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A Comparative Analysis Approach Based on Fuzzy AHP, TOPSIS and PROMETHEE for the Selection Problem of GSCM Solutions

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Abstract**—**Sustainable economic growth is nowadays driving firms to extend toward the adoption of many green supply chain management (GSCM) solutions. However, the evaluation and selection of these solutions is a matter of concern that needs very serious decisions, involving complexity owing to the presence of various associated factors. To resolve this problem, a comparative analysis approach based on multi-criteria decision-making methods is proposed for adequate evaluation of sustainable supply chain management solutions. In the present paper, we propose an integrated decision-making model based on FAHP (Fuzzy Analytic Hierarchy Process), TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) and PROMETHEE (Preference Ranking Organisation METHod for Enrichment Evaluations) to contribute to a better understanding and development of new sustainable strategies for industrial organizations. Due to the varied importance of the selected criteria, FAHP is used to identify the evaluation criteria and assign the importance weights for each criterion, while TOPSIS and PROMETHEE methods employ these weighted criteria as inputs to evaluate and rank the alternatives. The main objective is to provide a comparative analysis based on TOPSIS and PROMETHEE processes to help make sound and reasoned decisions related to the selection problem of GSCM solution.

Keywords**—**GSCM solutions, multi-criteria analysis, FAHP, TOPSIS, PROMETHEE, decision support system.

I. Introduction

MINING and supply chain activities have serious socio-environmental consequences that represent a major concern for societies, governments and professional organizations [1]. These activities have led to environmental degradation and depletion of natural resources which increases risks and reduces opportunities for sustainable industrial development and economic growth. An efficient manner to manage these environmental issues is through organizational practices that include the entire supply chain. The GSCM and their significant interest in the mining strategy have not been fully addressed. In this context, several researches, such as [9], [11], [14]-[16], have been proposed in order to develop new measurements related to GSCM practices to surmount the impact of these environmental problems. Indeed, the GSCM is among the sustainable development solutions to control and minimize waste in the industrial system in order to save energy and prevent the dissipation of harmful substances into the environment. It is based on the principle of integrating environmental thinking and supply chain management through the implementation of various green solutions, such as green purchasing, environmental technologies and green logistics [2], [3]. The right implementation of these solutions can lead to the creation of technological innovations in manufacturing firms [4]. According to [5], the application of these solutions and the selection of the most suitable are increasingly difficult owing to several obstacles. Besides, the lack of information availability leads organizations of mining industry to make decisions with significant uncertainty causing unexpected results. In this context, treating uncertain and heterogeneous information requires a systematic framework for collecting and organizing technical and analytical information. Hence, the selection of GSCM solutions is a multi-criteria decision making (MCDM) problem, which represents a key strategic decision in the management of a supply chain focused on sustainability [6] and needs to be examined in a methodical way to implement sustainable initiatives in supply chains [7]. Following these considerations, the investigation of GSCM concludes that there are positive significant relationships between the mechanisms of organizational learning, organizational support and the adoption of GSCM solutions [8]. As a result, several contributions [9]-[11] have tried to identify and evaluate barriers, practices, knowledge management and performance measures that have an impact on the development of GSCM. For example, [11] presents an interpretive structural modeling approach for the barrier analysis in implementing GSCM. In the same context, an analysis model of the drivers affecting the implementation of GSCM is presented by [9]. Many other GSCM contributions have been conducted, especially those concerning the GSCM strategies such as the contribution of [12] using fuzzy AHP-TOPSIS methodology for group multi-criteria evaluation of GSCM strategies, which include

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manufacturing, green procurement and green service to customer and environmental management process. The same approach using fuzzy AHP and TOPSIS methods is also applied by [13], for identifying and ranking the solutions of knowledge management adoption in supply chain to overcome its barriers, which will help organizations to develop new strategies to implement them on priority. In a parallel way, the contribution of [14] presents a detailed procedure for solving complex situations of GSCM strategy-selection, and evaluating the most suitable activity in each business function using the Analytic Network Process (ANP) methodology. Other scientific works such as [15], [16] have focused on identifying the success factors of GSCM for successful achievements of sustainability with different illustrations of case studies.

However, the use of a comparative analysis approach based on Fuzzy AHP, TOPSIS and PROMETHEE for the selection problem of GSCM solutions, has not received much interest, in terms of scientific research, from academia and industry.

In this sense, this research work has the following objectives:

- To understand and identify evaluation criteria related to the selection problem of GSCM solution;
- To distinguish the relative importance weights of these evaluation criteria;
- To rank and select the most appropriate sustainable GSCM solutions using Fuzzy TOPSIS and PROMETHEE methods;
- To compare and analyze the final results.

The remainder of this paper is organized as follows. In Section II, we discuss research methodology and develop our method. Section III is devoted to empirical study illustrating the effectiveness and performance of our decision-making framework. Section IV contains some concluding remarks.

II. Research Methodology

A. Choice of Analytical Methods

Many methods of multi-criteria analysis have been proposed in order to help decision makers to make the right decision. Indeed, in this contribution, the AHP method has been chosen as a hierarchical structuring process allowing the decomposition of the problem into sub problems, and then assigns the importance weight to the influential elements already identified by a decision-making committee. For the process of evaluating and ranking GSCM solutions, we have selected, firstly, the PROMETHEE method through its interactivity and ability to order and classify complex problems involving a lot of human perceptions and judgments. Secondly, we have chosen the fuzzy TOPSIS method due to its capability to deal with group decision making problems in uncertain environments. The decision group members can aid the implementation of the FAHP, fuzzy TOPSIS and PROMETHEE models by choosing linguistic terms that are ideal for GSCM practices evaluation and weighting the criteria as well as parameterizing the triangular fuzzy numbers corresponding to each linguistic term.

1. Fuzzy AHP

The AHP (Analytic Hierarchy Process) is a MCDM method for solving complicated and unstructured problems. Since its introduction by [17], it is based on an approach representing a decision-making situation by a hierarchical structure that reflects the interactions among the various elements of the situation. This interaction is performed by using many pairwise comparison judgments to evaluate and estimate the relative importance of criteria and alternatives. However, the AHP method has some limitations [18] due to its ineffectiveness when applied to an ambiguous problem. In fact, the use of the discrete scale of AHP is easy and simple but it does not take into consideration the ambiguity associated with the expression of human judgment by natural language. That's why several researchers such as [19]-[22], integrate fuzzy set techniques with AHP method to deal with this type of fuzzy decision problem.

