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Integrating evolving customer preferences into green supplier selection: a hybrid model integrating Markov chain and fuzzy MCDM

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Abstract: With growing awareness of environmental issues and increasing regulatory pressure to reduce carbon footprints, organizations are being forced to integrate green practices into their procurement processes. In today's sustainability-driven business environment, it is now crucial to integrate changing customer preferences into the Green Supplier Selection (GSS) process. This enables companies to ensure customer satisfaction and loyalty and adapt to market fluctuations. Indeed, by understanding customer preferences, companies can choose suppliers who meet market expectations while complying with environmental standards. However, existing literature reveals a significant gap in considering changing customer preferences when evaluating suppliers. The variability of customer preferences over time and the uncertainty in the GSS process, including vagueness in expert judgment and insufficient data, add to the complexity of decision-making. The need for a comprehensive customer-based GSS model is therefore undeniable. To fill this gap, this paper aims to introduce an innovative hybrid GSS model. This model uses the Markov chain to track and predict the evolution in customer preferences over time, then applies an improved and simplified fuzzy BWM method to establish a connection between selection criteria and customer preferences. Next, the fuzzy TOPSIS method ranks suppliers. To validate the effectiveness of the proposed model, a real-life case study is conducted evaluating three Green Suppliers of an industrial company, completed by a comparative analysis to verify the results obtained. The aim of this study is to evaluate suppliers and identify the best one able to meet customer requirements while aligning with the company's economic and environmental objectives.

1 Introduction

In the current environmental context, integrating green practices into supply chain management has become a key criterion for enhancing the overall performance of the company and its brand image in the market, enabling it to differentiate itself from competitors [1]. This goal can be achieved by improving the supply chain and adopting new practices with a lesser environmental impact. As the supplier evaluation and selection process is of paramount importance [2] in supply chain management, particular attention must be paid to integrating environmental concerns into this process [3]. Green supplier selection (GSS) is one of the most important aspects of transitioning to a more environmentally-friendly supply chain. On the other hand, suppliers play a crucial role in the manufacturing process and directly influence the quality of the final product [4]. Additionally, customer satisfaction levels are heavily dependent on the quality of the end product they consume. In some cases, despite a company being well-advanced with a high level of technology, the final product it offers may fail to achieve the expected success. This can be attributed to an excessive focus on certain criteria that may not align with customer expectations, or to a poor market needs analysis or inadequate understanding of customer requirements [5]. This interplay between these two actors—supplier and consumer—underscores the importance of studying the relationship between supplier selection criteria and customer requirements. This interrelationship must not be neglected and should be thoroughly considered by researchers for a deeper understanding and well-informed decision-making [6-8]. The literature review shows that few studies have focused on customer needs when selecting suppliers, however in real-world situations, this problem is very comment and is very important to consider [5]. [7] proposed a model combining the use of MCDM techniques and the QFD model for GSS. The main aim of the proposed model is to clarify and explain the interaction relationships between customer requirements and supplier selection criteria. The proposed approach is structured around two main phases: the first is based on a combination of methods (DEMATEL and QFD) to obtain the final weights of the selection criteria, while taking into account customer requirements. Secondly, the COPRAS method is used to classify and rate suppliers. This studies highlight the central importance of customers in the evaluation of supply chains. However, a significant limitation of these studies is that they neglect the dynamic and evolving nature of customer requirements, as well as the uncertainty and the fuzziness associated with this decision-making processes.

The conventional method of discerning customer preferences involves gathering information through surveys and interviews [9]. However, this approach is no longer adequate as the information collected may not accurately reflect the real-time needs of the customer. Indeed. Customers tend to constantly change their preferences; they may easily alter their preferences after experiencing a product or service, or due to external influences. Few studies in the literature have paid attention to the fluctuation in customer preferences.

The variability in customer preferences over time and the uncertainty associated with GSS process, including vagueness and ambiguity in expert judgment, as well as insufficient available data, accentuates the complexity of this Decision-Making. Therefore, the main objective of this study is to support Decision-Makers by proposing a comprehensive model for GSS in an uncertain environment. This model considers both changing customer preferences and environmental factors, aiming to provide a holistic approach to supplier selection that addresses the challenges posed by uncertainty and evolving customer preferences. This model is based on the use of Markov chain in combination with two popular MCDM methods and fuzzy theory. To the best of our knowledge, no method combines Markov chain, the Fuzzy BWM and the Fuzzy TOPSIS method for assessing green suppliers in the current literature. Markov Chain in applied to track and predict changes in Customers' Preferences, the Fuzzy BWM is used to connect selection criteria with the customers' requirements and find their optimal weights and finally the Fuzzy TOPSIS is used to rank and prioritize green supplier alternatives. The proposed approach is validated by conduction a real-world case study and comparing the results with another existing GSS models.

The following are the major contributions of this research that distinguish it from other studies related to the same topic:

- To propose a decision-making tool combining the use of Markov chain, an Improved fuzzy BWM and Fuzzy TOPSIS methods for the evaluation and selection of green suppliers.
- The weight of each criterion is calculated while considering customer preferences in a fuzzy environment
- Taking into account the uncertainty associated with customer preferences involves tracking the evolution of these preferences and predicting a new model independent of the initial one.
- Dealing with uncertainty in both customer needs and expert judgment.
- This paper contributes to helping researchers and practitioners to choose more effective and suitable green supplier that best meets the requirements of the decision makers and satisfies the customer's desires.

The remainder of the paper is structured as follows: Section 2 presents the findings of the literature review, highlighting the most important studies conducted in this field of study. Section 3 is dedicated to describing the steps of the proposed approach. In Section 4, a case study is conducted to test the proposed approach, and the results are validated in Section 5 through a comparative study. The results are then, analyzed and discussed in Section 6, followed by a conclusion in Section 7.

2 Related works

In this section, a brief presentation of the findings from the literature review regarding the most common selection criteria and approaches proposed by the authors, as well as the importance of considering the customer's preferences in GSS Problems.

