Advances in Applied Sciences
2024, Vol. 9, No. 4, pp. 87-98
https://doi.org/10.11648/j.aas.20240904.12

Research Article

A Novel H-FTOPSIS Based Consensus Process for Green Suppliers' Selection in the Context of Group Decision Making

Hichem Brahmi[1, *], Taicir Moalla Loukil[1], Maroua Ghram[2]

[1]Faculty of Economics and Management Sciences of Sfax, University of Sfax, Sfax, Tunisia
[2]Higher Institute of Business Administration of Sfax, University of Sfax, Sfax, Tunisia

Abstract

Recently, green suppliers 'selection problem (GSSP) is becoming a trend of any organization in order to satisfy their needs regarding environmental issues. It is one of the crucial activities in the development of the green supply chain and it attracted many researchers. As a result, many methods in the literature have dealt with this problem based on multi-criteria group decision-making ignoring the degree of consensus between the decision-makers, they take into consideration the level of priority between the decision-makers and the interdependence between the criteria. Due to the complexity of real environments and the subjective nature of human judgments, the proposal of a consensus model becomes very interesting in order to find agreements between decision makers using preference relations. We will present in this paper a study of the literature on the problems of consensus and selection of green suppliers, and then propose a model which is an extension of Hierarchical Fuzzy Technique for Order of Preference by Similarity to Ideal Solution (H-FTOPSIS) by integrating the concept of consensus. To the best of our knowledge, this combination with a consensus process has not been previously developed, and we did not find any related literature on this specific combination. This research bridges that gap and presents a novel approach. The proposed model is applied in this study for the first time.

Keywords

Green Supplier Selection, Consensus Decision Making, Group Decision, H-FTOPSIS

1. Introduction

Faced with unstable, increasingly competitive and globalized markets, many companies are seeking to explore new sources of competitiveness through the optimization of their supply chains and their relationships with their partners [2]. Providing the customer with the desired product and / or service, with better cost, quality and time conditions than those offered by competitors on the market, is nowadays the major concern of every company existing in a local and / or international market [21]. The supplier selection problem has been touted as one of the most critical issues an organization faces while maintaining a competitive position. Supplier selection has a direct effect on a company's profitability and traditionally it was primarily considered on the basis of economics, but in recent years, organizations have become increasingly concerned with privacy envi-

*Corresponding author: hichembrahmi@yahoo.fr (Hichem Brahmi)

Received: 21 May 2024; **Accepted:** 5 June 2024; **Published:** 16 December 2024

ronmental protection issues [6].

Due to the importance of considering environmental issues, all sectors face great pressure to consider environmental aspects in the supply chain. Green supplier selection is a crucial operational task in selecting a green partner through supplier assessment taking into account both economic and environmental factors [20]. The decision to select a green supplier is based on many contradictory criteria and multiple decision makers (DM), and is modeled as a multi-criteria Group Decision-Making Problem (MCGDM). Since the consideration of the importance of the green supply chain, many researchers have widely drawn attention to the design evaluation criteria, the optimization of the evaluation model and the application of various methods to solve this problem, Therefore, our main objective is to present a theoretical study and a case study dealing with the selection and evaluation of a group of suppliers, based on several environmental criteria.

This paper is organized as follows: Section II presents a literature review of main research papers dealing with this problem. Section III presents the methodology for solving the green supplier choice problem, and finally, section IV presents the implementation of our model in a practical case.

2. Literature Review

Green supplier selection has imposed considerable attention on the part of organizations based on the improvement of environmental regulations and environmental awareness. With the evolutions of the manufacturing systems, this decision becomes more and more critical. Recently, a number of green supplier selection methods have been developed in the literature.

2.1. Green Supplier Selection

Green supplier selection is defined as a strategic approach that involves identifying and choosing suppliers who prioritize sustainable and environmentally friendly practices. It is based on the recognition that the environmental impact of a company's supply chain can significantly affect its overall sustainability performance.