Before processing the different steps of the fuzzy AHP methodology, we briefly underline the rationale for the fuzzy theory as follows:

Definition 1. If μ_A is the membership function which characterizes the fuzzy set A, $\forall x \in X$ $\mu_A \in [0,1]$. The set A is specified by $A = \{(x, \mu_A(x)) \mid x \in X\}$.

If μ_A (x) = 0,90 then x belongs to the fuzzy set A with a very high membership degree of 90% (linguistic value "very high"), with respect to μ_A (x) = 0,10 which explains a low membership of 10% (linguistic value "low").

The fuzzy numbers are a special case of fuzzy sets used to model imprecise numerical quantities (Weak, Weak advantage, Good, Very Good, etc), they are also used to evaluate and rate the alternatives with respect to different criteria.

Definition 2. A membership function of a Triangular Fuzzy Number (TFN) A can be defined by a triplet (a, m, b) as follows:

$$\mu_M(x) = \begin{cases} 0, x \le a \\ (x-a)/(m-a), a < x \le m \\ (b-x)/(b-m), m < x \le b \\ 0, x > b \end{cases} \quad (1)$$

where m is the most probable value of A, 'a' and 'b' represent the smallest and the largest possible value of A (such that a ≤ m ≤ b).

Definition 3. Let $A_1(a_1, m_1, b_1)$ and $A_2(a_2, m_2, b_2)$ be two TFNs. The main arithmetic operations of triangular fuzzy numbers are as follows:

$$A_1 * A_2 = (a_1 * a_2, m_1 * m_2, b_1 * b_2) \quad (2)$$

$$A_1 + A_2 = (a_1 + a_2, m_1 + m_2, b_1 + b_2) \quad (3)$$

$$A_1 / A_2 = (a_1/b_2, m_1/m_2, b_1/a_2) \quad (4)$$

$$A_1^{-1} = (1/b_1, 1/m_1, 1/a_1) \quad (5)$$

For $a_1, a_2 > 0$; $m_1, m_2 > 0$; $b_1, b_2 > 0$

The different steps of AHP are then explained as follows:

Step 1. The problem must be divided into a hierarchy of interrelated factors (elements and sub-elements). At the top of the hierarchy we find the objective, and the elements helping to reach it are in the lower levels.

Step 2. The comparison matrices must be built by performing pairwise comparisons of the factors of each hierarchical level with respect to the factor of the upper hierarchical level.

$$\begin{array}{c} \\ C_1 \\ C_2 \\ C_3 \\ C_4 \\ C_5 \\ .. \\ C_n \end{array} \begin{array}{c} \begin{array}{ccccccc} C1 & C2 & C3 & C4 & C5 & .... & Cn \end{array} \\ \begin{bmatrix} 1 & a_{12} & a_{13} & a_{14} & a_{15} & \cdots & a_{1n} \\ a_{21} & 1 & a_{23} & a_{24} & a_{25} & \cdots & a_{2n} \\ a_{31} & a_{32} & 1 & a_{34} & a_{35} & \cdots & a_{3n} \\ a_{41} & a_{42} & a_{43} & 1 & a_{45} & \cdots & a_{4n} \\ a_{51} & a_{52} & a_{53} & a_{54} & 1 & \cdots & a_{5n} \\ \vdots & \vdots & \vdots & \vdots & \vdots & 1 & \vdots \\ a_{n1} & a_{n2} & a_{n3} & a_{n4} & a_{n5} & \cdots & 1 \end{bmatrix} \end{array} \quad (6)$$

where n = criteria number to be evaluated, Ci = i. criteria, a_{ij} = importance of i. criteria according to j^{th} criteria.

Step 3. The eigenvectors corresponding to the maximum eigenvalue of the comparison matrix is calculated in order to determine the relative importance of the elements. This comparison matrix has to be normalized into the range of [0, 1] by (7):

$$r_{ij} = a_{ij} * (\sum_{i=0}^{n} a_{ij})^{-1} \quad (7)$$

$$\begin{array}{c} \\ C_1 \\ C_2 \\ C_3 \\ .. \\ C_n \end{array} \begin{array}{c} \begin{array}{ccccc} C_1 & C_2 & C_3 & ... & C_n \end{array} \\ \begin{bmatrix} r_{11} & r_{12} & r_{13} & \cdots & r_{1n} \\ r_{21} & r_{22} & r_{23} & \cdots & r_{2n} \\ r_{31} & r_{32} & r_{33} & \cdots & r_{3n} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ r_{n1} & r_{n2} & r_{n3} & \cdots & r_{nn} \end{bmatrix} \end{array} \quad (8)$$

Step 4. The real elements of matrix (8) will be transformed into fuzzy numbers, or they can be given using linguistic variables provided in Table I to easily derive corresponding values of fuzzy numbers. Then the comparison matrix (6) has to be normalized by (7) before performing all the calculation of vector of priorities.

TABLE I
FUZZY COMPARISON MEASURES [23]

Linguistic terms	Triangular fuzzy numbers
Very Good (VG)	(7, 9, 9)
Good (Gd)	(5, 7, 9)
Preferable (P)	(3, 5, 7)
Weak advantage (WA)	(1, 3, 5)
Equal (EQ)	(1, 1, 1)
Less WA	(1/5, 1/3, 1)
Less P	(1/7, 1/5, 1/3)
Less G	(1/9, 1/7, 1/5)
Less VG	(1/9, 1/9, 1/7)

Step 5. The consistency of judgments across the consistency index CI, random index RI and the consistency ratio CR must be checked to reflect the consistency of the judgments of decision makers during the evaluation phase.

$$CI = (\lambda_{max} - N)/(N-1) \quad (9)$$

where λ_{max} = Principal eigenvalue of the judgment matrix. N = the order of the judgment matrix.