In the last decade, the literature on (GSS) has significantly increased, highlighting the growing importance of this field of study [2,10-12]. However, some studies have focused solely on assessing suppliers' environmental performance, thereby limiting the scope of their findings. [13] extended the (AHP) method under interval type-2 fuzzy environment and proposed a GSS model based on environmental criteria. This model was then applied in a real case study involving a home appliance manufacturer and the findings indicate that the criteria: green product, cleaner production, green design, and green package has a substantial positive impact on the performance of green suppliers. [12] proposed an integrated approach using fuzzy MCDMs to select green suppliers based on their green capabilities. The proposed model identified nine criteria which can assist decision-makers in distinguishing the key criteria for selecting strategic green suppliers. [14], in this work, authors proposed three-phase method to help Khouzestan Steel Company decision-makers assess their suppliers according to their green innovation ability, seven main criteria and thirty-eight environmental sub criteria were suggested, emphasizing ecological considerations. GSS is a complex decision, as it depends on various factors that can sometimes be contradictory. Indeed, prioritizing ecological criteria can be more costly than prioritizing conventional suppliers [15]. Finding a suitable supplier therefore involves reconciling economic and environmental objectives. Research has underlined the importance of considering both economic and ecological criteria when evaluating suppliers, to ensure informed and balanced decision-making [10]. In the literature, [16] proposed an integrated approach to develop a (GSS) model for the air-filter industry by focusing on both classic and green criteria. In this study, a modified two-phase fuzzy goal programming model is proposed to provide a solution satisfying the optimization of both classic and green supplier scores derived from the Intuitionistic Fuzzy TOPSIS. [2]'s study focused on the textile sector due to its significant environmental impact, highlighting the necessity of (GSS) for stakeholders. To address uncertainty in GSS, the study proposed an integrated model combining two (MCDM) methods, BWM and TODIM, within an enhanced fuzzy concept using Interval Type-2 Fuzzy Sets (IT2FSs). Recently, [17] introduces a novel approach to GSS for food business packaging operations. It offers a comprehensive set of key selection criteria derived from a literature review encompassing both green and traditional aspects. Suppliers are evaluated using the proposed Pythagorean Fuzzy TOPSIS method. As evident from the literature survey, the use of fuzzy theories is becoming increasingly widespread. This trend underscores the utility and effectiveness of this tool in addressing uncertainty and ambiguity within GSS problems leading to better-informed and more reliable decisions. We can therefore conclude that, although MCDMs have proven their effectiveness in solving multi-criteria problems, relying solely on these methods limits the findings. The current trend is to propose hybrid models combining different techniques in order to capitalize on the advantages of each [18-20]. In this paper we propose a hybrid model that combines the use of the Markov chain with two Fuzzy MCDM techniques.

In an increasingly demanding and sustainability-driven business landscape, integrating customer preferences into the GSS process is of paramount importance. This not only enables companies to meet increasingly stringent sustainability regulatory requirements but also strengthens their brand image and fosters customer loyalty. By understanding customer preferences, companies can choose suppliers that offer products that meet market expectations while adhering to environmental standards. However, the literature on this subject remains limited, with few studies specifically addressing the consideration of customer preferences in GSS. [5] is one of the leading authors to take customer attitudes into account in the supplier evaluation process. Authors proposed an integrated and innovative model based on the use of the SWARA and QFD method to weight supplier selection factors while giving greater importance to customer requirements, then the WASPAS method is applied to evaluate suppliers. In another study, [6] proposed an integrated approach for GSS by considering both customer and supplier criteria to investigate the influence of customer satisfaction indices on the supplier selection process. The author applied DEMATEL and QFD to weigh the decision criteria based on the importance given to customer requirements, and then applied COPRAS to classify and rate suppliers. In order to meet customer expectations, [21] proposed an integrated approach for GSS while considering both customer requirements and environmental performance criteria. The author utilized the combined (DEMATEL-QFD) method to examine the interrelations between customer requirements and supplier selection criteria. Subsequently, interval type-2 fuzzy AHP (IT2 FAHP) was applied to prioritize alternative suppliers. Later**,** [18] proposed a new customer-oriented approach to explore supplier relationship management in supply chains and identify suitable technical criteria for evaluating the organization's supply chain needs. The proposed model combines QFD and AHP to determine the weights of technical criteria, after which the suppliers are ranked using the simple additive weighting (SAW) method.

Most of the previously cited studies consider customer requirements as a constant parameter, which limits the results of their research. In reality, human beings tend to constantly modify their priorities and preferences, and this evolution should not be ignored, but rather tracked and anticipated. It is therefore crucial to recognize that these preferences are not static, but rather dynamic, evolving over time in response to factors such as market trends and technological advances. To the best of our knowledge, this study is the first to address the problem of GSS based on changing customer requirements in a fuzzy environment by introducing an integrated model that combines the use of Markov chain analysis with an improved Fuzzy BWM method and the Fuzzy TOPSIS approach.

The Markov chain is a mathematical model that describes a stochastic process in which a system moves from one state to another according to certain transition probabilities. In the context of changing customer preferences, this can be interpreted as the transition from one preference state to another over time [19]. Each state of the Markov chain could represent a specific set of customer preferences at a given time, and the transitions between these states would reflect changes in customer preferences over time. Markov chains have recently been successfully applied to capture the changing behavior of consumers and users [4,9,19,22,23]. [5] is a pioneer in the consideration of customer preferences in supplier selection problems, being the first to integrate Markov chain with MCDM methods in this area. However, his model could be improved by taking into account the uncertainty associated with this decision-making process, also by considering environmental factors.

Based on the preceding discussion, it is evident that numerous MCDM based approaches have been introduced in the literature to aid managers in supplier selection. However, these approaches often lack one or more of the following essential characteristics: the ability to take account of changing priorities in customer requirements when selecting suppliers, integration of customers' requirements into the weighting of selection criteria, consideration of both economic and environmental factors, addressing uncertainty and fuzziness in the decision-making process, and ensuring precise consistency in pairwise comparisons. This paper presents an integrated model for GSS and evaluation, exploiting Markov chain to track and predict the evolution of customer preferences. This approach is complemented by an enhanced and simplified Fuzzy BWM method, surpassing conventional Fuzzy BWM for criteria weighting. Additionally, the

Fuzzy TOPSIS method is employed to effectively rank and prioritize suppliers based on their performance.

