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A NOVEL APPROACH BASED ON SIMPLIFIED AND IMPROVED FUZZY BWM AND FUZZY TOPSIS FOR GREEN SUPPLIER SELECTION

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ABSTRACT

Integrating environmentally-friendly practices into industrial processes is crucial to meeting global environmental concerns. This is particularly crucial in the supplier selection process, where environmental considerations intermingle with economic requirements. However, the complexity of this process stems from a number of factors, mainly the uncertainties associated with this decision-making, the lack of comprehensive data and the inherent subjectivity of human judgment. Moreover, Green Supplier Selection requires the participation of multiple decision-makers with different areas and levels of expertise. The methods available to support these complex decisions are often themselves complex, requiring advanced mathematical modeling skills. In order to meet these requirements, this paper proposes a new Green Supplier Selection model combining the use of an improved and simplified Fuzzy BWM and Fuzzy TOPSIS. The key benefit of the suggested model is that it is easy for both researchers and participants to apply in a real-life scenario; it also takes into consideration the subjectivity of human judgment and the diversity of decision-makers. A real-life case study is conducted to demonstrate the effectiveness of our Green Supplier Selection approach. Three green suppliers of a building materials manufacturing company are evaluated. Our approach is validated by comparing its results with two other existing approaches. This comparative study reveals the superiority of the proposed method over previous studies. Thus, our research provides a powerful tool to guide decision-making in the selection of green suppliers.

Keywords: *Group Multi Criteria Decision-Making, Fuzzy Set Theory, Fuzzy BWM, Fuzzy TOPSI, Green Supplier Selection,*

1. INTRODUCTION

Given the current environmental context, the integration of environmental issues into supply chain management is of crucial importance in promoting sustainable development. The concept of GSCM was first introduced in the early 90s. Srivastava (1) defines GSCM as "*the integration of environmental awareness into supply chain management, including product design, materials sourcing and selection, manufacturing processes, delivery of the final product to consumers, as well as the management of the product's end-of-life after its useful life*". Among the various GSCM processes, the selection and evaluation of green suppliers occupies an essential place(2). This process enables companies to identify suppliers who adopt environmentally-friendly practices in their operations, and to ensure that they partner with suppliers aligned with their sustainability objectives. By integrating environmental criteria into this process, companies help to reduce the company's overall ecological footprint. This includes reducing negative impacts on natural resources, preventing pollution and minimizing waste. In addition, the process of selecting and evaluating green suppliers promotes transparency and accountability(3). By requiring detailed information on suppliers' environmental practices, companies can build more sustainable partnerships and create an ethical and responsible supply chain. This boosts the confidence of consumers, stakeholders and investors, who are increasingly attaching importance to sustainability and corporate social responsibility. In the same vein, Villanueva-Ponce et al., (4) proves the existence of a direct and positive effect on the financial benefits obtained when considering green attributes when evaluating suppliers in the context of a GSCM philosophy. Consequently, GSS is a subject of considerable theoretical importance and practical implications. It has become a major concern in contemporary operations management(2).

Selecting green suppliers offers a range of significant advantages for companies concerned about their environmental impact. However, choosing the best green supplier can be a complex and delicate task. Indeed, decision-making in this area involves taking into account several environmental, economic and social criteria. GSS is commonly viewed as a multiple-criteria group decision-making (Group MCDM) problem (5–8). It's a decision that usually requires the participation and collaboration of several decision-makers within an organization, and often involves different departments such as purchasing, environmental management, production management and general management. Each of these DMs brings specific expertise and a unique perspective to the decision-making process. It is therefore necessary to design appropriate tools that take into account the diversity of selection criteria, as well as the diversity of DMs.

In this dynamic and demanding context, our work stands out for its ambition to bring significant innovations to green supplier selection models. By integrating conceptual and methodological advances, and aligning ourselves with different perspectives in the literature, we aim to make a significant contribution to GSCM particularly with regard to GSS. From this perspective, we formulated the following research questions to guide our study.

1 How can we design an effective green supplier selection and evaluation model, incorporating an evaluation criteria weighting method that takes into account the heterogeneous nature of the criteria, the uncertainty involved in decision-making, while remaining easily applicable in the green supplier selection process?

2 How can we overcome the challenges of group decision-making with DMs from different backgrounds and perspectives?

These research questions will guide our work in developing an innovative approach to GSS taking into account the various environmental and economic dimensions, while meeting the needs of collective decision-making within organizations.

Faced with the complexity of GSS problems, researchers are putting more effort into creating effective decision-making tools. Among these tools, multi-criteria decision models (MCDMs) are the most commonly used(5,7,9–11) ,in addition to mathematical programming (MP) (12), data analysis techniques and artificial intelligence (AI) technologies (13–15). This preference is explained by the fact that they have been specifically designed to deal with situations involving various heterogeneous and even sometimes contradictory criteria in a simultaneous and weighted manner(16). Although MCDM methods offer a number of advantages, they lack robustness in the face of uncertainty(17). These methods are generally based on the preferences of DMs, and if the imprecision of human judgment is not taken into account, the results can be misleading. (7). This limitation is reduced by the application of fuzzy set theory (FST). Several earlier research have emphasized the need to fuzzify MCDM approaches (17–20). On the other hand, most models developed in a fuzzy environment often require complex calculations, a considerable amount of time and the use of related software, which can make decision-making even more complex(21). The need for a multi-criteria decision-making tool that takes into account all the aforementioned requirements in terms of simplifying calculations, considering multiple DMs and multiple criteria, and taking uncertainty into account, is still evident in the literature. In this paper, we attempt to enrich the literature in this field of study and propose a new approach that will support decision-makers in choosing the best ecological supplier using recently developed MCDM techniques, Fuzzy-BWM, and Fuzzy-TOPSIS.

The rest of this article is organized as follows: Section 2, present a literature review on different method used in evaluating green suppliers especially the literature related to the development of BWM and TOPSIS and their application. Section 3 describes the methodology using the proposed Fuzzy BWM and Fuzzy TOPSIS. In order to test the applicability of the proposed model a real-life case study is conducted in section 4. Section 5 presents the comparative results of the proposed method with previous studies. Finally, the last section presents conclusions and future research direction

2. LITERATURE REVIEW

The MCDM method offers a powerful analytical framework for evaluating and ranking alternatives according to several criteria. It is widely used in many fields to support DMs faced with complex decision-making. There are several methods in the literature, among the most popular: AHP(22), TOPSIS(23), DEMATEL (Fontela & Gabus, 1976), ELECTRE (Roy, 1991), VIKOR (1998) and PROMETHEE (Brans & Vincke, 1985). The principle of (MCDM) methods is based on three key steps: defining selection criteria and alternatives, weighting the criteria and finally ranking the alternatives(18). Allocating relative importance to the various criteria is a crucial stage in the decision-making process, since it illustrates the DM's preferences and directly influences the course and outcome of the process(24). It is therefore essential to carefully select the most appropriate weighting method. Various weighting techniques are available in the literature. Recently, Singh and Pant (24) carried out a literature review on weighting methods in MCDM problems and concluded that AHP, ANP and BWM are the three most popular techniques. The effectiveness of these methods for weighting criteria has prompted researchers to combine them with other alternative ranking methods and thereby to come up with hybrid models. This combination allows us to take advantage of the complementary nature of the different techniques and benefit from the specific advantages of each method, thus offering a more robust and efficient approach to MCDM problems.

These hybrid models are becoming increasingly popular. Various studies have shown that hybrid models can improve the quality of decision-making by providing a more efficient and comprehensive evaluation of alternatives (25). This paper proposes a hybrid model for GSS. We decided to develop a new simplified and improved Fuzzy BWM for criteria weighting and the Fuzzy TOPSIS method for supplier ranking.