The consistency ratio is then calculated using the formula:

$$CR=CI/RI \quad (10)$$

The AHP results are accepted as consistent if CR ≤ 0.10, otherwise, the pairwise comparisons should be revised to reduce inconsistencies.

Step 6. The weight of the criteria will be obtained by calculating the average of the elements of each row from the matrix obtained from step 3.

2. PROMETHEE

The Preference Ranking Organization METHod for Enrichment Evaluations (PROMETHEE) was developed by Brans and Vincke [24]. This outranking method has been successfully applied to real life planning problems. It is based on a pair-wise comparison of alternatives for each criterion, which means that the evaluation of alternatives is achieved with respect to different criteria which have to be maximized or minimized [25]. Basically, the PROMETHEE method, which is composed of a family of outranking methods such as PROMETHEE I, II, III, IV, V and VI, can provide complete ranking ordering of alternatives when decision makers need to choose a most appropriate decision option [26]-[30].

The PROMETHEE method can be described in the following steps:

Assume that a_i(i = 1, 2, . . . , m) is a set of m alternatives, and ω_j(j = 1, 2, . . . , n) represent the weight of n criteria

Step 1. Calculate the evaluative differences of any two alternative (a_i, a_k) with respect to criterion j, denoted as $d_j(a_i,a_k)$,

$$\text{i.e., } d_j(a_i,a_k) = f_j(a_i) - fj(a_k). \quad (11)$$

Step 2. Choose the preference function ($P_j(a_i,a_k)$) which means the preference of alternatives a_i with regard to alternative a_k as shown in (12):

$$P_j(a_i,a_k)= F_j(d_j(a_i,a_k)) \quad (12)$$

where F_j is a non-decreasing function of the observed deviation (d) between f_j (a_i) and f_j (a_k).

Six types for F_j have been suggested as shown in Fig. 1. If a is better than b according to j^{th} criterion, $F_j(a, b)>0$, otherwise $F_j(a, b)= 0$. These types are: (1) Usual criterion, (2) Quasi-criterion (U-shape), (3) Criterion with linear preference (V-shape), (4) level criterion, (5) V-shape with indifference criterion and (6) Gaussian criterion.

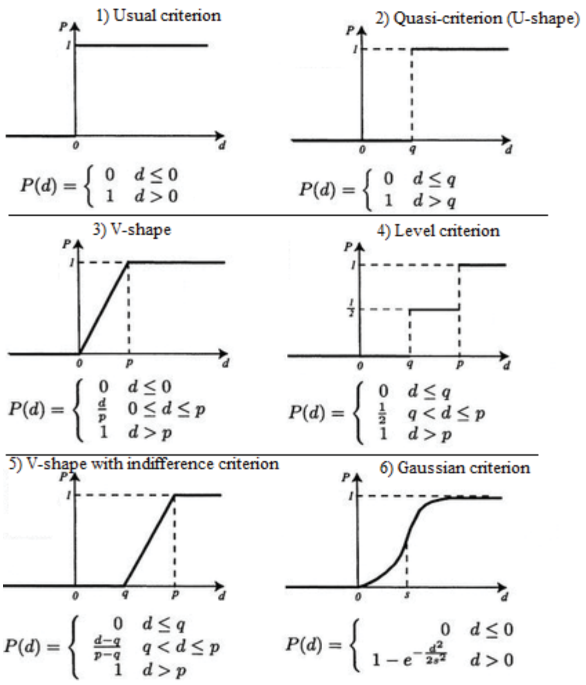


Fig. 1 Preference functions [31]

Step 3. Determine the aggregated preference function incorporating the weights:

$$\pi(a_i, a_k) = \sum_{j=1}^{n} \omega_j F_j(d_j(a_i, a_k)) \quad (13)$$

Step 4. Calculate the leaving and entering outranking flows. The leaving flows as a measure for the weakness of the alternative a_i, and the entering flows as a measure for the strength of the alternative a_i.

$$\Phi^-(a_i) = \frac{1}{h-1}\sum_{k=1}^{m}(a_i, a_k) \quad (14)$$
$$\Phi^+(a_i) = \frac{1}{h-1}\sum_{k=1}^{m}(a_k, a_i)$$

where *h* is the number of alternatives.

Step 5. Calculate the net outranking flow $\phi(a_i)$, then classify them from the highest value to the lowest to obtain the final rank of each proposed solution.

$$\phi(a_i) = \phi^+(a_i) - \phi^-(a_i) \quad (15)$$

3. TOPSIS

The Technique for Order Preference by Similarity to Ideal Solution which is known as TOPSIS is one of the classic multi-criteria decision-making methods developed by Hwang and Yoon [32] to identify decision-making solutions from a finite set of alternatives. Its underlying logic is that, the chosen alternative must have the shortest distance from the positive ideal solution (the best on all the criteria), and the farthest distance from the negative ideal solution (which degrades all the criteria). TOPSIS has many advantages. It has a simple process; it is easy to use and is programmable. The number of steps remains the same regardless of the number of attributes.

The TOPSIS method can be described in the following steps:

Step 1. The decision makers establish a decision matrix using linguistic variables with triangular fuzzy numbers, which is shown in Table I, for ratings 'm' alternatives with respect to each criterion ('n' criteria) as given below:

$$y = (g_{ij})_{mxn} = \begin{matrix} \\ g_1 \\ g_2 \\ .. \\ g_n \end{matrix} \begin{matrix} c_1 & c_2 & \dots & c_n \\ \end{matrix} \begin{bmatrix} g_{11} & g_{12} & \dots & g_{1n} \\ g_{21} & g_{22} & & g_{2n} \\ & & & r_{32} \end{bmatrix} \quad (16)$$

where $g_1, g_2, \dots, g_m$ = Feasible alternatives, $c_1, c_2, \dots, c_n$ = Evaluation criteria, g_{ij} = The rating given to alternative g_i against criterion c_j.

Step 2. Construct the normalized decision matrix r_{ij} as follows:

$$r_{ij} = g_{ij} / [\sum_{i=1}^{m}(g_{ij})^2]^{1/2} \quad (17)$$

Step 3. Calculate the weighted normalized decision matrix v_{ij} as given below:

$$v_{ij} = w_j r_{ij} \quad (18)$$

where w_j is the weight of criterion c_j.