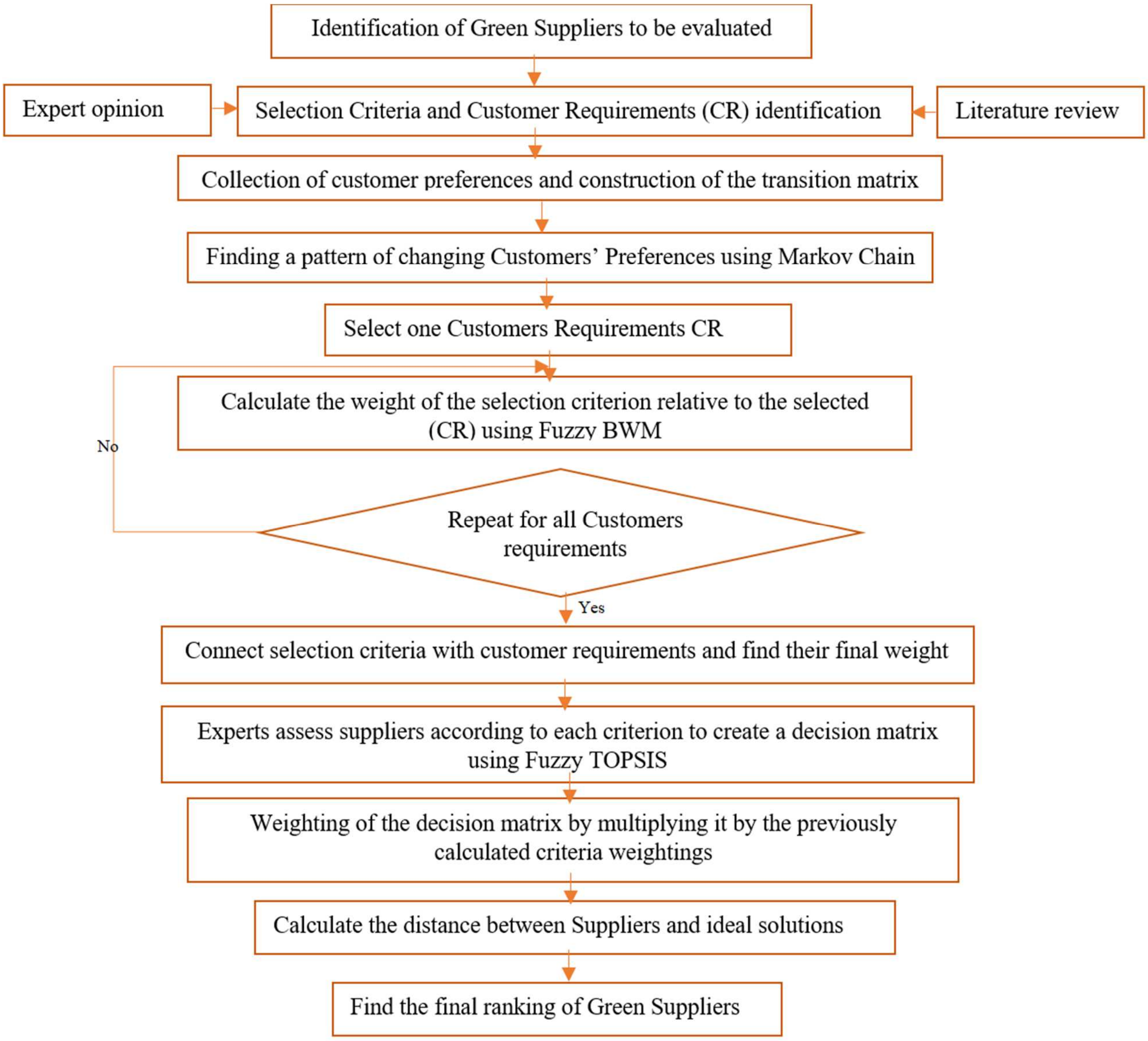

Figure 1 Flowchart of the proposed approach

3 Methods

In this paper we propose an integrated framework for GSS. This approach uses Markov Chain combined with Fuzzy MCDM methods to evaluate the ecological performance of suppliers based on changing customer preferences. Markov chain is applied to track and predict customer preferences. This Markov-generated model is then integrated with the Fuzzy BWM method to find weights for the selection criteria while taking into account customer requirements. These weights are then used to rank the alternatives using the Fuzzy TOPSIS method.

The main steps of the proposed approach proposed are illustrated in the flowchart in Figure1.

3.1 Data collection

This step aims to identify the list of potential suppliers to be evaluated, relevant selection criteria to be considered, and the customers' initial preferences. It is important to note that these preferences are not always stable and may evolve over time. Therefore, through a questionnaire survey among customers, we collect their initial preferences and need to monitor the evolution of these preferences over time, as customers reassess their priorities. To develop the questionnaire, we first carried out a literature review to identify the relevant customer requirements to be assessed. Next, we formulated the questions in collaboration with experts in the field to ensure their relevance and validity. The questionnaire was pre-tested on a pilot sample to refine the list of requirements and ensure clarity. The questionnaire was validated by a panel of experts comprising researchers and practitioners in the field of supply chain management.

In order to collect their initial preferences, the company's customers are asked to rate Customer Requirements (CR) on a 5-point Likert scale. These questionnaires are then regularly redistributed to monitor changes in customer preferences. The questionnaire is distributed once the purchase has been made, enabling customers to fully grasp their needs at that point. The questionnaire was distributed electronically via sales department e-mails to a targeted sample of the company's customers.

3.2 Markov Chain

The Markov chain is a mathematical model that describes a stochastic process in which a system moves from one state to another according to certain transition probabilities. In the context of changing customer preferences, this can be interpreted as the transition from one preference state to another over time. Each state of the Markov chain could represent a specific set of customer preferences at a given time, and the transitions between these states would reflect changes in customer preferences over time.