In this context, Dos-Santos B. M. Et al. [4] integrated fuzzy TOPSIS with the entropy method for the evaluation and selection of green supplier [4]. Lu JP. et al [11] used TOPSIS method for probabilistic linguistic MCGDM with entropy weight, and they applied it in selecting supplier of new agricultural machinery products [11]. Wen Z. et al [16] presented a model that combines Stepwise Weight Assessment Ratio Analysis (SWARA) with the Combined Compromise Solution (CoCoSo) method for probabilistic linguistic decision-making environments and subsequently applied it in a drug supplier selection problem [16]. Mousavi S. et al [12] proposed a new calculation approach based on Interval Type-2 Trapezoidal Fuzzy Numbers (IT2TrFNs) and they implemented it in the automotive industry [12]. Zhou F. et al [20] present an integrated approach to accurately solve the problem of selecting green suppliers under the Pythagorean fuzzy scenario (PF) based on AHP-VIKOR-MRM (Median Ranking Method) and they implemented it in agrifood company in China [20]. Xu D. et al [18] developed an extended EDAS method based single-valued complex neutrosophic sets and applied it for green supplier selection [18]. Wei G. et al [15] presented an extended version of the EDAS method with the Probabilistic Linguistic Term sets (PLTs) for the selection of green suppliers in order to guarantee the protection of the environment and have a sustainable economic development in China [15].

2.2. Consensus Based Multicriteria Group Decision Making

Consensus-based decision-making is a collaborative approach that aims to reach agreement among a group of individuals or stakeholders. It involves actively involving all participants in the decision-making process, seeking their input and striving to find a solution that is acceptable to everyone involved. it is often characterized as an iterative process. It involves multiple rounds of discussion, feedback, and revision to reach a collective agreement or shared understanding among participants.

Herrera-Viedma E. et al [7] affirmed that the consensus process is a crucial part of the consensus-based decision-making process and it can be classified into hard consensus, which is represented by an interval [0, 1] where 0 indicates there is no agreement and 1 indicates a full agreement among the decision makers and soft consensus which is allows the decision makers to reach a consensus when most of the decision makers involved in the group decision making process agree on a specific issue [7].

Much research has been done on the development of numerous approaches for consensus-based multicriteria group decision making.

Wibowo S. and Deng H. [17] developed a consensus-based approach for effectively solving the multicriteria group decision making problem in a fuzzy environment. The subjectiveness and imprecision of the selection process is modeled by using intuitionistic fuzzy numbers characterized by a membership function and a non-membership function. Next, they developed an interactive algorithm for solving the multicriteria group decision making problem [17].

Cabrerizo F. et al [3] proposed a method based on an allocation of information granularity in order to increase the consensus within the group of decision makers [3]. Liang R. and Chong H.-Y [10] developed a sorting decision framework for green supplier evaluation using the Qualitative Flexible Hesitant Fuzzy (QUALIFLEX) method and implemented and demonstrated this approach in the example of contract section CB02 in the Hong Kong-Zhuhai-Macau Bridge project [10]. In addition, Gao H. et al [5] proposed a group consensus decision making framework to help choosing the best green supplier for electronics manufacturing [5].

Zamora Y. [19] presented a hybrid method aimed at consensus building based of Analytic Hierarchy Process (AHP) with the Delphi method. A new approach characterized by the stability and exclusion analysis, as well as new coefficients of concordance and consistency with a statistical approach are proposed through a case study to explore the consensus building in the group decision-making process [19]. Huang J. et al [8] proposed a decision-making method based on attribute distribution information combined with the proposed distributed interval weighted arithmetic average (DIWAA) operator and provided examples to illustrate the feasibility and efficiency of the suggested approach based on distributed information for the selection of green suppliers [8].

Li H. et al [9] proposed a new method based on consensus mechanism in an interval type-2 fuzzy environment in order to resolve the multicriteria group decision making situation, and in order to evaluate the efficacy of this method, an example is illustrated by a comprehensive evaluation of old-age institutions in China [9].

The review above shows that there are several consensus-based methods for solving the multicriteria group decision making problem. These approaches are useful in dealing with the multicriteria group decision making problem under various circumstances. Some of these approaches require tedious mathematical computation in the decision-making process. In this situation, it is preferred to have a structured model for consensus building in solving the multicriteria group decision making problem.

3. The Proposed Model

We acknowledge the intricate and challenging nature of assessing the outcomes achieved through the majority of the suggested methods. The primary aim is to enhance the decision-making process and develop a more effective model that caters to the requirements of decision-makers (DMs). Consequently, we suggest a novel approach that combines the Fuzzy SWARA (Step-wise Weight Assessment Ratio Analysis) method with H-FTOPSIS to address the challenge of group multicriteria decision-making. Our proposed model leverages the strengths of both methods to provide an effective solution for the decision problem. The decision-making process is as follows: the selection of m green suppliers (A1, A2,..., Am) based on the opinions of decision-makers (D_k, k=1, 2,…s) and according to several green criteria (C_1, C_2,..., C_n). In group decision making, determining the degree of consensus among decision makers is an important element. Therefore, consensus aims to help decision makers reach agreement on the solution to a common decision problem. Figure 1 describes the proposed model.

