green suppliers. Within this context, a primary concern of the present study is to explore how a company can select green suppliers who employ GSCM practices based on a fuzzy approach. The aim of the article is to select the green suppliers based on the GSCM practices using the fuzzy TOPSIS approach. Additionally, this research discusses the case of a Brazilian company operating in an electronic sector. Brazil is an emerging country which belongs to the BRICS group; Brazil is also responsible for about 35% of all the Latin America GDP (European Commission, 2007), which certainly attracts the attention of many international economic players. Further, systematic searches – using the words “green supply chain,” “supplier selection,” “green,” “environmental,” or “green practices” – conducted in the ISI Web of Knowledge database during 2012 and 2013 showed no similar research to this proposal.

2. Literature review

2.1. Green supply chain management

Green supply chain management is not a concept on which all researchers agree (Ahi & Searcy, 2013). However, the majority of

authors state that it emerges from the ideas that companies must become greener (Marcus & Fremeth, 2009), must try to reach a win–win perspective (Hart & Dowell, 2011) and must link the supply chains and sustainable development (Seuring, 2013). The concepts of GSCM emerged from the realization that isolated implementations of environmental practices by companies are not as effective as collective actions that make the entire supply chain greener (Ageron et al., 2012). This broader systematic perspective of environmental management dispersed among all players in a supply chain has been called GSCM (Linton et al., 2007). This concept is a part of the broad effort to align operations management with the goal of improving the quality of life in society (Sarkis, 2012) and it is a theme that requires more attention and emphasis in future studies (Gunasekaran & Gallea, 2012).

GSCM is, therefore, a part of the environmental dimension of the Sustainable Supply Chain Management (SSCM) concept (Seuring & Müller, 2008). SSCM can be defined as the management of materials, the distribution of information, the flow of capital, and cooperation among companies in a supply chain as they strive to improve their economic, environmental, and social performances while simultaneously considering the expectations of other stakeholders (Seuring & Müller, 2008). The interest of the scientific community in this subject is increasing quickly (Seuring, 2013). A summary of the state-of-the art, most influential works on GSCM can be found in Table 1a. Using the keywords “green supply chain,” “green supply chain management,” and “environmental supply chain management,” a search in the ISI Web of Knowledge database produced the 10 most cited works in this field of knowledge; they are depicted in Table 1a.

From this literature review, several definitions of GSCM deserve attention:

- GSCM encompasses a set of environmental practices that encourage improvements to the environmental practices of two or more organizations within the same supply chain (Vachon & Klassen, 2006).
- GSCM is the process of incorporating environmental concerns into supply chain management including product design, material sourcing and selection, manufacturing, delivery of final products, and the management of product's end-of-life (Srivastava, 2007).
- GSCM can be achieved by considering environmental issues at the purchasing, product design and development, production, transportation, packaging, storage, disposal, and end of product life cycle management stages (Min & Kim, 2012).

Table 1b
GSCM practices used in this article.

Code	Name of the practice	Explanation
GSCM 1	Commitment of senior management to GSCM	The support of senior management is crucial in GSCM adoption, as there will be an eventual need for process adjustments or cultural changes
GSCM 2	Inter-functional cooperation for environmental improvement	Inter-functional cooperation (e.g., purchases and sustainability, research and development in sustainability, or marketing and stability, etc.) is important in implementing changes in the day-to-day activities of the functional areas. This type of cooperation can therefore promote environmental requirements externally via upstream suppliers, or internally via consumer demand
GSCM 3	Compliance with legal environmental requirements and auditing programs	Addressing environmental legal requirements and auditing programs demonstrates that the company is attempting to meet environmental regulation for their sector internally
GSCM 4	ISO 14001 Certification	The company has an ISO 14001 certified EMS
GSCM 5	Selection of suppliers includes environmental criteria	The selection process for suppliers considers environmental variables (e.g., ISO 14001) in addition to traditional criteria (e.g., cost, quality, reliability, etc.)
GSCM 6	Work with suppliers to meet environmental goals	Suppliers are asked to support initiatives and measures within their company to improve the environment
GSCM 7	Evaluations of the internal environmental management of suppliers	Inspections of supplier installations provide a way to check the environmental performance of the supplier and ensure that they comply with environmental management standards
GSCM 8	Evaluation of the environmental management of 2nd-tier suppliers	Suppliers of basic raw materials are also monitored to extend environmental concern beyond the direct relationship
GSCM 9	Work with clients for eco-design	Utilizing the close relationships that traditional supply chain management allows, companies seek to develop products together with clients to improve the products' environmental impact
GSCM 10	Work with clients to make production cleaner	Utilizing the close relationships that traditional supply chain management allows, companies seek to manufacture more cleanly with cooperation from the client
GSCM 11	Work with clients to use environmentally friendly packaging	Utilizing the close relationships that traditional supply chain management allows, companies seek to use environmentally friendly packaging with cooperation from clients
GSCM 12	Acquisition of the cleanest technologies by the company	The company buys equipment that allows it to make products as cleanly as possible
GSCM 13	Product designs that reduce, reuse, recycle, or reclaim materials, components, or energy	The company observes policies on material reduction, parts reuse, recycling of the product after use, and recuperation of materials, components, or energy throughout the product's life
GSCM 14	Product designs that avoid or reduce toxic or hazardous material use	In developing products, the company incorporates ways to avoid or reduce the use of dangerous or toxic products
GSCM 15	Sale of excess stock or materials	The company seeks to sell obsolete stock to recuperate its investment
GSCM 16	Sale of scrap and used materials	The company seeks to sell waste and used materials (i.e., materials that do not have value in the production line) to recuperate its investment
GSCM 17	Sale of used equipment (after buying new equipment)	The company sells used equipment to recuperate its investment

- GSCM is the integration of environmental concerns in the inter-organizational practices of supply chain management (Sarkis, Zhu, & Lai, 2011).

Companies can apply GSCM as a group of practices, as shown in Table 1b. In this research, we included 17 (Table 1b) of the 21 practices statistically confirmed by Zhu, Sarkis, and Lai (2008). The reduced number of GSCM practices was justified by the following considerations: (a) some practices were redundant, and excluding them reduces the number of variables in the study and (b) practices with similar approaches are grouped together. Thus, we excluded the overlapping of some GSCM practices, namely: environmental management systems (because ISO 14001 has been considered as a GSCM practice); TQEM (because it is not a clear approach to Brazilian companies); support of the middle-manager (because there is a GSCM practice entitled "top management commitment"); and green label (because there is a GSCM practice regarding the green criteria for selection suppliers). These four practices have not been considered from the set of GSCM practices considered in this research.

Some recent findings confirm the relevance of GSCM for companies' success. For example, Diabat, Khodaverdi, and Olfat (2013) found the three most relevant GSCM practices of the automotive industry in a developing country are design for environment, collaboration with clients, and reverse logistics. Based on a survey with 163 container shipping firms in Taiwan, Yang, Lu, Haider, and Marlow (2013) determined that internal green practices and external green collaboration have positive impacts on green performance, and as a result, a firm's competitiveness based on GSCM practices is enhanced. GSCM is particularly relevant in contemporary organizational management because it can create synergy

with other managerial principles such as lean manufacturing (Dües, Tan, & Lim, 2013).

However, not all companies adopt GSCM practices equally (Lai & Wong, 2012). For example, Ageron et al. (2012) conducted a study of more than 170 French companies to analyze the degree to which environmental sustainability in supply chain management may have been included. They discovered that: (a) strategic plans and actions are fundamental to the adoption of green supply chain management; (b) the size of the company and its international activities may influence its participation in a green supply chain; and (c) waste management is a central theme of these companies. In developing countries, GSCM may not be considered a realistic option for most firms (Diabat et al., 2013). In Brazil, for example, the internationalization of firms has positively motivated the adoption of GSCM practices, but at the national level, this process is still in the implementation stage for many companies (Jabbour, Azevedo, Arantes, & Jabbour, 2013b). For Brazil, the adoption of GSCM should be implemented to advance the production and marketing acceptance of environmentally-improved products (Tomasin da Silva, Pereira, Borchardt, & Sellitto, 2013).

2.2. Green supplier selection

The increased inclusion of environmental considerations in the fields of operations management and supply chains has become a strong trend (Gunasekaran & Ngai, 2012). One of the most important GSCM practices is to choose environmental considerations in supplier selection, maintenance, and development (Dekker et al., 2012). For Kumar et al. (2014) the supplier selection process involves a set of activities such as identifying, analyzing, and choosing suppliers to become a tier of the supply chain. Suppliers who

Table 1c
Ten top cited article in green supplier selection.

Author(s)	Purpose of paper	Supplier selection criteria	Method
Min and Galle (2001)	Examine the factors that influence the complacency of the buyer companies to adopt green purchasing strategy	(1) Environmental liability and penalty (2) A supplier's environmental commitment (3) Environmental cost	Statistics (hypothesis testing and factor analysis)
Lee et al. (2009)	Propose a model for evaluating green suppliers. It defined a hierarchy to evaluate the importance of the criteria for selection of green suppliers	(1) Quality (2) Technology capability (3) Pollution control (4) Environmental management (5) Green product (6) Green competencies	Fuzzy, AHP e Fuzzy expanded AHP
Jabbour and Jabbour (2009)	Verify if Brazilian companies are adopting environmental requirements based selection of suppliers	(1) Cost (2) Quality (3) Innovation (4) Delivery (5) Restrictions on the use of chemicals (6) ISO 14001	Case studies
Kuo et al. (2010)	Develop a selection of green suppliers using a model that integrates artificial neural network (ANN), data envelopment analysis (DEA) and analytic network process (ANP)	(1) Quality (2) Service (3) Corporate social responsibility (4) Delivery (5) Cost (6) Environment	ANN, DEA, ANP
Wolf and Seuring (2010)	Analyze whether environmental issues are part of the criteria for selection of logistics service providers	(1) Cost (2) Lead time (3) Reliability (4) Variety (5) Quality (6) Environment	Case studies
Büyükoçkan and Çifçi (2011)	Identify a model based on principles of sustainability to select suppliers for supply chains	(1) Organization (2) Financial performance (3) Quality (4) Technology (5) Corporate social and environmental responsibility	Fuzzy ANP
Büyükoçkan and Çifçi (2012)	Evaluate the selection of green suppliers for qualitative and quantitative factors	(1) Organization (2) Financial performance (3) Quality (4) Technology (5) Corporate social and environmental responsibility	Fuzzy Dematel, Fuzzy ANP, Fuzzy TOPSIS
Yeh and Chuang (2011)	Develop a model for optimal planning of mathematics to select partners greens	(1) Capability (2) Productivity (3) Cost (4) Quality (5) ISO 14000	Genetic algorithm
Tseng and Chiu (2013)	Illustrate a case of a company that aims to select green suppliers to meet requirements of GSCM	18 criteria, among which: (1) Delivery (2) Financial performance (3) Relationship (4) Quality (5) Price (6) Green design (7) ISO 14000 (8) Green purchasing (9) Cleaner production	Fuzzy, MDCM, Grey theory
Shaw et al. (2012)	Propose an integrative model to select suppliers for the supply chain considering carbon emissions	(1) Cost (2) Quality (3) Delivery (4) Emissions of greenhouse gases	Fuzzy-AHP, Fuzzy multi-objective linear programming

adopt GSCM practices can strengthen the environmental performances of companies throughout the supply chain. Addressing the environmental criteria during supplier selection process is even more important in developing countries because of the difficulties and barriers companies in these countries face (Akamp & Müller, in press).