Transition matrix construction process: The transition matrix is constructed by estimating the probability of a user transitioning from one requirement to another over time. This is done by observing customer's priorities over time and identifying the proportion of customers who regard a particular requirement as their most important and wish to switch to another requirement. The probability of this transition is then calculated using (1) that consider the number c_{ik} of customers who initially placed a requirement *(i)* at the top of their priority list and b_{ijk} the number of customers who wish to change their priority to another requirement *(j)* during the period k. Once the probabilities are estimated, they are used to construct the transition matrix. It is a square matrix that represents the probabilities of transitioning from one requirement to another and is used in the Markov chain analysis to track changes in customer's requirements over time.

$$\gamma_{ijk} = \frac{b_{ijk}}{c_{ik}} \tag{1}$$

Finding the final Pattern process: The final pattern of customer's requirements priorities ($FPCR$) can be derived by initially equating the values of this list $FPCR$ to those of the initial list of Customers' requirements $IPCR$. Subsequently, the iterative process involves the multiplication of the transpose of the vector ($FPCR$) by the transition matrix (TM), as illustrated in the following equation (2):

$$FPCR^{(k)T} = FPCR^{(k-1)T} \times TM \tag{2}$$

where $k = 1, 2,3, \dots, max$ is the number of multiplications. Due to the inherent convergence of stochastic matrices, it is anticipated that the matrices will converge to the same values after three to five multiplications. As stated in [4], [19], the adjusted priorities generated by the Markov chain represent a more robust model of future customer preferences, and are independent of initial customer preferences, suggesting the importance of concentrating efforts on the development of a transition matrix rather than on recording consumers' initial preferences.

3.3 Connecting Customers' Requirements and Selection Criteria using Fuzzy BWM

In order to obtain the optimal weight of selection criteria with respect to the selected (CR), the Fuzzy BWM is applied. The main steps of the improved simplified fuzzy BWM according to [24] are described as follows:

Step 1: From the set of criteria to be evaluated, the decision-maker is tasked with discerning the most favorable and unfavorable criteria from the set of selection criteria. The variables n_B^k and n_W^k respectively represent the counts of criteria identified as the best and worst ones in the decision-making process.

Step 2: The decision-maker express his preferences using linguistic terms to carry out comparisons of the "best" criteria against the remaining criteria. These preferences are then translated into triangular fuzzy numbers (TFN) and represented in the AB vector (3).

$$AB = (\tilde{a}_{B1}, \tilde{a}_{B2}, \dots, \tilde{a}_{Bn}) \tag{3}$$

Where $\tilde{a}_{Bi}$ represents the preference of the best criterion against the i^th criterion and logically $a_{BB} = 1$.

Step 3: similarly, the DM carries out a comparison in linguistic terms of all criteria over the worst criteria. After converting these preferences into (TFNs), they are listed in the AW vector (4):

$$AW = (\tilde{a}_{1W}, \tilde{a}_{2W}, \dots, \tilde{a}_{nW}) \tag{4}$$

Where $\tilde{a}_{iW}$ represents the preference of the i^th criterion against the worst criteria and logically $a_{WW} = 1$.

Step 4 : Calculation of criteria weight relative to *best-to-others vector AB* and are denoted as (5), (6), (7):
$\tilde{w}_i^{AB} = (l_i^{AB}, m_i^{AB}, u_i^{AB})$

From $$\tilde{w}_B^{AB} / \tilde{w}_i^{AB} = n_B \tilde{a}_{Bi} \tag{5}$$

and $$\sum_i^n \tilde{w}_i = 1 \tag{6}$$

we obtain: $$\tilde{w}_B^{AB} = \frac{1}{\sum \frac{1}{n_B * \tilde{a}_{Bi}}} \tag{7}$$

Replacing the value of $\widetilde{w}_B^{AB}$ in equation (3) we obtain the criteria weights relative to *best-to-others vector AB* (8):

$$\widetilde{w}_i^{AB} = \frac{\widetilde{w}_B^{AB}}{n_B * \tilde{a}_{Bi}} \tag{8}$$

Step 5 : Calculation of criteria weight relative to *others-to-worst vector* AW. and are denoted as: $\widetilde{w}_i^{AW} = (l_i^{AW}, m_i^{AW}, u_i^{AW})$. Similarly, using equation (9) we calculate the relative weight of the worst criterion, then replace its value in equation (10) to obtain criteria weight relative to *others-to-worst vector*.

$$\widetilde{w}_W^{AW} = \frac{1}{\sum n_W * \tilde{a}_{iW}} \tag{9}$$

$$\widetilde{w}_i^{AW} = \widetilde{w}_W^{AW} * n_W * \tilde{a}_{iW} \tag{10}$$

Step 6: The final weighting of each criterion with respect to the selected (CR) is determined by averaging the previously calculated relative weights using the following equation (11):

$$\widetilde{w}_i^{*} = \frac{\widetilde{w}_i^{AB} + \widetilde{w}_i^{AW}}{2} \tag{11}$$

The selection criteria {C1...Cn} are evaluated with respect to each customer requirement (CR). Whenever a set of weights for the criteria is calculated, these weights form the rows of the *(CR-C)* matrix. Now, the goal is to find the W_{CR} matrix (12) containing the final weights of the selection criteria considering their relationships with the customer requirements (CR). This matrix is determined by the product of the previously calculated weights matrix *(CR-C)* using the Fuzzy BWM method with the final pattern of customer's requirements priorities ($FPCR$) obtained by applying the Markov chain.

$$W_{CR} = (CR\text{-}C) * (FPCR) \tag{12}$$

3.4 Fuzzy TOPSIS approach for alternative prioritization

The main steps of the Fuzzy TOPSIS approach according to [25] are described as follows:

Step1: Construction of the fuzzy decision matrix D with *m* alternatives and *n* criteria by converting linguistic preferences into (13)

$$\text{TFNs: } D = \left[\widetilde{x_{ij}}\right]_{mxn} \tag{13}$$

where $\widetilde{x_{ij}} = (a_{ij}, b_{ij}, c_{ij})$.