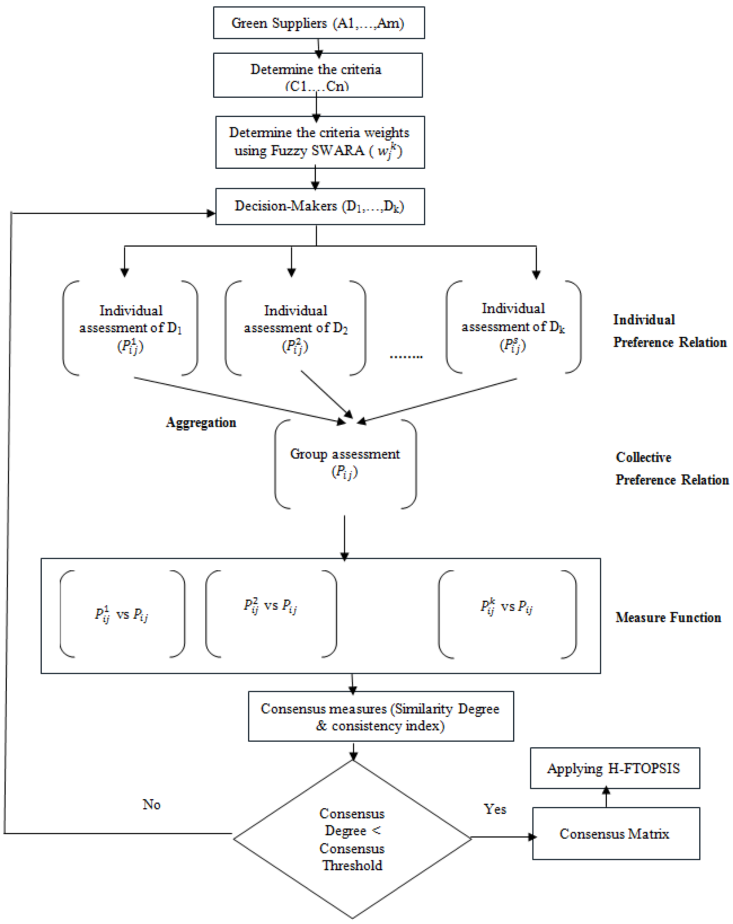

Figure 1. *The GSSP framework.*

The figure 1 explains our conception of our group decision-making problem. The first stage, we start with the identification of the number of green suppliers, decision-makers and the rating criteria in the multicriteria group decision making problem. Subsequently, we will determine the decision matrices of each decision maker. Then, we will determine the criteria weights with respect to each criterion. This is followed by the determination of the performance ratings of available alternatives with respect to each criterion by the decision makers.

The second stage is to obtain the agreed consensus threshold value, and measure the degree of existing consensus among decision makers' opinions. If CI is lower than the predefined threshold, we will return to the starting phase, otherwise a consensus agreement is achieved and we will consider the found matrix as a consensus matrix and H-FTOPSIS is applied.

3.1. Fuzzy SWARA

The Fuzzy SWARA is one of the new methods used in multicriteria decision-making that incorporates fuzzy logic to handle uncertainty and imprecision in the decision-making process [13]. This method helps the DMs to better understand and consider their preferences when determining the weights of attributes. It facilitates the process of appreciating the significance and meaning of attributes from the perspective of decision-makers.

The steps of this method are as follows:

a. Rank the criteria in descending order, based on their expected importance.

b. The process is started from the second factor where the experts allocate a score between zero and one to the factor j in relation to the previous criterion (j - 1). This process is then applied to each factor.