Supplier selection based on environmental criteria has attracted the attention of many investigators. In 2012, a search for papers about this topic were conducted. As a result, a summary of the 10 most cited articles in the ISI Web of Science journal have been selected and listed in Table 1c. It is important to note that these papers were selected only from the journals and not from the proceedings.

There are many others studies that discuss green supplier selection. For example, Large and Thomsen (2011) utilized data from more than 100 German companies and discovered that the degree of green supplier assessment and the level of green collaboration directly influence a company's environmental performance. These two practices are driven at the strategic level by the purchasing department and through the firm's level of environmental commitment. Other researchers have consistently indicated that including environmental considerations in supplier selection is a fundamental practice among organizations that strive for sustainability (Sarkis, 1998; Dekker et al., 2012).

However, although there is a consensus that supplier selection using environmental criteria is important, some challenges exist

Table 1d
Fuzzy TOPSIS application area.

Proposed by	Application area
Krohling and Campanharo (2011)	Oil spill problem
Ding (2011)	Partner selection of a shipping company
Wang and Elhag (2006)	Bridge risk assessment problem
Torlak et al. (2011)	Airline industry
Kelemenis, Ergazakis, and Askounis (2011)	Manager selection
Saremi, Mousavi, and Sanayei (2009)	TQM consultant section
Singh and Benyoucef (2011)	e-Sourcing
Wang, Cheng, and Huang (2009)	Supplier selection
Deviren et al. (2009)	Weapon selection
Kannan et al. (2009)	Reverse logistic provider selection
Liao and Kao (2011)	Supplier selection

in developing robust selection methods (Humphreys et al., 2003). Accordingly, several studies have proposed a variety of approaches to overcome these challenges.

A study by Baskaran et al. (2012) analyzed the inclusion of socio-environmental sustainability criteria in the Indian textile industry. This study indicated that the criterion of long working hours plays an important role in evaluating suppliers of garment manufacturers and ancillary suppliers. The study also found that pollution and unfair competition were important criteria when evaluating the garment manufacturers. Employing child labor was found to be a critical criterion when evaluating the ancillary suppliers.

Govindan et al. (2013) explored sustainable supply chain initiatives and presented a fuzzy multi-criteria approach to identify an effective model for supplier selection in supply chains based on the triple bottom line (TBL) approach (i.e., economic, environmental, and social considerations).

Hsu and Hu (2009) presented an Analytic Network Process (ANP) approach to incorporate the issue of Hazardous Substance Management (HSM) into the supplier selection. An illustrative example in an electronics company was presented to demonstrate how to select the most appropriate supplier in accordance with environmental regulatory requirements on hazardous substances.

However, environmental evaluation of the GSCM practices that suppliers could adopt is lacking. Suppliers who adopt GSCM practices may encourage improved environmental performance throughout the entire supply chain. Advances in the development of novel GSCM approaches for selecting suppliers may help companies that still struggle with green supplier selection (Handfield et al., 2002).

2.3. Fuzzy TOPSIS

The TOPSIS approach is a widely accepted method used for ranking problems in real time situations. The major limitation of the TOPSIS method lies in the inability to capture the vagueness or ambiguity inherent in the decision making process (Yu, 2002). In order to overcome this limitation, the fuzzy set theory can be used with the traditional TOPSIS approach to allow decision-makers to incorporate unquantifiable information, incomplete information, non-obtainable information, and partially ignorant facts into the decision model (Deviren, Yavuz, & Kilinc, 2009; Kulak, Durmusoglu, & Kahraman, 2005). Hence, the fuzzy TOPSIS approach should be more appropriate and effective than conventional TOPSIS (Gumus, 2009), and fuzzy TOPSIS can be successfully used in the various application areas of MCDM problems (Table 1d).

3. Problem description

A Brazilian electronics industry (company A²) is chosen for this study. Company A has approximately 4000 employees per shift; they assemble electronics products such as notebooks, tablets, and desktop computers. The company is one of the leaders in its product segment in Brazil; its main customers are major national retailers and the government.

This company has enacted changes in the structure of the final product in order to make it lighter, free of harmful chemicals, recyclable, and to lower its electricity consumption. These changes, in turn, meet both environmental legislation regulations and the demands of their customers. The company has also dedicated itself to an analysis of the life cycle assessment (LCA) of the product. LCA conducts an inventory of emissions, consumption of raw materials, and waste generation, and this inventory allows the company to evaluate its own usage of such resources and to implement reduction practices.

In Brazil, according to the 2010 National Policy on Solid Waste, all companies in the electronics sector are now required to take responsibility for their post-consumer products take-back and environmental impacts. Because of the Brazilian government's mandate, companies recognize that offering greener electronics products not only meets customer demand but also requires locating good green suppliers to improve their supply chain management.

Because of this new context in Brazil, the company's sustainability manager seeks a way to identify and to select suppliers who will support the company's adoption of GSCM practices. 12 major suppliers have been identified as candidates for company A. With this company's objectives in mind, the authors of this paper prepared a survey questionnaire (based on Section 2.1) and submitted it for content analysis to four academic experts. Then, we asked the opinion of three experts who work with the marketing context of GSCM in order to check their preferences when using GSCM practices to select suppliers. Fig. 1 shows the framework of this research and the five-phase methodology adopted in this work.

4. Development of solution methodology

In this work, we have adopted a fuzzy TOPSIS methodology for solving the multi-criteria decision making problem of green supplier selection for a Brazilian electronics company. This section briefly describes the fuzzy sets and linguistic variables, the TOPSIS method, and the proposed fuzzy TOPSIS method.

4.1. Fuzzy set theory

In several situations, crisp numbered data are insufficient to model real world systems due to the vagueness, imprecision, and subjective nature of human thinking, judgment, and preferences (Olfat, Govindan, & Khodaverdi, 2012). Also, because in various situations, performance ratings and weights cannot be given precisely, fuzzy set theory is introduced to model the uncertainty of human judgments; the process is called fuzzy multi-criteria decision making (FMCDM) (Singh & Benyoucef, 2011). Zadeh (1965, 1976) introduced the fuzzy set theory in multi-criteria decision making (MCDM) to resolve the uncertainty and vagueness of human cognitive and judgment by providing mathematical strengths to work out such uncertainties of human thinking and reasoning. Use of fuzzy sets to analysis the decision-making problem was first introduced by Bellman and Zadeh (1970) (Olfat et al., 2012). Fuzzy

² To maintain confidentiality, the company's name is designated as company A.