Step2: Construction of the normalized fuzzy decision matrix after identifying the cost and benefit criteria from the set of selection criteria. The matrix is presented as:

$\tilde{R} = \left[\widetilde{r_{ij}}\right]_{mxn}$, i=1,…,m ; j=1,2,…,n where (14), (15):

$$\widetilde{r_{ij}} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right) \text{ and } c_j^* = \max_i c_{ij} \text{ (benefit criteria)} \tag{14}$$

$$\widetilde{r_{ij}} = \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}}\right) \text{ and } a_j^- = \min_i a_{ij} \text{ (cost criteria)} \tag{15}$$

Step3: Construction of the weighted normalized fuzzy decision matrix by multiplying the previous matrix by the weights of each criterion calculated previously using the Fuzzy BWM method.

Step4: determine the Fuzzy positive ideal FPIS (A+) and Fuzzy negative ideal FNIS (A-) (16), (17):

$$A^+ = (v_1^+, v_2^+ \dots, v_n^+) \tag{16}$$

$$A^- = (v_1^-, v_2^- \dots, v_n^-) \tag{17}$$

Where (18), (19):

$$v_j^+ = \max(\widetilde{v_{ij}}) \tag{18}$$

and

$$v_j^- = \min(\widetilde{v_{ij}}) \tag{19}$$

Step 5: Calculate the distance of each weighted alternative from both (FPIS) and (FNIS) using the following equations (20), (21):

$$d_i^+ = \left\{\sum_{j=1}^n \left(v_{ij} - v_{ij}^+\right)^2\right\}^{\frac{1}{2}} \quad , i = 1 \dots m \tag{20}$$

$$d_i^- = \left\{\sum_{j=1}^n \left(v_{ij} - v_{ij}^-\right)^2\right\}^{\frac{1}{2}} \quad , i = 1 \dots m \tag{21}$$

Step 6: Calculate the closeness coefficient, used to rank the alternatives using the following formula (22):

$$CC_i = \frac{d_i^-}{d_i^- + d_i^+} \tag{22}$$

4 Case study

To assess the applicability and effectiveness of our proposed approach, we conducted a real-world case study within a Moroccan company specializing in the manufacturing of construction materials. This industry-leading company is committed to reducing its ecological footprint while providing high-quality products. It has already implemented Green initiatives such as the use of recycled materials, carbon emission reduction, and process optimization to minimize waste. This company has a keen interest in our study and is convinced that the findings could provide valuable recommendations to further enhance its commitment to sustainability and satisfying its customers' requirements.

Table 1 A brief description of selection criteria

Selection criteria	Description
Cost (C1)	Product cost, freight cost and cost reduction capability
Quality (C2)	Refers to the level of excellence of the product
Delivery (C3)	The ability to meet specified delivery schedules: order fill rate, the availability of the product, lead time, order frequency
Air emission (C4)	Measures to reduce greenhouse gas emissions, air pollutants, and other harmful airborne substances.
Waste water (C5)	The efficiency of wastewater treatment systems and compliance with environmental regulations regarding water pollution
Use of harmful materials (C6)	It assesses efforts to minimize or eliminate the use of harmful and toxic substances and replace them with eco-friendly alternatives.
Green packaging (C7)	Use of sustainable packaging materials and practices.
Recycle (C8)	The implementation of recycling programs, the percentage of materials recycled, and the use of recycled materials
EMS and ISO 14001 certification (C9)	The presence of an environmental management system (EMS), a regulatory compliance and environmental certification such as ISO14000

Selection criteria:

The identification of Supplier selection criteria requires meticulous attention, taking into account the characteristics of the industrial sector under study and responding to the specific requirements of decision-makers. Studies have shown that, when selecting green suppliers, the integration of sustainable practices should not be at the expense of traditional criteria. Both aspects need to be taken into account in the decision-making process. The criteria adopted in this study are based on previous research conducted by author [24], which identified nine selection criteria. Economic criteria include: Cost (C1), quality (C2), delivery (C3), and Ecologic criteria include: Air emission (C4), Waste water (C5), Use of harmful materials (C6), Green packaging (C7), Recycle (C8), Environmental Management Information System and ISO 14001 certification (C9). A brief description of each criterion is given in Table 1.

Table 2 A brief description of customer requirements

Customer Requirements	Description
Product Quality (CR1)	This includes durability, resilience, and compliance with industry standards and commonly adopted specifications.
Price (CR2)	Market-competitive prices, ability to offer payment facilities and discounts.
Compliance with environmental standards (CR3)	Materials that comply with environmental standards, minimize ecological impact and are manufactured in a sustainable manner.
Technical support and after-sales service (CR4)	Ability to provide technical advice and solutions to potential problems, installation assistance, warranty, easy replacement in the event of failure.
Stock availability (CR5)	Ability to supply requested quantities within reasonable lead times.

5 Results

The following section presents the results of applying the proposed approach, highlighting the data collected and the analyses carried out. These results are then compared with those obtained using different methods, to assess their relative effectiveness and relevance.

5.1 Results from the application of the proposed approach

Data collection:

The data collection process in this approach initiates with identifying customer preferences. Recognizing that these preferences may evolve over time, a questionnaire survey is implemented. Questionnaires are periodically redistributed to the organization's customers to capture the evolution of their preferences. By leveraging the questionnaire results, the transition matrix (*TM*) is constructed following the steps outlined in Section 3.2. The fallowing Set of Customer Requirements (CR) is adopted in this paper: (Product Quality (CR1), Price (CR2), Compliance with environmental standards (CR3), Technical support and after-sales service (CR4), Stock availability (CR5)). Table 2 provides a brief description of each (CR).