The ratio called the Comparative Importance of the Average Value S_j.

c. Calculation of the values of the coefficient $\hat{e}_j$.

$$\hat{e}_j = \begin{cases} 1, j = 1 \\ \hat{S}_j + 1, j > 1 \end{cases} \quad (1)$$

d. The recalculated fuzzy weights $\hat{g}_j$.

$$\hat{g}_j = \begin{cases} 1, j = 1 \\ \frac{\hat{g}_{j-1}}{\hat{e}_j}, j > 1 \end{cases} \quad (2)$$

e. The weight of fuzzy criteria $\hat{w}_j$.

$$\hat{w}_j = \frac{\hat{g}_j}{\sum_{k=1}^{n} \hat{g}_k} \quad (3)$$

3.2. H-FTOPSIS-CP (Hierarchical Fuzzy TOPSIS Based on Consensus Process)

Hierarchical Fuzzy TOPSIS is an extension of the Fuzzy TOPSIS method that incorporates a hierarchical structure and fuzzy logic to handle multicriteria decision-making problems and which is able to solve decision making problems in the form of hierarchy [14]. This method was initially introduced by [1] to evaluate university professors' performance.

The algorithm of the proposed model is as follows:

a. The construction of the decision matrix for each decision maker ($P^k = p_{ij}^k$),

1) De-Fuzzify to the fuzzified values

Set A= (a, b, c) a Triangular Fuzzy Number (TFN)

The defuzzify number is as follows:

$$A = \frac{1}{3}[(c-a)+(b-a)] + a \quad (4)$$

2) Group matrix aggregation (P= p_{ij})

3) Determine the degree of similarity (S) between individual decision makers' assessments and the group assessments for the preference relation with respect to each criterion, is obtained as:

$$S(p_{ij}^k, p_{ij}) = 1 - \frac{d(p_{ij}^k, p_{ij})}{\sum_{k=1}^{s} d(p_{ij}^k, p_{ij})} \quad (5)$$

Where $d(p_{ij}^k, p_{ij})$ is the distance between p_{ij}^k and p_{ij}

4) Determine the degree of similarity (M) between individual decision makers' assessments w_j^k and the group assessments p_j for the criteria weights, is obtained as:

$$M(w_j^k, p_j) = 1 - \frac{d(w_j^k, p_j)}{\sum_{k=1}^{s} d(w_j^k, p_j)} \quad (6)$$

Where $d(w_j^k, p_j)$ is the distance between $w_j^k = (x)$ and $p_j = \frac{\sum_{k=1}^{s} x^k}{s}$

5) Obtain the consistency index (CI) value for individual decision makers.

$$CI = Max\,(S(p_{ij}^k, p_{ij}), M(w_j^k, p_j)) \quad (7)$$

If the value of CI < the predefined threshold, the decision maker concerned needs to go back to Step 2. Otherwise, the consensus building process is finalized.

6) Construct the aggregate consensus matrix

b. Calculate the Fuzzy normalized decision matrix

$$\tilde{r}_{ij} = [\frac{a_{ij}}{c_j^+}, \frac{b_{ij}}{b_j^+}, \frac{c_{ij}}{a_j^+}], j \in B, \; a_j^+ = max\, a_{ij}, \; b_j^+ = max\, b_{ij}, \; c_j^+ = max\, c_{ij} \quad (8)$$

$$\tilde{r}_{ij} = [\frac{a_j^-}{c_{ij}}, \frac{b_j^-}{b_{ij}}, \frac{c_j^-}{a_{ij}}], j \in C, \ a_j^- = \min a_{ij}, \ b_j^- = \min \ b_{ij}, \ c_j^- = \min \ c_{ij} \quad (9)$$

B represents the profit criteria and C represents the cost criteria.

c. Obtaining weighted normalized matrix

$$\tilde{P}_{ij} = \tilde{r}_{ij} * \tilde{w}_j \quad (10)$$

Where $\tilde{w}_j$: weight of criteria j

d. Determine The generalized mean ($\boldsymbol{M(\tilde{v}ij)}$)

$$M(\tilde{v}_{ij}) = \frac{-a_{ij}^2 + c_{ij}^2 - a_{ij}b_{ij} + b_{ij}c_{ij}}{3(-a_{ij} + c_{ij})} \quad (11)$$

e. Determining positive and negative ideal solutions.

$$A^+ = [p_1^+, \dots \dots, p_n^+] = \{(Max_{j\in I} p_{ij}).(Min_{j\in J}\ p_{ij})\} \quad (12)$$

$$A^- = [p_1^-, \dots \dots, p_n^-] = \{(Min_{j\in I}\ p_{ij}).(Max_{j\in J}\ p_{ij})\} \quad (13)$$

f. Calculating distance of each criterion from the fuzzy positive (S^+) and negative (S^-) ideal solutions.