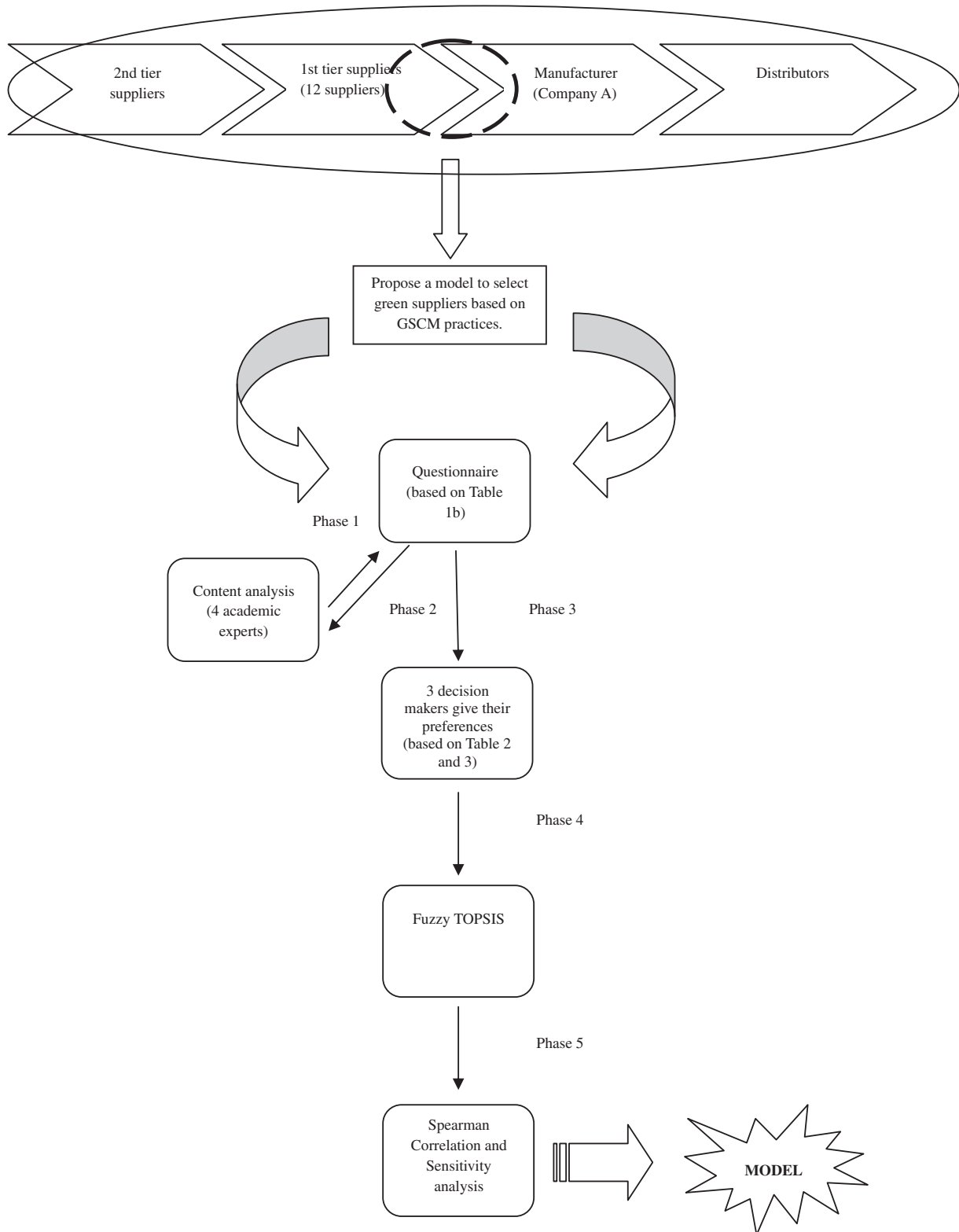


Fig. 1. Proposed framework and five-phase methodology.

set theory, an extension of the crisp set theory, uses linguistic terms to represent the decision maker’s selections. In FMCDM problems, the ratings and weights of the attributes estimated on vagueness, imprecision, and subjectivity are expressed in linguistic terms and then converted to fuzzy numbers (Kannan, Pokharel, &

Sasi Kumar, 2009). In this paper, fuzzy set theory is used to model the green supplier selection for a Brazilian electronics industry, and triangular fuzzy numbers (TFN) are used to review the decision maker’s preference because it captures the vagueness of the linguistic assessments and thereby contributes to the easy usage

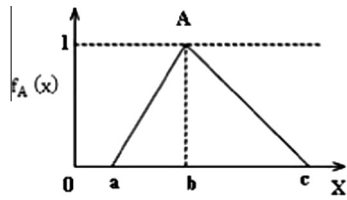


Fig. 2. Membership function of triangular fuzzy number A.

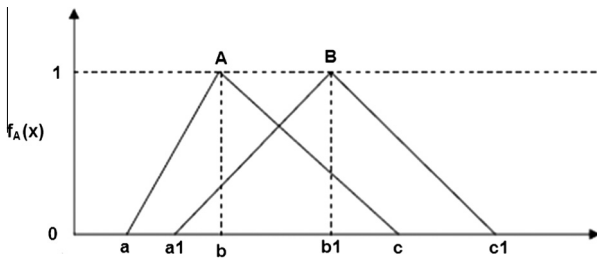


Fig. 3. Two triangular fuzzy numbers.

Table 2

Linguistic variables and fuzzy ratings of the alternative (Wang and Elhag, 2006).

Linguistic expression for rating alternatives (Green suppliers)	
Linguistic expression	Fuzzy numbers
Very Poor (VP)	(0,0,1)
Poor (P)	(0,1,3)
Medium poor (MP)	(1,3,5)
Fair (F)	(3,5,7)
Medium Good (MG)	(5,7,9)
Good (G)	(7,9,10)
Very Good (VG)	(9,10,10)

Table 3

Linguistic variables and fuzzy ratings of the criteria (Wang and Elhag, 2006).

Linguistic expression for relative importance weight of criteria (GSCM practices)	
Linguistic expression	Fuzzy numbers
Very Low (VL)	(0,0.2,0.4)
Low (L)	(0.2,0.4,0.5)
Medium (M)	(0.4,0.6,0.8)
High (H)	(0.6,0.8,1)
Very High (VH)	(0.8,0.9,1)

and computational simplicity (Kannan et al., 2009). From the literature it is proved that TFN is an effective way of formulating decision problems containing subjective and imprecise information (Torlak, Sevkli, Sanal, & Zaim, 2011; Deviren et al., 2009; Chang & Yeh, 2002; Chang, Chung, & Wang, 2007; Kahraman, Bes_kese, & Ruan, 2004; Zimmerman, 1996). A triangular fuzzy number is defined as (a, b, c) , where $a \leq b \leq c$. The parameters a , b , and c indicate the smallest possible value, the middle possible value, and the largest possible value, respectively that describe a fuzzy event. Some important definitions and notations of fuzzy set theory used in this article are as follows (Zadeh, 1965, 1976; Zimmerman, 1996; Awasthi, Chauhan, & Omrani, 2011; Kannan et al., 2012; Olfat et al., 2012; Singh & Benyoucef, 2011):

Definition 1 (Fuzzy set). Let X be the universe of discourse, $X = \{x_1, x_2, \dots, x_n\}$. A fuzzy set A of X is a set of order pairs $\{(x_1, f_A(x_1)), (x_2, f_A(x_2)), \dots, (x_n, f_A(x_n))\}$, where $f_A: X \rightarrow [0, 1]$ is the membership function of A , and $f_A(x_i)$ stands for the membership degree of x_i in A .

Definition 2 (Fuzzy number). A triangular fuzzy number can be expressed as a triplet (a, b, c) ; the membership function of the fuzzy number $f_A(x)$ is illustrated in Fig. 2 and defined as:

$$f_A(x) = \begin{cases} 0 & x < a, x > c \\ \frac{x-a}{b-a}, & a \leq x \leq b \\ \frac{c-x}{c-b}, & b \leq x \leq c \end{cases}$$

Due to their conceptual and computational simplicity, triangular fuzzy numbers are more commonly used in practical applications (Awasthi et al., 2011; Singh & Benyoucef, 2011).

Definition 3. Assume that $A = (a, b, c)$ and $B = (a_1, b_1, c_1)$ are real numbers, then the distance measurement $d(a_1, a_2)$, is identical to the Euclidean distance (Chen, 2000).

Definition 4. Let $A = (a, b, c)$ and $B = (a_1, b_1, c_1)$ be two triangular fuzzy numbers. Then the operational laws of these two triangular fuzzy numbers are as follows:

$$A(+)B = (a, b, c)(+)(a_1, b_1, c_1) = (a + a_1, b + b_1, c + c_1) \quad (1)$$

$$A(-)B = (a, b, c)(-)(a_1, b_1, c_1) = (a - c_1, b - b_1, c - a_1) \quad (2)$$

$$A(\times)B = (a, b, c)(\times)(a_1, b_1, c_1) = (aa_1, bb_1, cc_1) \quad (3)$$

$$A(\div)B = (a, b, c)(\div)(a_1, b_1, c_1) = \left(\frac{a}{c_1}, \frac{b}{b_1}, \frac{c}{a_1}\right) \quad (4)$$

$$kA = (ka, kb, kc) \quad (5)$$

$$(A^{-1}) = \left(\frac{1}{c}, \frac{1}{b}, \frac{1}{a}\right) \quad (6)$$

Definition 5. Let $A = (a, b, c)$ and $B = (a_1, b_1, c_1)$ be two triangular fuzzy numbers (Fig. 3). The distance between the two fuzzy numbers is calculated using the vertex method and the same is given by

$$d(A, B) = \sqrt{1/3[(a - a_1)^2 + (b - b_1)^2 + (c - c_1)^2]} \quad (7)$$

Definition 6. Assume that a decision making committee consists of K decision makers, and the fuzzy rating of each decision maker D_k ($k = 1, 2, \dots, K$) can be represented as a positive triangular fuzzy number R_k ($k = 1, 2, \dots, K$) with membership function $F_{R_k}(x)$. Then the aggregated fuzzy rating can be defined as:

$$R = (a, b, c), \quad k = 1, 2, \dots, K \quad (8)$$

where $a = \min_k\{a_k\}$, $b = 1/k \sum_{k=1}^K b_k$, $c = \max_k\{c_k\}$

4.1.1. Linguistic variable

A linguistic variable is a variable whose values are words or sentences of a natural or artificial language that are expressed in linguistic terms which are then represented by the triangular fuzzy number. Usually, conversion scales are used to transform linguistic terms into fuzzy numbers (Torlak et al., 2011; Singh & Benyoucef, 2011; Awasthi et al., 2011). In this research work, we use 0–1 scale and 0–10 scale to rate the criteria and alternatives respectively. The linguistic variables and fuzzy ratings used for the alternatives and criteria are presented in Tables 2 and 3, respectively.

4.2. Fuzzy TOPSIS

Hwang and Yoon (1981) proposed a technique for order preference by similarity to ideal solution which is known as TOPSIS (Yu et al., 2012). This technique is one of the classical methods for solving the MCDM problems (Olfat et al., 2012). The vital idea of the TOPSIS is to define the positive and negative ideal solutions and

Table 4
Decision makers preference of the criteria.

	D1	D2	D3
GSCM1	VH	VH	VH
GSCM2	H	H	VH
GSCM3	H	VH	VH
GSCM4	VH	H	M
GSCM5	H	VH	H
GSCM6	H	H	VH
GSCM7	H	H	M
GSCM8	H	M	M
GSCM9	VH	H	H
GSCM10	H	M	M
GSCM11	H	H	H
GSCM12	H	H	VH
GSCM13	VH	VH	VH
GSCM14	VH	H	VH
GSCM15	H	M	M
GSCM16	H	M	L
GSCM17	H	M	VL

then to measure the distance of the alternatives from the ideal solutions based on which the rankings of the alternatives are determined. The positive ideal solution (PIS) is the solution which maximizes the benefit criteria and minimizes the cost criteria, whereas the negative ideal solution (NIS) maximizes the cost criteria and minimizes the benefit criteria. The selected alternative should be closest to the PIS and farthest away from NIS. TOPSIS identifies an index called closeness coefficient (similarity) to the PIS and remoteness to the NIS. Finally, the method selects an alternative whose closeness coefficient to the PIS is maximum (Kahraman, Engin, Kabak, & Kaya, 2009; Torlak et al., 2011). In fuzzy TOPSIS, the ratings and the weights are defined by the linguistic variable which is then set to fuzzy numbers called TFN.