Step 4. Using the weighted normalized decision matrix v_{ij}, we determine the positive ideal and negative ideal solution as follows:

$$A+ = \begin{cases} Max\ v_{ij} \mid g_i \in G^1 \\ 1 \le j \le n \\ Min\ v_{ij} \mid g_i \in G^2 \\ 1 \le j \le n \end{cases} \quad (19)$$

$$A- = \begin{cases} Min\ v_{ij} \mid g_i \in G^1 \\ 1 \le j \le n \\ Max\ v_{ij} \mid g_i \in G^2 \\ 1 \le j \le n \end{cases} \quad (20)$$

where G^1 is the set of benefit criteria, and G^2 is the set of cost criteria.

Step 5. Calculate the Euclidean distance (D_i) for each alternative 'i' between positive ideal solution and negative ideal solution.

$$D_i^+ = [\sum_{j=1}^{n}(v_{ij} - v_j^+)^2]^{½} \quad (21)$$

$$D_i^- = [\sum_{j=1}^{n}(v_{ij} - v_j^-)^2]^{½} \quad (22)$$

Step 6. Calculate the relative closeness (C_i) to the ideal solution of each alternative as follows:

$$C_i = D_i^- / (D_i^+ + D_i^-) \quad (23)$$

Step 7. Classify the alternatives in descending order depending on the closeness coefficient C_i, the most suitable alternative should have the "shortest distance" of the positive ideal solution and the "farthest distance" of the negative ideal solution.

B. The Followed Approach

The proposed hybrid approach based on fuzzy AHP, TOPSIS and PROMETHEE allowing to identify, evaluate and rank the solutions of GSCM is explained in Fig. 2. The objective is to contribute to a better understanding and development of new sustainable strategies for industrial mining organizations by implementing the appropriate GSCM solutions.

The proposed approach uses three major processes as explained below:

Process I: In this process, a decision-making committee is formed in order to determine the most influential criteria to be considered for the evaluation of the suggested GSCM solutions. The committee starts by elaborating a detailed description of the problem and generates ideas about the required criteria to take into account when making the decision. The collection of the selected criteria and alternatives are established across the literature review and proved by the decision committee.

Process II: During this process, the decision committee will take care of: 1) Constructing the pairwise comparison matrices using the fuzzy AHP method. 2) Converting the linguistic judgments of decision makers assigned to each criterion using Table I. 3) Computing the importance weights of each criterion.

Process III: At this stage, the aim is to evaluate different solutions of GSCM defined by the decision-making committee and by consulting the literature review using Fuzzy TOPSIS and PROMETHEE processes. The importance weights of the specified criteria are considered as input throughout the Fuzzy TOPSIS and PROMETHEE processes, which will allow us to structure the preference functions and the criteria parameters, and then proceed to evaluate and rank the most appropriate solutions taking into account the existing needs of decision makers. At the end of these processes, we conduct a comparative analysis in order to measure the influence of the applied methods on the decision-making process.

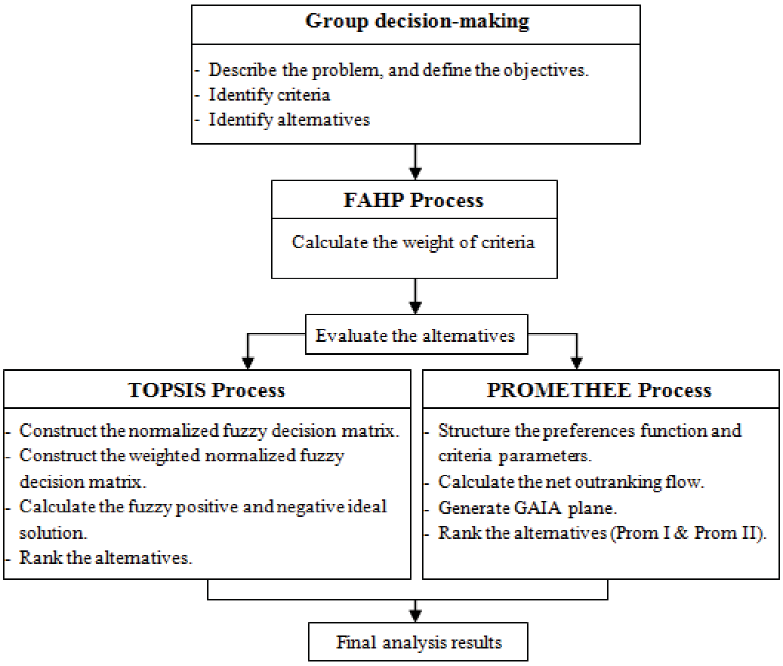


Fig. 2 Proposed Approach

III. Application

A. Problem Description

For many years, as the largest and the most populated agglomeration in the Maghreb, Casablanca accounts, according to statistics of Morocco Franchise, for more than 50 percent of total capital investment in Morocco, and provides over 48% of the industrial employment. In this regard, we choose as case study a company that works in the mining industry sector, established in Casablanca industrial region. This company is interested in identifying, ranking and prioritizing the solutions of GSCM to enhance its new manufacturing policy towards sustainable development.

1. Identification of Criteria

We present below a set of criteria identified by the decision-making committee and academic literature survey to take into consideration when evaluating the GSCM solutions. Thus, the committee reached to select three main criteria and ten sub-criteria (the most influencing) in which four benefit criteria and six cost criteria to consider as presented in Table II.

TABLE II
EVALUATION CRITERIA

Main criteria	Sub-criteria	References
Organizational criteria (OC)	• SC_OC1: Lack of Human resource.	[33]
	• SC_OC2: Lack of technical expertise.	[33], [34]
	• SC_OC3: Lack of proper organizational structure to create and share knowledge.	[35]
Economic criteria (EC)	• SC_EC1: Increase in productivity.	[10]
	• SC_EC2: Decrease costs of material purchasing and energy consumption.	[10], [36]
	• SC_EC3: Increased firm's competitiveness.	[37]
	• SC_EC4: Increase in profitability.	[36]
Environment criteria (EnC)	• SC_EnC1: Improvement in environmental quality of products/processes.	[38]
	SC_EnC2: Reduction in air emissions, liquid and solid wastes.	[36]
	• SC_EnC3: Decrease in use of harmful/hazardous materials/components.	[36]

2. Identification of GSCM Solutions

In the following, we present some of the most selected solutions of GSCM. Those solutions (from *SL1* to *SL10*) are proposed by the committee on the basis of several existing researches as illustrated in Table III.