$$S_i^+ = \sum_{i=1}^{m} D_{ij}^+ \quad (14)$$

$$S_i^- = \sum_{i=1}^{m} D_{ij}^- \quad (15)$$

Where

$$D_{ij}^+ = \begin{cases} 1 - \frac{c_{ij} - a^+}{b^+ + c_{ij} - a^+ - b_{ij}}, b_{ij} < b^+ \\ 1 - \frac{c^+ - a_{ij}}{b_{ij} + c^+ - a_{ij} - b^+}, b^+ < b_{ij} \end{cases} \quad (16)$$

$$D_{ij}^- = \begin{cases} 1 - \frac{c^- - a_{ij}}{b_{ij} + c^- - a_{ij} - b^-}, b^- < b_{ij} \\ 1 - \frac{c_{ij} - a^-}{b^- + c_{ij} - a^- - b_{ij}}, b_{ij} < b^- \end{cases} \quad (17)$$

g. Calculating relative closeness C of each criterion to ideals.

$$C_i = \frac{S_i^-}{S_i^- + S_i^+} \quad (18)$$

h. Ranking the alternatives.

4. Case Study

The proposed H-FTOPSIS based on consensus process model is intended to solve a variety of problems. The case study focuses on the sandwich panel industry in Sousse, Tunisia. The company has long been an innovative industrial company whose main activity is the manufacture and marketing of sandwich panels for building insulation, refrigeration panels for cold insulation and it has been ISO45001 certified. It is a typical example that has a great influence on climate and environmental change and adheres to environmental protection guidelines in daily activities. In practice, this company intends to buy chemical products, which are the ingredient in the injection of the foam of the Sandwich Panels and represents more than 70% of the supply costs. Therefore, this company should select an optimal green supplier. The potential candidates are: Wanhua, Vercolor, Itelyum Regeneration Spa, Galco, Ivonik, Plexint and Dutch2 B.V. In determining the best green supplier, the final decision lies with the administration team, which is composed of the President (DM 1), purchasing manager (DM2) and financial manager (DM3) who are usually involved in making the crucial decisions of the company.

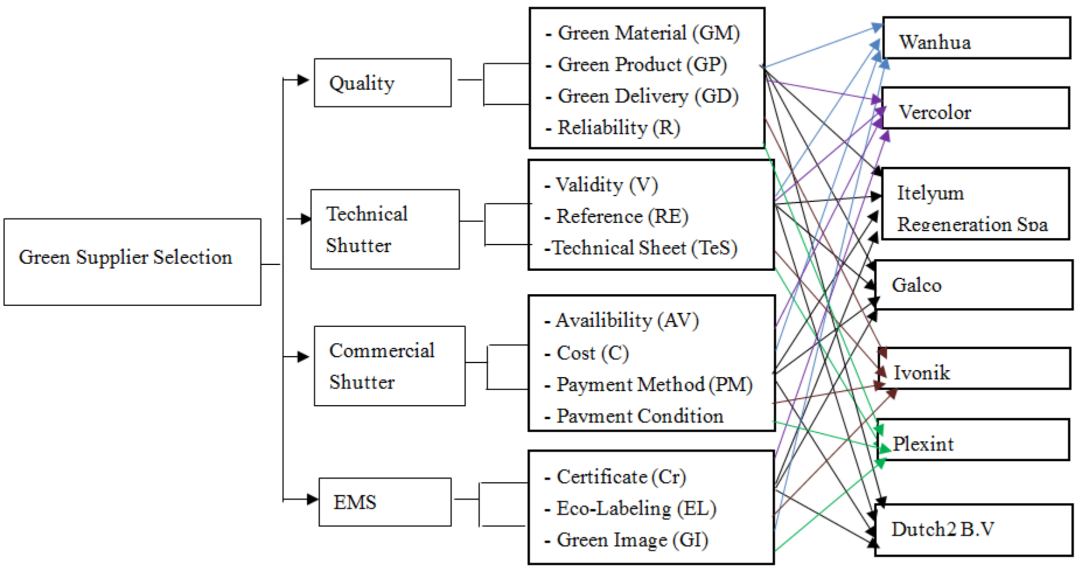

Figure 2. *The proposed hierarchical structure for green supplier selection.*

The figure 2 presents the hierarchical structure of criteria. The root criterion corresponds to the objective: Green supplier selection. Quality, Technical Shutter, Commercial Shutter and EMS present the intermediate criteria. The criteria at the next level, present the elementary criteria in which the DM can directly evaluates the alternatives. All of them to be maximized except the cost to be minimized.