The fuzzy TOSIS method, according to Hwang and Yoon (1981) and Kannan et al. (2009), is summarized as follows:

Step 1: Constructing the decision matrix

Let us consider a group of k decision makers (D_1, D_2, \dots, D_k) containing m alternatives (A_1, A_2, \dots, A_m) and n criteria (C_1, C_2, \dots, C_n) for a MCDM problem which is clearly expressed in a matrix format as:

$$D = \begin{matrix} & C_1 & C_2 & \dots & C_n \\ \begin{matrix} A_1 \\ A_2 \\ \vdots \\ A_m \end{matrix} & \begin{bmatrix} r_{11} & r_{12} & \dots & r_{1n} \\ r_{21} & r_{22} & \dots & r_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ r_{m1} & r_{m2} & \dots & r_{mn} \end{bmatrix} \end{matrix}$$

where r_{mn} be the rating of alternative A_m with respect to criterion C_n . Let $W_j = (W_1, W_2, \dots, W_n)$ be the relative weight vector of the n criteria that should be equal to 1.

Table 5a
Decision maker 1 (DM1) ratings of the alternatives.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17
A1	P	MP	VP	VP	VP	P	P	MP	MP	MP	P	P	P	VP	VP	F	F
A2	P	MG	VG	VP	VP	P	P	MP	F	F	P	MP	G	VG	F	VG	VG
A3	G	G	VG	VG	G	G	G	MG	MG	MG	VG	VG	VG	VG	G	VG	VG
A4	VG	G	VG	VG	VG	G	VG	MG	G	G	MP	G	G	VG	F	VG	VG
A5	VG	VG	VG	G	VG	VG	VG	G	G	F	G	VG	VG	VG	VG	VG	VG
A6	P	MP	MP	VP	VP	P	P	MP	MP	MP	P	P	VP	F	F	F	F
A7	G	G	G	P	VP	MG	P	MP	MG	G	MP	MP	G	F	P	G	G
A8	VP	G	MP	VP	VP	P	P	MP	MP	MP	P	F	F	F	F	F	F
A9	P	MG	VP	F	VP	P	MG	MG	MP	MP	P	F	F	F	VP	G	F
A10	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VP	VG	VG
A11	G	G	VG	VG	G	F	MG	MG	MP	MP	MP	MP	F	VG	VG	VG	VG
A12	VG	G	G	VG	G	G	G	G	G	G	G	G	G	G	F	F	F

Step 2: Aggregate the evaluation of decision makers

In this step, the decision makers' aggregate evaluations for determining the criteria weights and aggregate rating of alternatives are performed as follows:

Aggregate the criteria weights

Let $w_{jt} = (a_{jt}, b_{jt}, c_{jt})$, $j = 1, 2, \dots, n$, $t = 1, 2, \dots, k$ be the weight assigned by the decision-maker D_k to criterion C_j . First, the fuzzy number $w_{jt} = (a_{jt}, b_{jt}, c_{jt})$ is converted into a crisp number w'_{jt} using graded mean integration method (Kannan et al., 2009). Then, the aggregated importance weight W_j of criterion C_j assessed by the committee of k decision-makers can be evaluated as:

$$W_j = \frac{\sum_{t=1}^k W'_{jt}}{k} \tag{9}$$

where w'_{jt} is a crisp number whose value is the graded mean integration representation of fuzzy numbers.

Aggregate the rating of alternatives

Let $r_{ijt} = (o_{ijt}, p_{ijt}, q_{ijt})$, $r_{ijt} \in R^+$, $i = 1, 2, \dots, m$, $j = 1, 2, \dots, n$, $t = 1, 2, \dots, k$, be the suitable rating assigned to alternative A_i by decision-makers D_t with respect to criterion C_j . First, the rating r_{ijt} can be transformed into crisp numbers r'_{ijt} , based on the graded mean integration representation of fuzzy numbers. Then, the aggregated rating $R_{ij} = (o_{ij}, p_{ij}, q_{ij})$, of alternative A_i with respect to criteria C_j can be obtained as:

$$R_{ij} = \frac{\sum_{t=1}^k r'_{ijt}}{K} \tag{10}$$

Step 3: Construct the normalized decision matrix

Assume that the decision matrix be $X = (x_{ij})_{m \times n}$. The decision matrix for m alternatives and n criteria can be normalized as:

$$S = [s_{ij}]_{m \times n}$$

where

$$s_{ij} = \frac{r_{ij}}{\sqrt{\sum_{i=1}^m (r_{ij})^2}} \tag{11}$$

Step 4: Construct the weighted normalized decision matrix

The normalized matrix multiplied by the normalized aggregate weights of the criteria gives the weighted normalized decision matrix.

Let the weighted normalized decision matrix be $V = (v_{ij})_{m \times n}$.

$$v_{ij} = s_{ij} \times W_j \tag{12}$$

where $i = 1, 2, \dots, m$ and $j = 1, 2, \dots, n$.

Step 5: Determine the ideal and negative-ideal solutions

The "positive-ideal solution" and the "negative-ideal solution" can be defined as:

$$A^+ = (\tilde{v}_1^+, \tilde{v}_2^+, \dots, \tilde{v}_n^+) \tag{13}$$

$$A^- = (\tilde{v}_1^-, \tilde{v}_2^-, \dots, \tilde{v}_n^-) \tag{14}$$

Table 5b
Decision maker 2 (DM2) ratings of the alternatives.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17
A1	F	F	VP	VP	P	P	VP	MP	P	VP	VP	VP	P	VP	P	F	F
A2	F	MG	VG	VP	P	P	VP	MP	P	P	VP	VP	G	VG	MG	VG	VG
A3	G	G	VG	VG	VG	G	MG	MG	F	F	VG	VG	VG	VG	F	VG	VG
A4	VG	F	VG	VG	VG	G	VG	MG	MG	F	P	G	G	VG	MG	VG	VG
A5	VG	MG	F	G	VG	VG	VG	G	MG	VP	F	G	VG	VG	VG	VG	VG
A6	P	F	G	VP	P	P	P	MP	P	MG	VP	VP	P	MG	MG	F	VP
A7	G	G	G	P	P	MG	P	MP	F	VP	P	MP	G	MG	P	MG	G
A8	P	G	F	VP	P	P	P	MP	P	VP	VP	F	MG	MG	P	F	MG
A9	F	G	VP	F	P	P	F	MG	P	VG	VP	F	MG	MG	VP	MG	MG
A10	G	MG	VG	VG	VG	G	VG	VG	G	VP	G	VG	VG	VG	VP	VG	VG
A11	G	G	VG	VG	VG	P	F	F	P	VP	MP	F	MG	VG	VG	VG	VG
A12	VG	G	G	VG	VG	VG	MG	MG	F	G	VG	VG	G	G	F	G	MG

Table 5c
Decision maker 3 (DM3) ratings of the alternatives.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17
A1	P	P	VP	VP	VP	VP	VP	VP	VP	VP	VP	VP	P	VP	VP	G	G
A2	P	MP	VG	VP	VP	VP	VP	VP	MP	F	VP	P	MG	VG	MG	VG	VG
A3	MG	MG	VG	VG	G	MG	G	MG	F	MG	VG	VG	VG	VG	G	VG	VG
A4	VG	MG	VG	VG	VG	MG	VG	MG	G	G	MP	MG	MG	VG	MG	VG	VG
A5	VG	VG	VG	G	VG	VG	VG	G	G	G	F	MG	VG	VG	VG	VG	VG
A6	P	P	MP	VP	VP	VP	VP	VP	VP	VP	VP	VP	VP	MP	MG	G	VP
A7	MG	MG	MG	F	VP	MP	VP	VP	F	G	MP	P	MG	MP	F	G	VG
A8	VP	MG	MP	VP	VP	VP	VP	VP	VP	VP	VP	MP	MP	MP	MG	G	G
A9	P	MP	VP	MG	VP	VP	MG	MG	VP	VP	VP	MP	MP	MP	VP	G	G
A10	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VP	VG	VG
A11	MG	MG	VG	VG	G	P	MG	MG	VP	VP	MP	P	MP	VG	VG	VG	VG
A12	VG	MG	MG	VG	G	MG	G	G	G	G	G	MG	MG	MG	MG	G	G

Table 6
Calculated fuzzy aggregated weights of each criterion.

C1	(0.8,0.9,1)
C2	(0.6,0.833,1)
C3	(0.6,0.867,1)
C4	(0.4,0.767,1)
C5	(0.6,0.833,1)
C6	(0.6,0.833,1)
C7	(0.4,0.733,1)
C8	(0.4,0.667,1)
C9	(0.6,0.833,1)
C10	(0.4,0.667,1)
C11	(0.6,0.8,1)
C12	(0.6,0.833,1)
C13	(0.8,0.9,1)
C14	(0.6,0.867,1)
C15	(0.4,0.667,1)
C16	(0.2,0.6,1)
C17	(0,0.533,1)

$$CC_i = \frac{d^-}{d^+ + d^-} \tag{17}$$

Step 8: Find the ranks

The alternatives are ranked based on their closeness coefficient to the ideal solution. If CC_i is greater, then the best alternative will be A_i . An alternative will be the best alternative only with the largest relative closeness to the PIS.

4.3. Proposed fuzzy TOPSIS

In this work, in addition to the above methods we propose two more types of fuzzy TOPSIS based on Govindan et al. (2013) and Wang and Lee (2007), which utilizes different methods of aggregating the evaluation made by the decision makers.

The fuzzy TOPSIS solution method consists of the following steps: (Hwang & Yoon, 1981; Chen, Lin, & Huang, 2006; Wang & Lee, 2007; Singh & Benyoucef, 2011).