2.1 BWM development and applications

In 2015, J. Rezaei (26)criticized the well-known (AHP) method, highlighting in particular the problem of inconsistency in pairwise comparisons. To remedy this shortcoming, he proposed an alternative, the Best Worst Method (BWM), which is also based on pairwise comparisons, but with a reduced number of comparisons and more accurate results. In 2017, (27) argued that the BWM method cannot handle the ambiguity and uncertainty in expert judgment. To address this concern, they proposed the (Fuzzy BWM), which exhibits higher consistency in pairwise comparisons compared to the BWM method. (16) applied the FBWM with two other methods, COPRAS and WASPAS to select the optimal strategic supplier based on their environmental capabilities. In today's organizations, decision-makers (DMs) are often faced with an uncertain environment when making strategic and critical decisions. It is therefore necessary to use decision-making tools specially designed to cope with such conditions. For this reason, various theories have emerged, such as fuzzy set theory, D-numbers, rough theory, and grey theory, and are integrated into MCDM techniques(18). The literature contains various proposals for fuzzy MCDM, and BWM is no exception. (28) propose a novel extension of BWM based on hesitant fuzzy linguistic information to evaluate the performance of medical centers. (29) proposed a novel weighting technique based on BWM and fuzzy grey cognitive maps enabling interconnections between parameters to be considered. The proposed model is combined with an interval analysis approach to evaluate green suppliers. In 2020, (30) introduced Grey BWM (GBWM) using grey linguistic variables as input data. This proposal was accompanied by results demonstrating superior accuracy to (FBWM). In order to select the best intelligent vehicle service module, (31) Proposes a new rough-fuzzy BWM-DEA approach in which a group of decision-makers use rough-fuzzy numbers (RFN) to evaluate the selection criteria and subsequently obtain their corresponding weights using BWM, then an integrated Data Envelopment Analysis (DEA) is applied to rank the modules. (32) introduced a fuzzy approach for sustainable suppliers selection, using (BWM) and α-cut analysis. This method enables the evaluation of suppliers while considering varying levels of uncertainty by adjusting the α values. To validate the effectiveness of the proposed model, a case study is conducted involving three suppliers from an Iranian automotive company. The simplified BWM (SBWM) was first introduced in 2021 by Amiri et al. (21) to eliminates the need to solve the linear or nonlinear mathematical programming model in order to simplify the calculation. The results show a high level of robustness for weighting criteria compared to the original BWM. However, one of the most recent innovations in BWM is the study conducted by Amiri et al. in 2023(18), who proposed a fuzzy extension of the simplified BWM (F-SBWM) using TFNs. To demonstrate the effectiveness of the proposed approach, comparisons were made and the results show that it works exactly like the complex methods available in the literature.

2.2 FUZZY TOPSIS method and its application

TOPSIS Is a widely adopted group decision making method. It is first introduced by (23) in 1981. It is based on the concept that the best alternative should have the shortest distance, that is the Euclidian distance, from the ideal solution and the farthest distance from the negative ideal solution. In 2000, (33) proposed an extension of the classical TOPSIS method for collaborative decision-making in a fuzzy context. TOPSIS offers a robust and reliable approach for alternative ranking in multi-criteria decision making problem. It has several notable advantages, notably its ease of use and its ability to deliver accurate results. However, its main drawback lies in the need to determine the importance of the selection criteria. To overcome this limitation, TOPSIS is often combined with weighting techniques. (34) A study conducted in a Steel Company combined the use of Fuzzy TOPSIS with BWM to assess green suppliers on the basis of their green innovation capacity. Tu et al. (35) developed a hybrid fuzzy BWM-TOPSIS method to evaluate water resource security, taking into account the potential enhancement of people's quality of life. The study employed the Fuzzy BWM method to derive indicator weights. And the comparative analysis using the TOPSIS equal-weight method showed that the application of Fuzzy BWM give more accurate results. To address the issue of green supplier selection, (9) Flan proposed a hybrid approach based on the combination of the FAHP method for weighting criteria and three MCDM methods: Fuzzy-TOPSIS, Fuzzy-MABAC and Fuzzy-WASPAS for supplier evaluation and the three hybrid MCDM techniques yielded the same ranking of alternatives. D.Kannan et al. (36) also evaluated the green suppliers of a Brazilian electronics company based on (GSCM) practices. The study applied the Fuzzy TOPSIS method to rank the alternatives and compared the results with two other existing Fuzzy TOPSIS approaches. Recently a study (37) proposed a credit rating model that consider both financial and non-financial parameters. the suggested approach uses Fuzzy BWM to obtain the weight of criteria affecting creditworthiness, and proposes a new (fuzzy-TOPSIS)-Sort-C to assess the borrowers.

Table 1Summary of studies on development and applications of BWM-based methods

Reference	Year	Technique	Simplified approach	Group Decision-Making	uncertainty	Research area
(26)	2015	BWM	No	No	No	Numerical example
(27)	2017	Fuzzy BWM	No	No	Yes	Numerical Examples
(38)	2018	BWM	No	No	No	Cloud service selection
(28)	2019	Hesitant Fuzzy linguistic BWM	No	No	Yes	Hospital performance evaluation
(29)	2019	BWM+ Fuzzy Grey Cognitive Map (FGCM)	No	Yes	Yes	Green Supplier Selection
(30)	2020	Grey BWM	No	Yes	Yes	Numerical Examples
(35)	2020	Fuzzy BWM-TOPSIS	No		Yes	water resources security
(31)	2020	Rough-Fuzzy BWM-DEA	No	Yes	Yes	Smart Product Service Selection
(32)	2020	Fuzzy BWM+ α-cut analysis	No	Yes	Yes	Supplier selection
(39)	2020	Improved BWM (BWM-I)	No	No	No	Renewable Energy
(21)	2021	Simplified- BWM	Yes	No	No	Life cycle of buildings
(16)	2022	fuzzy BWM-WASPAS -COPRAS	No	No	Yes	Green Supplier Selection
(37)	2022	Fuzzy BWM + Fuzzy TOPSIS-Sort-C	No	No	Yes	Credit rating
(6)	2023	Simplified Group BWM (SGBWM)	Yes	Yes	No	stock portfolio selection
(18)	2023	Fuzzy Simplified BWM (FSBWM)	Yes	No	Yes	Numerical Examples
This paper	**2023**	**Improved and Simplified Group BWM – Fuzzy TOPSIS**	**Yes**	**Yes**	**Yes**	**Green Supplier Selection**

2.3 Research gap and main contribution

The main idea behind (BWM) is to identify the best criterion as well as the worst criterion from the set of selection criteria. However, in the context of complex decisions, particularly in problems reflecting reality, the decision-maker is confronted with multiple selection criteria, some of which may be of similar importance. As a result, designating a single optimal and unfavorable criterion becomes difficult (35). This issue also arises in green supplier selection problems, where economic and ecological criteria must be taken into account simultaneously. Both aspects are of paramount importance in the decision-making process. (35) proposed the (BWM-I) which takes this issue into account. However, it has the drawback of not handling uncertainty so for further improvement, it would be beneficial to integrate fuzzy set theory into its proposal. (27) emphasized the need to extend BWM to the fuzzy environment, in order to cope with the problems associated with the fuzziness of human thought. Consequently, he proposed the FBWM method. However, this method has a number of limitations. The main drawback lies in the complexity of the mathematical model required to obtain the optimal weights. In this context, Amiri et al. (18) has recently developed the (F-SBWM) method, which simplifies calculations using only simple fuzzy relations, without the need for specialized software or complex mathematical calculations to solve the programming model. However, it is possible to improve this model to solve a group MCDM problems and to take into account the possibility of dealing with multiple Best/Worst criteria.