B. Evaluation of Criteria: Fuzzy AHP Application

In this this process, the pairwise comparisons of all the selected criteria will be constructed using (1)-(5) and Table I for linguistic terms and TFN scale (we only provide the pairwise comparisons of three members of decision-making committee (CM_1 – CM_3) due to space limitation).

The approximate solution of the feature vector W= (0.567, 0.347, 0.086).

The results of the followed fuzzy AHP methodology can be considered as consistent for the main criteria. In fact, the result of consistency CI=0 (λ_{max} = 3) using (9), which implies that CR=0 (10).

The same calculation steps are considered for the sub-criteria evaluation, and the results of priority weights are shown in Table VIII.

TABLE III
IDENTIFICATION OF ALTERNATIVES

GSCM solutions	References
• Optimizes the operations of both integrated logistics and corresponding used-product reverse logistics in a given green-supply chain.	[39]
• Design of Multi agent system to improve information and knowledge sharing in SC.	[40]
• Make strategic alliances among the supply for positive impact on SC performance.	[41]
• A multi-objective optimization model that captures the trade-off between the total cost and the environment influence in GSCM.	[42]
• Establishment of Knowledge based Decision support system (KB-DSS) for SC.	[43]
• Electronic collaboration (e-collaboration) for systems to facilitate Internet-based coordination of decisions across all members of the SC.	[44]
• The use of collaborative practices like Vendor Managed Inventory, Efficient Consumer Response, Enhanced Web Reporting or Collaborative Planning, Forecasting and Replenishment to progressively develop knowledge.	[45]
• Strengthening the cultural cohesions and co-operation in SC members.	[41]
• Make strategic alliances among the supply for positive impact on SC performance.	[41]
• Establish a transparent work flow or open door policy.	[40]

TABLE IV
COMPARISON MATRIX FOR THE MAIN CRITERIA USING LINGUISTIC VARIABLES

Objective	EnC			EC			OC		
	CM_1	CM_2	CM_3	CM_1	CM_2	CM_3	CM_1	CM_2	CM_3
EnC	EQ	EQ	EQ	WA	WA	EQ	P	Gd	P
EC	EQ	L.WA	L.WA	EQ	EQ	EQ	Gd	P	P
OC	L.P	L.Gd	L.P	L.P	L.P	L.Gd	EQ	EQ	EQ

TABLE V
THE EVALUATION MATRIX FOR THE MAIN CRITERIA USING TFN SCALE

Objective	EnC	EC	OC
EnC	(1, 1, 1)	(1, 2.333, 5)	(3, 5.667, 9)
EC	(0.200, 0.429, 1)	(1, 1, 1)	(3, 5.667, 9)
OC	(0.111, 0.176, 0,333)	(0.111, 0.176, 0,333)	(1, 1, 1)

TABLE VI
THE NORMALIZED INTEGRATED MATRIX USING (7)

Objective	EnC	EC	OC
EnC	(0.763, 0.623, 0.429)	(0.474, 0.665, 0.789)	(0.429, 0.459, 0.474)
EC	(0.153, 0.267, 0.429)	(0.474, 0.285, 0.158)	(0.429, 0.459, 0.474)
OC	(0.085, 0.110, 0.143)	(0.053, 0.050, 0.053)	(0.143, 0.081, 0.053)

TABLE VII
FINAL WEIGHT OF FIRST HIERARCHY

Objective	Final weight	
EnC	(0.555, 0.582, 0.564)	0.567
EC	(0.352, 0.337, 0.353)	0.347
OC	(0.093, 0.08, 0.083)	0.086

As shown in Table VIII, the final results of analysis during the FAHP process show that the environmental criteria remain the most important in comparison with the other main criteria. This explains that the decision makers give more attention to environmental impacts, which is strengthened here through the sub-criterion '*SC_EnC3*' with an important weight of *0.341*, followed by the economic sub-criterion '*SC_EC3*', with an important weight of *0.220*. The low importance is given to the organizational criteria due to the nature of our case study which is more focused on sustainability. These results can be compared, for example, to others such in [13]; [27] using fuzzy AHP to determine the relative weights of evaluation criteria, and fuzzy TOPSIS for ranking alternatives.

TABLE VIII
FINAL RANKING OF CRITERIA WEIGHT USING TRIANGULAR FUZZY NUMBER

Criterion/Sub Criterion	Weight	Total weight	Rank
EnC	**0.567** (0.555, 0.582, 0.564)	-	-
SC_EnC1	(0.131, 0.106, 0.121)	(0.073, 0.062, 0.068) 0.068	4
SC_EnC2	(0.261,0.260, 0.319)	(0.145, 0.151, 0.180) 0.159	3
SC_EnC3	(0.608, 0.634, 0.560)	(0.337, 0.369, 0.316) **0.341**	**1**
EC	**0.347** (0.352, 0.337, 0.353)	-	-
SC_EC1	(0.123,0.133,0.151)	(0.043,0.045,0.053) 0.047	6
SC_EC2	(0.057,0.125,0.162)	(0.020,0.042,0.057) 0.041	7
SC_EC3	(0.719,0.629,0.555)	(0.253,0.212,0.196) 0.220	2
SC_EC4	(0.100,0.113,0.133)	(0.035,0.038,0.047) 0.040	8
OC	**0.086** (0.093, 0.080, 0.083)	-	-
SC_OC1	(0.317, 0.283, 0.341)	(0.029,0.023,0.028) 0.027	9
SC_OC2	(0.088, 0.074, 0.068)	(0.008,0.006,0.006) 0.007	10
SC_OC3	(0.597, 0.643, 0.591)	(0.056,0.051,0.049) 0.052	5