The initial list of (CR) Priorities (IPCR) and the transition Matrix (TM) are obtained as follows:

$$IPCR=\begin{array}{rl} \textbf{Quality } CR1 & 0.39 \\ \textbf{Price } CR2 & 0.14 \\ \textbf{Env.stand } CR3 & 0.16 \\ \textbf{Tech.supp } CR4 & 0.12 \\ \textbf{Stock avail } CR5 & 0.19 \end{array} \quad and \quad TM = \begin{array}{cccccc} & CR1 & CR2 & CR3 & CR4 & CR5 \\ CR1 & 0.35 & 0.22 & 0.09 & 0.11 & 0.23 \\ CR2 & 0.29 & 0.28 & 0.27 & 0.08 & 0.08 \\ CR3 & 0.16 & 0.10 & 0.31 & 0.15 & 0.28 \\ CR4 & 0.25 & 0.13 & 0.12 & 0.33 & 0.17 \\ CR5 & 0.28 & 0.30 & 0.10 & 0.10 & 0.29 \end{array}$$

Finding a pattern of changing Customers' Preferences using Markov Chain:

To predict future customer preferences based on initial preferences and the transition matrix, we applied the Markov Chain, as outlined in Section 3.2.

$$FPCR^{(1)\,T} = FPCR^{(0)\,T} \times TM = (0.286\ 0.20\ 0.156\ 0.137\ 0.221) \quad (19)$$
$$FPCR^{(2)\,T} = FPCR^{(1)\,T} \times TM = (0.283\ 0.199\ 0.164\ 0.139\ 0.215) \quad (20)$$
$$FPCR^{(3)\,T} = FPCR^{(2)\,T} \times TM = (0.282\ 0.197\ 0.168\ 0.141\ 0.212) \quad (21)$$
$$FPCR^{(4)\,T} = FPCR^{(3)\,T} \times TM = (0.277\ 0.201\ 0.170\ 0.139\ 0.213) \quad (22)$$
$$FPCR^{(5)\,T} = FPCR^{(4)\,T} \times TM = (0.277\ 0.201\ 0.170\ 0.139\ 0.213) \quad (23)$$

As demonstrated by (19), (20), (21), (22) and (23), the matrix stabilized after five multiplications, consistently yielding the same values thereafter. This stabilization illustrates the convergence of the model. The final pattern of customers' preferences is as follows:

$$FPCR = \begin{array}{ccccc} CR1 & CR2 & CR3 & CR4 & CR5 \\ 0.277 & 0.201 & 0.170 & 0.139 & 0.213 \end{array}$$

Connecting Customers' Requirements and Selection Criteria using Fuzzy BWM:

The final pattern of customers' priorities is obtained using the Markov Chain. This final list of priorities is then used as an input to the Fuzzy BWM method in order to connect the Customers' requirements to the selection criteria. For each chosen Customer Requirement, the Best and Worst criteria are identified, and pairwise comparisons are conducted. The weights of the selection criteria are then computed following the procedures outlined in Section 3.

Table 3 Selection criteria comparisons with respect to "CR1=ProductQuality"

		C1	C2	C3	C4	C5	C6	C7	C8	C9
Quality	C_B: C2	(2,3,4)	(1,1,1)	(5,6,7)	(5,6,7)	(5,6,7)	(3,4,5)	(4,5,6)	(3,4,5)	(2,3,4)
	C_W: C3	(6,7,8)	(7,8,9)	(1,1,1)	(2,3,4)	(2,3,4)	(3,4,5)	(4,5,6)	(5,6,7)	(6,7,8)
Optimal weights		(0.094, 0.140, 0.214)	(0.211, 0.267, 0.329)	(0.030, 0.041, 0.054)	(0.040, 0.064, 0.097)	(0.040, 0.064, 0.097)	(0.058, 0.090, 0.138)	(0.063, 0.093, 0.136)	(0.068, 0.102, 0.153)	(0.094, 0.140, 0.214)

Table 3 shows the values of the pairwise comparisons and the optimal weights for the selection criteria associated with the customer requirement CR1. In a similar way, pairwise comparisons are carried out for the other remaining customer requirements: (CR2, CR3, CR4 and CR5) and the criteria weights are retained for each iteration.

The resultant weights are systematically organized and presented in the following Fuzzy matrix (*CR-C)*:

CR-C) =

	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**
(CR1)	(0.094, 0.140, 0.214)	(0.211, 0.267, 0.329)	(0.030, 0.041, 0.054)	(0.040, 0.064, 0.097)	(0.040, 0.064, 0.097)	(0.058, 0.090, 0.138)	(0.063, 0.093, 0.136)	(0.068, 0.102, 0.153)	(0.094, 0.140, 0.214)
(CR2)	(0.245, 0.299, 0.355)	(0.095, 0.136, 0.192)	(0.095, 0.136, 0.192)	(0.029, 0.037, 0.047)	(0.03, 0.037, 0.047)	(0.059, 0.089, 0.129)	(0.055, 0.082, 0.118)	(0.045, 0.07, 0.133)	(0.08, 0.113, 0.159)
(CR3)	(0.022, 0.028, 0.035)	(0.057, 0.082, 0.117)	(0.033, 0.052, 0.078)	(0.061, 0.089, 0.129)	(0.061, 0.089, 0.129)	(0.183, 0.225, 0.270)	(0.076, 0.111, 0.168)	(0.067, 0.100, 0.155)	(0.183, 0.225, 0.270)
(CR4)	(0.093. 0.134. 0.198)	(0.113. 0.165. 0.252)	(0.249. 0.309. 0.379)	(0.030. 0.039. 0.049)	(0.030. 0.039. 0.049)	(0.051. 0.082. 0.126)	(0.047. 0.075. 0.115)	(0.047. 0.075. 0.115)	(0.051. 0.082. 0.126)
(CR5)	(0.107. 0.157. 0.239)	(0.107. 0.157. 0.239)	(0.234. 0.295. 0.362)	(0.029. 0.037. 0.047)	(0.029. 0.037. 0.047)	(0.060. 0.091. 0.136)	(0.045. 0.072. 0.109)	(0.031. 0.054. 0.085)	(0.065. 0.101. 0.154)

The final fuzzy weighting (Table 4) of the selection criteria taking into account customer requirements is then obtained according to equation (9).