The experts listed the criteria according to their expected level of importance.

Table 1. *Criteria.*

Criteria	Designation	Maximize or minimize the value of the criterion (Max/Min)
Green Material	GM	Max
Green Product	GP	Max
Green Delivery	GD	Max
Reliability	R	Max
Validity	V	Max
Reference	RE	Max
Technical Sheet	TeS	Max
Availibility	AV	Max
Cost	C	Min
Payment Method	PM	Max
Payment Condition	PC	Max
Certificate	Cr	Max
Eco-Labeling	EL	Max
Green Image	GI	Max

Table 2. *Linguistic Values By (Chang, 1996)*

Linguistic Scale	Triangular Fuzzy Number (TFN)
Much Less Important	(0.222, 0.25, 0.286)
Very Less Important	(0.286, 0.333, 0.40)
Less Important	(0.4, 0.5, 0.667)
Moderately Important	(0.667, 1, 1.5)
Equally Important	(1, 1, 1)

The decision-maker utilizes the values presented in Table 2 to compare the (j-1)th criterion with the jth criterion. In this comparison, the decision-maker employs linguistic values denoted as $\hat{S}j$, which represent the initial step in Fuzzy SWARA. Based on these values, the decision-maker proceeds to rank the factors in terms of their priority.

The decision matrix provided by the decision makers (DMs) consists of evaluations from each expert for the alternatives based on the elementary criteria.

Table 3. Intermediate Criteria Weights.

Criteria	DM1	DM2	DM3
Quality (Q)	0.458	0.513	0.498
Technical shutter (TS)	0.239	0.267	0.259
Commercial shutter (CS)	0.181	0.142	0.138
EMS	0.123	0.077	0.105

Table 4. Sub-Criteria Weights.

Sub-Criteria	DM1	DM2	DM3
GM	0,220	0,245	0,240
GP	0,118	0,131	0,129
GD	0,081	0,090	0,088
R	0,062	0,069	0,067
V	0,097	0,108	0,118
RE	0,066	0,074	0,064
TeS	0,054	0,060	0,051
AV	0,090	0,071	0,070
C	0,049	0,039	0,039
PM	0,034	0,027	0,027
PC	0,026	0,021	0,021
Cr	0,054	0,034	0,047
EL	0,029	0,019	0,026
GI	0,020	0,013	0,014

The criteria and the intermediate criteria weights in tables 3 and 4 are determined by Fuzzy SWARA method.

Table 5. Linguistic variables for ratings (Jinus at al, 2013).

Linguistic Scale	Triangular Fuzzy Number (TFN)
Very weak	(1,1,3)
Weak	(1, 3, 5)
Medium	(3, 5, 7)
Good	(5, 7, 9)
Very good	(7, 9, 9)

Table 6. Importance weights of decision-makers.

DMs	Weight
President	0.500
Purchasing Manager	0.200
Financial Manager	0.300

Table 5 provides the rating scale that was used to generate the importance weights of the decision-makers. The weights of the decision-makers are shown in Table 6.

Table 7. President's decision matrix.

DM (1)	President													
Criteria	Q			TS				CS			EMS			
Sub-Criteria	GM	GP	GD	R	V	RE	TeS	AV	C	PM	PC	Cr	EL	GI
Itelyum Regeneration Spa	(7,9,9)	(5,7,9)	(5,7,9)	(3,5,7)	(5,7,9)	(1,3,5)	(7,9,9)	(1,3,5)	(3,5,7)	(3,5,7)	(3,5,7)	(5,7,9)	(5,7,9)	(3,5,7)
Galco	(5,7,9)	(5,7,9)	(7,9,9)	(1,3,5)	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)	(1,3,5)	(7,9,9)	(5,7,9)	(5,7,9)