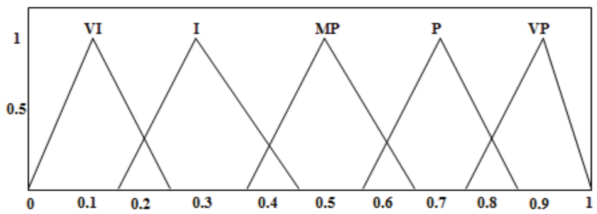


Fig. 3 Linguistic scale for evaluation

TABLE IX
TRANSFORMATION FOR FUZZY MEMBERSHIP FUNCTIONS

Linguistic Variables	Membership functions
Very Insufficient (VI)	*(0.00, 0.10, 0.25)*
Insufficient (I)	*(0.15, 0.30, 0.45)*
Medium Importance (MP)	*(0.35, 0.50, 0.65)*
Important (P)	*(0.55, 0.70, 0.85)*
Very Important (VP)	*(0.75, 0.90, 1.00)*

TABLE X
THE ALTERNATIVES' EVALUATION MATRIX USING LINGUISTIC VARIABLES

Criteria	SC_EnC1	SC_EnC2	SC_EnC3	SC_EC1	SC_EC2	SC_EC3	SC_EC4	SC_OC1	SC_OC2	SC_OC3
Preference Fct.	V-shape	V-shape	V-shape	V-shape	V-shape	V-shape	V-shape	V-shape	V-shape	V-shape
Preference (P)	2	2	2	2	2	2	2	2	2	2
Max/Min	max	min	min	max	min	max	max	min	min	min
Weight	*0.068*	*0.159*	*0.341*	*0.047*	*0.041*	*0.220*	*0.040*	*0.027*	*0.007*	*0.052*
SL1	MP	I	P	VI	P	P	I	MP	P	MP
SL2	I	P	MP	P	VP	P	MP	I	I	MP
SL3	MP	VI	I	P	MP	MP	I	MP	MP	P
SL4	MP	I	VP	P	MP	MP	VP	P	I	MP
SL5	P	VP	P	I	I	MP	MP	P	P	I
SL6	I	MP	MP	P	VI	P	I	MP	VP	I
SL7	I	P	VI	MP	P	VI	VP	MP	I	P
SL8	P	I	MP	P	VI	I	MP	P	I	VP
SL9	MP	I	VP	P	I	VI	MP	I	VP	P
SL10	P	MP	MP	VP	I	I	P	MP	VP	P

C. Evaluation and Ranking of GSCM Solutions

1. PROMETHEE Application

As explained in the proposed methodology, the importance weights assigned to criteria during the Fuzzy AHP process will be used as input in the PROMETHEE process to evaluate, rank and prioritize the GSCM solutions. In this direction, a detailed study was carried by the committee so as to fix the related preference function of each selected criterion. The committee has concluded to use V-shape preference function and set the parameter value "p" of the V-shape function to 2 for all the selected criteria, as shown in Table X.

The evaluation (decision makers judgments) of GSCM solutions with respect to all selected criteria is carried out using linguistic scale for evaluation (Fig. 3 and Table IX) as mentioned in Tables X and XI.

The Geometrical Analysis for Interactive Aid (GAIA) integrated in Visual Promethee program [46] is used as a visualization method complementing the PROMETHEE ranking methodology, which will help to display graphically the relative position of the solutions in terms of contributions to the selected criteria, where criteria are represented by vectors and alternatives, by points as shown in Fig. 4. Additionally, the conflicting criteria appear clearly in the GAIA plane visualization. Criteria vectors that express similar preferences are oriented in the same direction, while conflicting criteria are pointing in opposite directions.

The evaluation of GSCM solutions is performed by using the PROMETHEE-GAIA tool based on the steps (steps 1-5) of PROMETHEE process. In brief, the net outranking flow, based on the positive and negative flow, representing the final classification of the proposed GSCM solutions is carried out by using Visual Promethee program as shown in Fig. 5.

2. TOPSIS Application

During this process, the weights of importance assigned to all criteria using fuzzy AHP will be used as input to evaluate and rank alternatives.

The computational procedure to follow during this proposed process is summarized as explained below:

Step 1. The rating of alternatives with respect to each criterion (16) is performed by the decision-making group using linguistic rating variables with (TFN) numbers as shown in Table IX.

Step 2. The normalized decision matrix is constructed (17), as mentioned in Table XII, on the basis of the performance ratings of the ten alternatives.

Step 3. The weighted normalized decision matrix is obtained by (18) as in Table XIII using the importance weights of the criteria already calculated from fuzzy AHP process.

Step 4. In Table XIII, the positive ideal solution and negative ideal solution is performed (19) and (20) taking into consideration the benefit criteria (Bnf_C) and the cost criteria (Cst_C).

Step 5. As explained in Table XV, the relative distance D_i^+ and D_i^- of each alternative with respect to each criterion is calculated using (21) and (22).

Step 6. & Step 7. The closeness coefficient of each alternative is determined by (23) using the relative distance (D_i^+ and D_i^-). The final ranking of the alternatives (GSCM practices) depending on the descending order of closeness coefficient is shown in Table XV.