On the other hand, the TOPSIS method is particularly appreciated for its ease of use and its ability to provide accurate rankings of alternatives according to multiple criteria. However, it has an obvious drawback when it comes to the importance of selection criteria. TOPSIS always assumes that the weights of the indicators are known, and are generally equal when the importance of the indicators varies (34). It is therefore necessary to combine it with a criteria weighting method for more precise and realistic results

After analyzing the literature review, none of the proposed approaches for addressing green supplier selection problems offers a comprehensive framework that fully meets all the requirements of the problem and simultaneously takes into account all the above-mentioned concerns. It seems judicious to us to develop a model that fills the aforementioned gaps. Indeed, a new Fuzzy BWM is proposed using TFNs to cope with uncertainty related problems and which takes into consideration multiple DMs and gives them the possibility to choose multiple "best" or/and "worst" from the list of selection criteria. Furthermore, the proposed method is based on a simplified approach using simple mathematical operation without the need to solve complex mathematical programming models. The proposed method, Fuzzy BWM, is combined with Fuzzy TOPSIS to obtain the final ranking of alternatives based on the optimal fuzzy weights generated. This combination allows us to take advantage of the benefits offered by each of these two methods.

3. METHOD

The following section describes the proposed methodology used to solve a group MCDM which is GSS problem. This paper proposes a hybrid model that employs a new Fuzzy BWM in combination with Fuzzy TOPSIS. The proposed Fuzzy BWM aims to find the optimal fuzzy weights of the selection criteria and then Fuzzy TOPSIS will be applied to evaluate and rank suppliers relying on the previously calculated fuzzy weights. The proposed framework is structured around 3 main phases: the first phase consists in collecting all the data required for the decision. A team of experts is formed, and a weighting is assigned to each member of the expert group according to his or her level of expertise. Then, on the basis of a detailed and extensive literature review, a set of selection criteria is identified. This list of criteria is then examined by the group of experts to identify the most relevant criteria to consider. In the second phase, the experts compare the selection criteria using the proposed Fuzzy BWM method, and finally obtain the optimum weight for each criterion. The final phase consists of evaluating the suppliers based on the calculated criteria weights and then obtaining the final ranking of the alternatives using the Fuzzy TOPSIS method.

The different stages of each method are detailed and presented later in this section.

3.1 Preliminary

Triangular Fuzzy Numbers (TFNs):

TFNs are widely employed in fuzzy set theory as one of the most popular types of fuzzy numbers. Unlike crisp numbers that possess precise values, fuzzy numbers encompass a range of potential values with varying degrees of membership to express uncertainty or imprecision in measurements.

A TFN $\tilde{A}$ is represented by the triplet $\tilde{A} = (l, m, u)$ where l < u; m, and u represents respectively, the lower, middle, and upper limit of the TFN $\tilde{A}$ (27).

The degree of membership of an element x in the fuzzy number is determined by the membership function μ(x), which ranges from 0 to 1 and is defined as:

$$\mu_{\tilde{A}}(x) = \begin{cases} \frac{x-l}{m-l}, & if\ l \leq x \leq m \\ u\frac{-x}{u-m}, & if\ if\ m \leq x \leq u \\ 0, & if\ x < l\ or\ x > u \end{cases}$$

mathematical operators of TFNs (40)

Let $\tilde{A} = (l_1, m_1, u_1)$ and $\tilde{B} = (l_2, m_2, u_2)$ two TFNs. The main operations of TFNs are presented below.

Addition $$\tilde{A} + \tilde{B} = (l_1 + l_2, m_1 + m_2, u_1 + u_2) \quad (1)$$

Soustraction $$\tilde{A} - \tilde{B} = (l_1 - l_2, m_1 - m_2, u_1 - u_2) \quad (2)$$

Multiplication $$\tilde{A} \times \tilde{B} = (l_1 l_2, m_1 m_2, u_1 u_2) \quad (3)$$

Division $$\frac{\tilde{A}}{\tilde{B}} = \left(\frac{l_1}{u_2}, \frac{m_1}{m_2}, \frac{u_1}{l_2}\right) \quad (4)$$

3.2 The proposed Fuzzy Simplified BWM for weight determination

the steps of the proposed fuzzy Simplified BWM are presented as follows:

Step 1: determine the set of selection criteria $\{C_1,\ C_2, \ldots C_n\}$

Step 2: Form the group of experts participating in this decision-making process and assign a relative weighting to each member of the expert panel, according to his or her level of expertise. The total sum of each group member's weight must be equal to one.

p_k indicates the weight of the k*th* DM

Step 3: Each member of the panel is asked to identify the best and worst criteria from the set of selection criteria. This amounts to identifying as many best and worst criteria as there are in the decision problem. $n_B^k$and n_W^kindicate respectively the number of criteria identified as best and worst by the k*th* decision-maker.

Step 4: Each DM is required to express his preferences in linguistic terms of the best criteria overs the others. These preferences will then be converted to a Triangular Fuzzy Numbers (TFNs) and are represented in the vector *AB*. Assuming that the k*th* decision-maker considered C_1 and C_2 as Best criteria, the *best-to-others vector* is expressed as: $AB^k = \left(n_B^k * \tilde{a}_{BB}, \tilde{a}_{B(n_B^k+1)}, \ldots, \tilde{a}_{Bn}\right)$

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

For $n_B^k = 1$ the vector of comparisons becomes identical to the one corresponding to the original BWM method

Step5: similarly, each DM is asked to express his preferences in linguistic terms of all criteria over the worst criteria. These preferences are converted to a (TFNs) and then represented in the vector *AW*.

Assuming that the k*th* decision-maker considered C_n and C_{n-1} as the worst criteria, then $n_W^k = 2$ and the *others-to-worst vector* is expressed as $AW^k = \left(\tilde{a}_{1W}, \tilde{a}_{2W}, \ldots, \tilde{a}_{(n-3)W}, \tilde{a}_{(n-2)W}, n_W^k * \tilde{a}_{nW}\right)$

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

For $n_W^k = 1$ the vector of comparisons becomes identical to the one corresponding to the original BWM method.

Step 6: For each DM, calculate criteria weight relative to *best-to-others vector* AB^k. And are denoted as: $\tilde{w}_i^{AB-k} = (l_i^{AB-k}, m_i^{AB-k}, u_i^{AB-k})$

According to the Fuzzy-SBWM principle (18), the optimal weight relative to *best-to-others vector* AB^k is the one that satisfies the following condition:$\tilde{w}_B/\tilde{w}_i = \tilde{a}_{Bi}$ and $\tilde{w}_i/\tilde{w}_W = \tilde{a}_{iW}$.

When n_B^k >1, (i.e. more than one criterion is considered as best), the procedure for calculating relative weights must be revised:

From $\tilde{w}_B^{AB-k}/\tilde{w}_i^{AB-k} = n_B\tilde{a}_{Bi}$ (1) and $\sum_i^n \tilde{w}_i = 1$ we obtain: $\tilde{w}_B^{AB-k} = \frac{1}{\sum \frac{1}{n_B * \tilde{a}_{Bi}}}$ (2)

Replacing the value of $\tilde{w}_B^{AB-k}$ in equation (1) we obtain the criteria weights relative to *best-to-others vector* AB^k: $\tilde{w}_i^{AB-k} = \frac{\tilde{w}_B^{AB-k}}{n_B * \tilde{a}_{Bi}}$ (3)

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It is important to note that: $\widetilde{w}_B^{AB-k}$ represents the sum of the weights of all the criteria that are considered as best criteria: $\widetilde{w}_B^{AB-k} = \sum_{i=1}^{n_B^k} \widetilde{w}_i$. (4)

Step 7 : For each DM, calculate criteria weight relative to *others-to-worst vector* AW^k. And are denoted as: $\widetilde{w}_i^{AW-k} = (l_i^{AW-k}, m_i^{AW-k}, u_i^{AW-k})$.