DM (1)	President													
Criteria	**Q**			**TS**				**CS**				**EMS**		
Sub-Criteria	**GM**	**GP**	**GD**	**R**	**V**	**RE**	**TeS**	**AV**	**C**	**PM**	**PC**	**Cr**	**EL**	**GI**
Dutch2 B. V	(5,7,9)	(7,9,9)	(5,7,9)	(1,1,3)	(3,5,7)	(1,1,3)	(7,9,9)	(1,3,5)	(7,9,9)	(5,7,9)	(1,1,3)	(7,9,9)	(1,3,5)	(7,9,9)
Wanhua	(3,5,7)	(7,9,9)	(3,5,7)	(1,3,5)	(3,5,7)	(3,5,7)	(7,9,9)	(3,5,7)	(3,5,7)	(5,7,9)	(3,5,7)	(5,7,9)	(1,3,5)	(5,7,9)
Vercolor	(1,3,5)	(5,7,9)	(1,3,5)	(1,1,3)	(1,3,5)	(1,3,5)	(5,7,9)	(1,3,5)	(1,3,5)	(5,7,9)	(1,3,5)	(5,7,9)	(3,5,7)	(5,7,9)
Ivonic	(3,5,7)	(5,7,9)	(3,5,7)	(1,3,5)	(3,5,7)	(3,5,7)	(5,7,9)	(3,5,7)	(3,5,7)	(3,5,7)	(7,9,9)	(3,5,7)	(1,1,3)	(3,5,7)
Plexint	(1,1,3)	(3,5,7)	(1,1,3)	(1,1,3)	(1,1,3)	(1,1,3)	(3,5,7)	(1,1,3)	(1,1,3)	(1,1,3)	(1,1,3)	(5,7,9)	(3,5,7)	(1,1,3)

Table 8. *Financial manager's decision matrix.*

DM (2)	**Financial Manager**													
Criteria	**Q**				**TS**			**CS**				**EMS**		
Sub-Criteria	**GM**	**GP**	**GD**	**R**	**V**	**RE**	**TeS**	**AV**	**C**	**PM**	**PC**	**Cr**	**EL**	**GI**
Itelyum Regeneration Spa	(5,7,9)	(5,7,9)	(5,7,9)	(3,5,7)	(7,9,9)	(1,1,3)	(7,9,9)	(5,7,9)	(7,9,9)	(7,9,9)	(3,5,7)	(7,9,9)	(5,7,9)	(3,5,7)
Galco	(7,9,9)	(7,9,9)	(5,7,9)	(3,5,7)	(5,7,9)	(5,7,9)	(7,9,9)	(7,9,9)	(5,7,9)	(7,9,9)	(5,7,9)	(7,9,9)	(5,7,9)	(5,7,9)
Dutch2 B. V	(7,9,9)	(7,9,9)	(5,7,9)	(1,3,5)	(3,5,7)	(1,1,3)	(7,9,9)	(7,9,9)	(5,7,9)	(5,7,9)	(5,7,9)	(7,9,9)	(1,3,5)	(7,9,9)
Wanhua	(5,7,9)	(7,9,9)	(3,5,7)	(1,3,5)	(5,7,9)	(7,9,9)	(5,7,9)	(7,9,9)	(3,5,7)	(5,7,9)	(3,5,7)	(5,7,9)	(7,9,9)	(5,7,9)
Vercolor	(3,5,7)	(5,7,9)	(1,3,5)	(1,1,3)	(5,7,9)	(5,7,9)	(1,3,5)	(5,7,9)	(1,3,5)	(5,7,9)	(1,3,5)	(5,7,9)	(5,7,9)	(1,3,5)
Ivonic	(1,3,5)	(5,7,9)	(3,5,7)	(1,3,5)	(3,5,7)	(3,5,7)	(3,5,7)	(5,7,9)	(3,5,7)	(3,5,7)	(3,5,7)	(3,5,7)	(3,5,7)	(3,5,7)
Plexint	(3,5,7)	(3,5,7)	(3,5,7)	(3,5,7)	(1,1,3)	(1,3,5)	(1,1,3)	(3,5,7)	(1,1,3)	(1,1,3)	(1,1,3)	(1,1,3)	(1,3,5)	(1,1,3)