Step 1: Construct the fuzzy decision making matrix

Let us consider a group of k decision makers (D_1, D_2, \dots, D_k) containing m alternatives (A_1, A_2, \dots, A_m) and n criteria (C_1, C_2, \dots, C_n) for a MCDM problem which is clearly expressed in a matrix format as:

$$D = \begin{matrix} & C_1 & C_2 & \dots & C_n \\ \begin{matrix} A_1 \\ A_2 \\ \vdots \\ A_m \end{matrix} & \begin{bmatrix} r_{11} & r_{12} & \dots & r_{1n} \\ r_{21} & r_{22} & \dots & r_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ r_{m1} & r_{m2} & \dots & r_{mn} \end{bmatrix} \end{matrix}$$

where r_{mn} be the rating of alternative A_m with respect to criteria C_n which is expressed as a linguistic triangular fuzzy number. Each

where $\tilde{v}_j^+ = \max_{i=1,2,\dots,m}(\tilde{v}_{ij})$ and $\tilde{v}_j^- = \min_{i=1,2,\dots,m}(\tilde{v}_{ij})$.

Step 6: Calculate the distance of each alternative from A^+ and A^-
The distance of each alternative from A^+ and A^- is now calculated, respectively, as follows:

$$d^+ = \sqrt{\sum_{j=1}^n (\tilde{v}_{ij} - \tilde{v}_j^+)^2} \tag{15}$$

$$d^- = \sqrt{\sum_{j=1}^n (\tilde{v}_{ij} - \tilde{v}_j^-)^2} \tag{16}$$

Step 7: Calculate the closeness coefficient

A closeness coefficient is defined to determine the ranking order of all alternatives once the d^- of each alternative A_i ($i = 1, 2, \dots, m$) has been calculated. The closeness coefficient of each alternative is calculated as:

Table 7
Calculated fuzzy aggregated decision matrix.

	C1	C2	C3	C4	C5	C6	C7	C8	
A1	(0,2.33,7)	(0,3,7)	(0,0,1)	(0,0,1)	(0,0.333,3)	(0,0.667,3)	(0,0.333,3)	(0,2,5)	
A2	(0,2.33,7)	(1,5.67,9)	(9,10,10)	(0,0,1)	(0,0.333,3)	(0,0.667,3)	(0,0.333,3)	(0,2,5)	
A3	(5,8.33,10)	(5,8.33,10)	(9,10,10)	(9,10,10)	(7,9.33,10)	(5,8.33,10)	(5,8.33,10)	(5,7,9)	
A4	(9,10,10)	(3,7,10)	(9,10,10)	(9,10,10)	(9,10,10)	(5,8.33,10)	(9,10,10)	(5,7,9)	
A5	(9,10,10)	(5,9,10)	(3,8.33,10)	(7,9,10)	(9,10,10)	(9,10,10)	(9,10,10)	(7,9,10)	
A6	(0,1,3)	(0,3,7)	(1,5,10)	(0,0,1)	(0,0.333,3)	(0,0.667,3)	(0,0.667,3)	(0,2,5)	
A7	(5,8.33,10)	(5,8.33,10)	(5,8.33,10)	(0,2.33,7)	(0,0.333,3)	(1,5.67,9)	(0,0.667,3)	(0,2,5)	
A8	(0,0.333,3)	(5,8.33,10)	(1,3.67,7)	(0,0,1)	(0,0.333,3)	(0,0.667,3)	(0,0.667,3)	(0,2,5)	
A9	(0,2.33,7)	(1,6.33,10)	(0,0,1)	(3,5.67,9)	(0,0.333,3)	(0,0.667,3)	(3,6.33,9)	(5,7,9)	
A10	(7,9.67,10)	(5,9,10)	(9,10,10)	(9,10,10)	(9,10,10)	(7,9.67,10)	(9,10,10)	(9,10,10)	
A11	(5,8.33,10)	(5,8.33,10)	(9,10,10)	(9,10,10)	(7,9.33,10)	(0,2.33,7)	(3,6.33,9)	(3,6.33,9)	
A12	(9,10,10)	(5,8.33,10)	(5,8.33,10)	(9,10,10)	(7,9.33,10)	(5,8.67,10)	(5,8.33,10)	(5,8.33,10)	
	C9	C10	C11	C12	C13	C14	C15	C16	C17
A1	(0,1.33,5)	(0,1,5)	(0,0.333,3)	(0,0.333,3)	(0,1,3)	(0,0,1)	(0,0.333,3)	(3,6.33,10)	(3,6.33,10)
A2	(0,3,7)	(0,3.67,7)	(0,0.333,3)	(0,1.33,5)	(5,8.33,10)	(9,10,10)	(3,6.33,9)	(9,10,10)	(9,10,10)
A3	(3,5.67,9)	(3,6.33,9)	(9,10,10)	(9,10,10)	(9,10,10)	(9,10,10)	(3,7.67,10)	(9,10,10)	(9,10,10)
A4	(5,8.33,10)	(3,7.67,10)	(0,2.33,5)	(5,8.33,10)	(5,8.33,10)	(9,10,10)	(3,6.33,9)	(9,10,10)	(9,10,10)
A5	(5,8.33,10)	(0,6,10)	(3,5,7)	(5,8.33,10)	(9,10,10)	(9,10,10)	(9,10,10)	(9,10,10)	(9,10,10)
A6	(0,1.33,5)	(0,3.33,9)	(0,0.333,3)	(0,0.333,3)	(0,0.333,3)	(1,5,9)	(3,6.33,9)	(3,6.33,10)	(0,1.67,7)
A7	(3,5.67,9)	(0,6,10)	(0,2.33,5)	(0,2.33,5)	(5,8.33,10)	(1,5,9)	(0,2.33,7)	(5,8.33,10)	(7,9.33,10)
A8	(0,1.33,5)	(0,1,5)	(0,0.333,3)	(1,4.33,7)	(1,5,9)	(1,5,9)	(0,4.33,9)	(3,6.33,10)	(3,7,10)
A9	(0,1.33,5)	(0,4.33,10)	(0,0.333,3)	(1,4.33,7)	(1,5,9)	(1,5,9)	(0,0,1)	(5,8.33,10)	(3,7,10)
A10	(7,9.67,10)	(0,6.67,10)	(7,9.67,10)	(9,10,10)	(9,10,10)	(9,10,10)	(0,0,1)	(9,10,10)	(9,10,10)
A11	(0,1.33,5)	(0,1,5)	(1,3,5)	(0,3,7)	(1,5,9)	(9,10,10)	(9,10,10)	(9,10,10)	(9,10,10)
A12	(3,7.67,10)	(7,9,10)	(7,9.33,10)	(5,8.67,10)	(5,8.33,10)	(5,8.33,10)	(3,5.67,9)	(3,7.67,10)	(3,7,10)

Table 8
Normalized matrix.

	C1	C2	C3	C4	C5	C6	C7	C8	C9
A1	(0,0.233,0.7)	(0,0.3,0.7)	(0,0,0.1)	(0,0,0.1)	(0,0.0333,0.3)	(0,0.0667,0.3)	(0,0.0333,0.3)	(0,0.2,0.5)	(0,0.133,0.5)
A2	(0,0.233,0.7)	(0.1,0.567,0.9)	(0.9,1,1)	(0,0,0.1)	(0,0.0333,0.3)	(0,0.0667,0.3)	(0,0.0333,0.3)	(0,0.2,0.5)	(0,0.3,0.7)
A3	(0.5,0.833,1)	(0.5,0.833,1)	(0.9,1,1)	(0.9,1,1)	(0.7,0.933,1)	(0.5,0.833,1)	(0.5,0.833,1)	(0.5,0.7,0.9)	(0.3,0.567,0.9)
A4	(0.9,1,1)	(0.3,0.7,1)	(0.9,1,1)	(0.9,1,1)	(0.9,1,1)	(0.5,0.833,1)	(0.9,1,1)	(0.5,0.7,0.9)	(0.5,0.833,1)
A5	(0.9,1,1)	(0.5,0.9,1)	(0.3,0.833,1)	(0.7,0.9,1)	(0.9,1,1)	(0.9,1,1)	(0.9,1,1)	(0.7,0.9,1)	(0.5,0.833,1)
A6	(0,0.1,0.3)	(0,0.3,0.7)	(0.1,0.5,1)	(0,0,0.1)	(0,0.0333,0.3)	(0,0.0667,0.3)	(0,0.0667,0.3)	(0,0.2,0.5)	(0,0.133,0.5)
A7	(0.5,0.833,1)	(0.5,0.833,1)	(0.5,0.833,1)	(0,0.233,0.7)	(0,0.0333,0.3)	(0.1,0.567,0.9)	(0,0.0667,0.3)	(0,0.2,0.5)	(0.3,0.567,0.9)
A8	(0,0.0333,0.3)	(0.5,0.833,1)	(0.1,0.367,0.7)	(0,0,0.1)	(0,0.0333,0.3)	(0,0.0667,0.3)	(0,0.0667,0.3)	(0,0.2,0.5)	(0,0.133,0.5)
A9	(0,0.233,0.7)	(0.1,0.633,1)	(0,0,0.1)	(0.3,0.567,0.9)	(0,0.0333,0.3)	(0,0.0667,0.3)	(0.3,0.633,0.9)	(0.5,0.7,0.9)	(0,0.133,0.5)
A10	(0.7,0.967,1)	(0.5,0.9,1)	(0.9,1,1)	(0.9,1,1)	(0.9,1,1)	(0.7,0.967,1)	(0.9,1,1)	(0.9,1,1)	(0.7,0.967,1)
A11	(0.5,0.833,1)	(0.5,0.833,1)	(0.9,1,1)	(0.9,1,1)	(0.7,0.933,1)	(0,0.233,0.7)	(0.3,0.633,0.9)	(0.3,0.633,0.9)	(0,0.133,0.5)
A12	(0.9,1,1)	(0.5,0.833,1)	(0.5,0.833,1)	(0.9,1,1)	(0.7,0.933,1)	(0.5,0.867,1)	(0.5,0.833,1)	(0.5,0.833,1)	(0.3,0.767,1)
	C10	C11	C12	C13	C14	C15	C16	C17	
A1	(0,0.1,0.5)	(0,0.0333,0.3)	(0,0,0)	(0,0.1,0.3)	(0,0,0.1)	(0,0.0333,0.3)	(0.3,0.633,1)	(0.3,0.633,1)	
A2	(0,0.367,0.7)	(0,0.0333,0.3)	(0,0,0)	(0.5,0.833,1)	(0.9,1,1)	(0.3,0.633,0.9)	(0.9,1,1)	(0.9,1,1)	
A3	(0.3,0.633,0.9)	(0.9,1,1)	(0,0,0)	(0.9,1,1)	(0.9,1,1)	(0.3,0.767,1)	(0.9,1,1)	(0.9,1,1)	
A4	(0.3,0.767,1)	(0,0.233,0.5)	(0,0,0)	(0.5,0.833,1)	(0.9,1,1)	(0.3,0.633,0.9)	(0.9,1,1)	(0.9,1,1)	
A5	(0,0.6,1)	(0.3,0.5,0.7)	(0,0,0)	(0.9,1,1)	(0.9,1,1)	(0.9,1,1)	(0.9,1,1)	(0.9,1,1)	
A6	(0,0.333,0.9)	(0,0.0333,0.3)	(0,0,0)	(0,0.0333,0.3)	(0.1,0.5,0.9)	(0.3,0.633,0.9)	(0.3,0.633,1)	(0,0.167,0.7)	
A7	(0,0.6,1)	(0,0.233,0.5)	(0,0,0)	(0.5,0.833,1)	(0.1,0.5,0.9)	(0,0.233,0.7)	(0.5,0.833,1)	(0.7,0.933,1)	
A8	(0,0.1,0.5)	(0,0.0333,0.3)	(0,0,0)	(0.1,0.5,0.9)	(0.1,0.5,0.9)	(0,0.433,0.9)	(0.3,0.633,1)	(0.3,0.7,1)	
A9	(0,0.433,1)	(0,0.0333,0.3)	(0,0,0)	(0.1,0.5,0.9)	(0.1,0.5,0.9)	(0,0,0.1)	(0.5,0.833,1)	(0.3,0.7,1)	
A10	(0,0.667,1)	(0.7,0.967,1)	(0,0,0)	(0.9,1,1)	(0.9,1,1)	(0,0,0.1)	(0.9,1,1)	(0.9,1,1)	
A11	(0,0.1,0.5)	(0.1,0.3,0.5)	(0,0,0)	(0.1,0.5,0.9)	(0.9,1,1)	(0.9,1,1)	(0.9,1,1)	(0.9,1,1)	
A12	(0.7,0.9,1)	(0.7,0.933,1)	(0,0,0)	(0.5,0.833,1)	(0.5,0.833,1)	(0.3,0.567,0.9)	(0.3,0.767,1)	(0.3,0.7,1)	