Similarly, using equation (5) we calculate the relative weight of the worst criterion, then replace its value in equation (6) to obtain criteria weight relative to *others-to-worst vector*.

$$\widetilde{w}_W^{AW-k} = \frac{1}{\sum n_W * \tilde{a}_{iW}} \quad (5)$$

$$\widetilde{w}_i^{AW-k} = \widetilde{w}_W^{AW-k} * n_W * \tilde{a}_{iW} \quad (6)$$

It is important to note that: $\widetilde{w}_W^{AW-k}$ represents the sum of the weights of all the criteria that are considered as worst criteria: $\widetilde{w}_W^{AW-k} = \sum_{i=1}^{n_W^k} \widetilde{w}_i$. (7)

Step 8 : The aggregation of the relative weights of the selection criteria, taking into account the importance of each DM. The aggregated weight of the criteria is obtained according to the following equations: $\widetilde{w}_i^{AB} = \prod(\widetilde{w}_i^{AB-k})^{p_k}$ (8) and $\widetilde{w}_i^{AW} = \prod(\widetilde{w}_i^{AW-k})^{p_k}$ (9)

Step 9: The calculation of the final weights of selection criteria is obtained from the aggregated relative weights obtained in step 8. using the following equation: $\widetilde{w}_i^* = \frac{\widetilde{w}_i^{AB} + \widetilde{w}_i^{AW}}{2}$ (10)

consistency testing

MCDM methods help to evaluate and prioritize different criteria through pairwise comparisons. However, if the comparisons made are not consistent, this can lead to inaccurate and biased results. Consistency testing helps to detect any inconsistencies in individual judgments, and to ensure the validity of the results obtained. The proposed method is not an exception and a consistency test is required. It is calculated using Equation (11). The comparisons are more consistent when the value obtained is closer to zero.

$$CR = \sum_i \left|\widetilde{w}_i^{AB} - \widetilde{w}_i^{AW}\right|^2 \quad (11)$$

to facilitate calculations, the fuzzy weights obtained can be converted into crisp weights using the following formula $w_i^* = \frac{l + 4*m + u}{6}$ or any other defuzzification method.

Fuzzy TOPSIS for alternative ranking

Table 2 Linguistic terms for alternative evaluations and their corresponding triangular fuzzy numbers

Linguistic assessment	Crisp value	Fuzzy triangular scale
Very Poor (VP)	1	(1,1,3)
Poor (P)	3	(1,3,5)
Fair (F)	5	(3,5,7)
Good (G)	7	(5,7,8)
Very Good (VG)	9	(7,9,9)

The calculation steps of Fuzzy TOPSIS according to (41) are presented below:

Step1: Construct the fuzzy decision matrix D with *m* alternatives and *n* criteria by converting linguistic preferences into TFNs using table2

$$D = \begin{bmatrix} \widetilde{x_{11}} & \widetilde{x_{12}} & \dots & \widetilde{x_{1n}} \\ \widetilde{x_{21}} & \widetilde{x_{22}} & \dots & \widetilde{x_{2n}} \\ \dots & \dots & \dots & \dots \\ \widetilde{x_{m1}} & \dots & \dots & \widetilde{x_{mn}} \end{bmatrix} \quad \text{where}$$

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

Step2: Create the weighted normalized fuzzy decision matrix by selecting cost and benefit criteria from the set of selection criteria.

The matrix is presented as $\tilde{R} = [\widetilde{r_{ij}}]_{mxn}$,

i=1, 2,…,m ; j=1,2,…,n where:

$$\widetilde{r_{ij}} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right) \text{ and } c_j^* = \max_i c_{ij} \quad (12)$$

(benefit criteria)

$$\widetilde{r_{ij}} = \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}}\right) \text{ and } a_j^- = \min_i a_{ij} \quad (13)$$

(cost criteria)

Next, multiply the normalized matrix by the weights of each criterion calculated using the Fuzzy BWM method.

Step3: determine the Fuzzy positive ideal FPIS (A+) and Fuzzy negative ideal FNIS (A-) :

$$A^+ = (v_1^+, v_2^+ \dots, v_n^+) \quad (14)$$
$$A^- = (v_1^-, v_2^- \dots, v_n^-) \quad (15)$$

Where:

$$v_j^+ = \max(\widetilde{v_{ij}}) \quad (16)$$
$$v_j^- = \min(\widetilde{v_{ij}}) \quad (17)$$

Step 4: Calculate the distance of each alternative from both (FPIS) and (FNIS) using the following equations:

$$d_i^+ = \left\{\sum_{j=1}^{n}(v_{ij} - v_{ij}^+)^2\right\}^{1/2}, i = 1 \dots m \quad (18)$$
$$d_i^- = \left\{\sum_{j=1}^{n}(v_{ij} - v_{ij}^-)^2\right\}^{1/2}, i = 1 \dots m \quad (19)$$

Step5: The closeness coefficient is determined by the proximity to both (FPIS) and (FNIS) and is computed using the following formula:

$$CC_i = \frac{d_i^-}{d_i^- + d_i^+} \quad (19)$$

4. A REAL CASE STUDY OF GREEN SUPPLIER SELECTION

In order to test the applicability and practicality of the model proposed in this paper, we carried out a real case study with real data, in a company operating in the building materials manufacturing sector. The choice of this industrial sector is not arbitrary, but is due to the fact that it is one of the most polluting sectors in Morocco, according to the Moroccan Ministry of the Environment. The identity of the company will not be revealed for confidentiality reasons, and will be referred to as ABC. ABC is a major player in the Moroccan construction industry, specializing in the manufacture of ceramic tiles. Backed by decades of experience, it has positioned itself as a leader by offering a wide range of high-quality ceramic tiles. Their products combine aesthetics, durability and functionality, meeting customers' needs and requirements. As part of a case study on the application of GSS model, this company stands out for its commitment to environmental sustainability. It actively seeks out suppliers who share its ecological values, focusing on the use of sustainable raw materials, the reduction of CO2 emissions and the implementation of environmentally-friendly practices throughout the supply chain. This case study will enable the company to evaluate three potential suppliers by integrating ecological criteria into its supplier selection process, thus helping to reinforce its positioning as a socially responsible company.

4.1. Phase 1: data collection

Expert group

An expert panel of four professionals is involved in the Green Supplier evaluation process. The composition of the panel has been carefully worked out. Each member of the panel has considerable experience in the construction materials manufacturing field. The stakeholders involved in this project assign a weighting to each panel member by taking into consideration various parameters such as their level of expertise, academic qualification, and the recommendations of their colleagues. This approach ensures a balanced assessment and incorporates the perspectives and specialist knowledge of each expert into the decision-making process. Table3 shows the evaluation details of the experts.