Table 4 final weights of selection criteria considering CR

Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9
final aggregated weights	(0.115, 0.156, 0.215)	(0.126, 0.172, 0.236)	(0.118, 0.153, 0.197)	(0.038, 0.054, 0.075)	(0.038, 0.054, 0.075)	(0.079, 0.112, 0.157)	(0.058, 0.087, 0.129)	(0.052, 0.081, 0.129)	(0.094, 0.132, 0.188)

Green Supplier Assessment using Fuzzy TOPSIS:

In this section, we utilize the Fuzzy TOPSIS method for evaluating green suppliers and determining their final ranking. Each expert contributes individual linguistic assessments, translated into triangular fuzzy numbers. These assessments are aggregated into a consensus Fuzzy decision matrix, normalized with consideration to the previously obtained criteria weights through the Fuzzy BWM method. The weighted normalized fuzzy decision matrix is then calculated based on the multiplication of the normalized matrix and the criteria weights previously calculated, the results are shown in Table 5. Finally, the closeness coefficient is computed, relying on both FPIS and FNIS, resulting in the final ranking of green suppliers showed in Table 6.

Table 5 The Weighted and Normalized fuzzy decision matrix

	C1	C2	C3	C4	C5	C6	C7	C8	C9
GS1	(0.018, 0.036, 0.092)	(0.054, 0.123, 0.236)	(0.056, 0.113, 0.197)	(0.006, 0.012, 0.028)	(0.004,0.007, 0.011)	(0.023, 0.051, 0.157)	(0.032, 0.068, 0.129)	(0.021, 0.049, 0.104)	(0.066, 0.123, 0.188)
GS2	(0.038,0.156, 0.215)	(0.024, 0.041, 0.067)	(0.051, 0.087, 0.137)	(0.004, 0.007, 0.013)	(0.006, 0.01, 0.017)	(0.016, 0.029, 0.049)	(0.009, 0.016, 0.029)	(0.008, 0.016, 0.041)	(0.010, 0.015, 0.035)
GS3	(0.013, 0.02, 0.038)	(0.018, 0.074, 0.168)	(0.015,0.033, 0.094)	(0.009,0.023, 0.075)	(0.01,0.032, 0.075)	(0.021,0.043, 0.112)	(0.036, 0.074, 0.129)	(0.027,0.062, 0.129)	(0.073,0.132, 0.188)

Table 6 The final ranking of the three Green Suppliers

	d+	d-	CC	Ranking
GS1	0,196	0,514	0,724	1
GS2	0,528	0,182	0,256	3
GS3	0,287	0,420	0,594	2

5.2 Comparison with other methods

To assess the effectiveness of the proposed model and validate the obtained results, a comparative study is conducted.

Comparing criteria weightings: This study involves calculating the weights of selection criteria in two different ways: using the methodology proposed in this paper and using the Fuzzy BWM method without considering customer requirements. The aim of this comparative study is to evaluate the impact of customer requirements on the criteria weighting process in the context of GSS. The comparison results are presented in Figure 2.

Comparing green suppliers ranking: Beyond the methodology proposed in this paper, three other existing GSS models from literature are considered for comparison. Specifically, the Fuzzy TOPSIS method. [24] proposes a novel model combining the use of an improved and simplified Fuzzy BWM and Fuzzy TOPSIS. Authors have demonstrated the superiority of the proposed model over other existing methods in terms of consistency and relevance of the results obtained. Additionally, the combination of the well-known Fuzzy AHP and Fuzzy TOPSIS methods is chosen as another comparative approach. The comparison results are presented in Figure 3.

6 Discussion and implication

In this paper, we propose a hybrid approach combining Markov Chain, fuzzy theory and MCDM techniques to address GSS. This approach takes into account customer requirements, and pays particular attention to the fact that customer priorities are constantly changing over time. The application of Markov chain enabled us to track this change and predict a pattern of customer preferences.

After applying the Markov chain to initial customer preferences, the resulting pattern shows an adjustment in customer preference priorities over time. Initially, **quality** was the dominant priority with a weighting of 0.39, but according to the Markov model, this weighting decreased to 0.277. In contrast, **stock availability**, initially at 0.19, increased to 0.213, indicating a shift in priority towards this criterion. These results suggest a shift in customer preferences towards a greater focus on stock availability, while quality has become relatively less dominant. As for the "**Technical support and after-sales service**" criterion, initially it had a weighting of 0.12, but according to the Markov model, this weighting increased slightly to 0.139. This could indicate a growing recognition of the importance of technical support and after-sales service for customers over time. Indeed, in this industrial sector, the purchase of building materials is often a major investment for customers, and they are keen to ensure that their money is well spent. Customers often need technical support for the installation and use of materials, particularly for complex or specialized products. An effective after-sales service can ensure that customers receive the assistance they need to resolve potential problems and maximize the value of their purchases [26]. This interpretation highlights the importance of monitoring trends in customer preferences to proactively adjust supplier selection strategies.

After obtaining the new pattern of customers' future preferences, a connection between these preferences and the selection criteria is established by applying the Fuzzy BWM method to obtain the final weights of the selection criteria. These results indicate that **Quality** (0.175) is the most important criterion, followed by **Cost** (0.159), **Delivery** (0.155) and **EMS** (0.140), suggesting that customers attach great importance to the quality of building materials. We conducted a comparative study with the aim of obtaining the weights of the selection criteria in two different ways: using the methodology proposed in this paper, and using a criteria weighting method existing in the literature without considering customer requirements. The results of this comparative study reveal a difference in the weights of the selection criteria between the two approaches. When customer requirements are taken into account, the weights assigned to certain criteria, such as **Cost**, **Delivery** and **Use of Harmful Materials,** increase considerably compared to the method that does not take these requirements into account. This suggests that customers attach greater importance to these aspects. On the other hand, criteria such as **quality** and **EMS** see their weights decrease slightly when assessed against customer requirements. This may indicate that customers attach great importance to these criteria, and are willing to pay a higher price for quality and environmentally-friendly products. These results underline the importance of understanding and responding to changing customer needs and preferences in the supplier selection process.

These criteria have practical implications for environmental policy makers and for companies seeking to improve their sustainable supply chain. Our recommendations include adopting strategies to strengthen performance on each of these criteria in order to optimize overall sustainability results.