decision maker evaluates the alternatives with respect to the criteria using the ratings given in Table 2. In order to aggregate the decisions on alternatives made by each decision maker, we use Definition 6 mentioned in Section 4.1.

Step 2: Normalize the aggregated fuzzy decision matrix

The data in the aggregated fuzzy decision matrix are normalized to remove the anomalies with different measurement units and scales available in the problem (Singh & Benyoucef, 2011). The normalized aggregated fuzzy-decision matrix can be represented as:

$$R = [r_{ij}]_{m \times n} \tag{18}$$

The normalized values for benefit and cost related criteria are calculated using the following equations:

$$r_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*} \right), j \in B \tag{19}$$

$$c_j^* = \max_i c_{ij}, j \in B$$

$$r_{ij} = \left(\frac{a_{ij}^-}{c_{ij}^-}, \frac{a_{ij}^-}{b_{ij}^-}, \frac{a_{ij}^-}{a_{ij}^-} \right), j \in C \tag{20}$$

$$a_{ij}^- = \min_i a_{ij}, j \in C$$

where B and C are the sets of benefit and cost criteria respectively.

Table 9
Distance.

	D+ solutions	D- solutions
A1	13.6	4.14
A2	11	7.19
A3	7.02	11.5
A4	7.3	11.1
A5	6.75	11.7
A6	12.8	5.44
A7	10.3	8.39
A8	12.4	5.88
A9	11.8	6.75
A10	6.77	11.4
A11	8.71	9.75
A12	7.38	11.4

Table 10
Closeness coefficient.

A1	0.234
A2	0.396
A3	0.62
A4	0.604
A5	0.634
A6	0.298
A7	0.448
A8	0.322
A9	0.364
A10	0.628
A11	0.528
A12	0.606

Table 11
Rank.

A1	12
A2	8
A3	3
A4	5
A5	1
A6	11
A7	7
A8	10
A9	9
A10	2
A11	6
A12	4

Step 3: Construct the weighted normalized fuzzy decision matrix
The weighted normalized fuzzy decision matrix v_{ij} is calculated by multiplying the normalized matrix with the weights of the evaluation criteria. The weighted normalized fuzzy decision matrix V is defined as follows:

$$V = [v_{ij}]_{m \times n} \quad i = 1, 2, \dots, m \quad j = 1, 2, \dots, n \quad (21)$$

where $v_{ij} = r_{ij} \cdot w_j$ and w_j is the weight of the j th criterion.

Step 4: Determine the fuzzy positive-ideal solution (A^*) and fuzzy negative-ideal solution (A^-)

The fuzzy positive-ideal solution (FPIS, A^*) and negative-ideal solution (NIS, A^-) can be calculated as:

$$A^* = (v_1^*, v_2^*, \dots, v_n^*) \quad (22)$$

$$A^- = (v_1^-, v_2^-, \dots, v_n^-) \quad (23)$$

where $v_j^* = \max_i\{v_{ij}\}$ and $v_j^- = \min_i\{v_{ij}\}$, $i = 1, 2, \dots, m$, $j = 1, 2, \dots, n$

Step 5: Calculate the distance of each alternative from FPIS and FNIS

Table 12
Final Ranks of the different Fuzzy TOPSIS approaches.

	Graded	GeoM	MAM
A1	12	12	12
A2	8	8	8
A3	2	3	3
A4	5	5	5
A5	3	2	1
A6	11	11	11
A7	7	7	7
A8	10	10	10
A9	9	9	9
A10	4	1	2
A11	6	6	6
A12	1	4	4

The distance of each alternative from FPIS and FNIS are calculated as follows:

$$d_i^* = \sum_{j=1}^n d_v(v_{ij}, v_j^*), \quad i = 1, 2, \dots, m \quad (24)$$

$$d_i^- = \sum_{j=1}^n d_v(v_{ij}, v_j^-), \quad i = 1, 2, \dots, m \quad (25)$$

where $d_v(v_{ij}, v_j^*)$ denotes the distance between two fuzzy numbers and is calculated by Eq. (7).

Step 6: Obtain the closeness coefficient (CC_i)

The closeness coefficient (CC_i) of each alternative is calculated as:

$$(CC_i) = \frac{d_i^-}{d_i^- + d_i^*}, \quad i = 1, 2, \dots, m \quad (26)$$

Step 7: Rank determination

At the end of the analysis, the ranking of alternatives is determined by comparing CC_i values. Alternative A_i is closer to the FPIS (A^*) and further from FNIS (A^-) as CC_i approaches to 1. The ranking order of all alternatives is determined according to the descending order of CC_i . The alternative A_i will be the best only if its CC_i is higher.

4.4. Spearman rank correlation coefficient

By applying the previously discussed methods to the case problem, we obtain the ranks based on graded mean integration fuzzy TOPSIS, geometric mean based fuzzy TOPSIS (Chen et al., 2011), and proposed fuzzy TOPSIS. The major issue before taking the final decision is the reliability of the results (Kahraman et al., 2009). The Spearman rank correlation coefficient (R) is one of the useful and important measures (Chamodrakas, Leftheriotis, & Martakos, 2011) to determine the measure of association between ranks obtained by different approaches (Raju & Kumar, 1999).

In this paper we used Spearman's rank-correlation test to find the statistical significance of the difference between the ranking obtained using the proposed fuzzy TOPSIS and the ones obtained from the graded mean integration fuzzy TOPSIS and geometric mean based fuzzy TOPSIS. The Spearman co-efficient is defined as follows (Raju & Kumar, 1999):

$$R = 1 - \frac{6 \sum_{a=1}^A D_a^2}{A(A^2 - 1)} \quad (27)$$

where a is the number of alternatives; A is the total number of alternatives; D_a is the difference between ranks obtained through two different methods. $R = 1$ represents perfect association between

Table 13
Spearman correlation co-efficient (R).

	Proposed fuzzy TOPSIS	Geometric mean based fuzzy TOPSIS	Graded mean integration fuzzy TOPSIS
Proposed fuzzy TOPSIS	1	0.993007	0.937063
Geometric mean based fuzzy TOPSIS		1	0.93007
Graded mean integration fuzzy TOPSIS			1

Table 14
Ranking of criterion weights.

Criterion	Weights	Ranking
C1	(0.8,0.9,1)	1
C2	(0.6,0.833,1)	3
C3	(0.6,0.867,1)	2
C4	(0.4,0.767,1)	5
C5	(0.6,0.833,1)	3
C6	(0.6,0.833,1)	3
C7	(0.4,0.733,1)	6
C8	(0.4,0.667,1)	7
C9	(0.6,0.833,1)	3
C10	(0.4,0.667,1)	7
C11	(0.6,0.8,1)	4
C12	(0.6,0.833,1)	3
C13	(0.8,0.9,1)	1
C14	(0.6,0.867,1)	2
C15	(0.4,0.667,1)	7
C16	(0.2,0.6,1)	8
C17	(0,0.533,1)	9

the ranks; $R = 0$ represents no association between the ranks; and $R = -1$ represents perfect disagreement between the ranks.