Table 3information of DMs

Expert	Professional experience	Academic qualifications	Participation in similar projects	Reputation and recommendations	Weight
DM1	4	3	5	5	0.274
DM2	4	4	4	4	0.260
DM3	3	5	2	4	0.225
DM4	4	5	2	4	0.241

Criteria Selection:

A rigorous approach is used to identify the selection criteria. The choice of criteria must take into account the characteristics of the industrial sector studied and must meet the needs of decision-makers. A literature review is undertaken by consulting scientific articles related to the supplier selection issue, El Bettioui et al., (42), carried out a study aiming to identify the most relevant selection criteria to consider when evaluating green suppliers in building materials industry. In parallel, in-depth discussions are held

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with expert members of the group, in order to benefit from their knowledge and practical experience in the field. In this case study, we opted for three economic and seven ecological criteria. Cost (C1), quality (C2), delivery (C3), Air emission (C4), Waste water (C5), Use of harmful materials (C6), Green packaging (C7), Recycle (C8), Environmental Management Information System (C9), ISO 14001 certification (C10).

4.2. Phase 2: criteria Weighting

Each member of the expert group identifies the criteria considered as "best" and "worst" from the set of selection criteria and expresses the priorities in linguistic terms according to Table4. Table5 summarizes the pairwise comparisons made by the 4 DMs. It is important to note that CR is calculated for each DM to test consistency of the comparisons made.

Table 4 linguistic terms for criteria comparison

Linguistic terms	Fuzzy scales
Equally importance (EI)	(1,1,3)
Weakly important(WI)	(1,3,5)
Fairly Important (FI)	(3,5,7)
Very important(VI)	(5,7,8)
Absolutely important(AI)	(7,8,9)

A high CR will prompt the DM to correct his preferences. Table5 shows that all the DMs agreed on the choice of the best criterion (C2 and C9) except for DM2, who identified C2, C3 and C9 as "best". And all the DMs have identified a single "worst" criterion, which is C4, except for DM2, who identified two "worst" criteria, C4 and C5.

Table 5 pairwise comparisons

		Cost C1	**Quality C2**	**Delivery C3**	**Air emission C4**	**Waste water C5**	**Use of harmful material C6**	**Green packaging C7**	**Recycle C8**	**EMS C9**
DM1	C_B: C2 C9	(3,2,4)	(1,1,1)	(3,4,5)	(5,6,7)	(7,8,9)	(4,5,6)	(5,6,7)	(6,7,8)	(1,1,1)
	C_W: C5	(6,7,8)	(7,8,9)	(5,6,7)	(3,4,5)	(1,1,1)	(5,6,7)	(4,5,6)	(2,3,4)	(7,8,9)
DM2	C_B :C3 C2 C9	(3,4,5)	(1,1,1)	(1,1,1)	(7,8,9)	(7,8,9)	(2,3,4)	(4,5,6)	(4,5,6)	(1,1,1)
	C_W: C5 C4	(5,6,7)	(7,8,9)	(6,7,8)	(1,1,1)	(1,1,1)	(5,6,7)	(3,4,5)	(4,5,6)	(7,8,9)
DM3	C_B :C2 C9	(2,3,4)	(1,1,1)	(2,3,4)	(6,7,8)	(7,8,9)	(3,4,5)	(5,6,7)	(4,5,6)	(1,1,1)
	C_W: C5	(5,6,7)	(7,8,9)	(5,6,7)	(2,3,4)	(1,1,1)	(5,6,7)	(4,5,6)	(6,7,8)	(7,8,9)
DM4	C_B :C2 C9	(1,2,3)	(1,1,1)	(1,2,3)	(6,7,8)	(7,8,9)	(2,3,4)	(4,5,6)	(3,4,5)	(1,1,1)
	C_W: C5	(6,7,8)	(7,8,9)	(6,7,8)	(2,3,4)	(1,1,1)	(6,7,8)	(4,5,6)	(5,6,7)	(7,8,9)

To calculate $\widetilde{w}_i^{AB-k}$, the Fuzzy weights of the criteria relative to best-to-others vector for the k*th* DM, we must first find the Fuzzy weight of the best criteria $\widetilde{w}_B^{AB-k}$ according to equation 2. and then by replacing this weight in equation 3 we obtain the desired criteria weights.

$$\widetilde{w}_B^{AB-1} = \frac{1}{\sum \frac{1}{n_B * \tilde{a}_{Bi}}} = \frac{1}{\frac{1}{2}*\left(\frac{1}{(2,3,4)}+\frac{2}{(1,1,1)}+\frac{1}{(3,4,5)}+\frac{1}{(5,6,7)}+\frac{1}{(7,8,9)}+\frac{1}{(4,5,6)}+\frac{1}{(5,6,7)}+\frac{1}{(6,7,8)}\right)} = (0.527, 0.59, 0.637)$$

$$\widetilde{w}_1^{AB-1} = \frac{\widetilde{w}_B^{AB-1}}{n_B * \tilde{a}_{B1}} = \frac{(0.527,0.59,0.637)}{2*(2,3,4)} = (0.066, 0.098, 0.159)$$

$$\widetilde{w}_3^{AB-1} = \frac{\widetilde{w}_B^{AB-1}}{n_B * \tilde{a}_{B3}} = \frac{(0.527,0.59,0.637)}{2*(3,4,5)} = (0.053, 0.074, 0.106)$$

$$\widetilde{w}_4^{AB-1} = \frac{\widetilde{w}_B^{AB-1}}{n_B * \tilde{a}_{B4}} = \frac{(0.527,0.59,0.637)}{2*(5,6,7)} = (0.038, 0.049, 0.064)$$

$$\widetilde{w}_5^{AB-1} = \frac{\widetilde{w}_B^{AB-1}}{n_B * \tilde{a}_{B5}} = \frac{(0.527,0.59,0.637)}{2*(7,8,9)} = (0.029, 0.037, 0.046)$$

$\widetilde{w}_6^{AB-1} = \frac{\widetilde{w}_B^{AB-1}}{n_B * \tilde{a}_{B6}} = \frac{(0.527,0.59,0.637)}{2*(4,5,6)}$=(0.044, 0.059, 0.080)

$\widetilde{w}_7^{AB-1} = \frac{\widetilde{w}_B^{AB-1}}{n_B * \tilde{a}_{B7}} = \frac{(0.527,0.59,0.637)}{2*(5,6,7)}$=(0.038, 0.049, 0.064)

$\widetilde{w}_8^{AB-1} = \frac{\widetilde{w}_B^{AB-1}}{n_B * \tilde{a}_{B8}} = \frac{(0.527,0.59,0.637)}{2*(6,7,8)}$=(0.033, 0.042, 0.053)

$\widetilde{w}_2^{AB-1} = \widetilde{w}_9^{AB-1} = \frac{1}{2} * \widetilde{w}_B^{AB-1}$= (0.264, 0.295, 0.319)

in order to obtain $\widetilde{w}_i^{AW-k}$, the fuzzy weights of the criteria with respect to the best-to-others vector for the kth DM, we first need to find the fuzzy weight of the worst criterion $\widetilde{w}_W^{AW-k}$ from equation 5. then by substituting this weight in equation 6, we obtain the weights of the desired criteria.