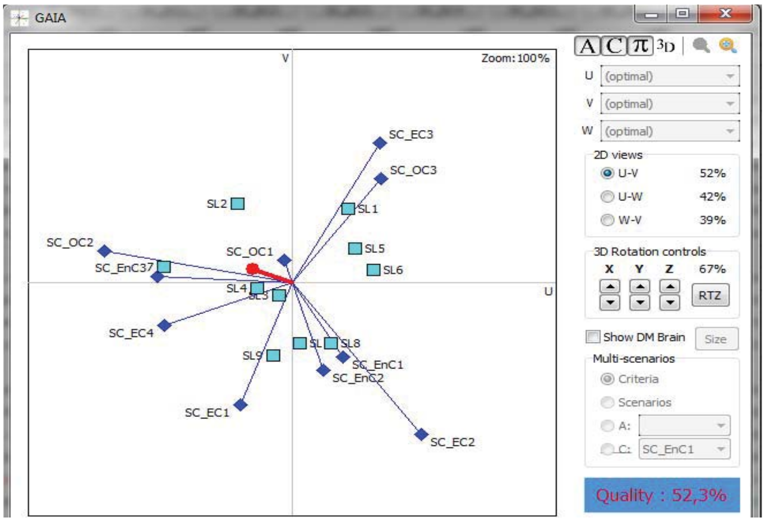
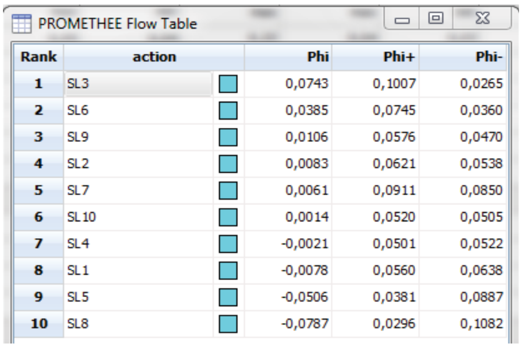


Fig. 4 GAIA Plane generated by visual PROMETHEE

TABLE XI
THE ALTERNATIVES' EVALUATION MATRIX USING FUZZY MEMBERSHIP FUNCTIONS OF TABLE IX

Sol/Crt	SC_EnC1	SC_EnC2	SC_EnC3	SC_EC1	SC_EC2	SC_EC3	SC_EC4	SC_OC1	SC_OC2	SC_OC3
SL1	0.500	0.300	0.700	0.117	0.700	0.700	0.300	0.500	0.700	0.500
SL2	0.300	0.700	0.500	0.700	0.833	0.700	0.500	0.300	0.300	0.500
SL3	0.500	0.117	0.300	0.700	0.500	0.500	0.300	0.500	0.500	0.700
SL4	0.500	0.300	0. 700	0.700	0.500	0. 500	0.833	0.700	0.300	0.500
SL5	0.700	0.833	0.700	0.300	0.300	0.500	0.500	0.700	0.700	0.300
SL6	0.300	0.500	0.500	0.700	0.117	0.700	0.300	0.500	0.833	0.300
SL7	0.300	0.700	0.117	0.500	0.700	0.117	0.833	0.500	0.300	0.700
SL8	0.500	0.300	0.833	0.700	0.300	0. 117	0.500	0.300	0.833	0.700
SL9	0.700	0.300	0.500	0.700	0.117	0.300	0.500	0.700	0.300	0.833
SL10	0.700	0.500	0.500	0.833	0.300	0.300	0.700	0.500	0.833	0.700



PROMETHEE Flow Table

Rank	action	Phi	Phi+	Phi-
1	SL3	0,0743	0,1007	0,0265
2	SL6	0,0385	0,0745	0,0360
3	SL9	0,0106	0,0576	0,0470
4	SL2	0,0083	0,0621	0,0538
5	SL7	0,0061	0,0911	0,0850
6	SL10	0,0014	0,0520	0,0505
7	SL4	-0,0021	0,0501	0,0522
8	SL1	-0,0078	0,0560	0,0638
9	SL5	-0,0506	0,0381	0,0887
10	SL8	-0,0787	0,0296	0,1082

Fig. 5 Leaving, entering and net outranking flows using visual PROMETHEE

D. *Comparative Analysis*

As presented in Figs. 5 and 6, and Table XVI, the final evaluation of the best GSCM solutions is provided using PROMETHEE and TOPSIS methodologies. Indeed, each solution has its relative score which is displayed on the basis of the contribution of the selected criteria. It can be seen in Table XVI that SL3 is the first highest ranked GSCM solution for sustainability performance. For the remaining solutions, the rankings do not match, exactly. In fact, TOPSIS and PROMETHEE methods are both suitable for the problem selection of GSCM solutions.

TABLE XII
NORMALIZED DECISION MATRIX (R_{IJ})

Alternative	Criteria									
	SC_EnC1	SC_EnC2	SC_EnC3	SC_EC1	SC_EC2	SC_EC3	SC_EC4	SC_OC1	SC_OC2	SC_OC3
SL1	0,151	0,056	0,271	0,007	0,312	0,315	0,051	0,147	0,256	0,132
SL2	0,054	0,307	0,138	0,245	0,441	0,315	0,141	0,053	0,047	0,132
SL3	0,296	0,435	0,271	0,045	0,057	0,160	0,141	0,288	0,256	0,048
SL4	0,151	0,056	0,271	0,245	0,159	0,160	0,391	0,288	0,047	0,132
SL5	0,151	0,009	0,050	0,245	0,159	0,160	0,051	0,147	0,130	0,259
SL6	0,054	0,157	0,138	0,245	0,009	0,315	0,051	0,147	0,362	0,048
SL7	0,054	0,307	0,008	0,125	0,312	0,009	0,391	0,147	0,047	0,259
SL8	0,296	0,056	0,138	0,245	0,009	0,058	0,141	0,288	0,047	0,367
SL9	0,151	0,056	0,384	0,245	0,057	0,009	0,141	0,053	0,362	0,259
SL10	0,296	0,157	0,138	0,347	0,057	0,058	0,276	0,147	0,362	0,259

TABLE XIII
WEIGHTED NORMALIZED DECISION MATRIX (V_{IJ})

Alternative	Criteria									
	SC_EnC1	SC_EnC2	SC_EnC3	SC_EC1	SC_EC2	SC_EC3	SC_EC4	SC_OC1	SC_OC2	SC_OC3
SL1	0,010	0,009	0,092	0,000	0,013	0,069	0,002	0,004	0,002	0,007
SL2	0,004	0,049	0,047	0,012	0,018	0,069	0,006	0,001	0,000	0,007
SL3	0,020	0,069	0,092	0,002	0,002	0,036	0,006	0,008	0,002	0,002
SL4	0,010	0,009	0,092	0,012	0,007	0,035	0,016	0,008	0,000	0,007
SL5	0,010	0,001	0,017	0,012	0,007	0,035	0,002	0,004	0,001	0,013
SL6	0,004	0,025	0,047	0,012	0,000	0,069	0,002	0,004	0,003	0,002
SL7	0,004	0,049	0,003	0,006	0,013	0,002	0,016	0,004	0,000	0,013
SL8	0,021	0,009	0,047	0,012	0,000	0,013	0,006	0,008	0,000	0,019
SL9	0,010	0,009	0,131	0,012	0,002	0,002	0,006	0,001	0,003	0,013
SL10	0,020	0,025	0,047	0,016	0,002	0,013	0,011	0,004	0,003	0,013