5. Application of the proposed model

In this work, a five-phase methodology is utilized to select the green suppliers based on 12 suppliers of a Brazilian electronics company and the methodology is described as follows:

- Phase 1:* In phase 1, the criteria used for the green supplier selection is identified through literature. The researcher develops the questionnaire to obtain the weight preference for the criteria and to rate the alternatives based on the criteria.
- Phase 2:* In the second phase, a questionnaire was send to the academic experts' team for content analysis. Based on the review of four academicians, the questionnaire was improved.
- Phase 3:* In the third phase, three decision makers, who work with the marketing context of GSCM are invited to evaluate the alternatives of improved questionnaire. In order to determine the weights of the criteria used in the study and to evaluate the alternatives the decision makers are asked to complete the questionnaires³ using the linguistic terms given in Tables 2 and 3. The fuzzy weights of each criterion based on each decision maker are presented in Table 4 and the fuzzy decision matrix for each decision maker is given in Tables 5a, 5b, 5c.
- Phase 4:* In this phase, the fuzzy TOPSIS methodology proposed in Section 4.3 is used to rank the green suppliers. The fuzzy weights of each criterion (Table 4) and fuzzy decision matrix (Tables 5a, 5b and 5c) from the above phase are used to find the aggregated weights of each criterion (W_j) and aggregated ratings of each alternative (R_{ij}) by using Eq. (8). Depending on the benefit or cost criteria,

Table 15
Details for sensitivity analysis.

Case	Description (changes made in W_{jt}), $J = C1, C2, \dots, C17, t = 1, 2, 3$
Case 1	$W_{C1t} = (0, 0.2, 0.4), {}^1W_{C2t-C17t}$
Case 2	$W_{C1t} = (0.2, 0.4, 0.5), {}^1W_{C2t-C17t}$
Case 3	$W_{C1t} = (0.4, 0.6, 0.8), {}^1W_{C2t-C17t}$
Case 4	$W_{C1t} = (0.6, 0.8, 1), {}^1W_{C2t-C17t}$
Case 5	$W_{C1t} = (0.8, 0.9, 1), {}^1W_{C2t-C17t}$
Case 6	$W_{C13t} = (0, 0.2, 0.4), {}^1W_{C1t-C12t, C14t-C17t}$
Case 7	$W_{C13t} = (0.2, 0.4, 0.5), {}^1W_{C1t-C12t, C14t-C17t}$
Case 8	$W_{C13t} = (0.4, 0.6, 0.8), {}^1W_{C1t-C12t, C14t-C17t}$
Case 9	$W_{C13t} = (0.6, 0.8, 1), {}^1W_{C1t-C12t, C14t-C17t}$
Case 10	$W_{C13t} = (0.8, 0.9, 1), {}^1W_{C1t-C12t, C14t-C17t}$
Case 11	$W_{C3t} = (0, 0.2, 0.4), {}^1W_{C1t-C2t, C4t-C17t}$
Case 12	$W_{C3t} = (0.2, 0.4, 0.5), {}^1W_{C1t-C2t, C4t-C17t}$
Case 13	$W_{C3t} = (0.4, 0.6, 0.8), {}^1W_{C1t-C2t, C4t-C17t}$
Case 14	$W_{C3t} = (0.6, 0.8, 1), {}^1W_{C1t-C2t, C4t-C17t}$
Case 15	$W_{C3t} = (0.8, 0.9, 1), {}^1W_{C1t-C2t, C4t-C17t}$
Case 16	$W_{C14t} = (0, 0.2, 0.4), {}^1W_{C1t-C13t, C15t-C17t}$
Case 17	$W_{C14t} = (0.2, 0.4, 0.5), {}^1W_{C1t-C13t, C15t-C17t}$
Case 18	$W_{C14t} = (0.4, 0.6, 0.8), {}^1W_{C1t-C13t, C15t-C17t}$
Case 19	$W_{C14t} = (0.6, 0.8, 1), {}^1W_{C1t-C13t, C15t-C17t}$
Case 20	$W_{C14t} = (0.8, 0.9, 1), {}^1W_{C1t-C13t, C15t-C17t}$
Case 21	$W_{C1t, C13t} = (0, 0.533, 1), W_{C17t} = (0.8, 0.9, 1), {}^1W_{C2t-C12t, C14t-C16t}$
Case 22	$W_{C3t, C14t} = (0.2, 0.6, 1), W_{C16t} = (0.6, 0.867, 1), {}^1W_{C1t-C2t, C4t-C13t, C15t, C17t}$

¹ Same as in Table 4.

the obtained fuzzy decision matrix is normalized by following Eqs. (19) and (20). Then the weights of the evaluation criteria are multiplied with the normalized matrix to form a weighted normalized fuzzy decision matrix (by Eq. (21)).

After obtaining the weighted normalized fuzzy decision matrix, FPIS and FNIS are determined using Eqs. (22) and (23) respectively. As a next step, the distance of the suppliers from the FPIS and FNIS is calculated using Eqs. (24) and (25). In order to rank the green suppliers based on their closeness to the FPIS and remoteness to the FNIS, the closeness coefficient is calculated using Eq. (26). Depending on the maximum closeness of the alternatives to the FPIS, ranks are given for the chosen alternatives of green suppliers.

The aggregated weights of each criterion, aggregated ratings of each alternative, normalized decision matrix, the distance of each supplier to FPIS and FNIS, closeness coefficient, and ranks obtained by each suppliers are shown in Tables 6–11 respectively.

In order to receive some feedback from the management, the fuzzy TOPSIS results obtained were discussed. After the discussion, management raised a question about the reliability of the proposed fuzzy methodology results. They also suggested to compare the current results with other fuzzy approaches for validity. Hence, we utilized the two known other fuzzy TOPSIS methods (graded mean integration fuzzy TOPSIS and geometric mean based fuzzy TOPSIS) for comparison purposes. The final ranks of the other two fuzzy TOPSIS approaches are shown in Table 12.

³ A sample questionnaire is provided in Appendix A.

Table 16
Results of sensitivity analysis.

Case	Alternatives												Ranking
	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	
Case 1	0.228	0.397	0.613	0.588	0.618	0.303	0.436	0.328	0.363	0.616	0.518	0.59	A5 > A10 > A3 > A12 > A4 > A11 > A7 > A2 > A9 > A8 > A6 > A1
Case 2	0.229	0.398	0.616	0.593	0.623	0.302	0.439	0.327	0.364	0.62	0.521	0.595	A5 > A10 > A3 > A12 > A4 > A11 > A7 > A2 > A9 > A8 > A6 > A1
Case 3	0.232	0.397	0.616	0.595	0.624	0.3	0.442	0.324	0.363	0.621	0.522	0.597	A5 > A10 > A3 > A12 > A4 > A11 > A7 > A2 > A9 > A8 > A6 > A1
Case 4	0.233	0.396	0.617	0.599	0.628	0.298	0.445	0.322	0.363	0.624	0.525	0.601	A5 > A10 > A3 > A12 > A4 > A11 > A7 > A2 > A9 > A8 > A6 > A1
Case 5	0.234	0.396	0.62	0.604	0.634	0.298	0.448	0.322	0.364	0.628	0.528	0.606	A5 > A10 > A3 > A12 > A4 > A11 > A7 > A2 > A9 > A8 > A6 > A1
Case 6	0.236	0.381	0.604	0.597	0.618	0.303	0.436	0.314	0.357	0.612	0.528	0.599	A5 > A10 > A3 > A12 > A4 > A11 > A7 > A2 > A9 > A8 > A6 > A1
Case 7	0.235	0.385	0.609	0.6	0.623	0.303	0.439	0.316	0.359	0.617	0.529	0.602	A5 > A10 > A3 > A12 > A4 > A11 > A7 > A2 > A9 > A8 > A6 > A1
Case 8	0.234	0.389	0.611	0.6	0.624	0.3	0.442	0.319	0.361	0.619	0.527	0.602	A5 > A10 > A3 > A12 > A4 > A11 > A7 > A2 > A9 > A8 > A6 > A1
Case 9	0.233	0.393	0.615	0.601	0.628	0.298	0.445	0.321	0.363	0.623	0.527	0.603	A5 > A10 > A3 > A12 > A4 > A11 > A7 > A2 > A9 > A8 > A6 > A1
Case 10	0.234	0.396	0.62	0.604	0.634	0.298	0.448	0.322	0.364	0.628	0.528	0.606	A5 > A10 > A3 > A12 > A4 > A11 > A7 > A2 > A9 > A8 > A6 > A1
Case 11	0.24	0.377	0.609	0.592	0.632	0.289	0.438	0.319	0.374	0.617	0.514	0.602	A5 > A10 > A3 > A12 > A4 > A11 > A7 > A2 > A9 > A8 > A6 > A1
Case 12	0.239	0.383	0.614	0.597	0.634	0.291	0.441	0.32	0.372	0.622	0.519	0.604	A5 > A10 > A3 > A12 > A4 > A11 > A7 > A2 > A9 > A8 > A6 > A1
Case 13	0.236	0.389	0.616	0.6	0.633	0.295	0.444	0.321	0.367	0.624	0.522	0.604	A5 > A10 > A3 > A12 > A4 > A11 > A7 > A2 > A9 > A8 > A6 > A1
Case 14	0.234	0.395	0.619	0.603	0.633	0.298	0.448	0.322	0.364	0.627	0.527	0.606	A5 > A10 > A3 > A12 > A4 > A11 > A7 > A2 > A9 > A8 > A6 > A1
Case 15	0.234	0.401	0.625	0.609	0.635	0.299	0.451	0.323	0.364	0.633	0.532	0.609	A5 > A10 > A3 > A12 > A4 > A11 > A7 > A2 > A9 > A8 > A6 > A1
Case 16	0.24	0.377	0.609	0.592	0.622	0.29	0.446	0.315	0.358	0.617	0.514	0.602	A5 > A10 > A3 > A12 > A4 > A11 > A7 > A2 > A9 > A8 > A6 > A1
Case 17	0.239	0.383	0.614	0.597	0.627	0.292	0.447	0.317	0.359	0.622	0.519	0.604	A5 > A10 > A3 > A12 > A4 > A11 > A7 > A2 > A9 > A8 > A6 > A1
Case 18	0.236	0.389	0.616	0.6	0.629	0.295	0.447	0.319	0.361	0.624	0.522	0.604	A5 > A10 > A3 > A12 > A4 > A11 > A7 > A2 > A9 > A8 > A6 > A1
Case 19	0.234	0.395	0.619	0.603	0.633	0.298	0.448	0.322	0.363	0.627	0.527	0.606	A5 > A10 > A3 > A12 > A4 > A11 > A7 > A2 > A9 > A8 > A6 > A1
Case 20	0.234	0.401	0.625	0.609	0.638	0.299	0.449	0.323	0.364	0.633	0.532	0.609	A5 > A10 > A3 > A4 > A12 > A11 > A7 > A2 > A9 > A8 > A6 > A1
Case 21	0.238	0.403	0.608	0.592	0.613	0.299	0.442	0.325	0.366	0.612	0.532	0.583	A5 > A10 > A3 > A4 > A12 > A11 > A7 > A2 > A9 > A8 > A6 > A1
Case 22	0.233	0.382	0.606	0.59	0.626	0.294	0.443	0.318	0.364	0.614	0.514	0.595	A5 > A10 > A3 > A12 > A4 > A11 > A7 > A2 > A9 > A8 > A6 > A1

Phase 5: In the fifth phase, the Spearman rank correlation coefficient is calculated to find the statistical difference between the ranks obtained through all three methods. The Spearman co-efficient (R) between the graded mean integration fuzzy TOPSIS, geometric mean based fuzzy TOPSIS, and proposed fuzzy TOPSIS is shown in Table 13. From Table 13, it is inferred that the value of R is in between 0.930 and 0.993, which indicates that there occurs a nearly perfect association between the methods. There is no significant difference in ranks obtained between our proposed method and the geometric mean based fuzzy TOPSIS.