$\widetilde{w}_W^{AW-1} = \widetilde{w}_5^{AW-1} = \frac{1}{\sum n_W * \tilde{a}_{iW}} = \frac{1}{(6,7,8)+(7,8,9)+(5,6,7)+(3,4,5)+(1,1,1)+(5,6,7)+(4,5,6)+(2,3,4)+(7,8,9)} =$ $(0.017, 0.020, 0.025)$

$\widetilde{w}_1^{AW-1} = \widetilde{w}_W^{AW-1} * n_W * \tilde{a}_{1W}$ =1*(0.017,0.02,0.025) * (6,7,8) = (0.107, 0.146, 0.200)

$\widetilde{w}_2^{AW-1} = \widetilde{w}_W^{AW-1} * n_W * \tilde{a}_{2W}$ =1*(0.017,0.02,0.025) * (7,8,9) = (0.125, 0.167, 0.225)

$\widetilde{w}_3^{AW-1} = \widetilde{w}_W^{AW-1} * n_W * \tilde{a}_{1W}$ =1*(0.017,0.02,0.025) * (5,6,7) = (0.089, 0.125, 0.175)

$\widetilde{w}_4^{AW-1} = \widetilde{w}_W^{AW-1} * n_W * \tilde{a}_{4W}$ =1*(0.017,0.02,0.025) * (3,4,5) = (0.054, 0.083, 0.125)

$\widetilde{w}_6^{AW-1} = \widetilde{w}_W^{AW-1} * n_W * \tilde{a}_{6W}$ =1*(0.017,0.02,0.025) * (5,6,7) = (0.089, 0. 125, 0.175)

$\widetilde{w}_7^{AW-1} = \widetilde{w}_W^{AW-1} * n_W * \tilde{a}_{7W}$ =1*(0.017,0.02,0.025) * (4,5,6) = (0.071, 0.104, 0.150)

$\widetilde{w}_8^{AW-1} = \widetilde{w}_W^{AW-1} * n_W * \tilde{a}_{8W}$ =1*(0.017,0.02,0.025) * (2,3,4) = (0.036, 0.063, 0.100)

$\widetilde{w}_9^{AW-1} = \widetilde{w}_W^{AW-1} * n_W * \tilde{a}_{9W}$ =1*(0.017,0.02,0.025) * (7,8,9) = (0.125, 0.167, 0.225)

A similar procedure is used to obtain the relative fuzzy weights for the remaining members of the expert team. The next step is to aggregate the relative weights previously calculated for the four experts using equations 8 and 9, while taking into account the importance of each expert. The final fuzzy weights for the selection criteria are obtained using equation 10 and are shown in Table 6.

Table 6 final weight of criteria

		Cost C1	**Quality C2**	**Delivery C3**	**Air emission C4**	**Waste water C5**	**Use of harmful material C6**	**Green packaging C7**	**Recycle C8**	**EMS C9**
DM 1	$\widetilde{w}_i^{AB-1}$	(0.066, 0.098, 0.159)	(0.26, 0.295, 0.319)	(0.053, 0.074, 0.106)	(0.038, 0.049, 0.064)	(0.03, 0.037, 0.046)	(0.044, 0.059, 0.080)	(0.038, 0.049, 0.064)	(0.033, 0.042, 0.053)	(0.264, 0.295, 0.319)
	$\widetilde{w}_i^{AW-1}$	(0.107, 0.146, 0.200	0.125, 0.167, 0.225	0.089, 0.125, 0.175	0.054, 0.083, 0.125	0.018, 0.021, 0.025	0.089, 0.125, 0.175)	0.071, 0.104, 0.150	0.036, 0.063, 0.100	0.125, 0.167, 0.225
DM 2	$\widetilde{w}_i^{AB-2}$	(0.043, 0.059, 0.083)	(0.21, 0.236, 0.25)	(0.216, 0.236, 0.250)	(0.024, 0.030, 0.036)	(0.024, 0.03, 0.04)	(0.054, 0.079, 0.125)	(0.036, 0.047, 0.062)	(0.036, 0.047, 0.062)	(0.216, 0.236, 0.250)
	$\widetilde{w}_i^{AW-2}$	(0.094, 0.130, 0.179)	(0.13, 0.174, 0.231)	(0.113, 0.152, 0.205)	(0.019, 0.022, 0.026)	(0.02, 0.022, 0.026)	(0.094, 0.130, 0.179)	(0.057, 0.087, 0.128)	(0.075, 0.109, 0.154)	(0.132, 0.174, 0.231)

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DM 3	$\widetilde{w}_i^{AB-3}$	(0.061, 0.094, 0.154)	(0.24, 0.282, 0.308)	(0.061, 0.094, 0.154)	(0.031, 0.040, 0.051)	(0.03, 0.035, 0.044)	(0.049, 0.070, 0.103)	(0.035, 0.047, 0.062)	(0.041, 0.056, 0.077)	(0.244, 0.282, 0.308)
	$\widetilde{w}_i^{AW-3}$	(0.086, 0.120, 0.167)	(0.12, 0.160, 0.214)	(0.086, 0.120, 0.167)	(0.034, 0.060, 0.095)	(0.017 ,0.02 ,0.024)	(0.086, 0.120, 0.167)	(0.069, 0.10, 0.143)	(0.103, 0.14, 0.190)	0.121, 0.16, 0.214)
DM 4	$\widetilde{w}_i^{AB-4}$	(0.062, 0.123, 0.284)	(0.185, 0.247, 0.284)	(0.062, 0.123, 0.284)	(0.023, 0.035, 0.047)	(0.021, 0.031, 0.041)	(0.046, 0.082, 0.142)	(0.03, 0.049, 0.071)	(0.037, 0.062, 0.095)	(0.185, 0.247, 0.284)
	$\widetilde{w}_i^{AW-4}$	(0.100, 0.135, 0.182)	(0.117, 0.154, 0.205)	(0.100, 0.135, 0.182)	(0.033, 0.058, 0.091)	(0.017, 0.02, 0.023)	(0.100, 0.135, 0.182)	(0.067, 0.096, 0.136)	(0.083, 0.115, 0.159)	(0.117, 0.154, 0.205)
Final weights		**0,117**	**0,214**	**0,132**	**0,045**	**0,027**	**0,102**	**0,074**	**0,080**	**0,214**

The consistency test:

After obtaining the fuzzy relative weights by applying the proposed Fuzzy BWM, the consistency rate CR is calculated to check the consistency of each DM's preferences. Applying equation 11, the values 0.042 0.023 0.043 and 0.021 represent respectively the consistency rate CR for DM1, DM2, DM3 and DM4. The values obtained are very low, indicating a high degree of consistency in the results.

4.3. Phase 3: Green Suppliers Ranking

In this section, an assessment of green suppliers is carried out through the application of the Fuzzy TOPSIS method to attain the final supplier ranking. The initial step involves the creation of a supplier evaluation matrix. Each member within the expert group individually provides their linguistic assessment of the performance of potential Green Suppliers against each criterion. These evaluations are then translated into triangular fuzzy numbers based on the guidelines outlined in Table 2. Then the collective judgments of all experts are aggregated into a unified decision matrix, reflecting a single consensus. This matrix is then normalized using equations 12 and 13, after determining the "cost" and "benefit" criteria. Next comes the construction of the weighted normalized fuzzy decision matrix, resulting from the multiplication of the normalized matrix and the weights of the criteria previously calculated using the proposed Fuzzy BWM and the results are shown in table7.

The final step is to calculate the closeness coefficient for each green supplier by determining the closeness of both the (FPIS) and the (FNIS) using equation14 in order to obtain the final ranking of alternatives. The results are shown in table8.