The Markov chain has been successfully used in previous studies to predict the evolution of customer needs [4,9,19,23]. However, after reviewing the existing literature, few articles combine the use of the Markov chain with MCDM techniques when selecting suppliers. The only existing supplier selection model in the literature that integrates Markov chain with MCDM techniques does not take into account the uncertainty associated with this selection process [5]. Our approach, which takes advantage of fuzzy set theory, offers an effective response to this uncertainty, thus establishing a robust framework for managing ambiguous or imprecise information. Moreover, the model proposed by [5] evaluates suppliers solely on the basis of economic criteria. Our study demonstrated the importance attached by customers to environmentally-friendly products, underlining the need to integrate ecological criteria into the supplier selection process.

After obtaining the weights of the selection criteria, these weights are then integrated into the Fuzzy TOPSIS method to rank the suppliers. The ranking results in the following order: GS1, followed by GS3, then GS2. In order to validate the results obtained, we carried out a comparative study in which we ranked the 3 suppliers using four different methods. Figure 3 shows the ranking results based on the proposed framework and the three methods involving the same data used in the case study. According to Figure 3, the results of the four methods are quite similar. All methods ranked **GS1** as the best green supplier. And **GS3** is ranked second in all methods, with the exception of the Fuzzy TOPSIS method, where it is ranked last. Thus, it can be concluded that the results obtained are consistent and can be considered valid and robust, reinforcing the reliability of the proposed approach and its applicability in the decision-making process.

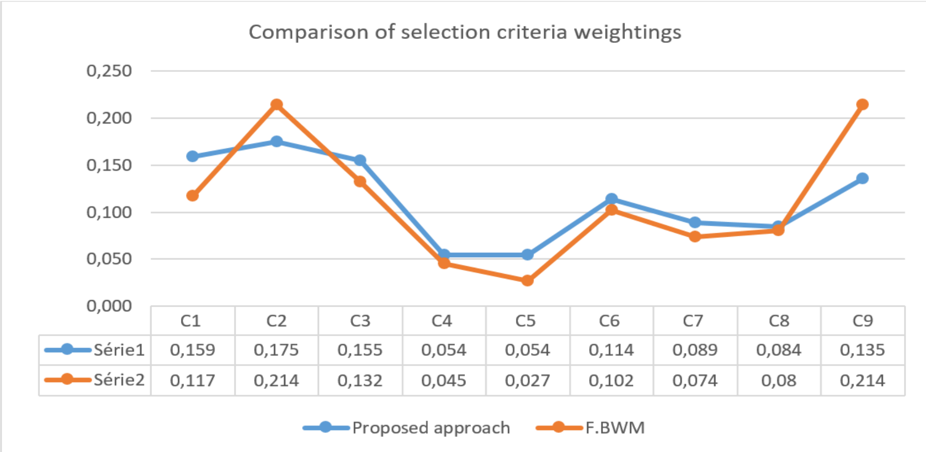

Figure 2 Comparison of selection criteria weightings

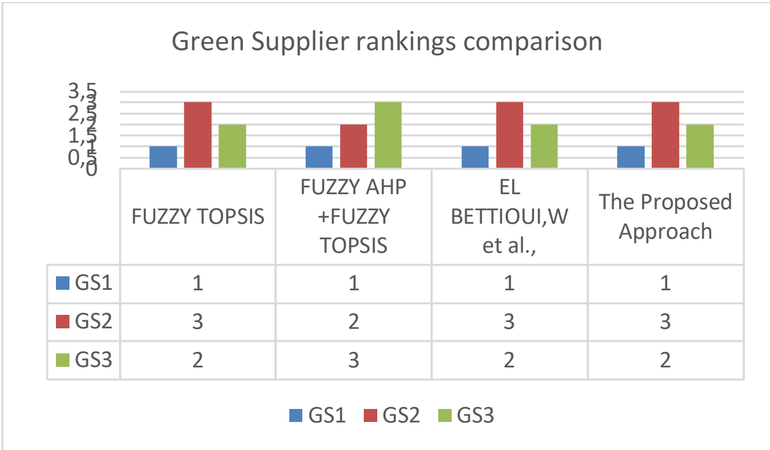

Figure 3 Green Supplier rankings comparison

7 Conclusion

GSS presents crucial challenges in today's sustainability-driven environment. Taking customer requirements into account in this process has become essential, as it helps to ensure that the chosen suppliers meet customers' specific expectations for environmentally-friendly products. However, customer preferences are not static; they evolve over time. This dynamic requires an anticipatory approach to predicting future customer preferences. Understanding how customers can change their minds and adapt their preferences becomes a key element in more accurate supplier selection, aligned with market trends and consumer expectations.

In this paper we propose an integrated framework for GSS. This approach uses Markov Chain combined with Fuzzy MCDM methods to evaluate the ecological performance of suppliers based on changing customer preferences. Markov chain is applied to track and predict customer preferences. This Markov-generated model is then integrated with the Fuzzy BWM method to find weights for the selection criteria while taking into account customer requirements. These weights are then used to rank the alternatives using the Fuzzy TOPSIS method.

To test the effectiveness of the proposed model, we conducted a real-life case study involving the evaluation of three green suppliers, taking into account five customer requirements and nine selection criteria. To validate the results obtained, we conducted a comparative study involving the calculation of selection criteria weights in two different ways: one in which customer requirements were integrated into the supplier evaluation process, and one in which these requirements were not taken into account. In addition, we compared the ranking of green suppliers using three different supplier selection models existing in the literature. The results obtained in this work demonstrate that the proposed hybrid framework is very consistent, overcomes the uncertainty associated with this decision-making and is capable of proactively satisfying customer requirements.

This research aims to enrich the current literature in the area of GSS. Despite its advantages, our method also presents some critical limitations that need to be considered. Firstly, a sensitivity analysis of the proposed model is required to test different scenarios reflecting various situations that decision-makers may face when evaluating suppliers. This could involve modifying the list of customer requirements or the list of alternatives to ensure the consistency of the results obtained. The second limitation concerns the non-generalizability of the proposed model, as it is based on a specific case study and may not be applicable to all GSS problems. In view of the limitations raised, we propose to add a new perspective to the scientific literature by considering different possible scenarios and extending the study to different industries and economic contexts.

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