TABLE XIV
POSITIVE AND NEGATIVE IDEAL SOLUTION

Ideal solution	Criteria									
	SC_EnC1	SC_EnC2	SC_EnC3	SC_EC1	SC_EC2	SC_EC3	SC_EC4	SC_OC1	SC_OC2	SC_OC3
A^+	0,021	0,069	0,131	0,016	0,018	0,069	0,016	0,001	0,000	0,002
A^-	0,004	0,001	0,003	0,000	0,000	0,002	0,002	0,008	0,003	0,019

Depending on the nature of this problem, the most appropriate method should be chosen taking into consideration the shortcomings, advantages and similarities of these methods.

For example, (i) both methods require the same amount of calculation and time when compared against the agility in the decision process and time complexity: TOPSIS process uses (21) and (22) to calculate the Euclidean distance for each alternative between positive ideal solution and negative ideal solution, and PROMETHEE process uses (14) to calculate the leaving and entering outranking flows; TOPSIS process uses (23) to calculate the final relative closeness coefficient and PROMETHEE process uses (15) to calculate the final net outranking flow. However, the analysis results obtained by applying these equations are different for both methods. (ii)

TOPSIS performs better than PROMETHEE concerning the ability to support the group decision making. (iii) No limitation concerning the number of criteria and alternatives for both methods. (iv) Both methods are limited at the level of uncertainty modelling, which needs to incorporate Fuzzy set theory to these methods in order to deal with imprecision and subjectivity in the selection problems of GSCM solutions. (v) The weights affect the ranking of alternatives provided by both methods, which will enable decision makers to enhance their decision-making process by fitting weighting and scoring and performing sensitivity analyses.

TABLE XV
THE RELATED CLOSENESS COEFFICIENTS (C_i) AND FINAL RANKING OF GSCM PRACTICES

Alternatives	Distance D_i^+	Distance D_i^-	Closeness coefficient C_i	Final Ranking
SL1	0,07557	0,11409	0,60154	2
SL2	0,08869	0,09700	0,52238	5
SL3	0,05634	0,11996	0,68043	1
SL4	0,08111	0,09895	0,54954	4
SL5	0,13893	0,03970	0,22224	10
SL6	0,09900	0,08649	0,46628	6
SL7	0,14821	0,05170	0,25862	9
SL8	0,12072	0,05103	0,29711	8
SL9	0,06792	0,10816	0,61428	2
SL10	0,11332	0,02917	0,20472	9

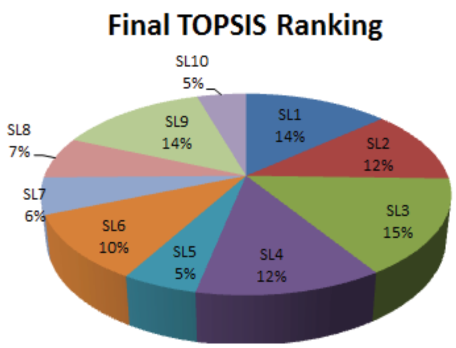


Fig. 6 Final TOPSIS Ranking

TABLE XVI
FINAL RANKING OF GSCM SOLUTIONS USING TOPSIS AND PROMETHEE METHODS

Alternatives	Final TOPSIS Ranking	Final PROMETHEE Ranking
SL1	2	8
SL2	5	4
SL3	1	1
SL4	4	7
SL5	10	9
SL6	6	2
SL7	9	5
SL8	8	10
SL9	2	3
SL10	9	6

IV. CONCLUSION

The present study explores the use of Fuzzy AHP TOPSIS-PROMETHEE based approach as a comparative analysis for identifying, ranking and prioritizing the GSCM solutions. This approach tested in a Moroccan corporation was intended to improve the success rate of the proposed solutions of GSCM, which will contribute to manage environmental impacts where and before they occur. The proposed methodology that we have chosen in this contribution is based on three major processes. For the first one, the decision-making committee specifies objectives and determines the set of evaluation criteria needed to take into account when evaluating GSCM solutions. In fact, the consideration of these criteria can affect directly on the final decision of a company concerning the sustainability of its activities. Thus, we need to recognize influential criteria that have an impact on the selection of the appropriate GSCM solution. The second process based on fuzzy AHP is employed to decompose the decision-making problem into its constituent parts and construct hierarchies of the influential criteria, already identified from the first process, in order to generate the criteria and sub-criteria weights. The third process based on TOPSIS and PROMETHEE allow to use these importance weights of all criteria as inputs in order to evaluate and rank the proposed GSCM solutions.

The implementation of this proposed methodological approach enables the decision makers of an organization not only to define the significant criteria, but also to select the suitable multi-criteria analysis method for comparing, evaluating and selecting the proposed GSCM solutions appropriately. In short, these solutions ranking help organizations in their decisions about their priorities of solutions implementation in order to get future sustainable strategies.

Finally, we can underline some real contributions of this study as follows:

- This is the first study to evaluate and analyze the accuracy of multi-criteria analysis techniques for the selection problem of GSCM solutions taking into consideration the alignment of the particularities of the problem with the features of the techniques. A study such as this can help researchers and decision makers to choose more approaches and methodologies that are effective for the selection of GSCM solutions.
- This study represents the first comparative analysis to explore and presents numeric examples of TOPSIS method with other multi-criteria decision-making methods such as PROMETHEE.
- It also represents the first contribution integrating FAHP, TOPSIS and PROMETHEE for the selection problem of GSCM solutions. This study can also be applied to other multi-criteria decision-making situations such as supplier selection and partner selection.

For further research, other fuzzy MCDM methods, such as fuzzy TODIM and fuzzy VIKOR, can be used in this integrated methodology and comparison of the results can be presented.

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