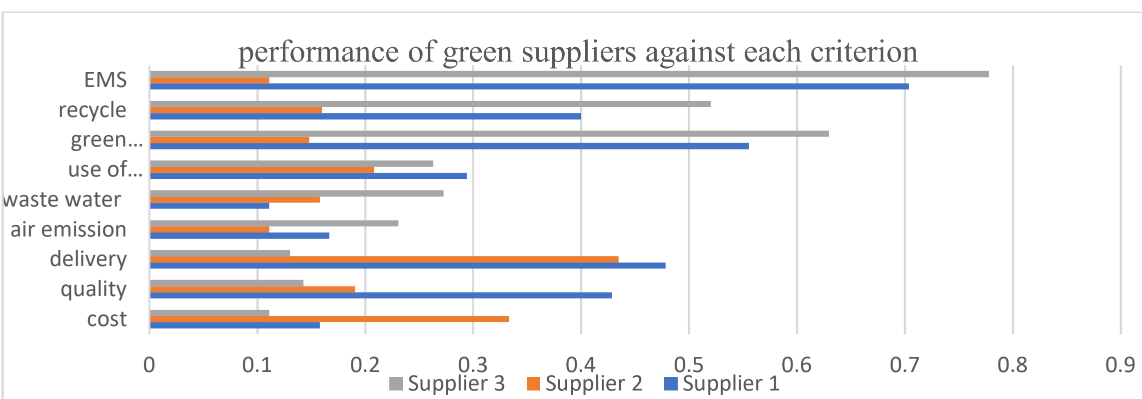

Figure 1 performance of green suppliers against each criterion

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Table 7 the Weighted and Normalized fuzzy aggregated decision matrix

	Cost C1	Quality C2	Delivery C3	Air emission C4	Waste water C5	Use of harmful material C6	Green packaging C7	Recycle C8	EMS C9
GS1	(0.0185, 0.027, 0.05)	(0.0917, 0.1529, 0.214)	(0.063, 0.098, 0.132)	(0.008, 0.010, 0.017)	(0.003, 0.004, 0.004)	(0.030, 0.046, 0.102)	(0.041, 0.058, 0.074)	(0.032, 0.048, 0.064)	(0.151, 0.198, 0.214)
GS2	(0.039, 0.117, 0.117)	(0.0408, 0.051, 0.06114)	(0.057, 0.075, 0.092)	(0.005, 0.006, 0.008)	(0.004, 0.005, 0.006)	(0.021, 0.027, 0.032)	(0.011, 0.014, 0.016)	(0.013, 0.016, 0.026)	(0.024, 0.024, 0.040)
GS3	(0.013, 0.0153, 0.0206)	0.0306, 0.0917, 0.152)	(0.017, 0.029, 0.063)	(0.010, 0.019, 0.045)	(0.007, 0.016, 0.027)	(0.027, 0.039, 0.073)	(0.047, 0.063, 0.074)	(0.042, 0.061, 0.080)	(0.166, 0.214, 0.214)

Table 8 the final ranking of the three Green Suppliers

	d+	d-	CC	Ranking
GS1	0,1288	0,477	0,787	1
GS2	0,478	0,1288	0,212	3
GS3	0,223	0,3838	0,6325	2

4.4. Comparison with Existing Weighting Criteria methods

In order to test and validate the effectiveness of our proposed approach to criteria weighting, we carried out a comparative study. This involved calculating optimal criteria weights using two distinct BWMs available in the literature. The first is the fuzzy BWM proposed by (27), who was the pioneer in developing a fuzzy extension of the traditional BWM. The second method is that proposed by (6), which is a new Simplified Group BWM model. As a means of comparison, we chose to evaluate both the Consistency Rate (CR) and the Total Deviation (TD) rates. The comparison results are shown in Table 9. The Total deviation (TD) rates is a widely recognized measure. It is commonly used in the field of (MCDM) to facilitate the comparative evaluation of different methods. Its primary objective is to assess the level of acceptability of the results produced by different approaches. A lower TD value means a higher degree of consistency with the judgments provided by DMs, underlining the consistency and reliability of the results produced by the respective methods(18). The TD is calculated using the following equation :

$$TD = \sum_i (\tilde{a}_{Bi} - \frac{\tilde{w}_B^*}{\tilde{w}_i^*})^2 + \sum_i (\tilde{a}_{iW} - \frac{\tilde{w}_i^*}{\tilde{w}_W^*})^2 \quad (15)$$

Table 9comparison of final weights obtained using three different methods

Approach		Criteria Weights									CR	TD
		C1	C2	C3	C4	C5	C6	C7	C8	C9		
Proposed Fuzzy BWM	Fuzzy weights	(0.1, 0.102, 0.2)	(0.113, 0.197 0.392)	(0.098, 0.141, 0.143)	(0.027, 0.05, 0.06)	(0.022, 0.04, 0.08)	(0.082, 0.099, 0.122)	(0.058, 0.089, 0.1)	(0.057, 0.073, 0.122)	(0.113, 0.197 , 0.392)	0.045	64.16
	Crisp weights	**0.117**	**0.214**	**0.132**	**0.048**	**0.027**	**0.102**	**0.074**	**0.08**	**0.214**		
Fuzzy BWM(27)	Fuzzy weights	(0.13, 0.202, 0.22)	(0.173, 0.377 0.411)	(0.197, 0.241, 0.343)	(0.031, 0.058, 0.081)	(0,012, 0.051, 0.07)	(0.108, 0.159, 0.243)	(0.073, 0.089, 0.136)	(0.07, 0.113, 0.182)	(0.18, 0.229, 0.324)	0.098	65.68
	Crisp weights	**0.195**	**0.341**	**0.251**	**0.054**	**0.041**	**0.187**	**0.096**	**0.124**	**0.281**		

SGBWM(6)	**Crisp weights**	**0.175**	**0.257**	**0.212**	**0.067**	**0.054**	**0.137**	**0.087**	**0.102**	**0.214**	0.067	142.01

Analysis of the results revealed a significant finding: although the weighting values differed between the three methods, the relative ranking of the criteria remained remarkably consistent and similar. This consistency suggests a convergence of perspectives, indicating that despite variations in the weightings, the criteria were evaluated in a similar way in terms of importance and contribution to the decision. We succeeded in obtaining weights for the selection criteria relatively close to those obtained by the Fuzzy BWM(27) without needing to formulate complex mathematical models or use optimization software, but simply by performing simple calculations. In addition, the proposed method demonstrated superior performance in terms of consistency rate (CR) and Total Deviation rate (TD). The lower CR and TD values obtained with the proposed method attest to the robustness and stability of this new approach to weighting construction, reinforcing its potential as a Fuzzy MCDM tool.