5.1. Final results

The results obtained from the proposed fuzzy TOPSIS approach for the MCDM problem of green supplier selection required for the Brazilian electronics companies are summarized and shown in the Table 12. Based on the closeness coefficient, the ranks obtained using three types of fuzzy TOPSIS methods for the available 12 green suppliers are summarized as follows:

(1) By proposed fuzzy TOPSIS method

A5 > A10 > A3 > A12 > A4 > A11 > A7 > A2 > A9 > A8 > A6 > A1

(2) By Geometric mean method of fuzzy TOPSIS

A10 > A5 > A3 > A12 > A4 > A11 > A7 > A2 > A9 > A8 > A6 > A1

(3) By Graded mean method of fuzzy TOPSIS

A12 > A3 > A5 > A10 > A4 > A11 > A7 > A2 > A9 > A8 > A6 > A1

From the obtained results, we can conclude that the **supplier 5** and **supplier 10** get first preference to be selected for the green supplier under two types of fuzzy TOPSIS method (namely, the pro-

posed method and the geometric mean method, respectively). Results acquired from Table 13 for the Spearman rank correlation coefficient emphasize that the R value establishes a nearly perfect association between the proposed method and geometric mean method of fuzzy TOPSIS methodology.

6. Sensitivity analysis

The sensitivity analysis is performed to examine the influence of the preferences given by the decision makers for GSCM practices on the selection of green suppliers. To perform the sensitivity analysis, we ranked the major and minor influencing GSCM practices from Table 6. The weights of major and minor influencing GSCM practices vary from very low (VL) preference to very high (VH) preference. The ranking of various GSCM practices is shown in Table 14. From Table 14, the major influencing criteria are ranked 1 and 2 (i.e., Commitment of senior management to GSCM; Product designs that reduce, reuse, recycle, or reclaim materials, components, or energy; Compliance with legal environmental requirements and auditing programs; Product designs that avoid or reduce toxic or hazardous material use). Minor influencing practices are ranked 8 and 9 (i.e., Sale of used equipment (after buying new equipment); Sale of scrap and used materials).

In order to perform the sensitivity analysis, 22 cases were conducted. In the first 10 cases (case 1 to case 10), the decision makers' preference for rank 1 criteria (C1 and C13) are varied from VL to VH (VL, L, M, H, VH) by maintaining the other criteria preference as shown in Table 4. In the next 10 cases (case 11 to case 20), the decision makers' preference for rank 2 criteria (C3 and C14) are also varied from VL to VH (VL, L, M, H, VH) by maintaining the other criteria preference as shown in Table 4. In the 21st case, the preference between rank 1 and rank 9 criteria is interchanged and, in the last case, the preference between rank 2 and rank 8 criteria is similarly interchanged. Details of the 22 cases are shown in Table 15, and the closeness coefficient and ranking of the 22 cases is shown both in Table 16 and Fig. 4. From Table 16 and Fig. 4 one can see that the ranking of green suppliers changed a bit with respect to different preferences of criteria, but green supplier 5 is still the preferred alternative in all 22 cases.

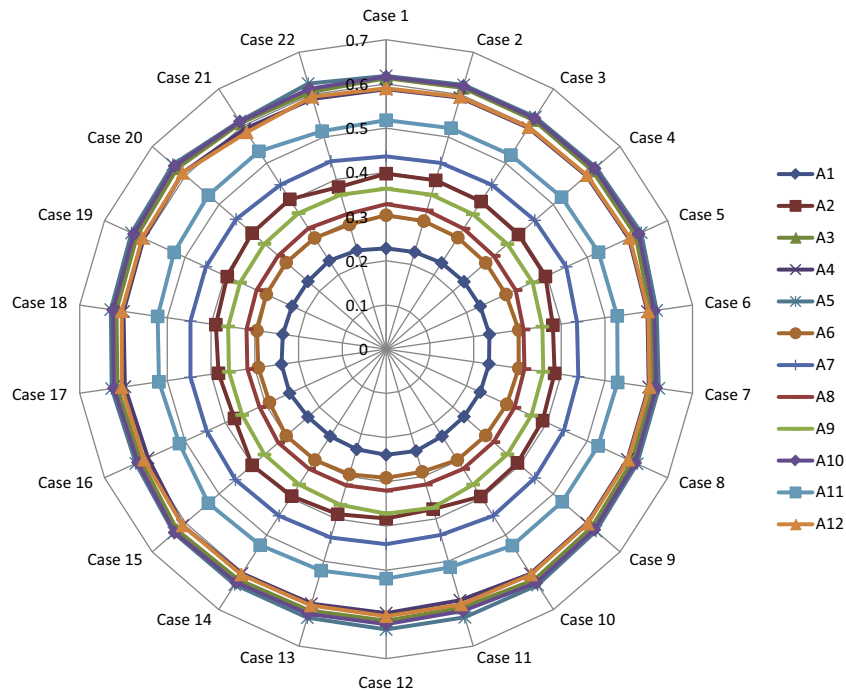


Fig. 4. Results of sensitivity analysis.

7. Conclusion

GSCM is still a relatively new concept in Brazil, but companies have started to realize the importance of GSCM due to the Brazilian government's legislation on reverse logistics. As a result, many companies have begun to demonstrate their commitment to implementing GSCM principles (Jabbour et al., 2013a). This research work presents an extension of the classical TOPSIS method called fuzzy TOPSIS methodology for solving a real world MCDM problem of green supplier selection based on the GSCM practices which deals with linguistic environments. In this work, three types of fuzzy TOPSIS– the proposed method, the geometric mean method, and graded mean method– are utilized to rank green suppliers according to the value given to carry out the GSCM practices in the company. The proposed framework is demonstrated and validated by a numerical example taken from a Brazilian company that assembles electronics equipment. The results obtained through the proposed framework are compared with the results attained by the geometric and graded mean methods. The foremost concern in any good decision making model is the reliability of the results. In order to obtain reliable results through the proposed framework, the Spearman rank correlation coefficient has been applied. Its results also suggest that there is nearly a perfect association between the ranks obtained by the proposed method and the geometric mean method of fuzzy TOPSIS. Thus, the obtained results allow the company to select the best green suppliers to enhance their supply chain management.

The results indicate that the major influencing criteria for GSCM practices include: Commitment of senior management to GSCM; Product designs that reduce, reuse, recycle, or reclaim materials, components, or energy; Compliance with legal environmental requirements and auditing programs; and Product designs that avoid or reduce toxic or hazardous material use. Top management support is a fundamental requirement for a company to manufacture environmentally-friendly products, and a primary decision rests on which supplier will enhance the green supply chain of a company. In Brazil, suppliers need to be trained to review

procedures for product design and to more proactively embrace environmental management practices.

While we have selected the best supplier through fuzzy TOPSIS, limitations may exist in terms of capacity, delivery lead time, and so forth. These potential limitations should be considered when integrating this MCDM model into the allocation model. However, recognizing these potential limitations also forms the basis for future work. Other possible techniques that might be employed for future research include VIKOR and PROMETHEE; results obtained from these methods could be compared with the results obtained from this work.

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Appendix A

Greetings!

This research addresses “Selecting green suppliers based on GSCM practices: Using Fuzzy TOPSIS applied to a Brazilian electronics company”.

The Table A refers to the format of the questionnaire used to determine the preference or importance given by the decision makers for the various available criteria, namely the GSCM practices that have been considered for the green supplier selection. Likewise, Table B shows the questionnaire format used to determine the ratings given for the chosen alternatives, namely the green suppliers by the decision makers based on the identified 17 criteria. The tick mark (✓) shows the importance given by the decision makers for the various alternatives and criteria required for the green supplier selection. In Table A the order prefer-

Table A
Questionnaire used to find the decision maker's preference for the identified criteria.

Criteria	VL	L	M	H	VH
GSCM1		✓			
GSCM2					
.					
.					
.					
GSCM17					

Table B
Questionnaire used to find the decision maker's preference for the available alternatives based on the identified criteria.

ALTERNATIVE	C1						C2						...	C17								
	VP	P	MP	F	MG	G	VG	VP	P	MP	F	MG		G	VG	VP	P	MP	F	MG	G	VG
A1			✓																			
A2																						
.																						
.																						
.																						
A12																						

ence ranges used varies from Very low (VL), Low (L), Medium (M), High (H) and Very high (VH).⁴ Also Table B shows the order preference ranging from Very poor (VP), Poor (P), Medium poor (MP), Fair (F), Medium good (MG) and Good (G).⁵ For example, from Table A, it is obvious that the decision maker gives low (L) importance to the GSCM1 practice called senior manager commitment to the GSCM practices. And Table B shows that the decision maker gives medium poor (MP) rating/importance to the Supplier1 based on the criteria 1 namely the GSCM1.

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⁴ The definition of preference ranges can be found from Table 3.

⁵ The definition of preference ranges can be found from Table 2.

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