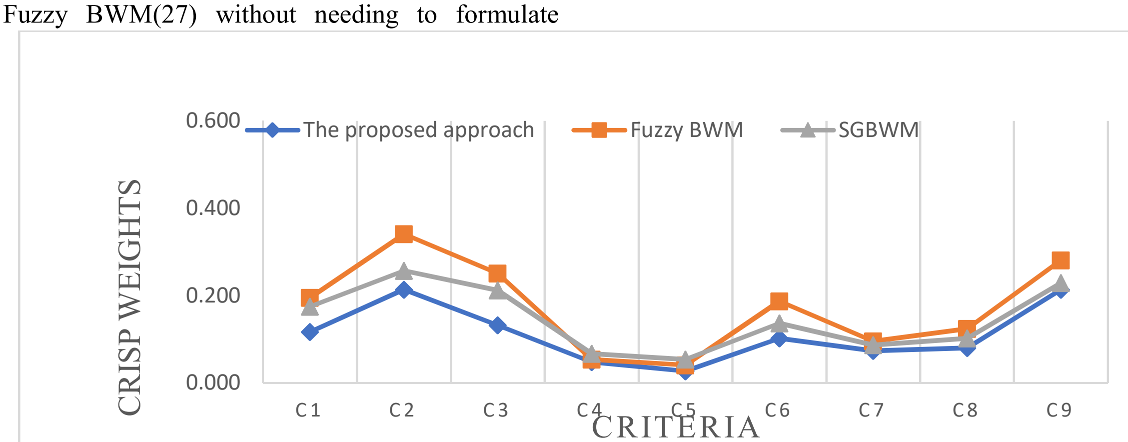

Figure 2 comparison of final criteria weights using 3 different methods

5. DISCUSSION

In this case study, three green suppliers are evaluated on the basis of ecological and economic criteria. For weighting the selection criteria, we proposed in this paper a new approach which is an improvement of the Fuzzy BWM method. The classic F.BWM method proposed by (27) calculates fuzzy weights by solving a mathematical program model, which is a complex task and requires specific optimization software. The results obtained showed that the proposed method succeeded in obtaining weights relatively close to those obtained by the classic F.BWM by performing simple mathematical operations. The criteria are thus classified in the following order: C2=C9>C3>C1>C6>C8>C7>C4>C5. We note that C2 and C9 have equal weights according to our method, unlike the other two methods. This difference can be justified by the fact that the proposed model offers decision-makers the possibility of choosing multiple "best" and "worst" criteria. Indeed, in the case of complex decision-making problems involving a large number of decision criteria, some criteria may exert the same influence and have the same degree of importance. It is therefore not easy to identify a single criterion as being the best or the worst. The classical F.BWM does not offer this possibility, and requires the identification of a single "best" and a single "worst". So the proposed F.BWM is more realistic and better reflects reality, allowing decision-makers to freely express their preferences. The differences in weightings obtained by the different methods applied can also be explained by the fact that the classic F.BWM considers the opinion of a single decision-maker, whereas our proposed method involves four decision-makers, each of whom has been assigned a weighting according to his or her degree of expertise.

After evaluating the selection criteria, we applied the Fuzzy TOPSIS method to rank the suppliers on the basis of the weights already calculated. The ranking results in the following order: GS1, followed by GS3, then GS2. The performance of green suppliers against each criterion are presented in figure2. GS2 occupies last place in the ranking, although it stands out for its competitive pricing. However, it performs less well in terms of ecological criteria, raising concerns about its environmental impact. Although price is an important factor, ecological performance also plays a crucial role in supplier selection, particularly in an environmentally-oriented context. GS3: Although this supplier ranks second, it particularly stands out in terms of ecological criteria, being the best performer on ecological criteria when compared with its competitors. However, it performs relatively poorly in terms of economic criteria such as price, quality and delivery time. This indicates that supplier 3 is more oriented towards ecological practices, but may need improvement in other aspects to better meet the economic needs of managers. Figure 2 shows that GS1, in first place in the ranking, excels in terms of both economic and ecological criteria. This means that, compared with other suppliers, it offers a good balance between price, quality and delivery time, while meeting environmental criteria such as eco-friendly packaging, ecological certifications, recycling and reduction of pollutant emissions. It can be seen as a solid, balanced choice that meets managers' economic and ecological objectives.

By carefully analyzing the literature review to identify similar methodologies and claims, we have compiled the results in Table 1. This synthesis of studies on the development and applications of BWM-based methods highlights a gap: to date, no BWM-based method simultaneously addresses the following four challenges: a simplified approach, flexibility in criteria selection, consideration of multiple decision-makers and uncertainty management. And now, following the case study conducted, it is now apparent that the proposed approach stands out for several significant improvements while addressing the four challenges mentioned above.

Although the (fuzzy BWM) method introduced by (27) is effective for dealing with uncertainty in decision-making problems, its main drawback lies in its complexity to solve. In this context, (18) recently developed the (F-SBWM) method, which simplifies calculations by using only simple fuzzy relations, without the need to solve complex mathematical models. However, it is possible to improve this model to solve group decision-making problems and to take into account the possibility of dealing with multiple "Best/Worst" criteria. (39) proposed the (BWM-I) method, which has the capacity to accommodate multiple "best" and "worst" criteria. However, it has the disadvantage of not handling uncertainty.

The method we propose in this article is an innovative methodology that introduces an improved and simplified (BWM)-based approach to solving decision-making and criteria weighting problems in particular, while simultaneously addressing the four challenges outlined above. Firstly, unlike traditional methods, it does not require the resolution of complex mathematical models, which improves its accessibility and applicability in real-life decision-making. Secondly, flexibility in criteria selection: one of the significant advances of our method lies in its ability to accommodate multiple "best" and "worst" criteria. This flexibility resolves a common limitation of previous approaches, which generally required the identification of a single "best" and "worst" criterion. Finally, by taking advantage of FST, our approach effectively deals with uncertainty in decision-making, offering a robust framework for handling imprecise or ambiguous information.

These significant improvements considerably enhance the practicality and effectiveness of our proposed methodology.

6. CONCLUSION

This research paper presents an innovative model to address the complex challenge of Group multi-criteria decision-making, specifically in green supplier selection. By integrating economic and ecological criteria, our model aims to offer a comprehensive approach that meets companies' growing sustainability needs, while preserving their operational efficiency.

The GSS model we have developed is based on three key phases. Initially, the collection of essential data made it possible to bring together the members of the group of experts involved in the decision-making process, as well as the set of selection criteria to be taken into account and the potential suppliers to be evaluated. The selection criteria were then weighted using an Improved Fuzzy BWM method proposed in this paper. Finally, suppliers were ranked using the Fuzzy TOPSIS method, taking into account the fuzzy weights of the criteria previously calculated.

The Fuzzy BWM model proposed here offers significant improvements over the traditional method. This improvement lies in its ability to handle group decision-making problems involving multiple DMs with different levels of expertise. In addition, our method allows the identification of several "best" and "worst" criteria, instead of being

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limited to a single "best" and "worst". Moreover, our method simplifies the calculation of weights, eliminating the mathematical complexities associated with the classical method. The final Fuzzy weights are obtained by performing simple calculations without needing to formulate complex mathematical models or use optimization software.

To validate the proposed Fuzzy BWM, we conducted a comparative study by calculating optimal criteria weights using two separate BWM methods available in the literature; the classic Fuzzy BWM(27) and SGBWM(6). The results of applying the improved Fuzzy BWM method showed remarkable agreement with the traditional method, both in terms of the weights assigned to the criteria and the ranking of criteria. Furthermore, the lower values of the consistency index (CR) confirmed the robustness and consistency of the proposed method.

In summary, our GSS model makes a significant contribution to Green supply chain management. It enables companies to make informed decisions by taking into account a variety of economic and environmental considerations. As companies adapt to a constantly changing business environment, our model offers a flexible and adaptive approach to achieving environmental goals while maintaining economic competitiveness.

7. LIMITATION AND FUTURE WORK

This paper has enriched the literature by proposing a robust model for Group MCDM in the field of green supplier selection. Despite the various benefits derived from improving the Fuzzy BWM method, this GSS model, as with any research, does present certain limitations and there are areas that might warrant critique. Firstly, Critics might raise questions about the sensitivity of the propose method to different scenarios or datasets. An exploration of how varying inputs or conditions might impact the results could add robustness to your approach. Secondly, the selection criteria used in this model were selected on the basis of a literature review and following interviews with members of the expert team, thus they are specific to the building materials sector and may not be valid for other industrial sectors. furthermore, the interaction between these criteria is not taken into account in this approach. It is important to recognize these limitations and take them into account in future studies. Thus, in order to contribute to the advancement and further promotion of MCDM methods, we propose to extend the range of economic and ecological criteria used in this paper and to consider different industries and economic contexts. Furthermore, the proposed fuzzy BWM can be extended to other uncertain environments using different fuzzy numbers such as Type 2 fuzzy sets, hesitant fuzzy sets (HFS) and intuitionistic fuzzy sets (IFS).

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