Table 9. *Purchasing manager's decision matrix.*

DM (3)	**Purchasing Manager**													
Criteria	**Q**				**TS**			**CS**				**EMS**		
Sub-Criteria	**GM**	**GP**	**GD**	**R**	**V**	**RE**	**TeS**	**AV**	**C**	**PM**	**PC**	**Cr**	**EL**	**GI**
Itelyum Regeneration Spa	(5,7,9)	(5,7,9)	(5,7,9)	(3,5,7)	(7,9,9)	(1,1,3)	(7,9,9)	(5,7,9)	(7,9,9)	(7,9,9)	(3,5,7)	(7,9,9)	(5,7,9)	(3,5,7)
Galco	(7,9,9)	(7,9,9)	(5,7,9)	(3,5,7)	(5,7,9)	(5,7,9)	(7,9,9)	(7,9,9)	(5,7,9)	(7,9,9)	(5,7,9)	(7,9,9)	(5,7,9)	(5,7,9)
Dutch2 B. V	(7,9,9)	(7,9,9)	(5,7,9)	(1,3,5)	(3,5,7)	(1,1,3)	(7,9,9)	(7,9,9)	(5,7,9)	(5,7,9)	(5,7,9)	(7,9,9)	(1,3,5)	(7,9,9)
Wanhua	(5,7,9)	(7,9,9)	(3,5,7)	(1,3,5)	(5,7,9)	(7,9,9)	(5,7,9)	(7,9,9)	(3,5,7)	(5,7,9)	(3,5,7)	(5,7,9)	(7,9,9)	(5,7,9)
Vercolor	(3,5,7)	(5,7,9)	(1,3,5)	(1,1,3)	(5,7,9)	(5,7,9)	(1,3,5)	(5,7,9)	(1,3,5)	(5,7,9)	(1,3,5)	(5,7,9)	(5,7,9)	(1,3,5)
Ivonic	(1,3,5)	(5,7,9)	(3,5,7)	(1,3,5)	(3,5,7)	(3,5,7)	(3,5,7)	(5,7,9)	(3,5,7)	(3,5,7)	(3,5,7)	(3,5,7)	(3,5,7)	(3,5,7)

DM (3)	Purchasing Manager													
Criteria	Q				TS			CS				EMS		
Sub-Criteria	GM	GP	GD	R	V	RE	TeS	AV	C	PM	PC	Cr	EL	GI
Plexint	(3,5,7)	(3,5,7)	(3,5,7)	(3,5,7)	(1,1,3)	(1,3,5)	(1,1,3)	(3,5,7)	(1,1,3)	(1,1,3)	(1,1,3)	(1,1,3)	(1,3,5)	(1,1,3)

Tables 7, 8 and 9 present the decision matrices of each member of group decision making.

Table 10. *The degree of similarity of decision makers.*

Alternatives	DM (i)	Q				TS			CS				EMS		
		GM	GP	GD	R	V	RE	TeS	AV	C	PM	PC	Cr	EL	GI
Itelyum Re-generation Spa	DM1	0,638	0,696	0,667	0,667	0,696	0,782	0,667	0,907	0,793	0,815	0,725	0,722	0,667	0,725
	DM2	0,724	0,696	0,667	0,667	0,608	0,954	0,667	0,598	0,556	0,593	0,725	0,639	0,667	0,725
	DM3	0,638	0,607	0,667	0,667	0,696	0,264	0,667	0,495	0,651	0,593	0,55	0,639	0,667	0,55
Galco	DM1	0,696	0,696	0,606	0,815	0,696	0,494	0,722	0,696	0,696	0,722	0,855	0,667	0,667	0,614
	DM2	0,608	0,608	0,697	0,593	0,696	0,494	0,639	0,608	0,696	0,639	0,478	0,667	0,667	0,614
	DM3	0,696	0,696	0,697	0,593	0,607	1,013	0,639	0,696	0,607	0,639	0,667	0,667	0,667	0,772
Dutch2 B.V	DM1	0,722	0,667	0,667	0,833	0,667	0,667	0,667	0,921	0,606	0,667	0,98	0,667	0,667	0,667
	DM2	0,639	0,667	0,667	0,583	0,667	0,667	0,667	0,54	0,697	0,667	0,51	0,667	0,667	0,667
	DM3	0,639	0,667	0,667	0,583	0,667	0,667	0,667	0,54	0,697	0,667	0,51	0,667	0,667	0,667
Wanhua	DM1	0,794	0,481	0,725	0,757	0,769	0,815	0,606	0,793	0,757	0,614	0,589	0,614	0,876	0,696
	DM2	0,651	0,481	0,725	0,757	0,615	0,593	0,697	0,556	0,757	0,614	0,589	0,614	0,419	0,696
	DM3	0,555	1,037	0,55	0,486	0,615	0,593	0,697	0,651	0,486	0,772	0,822	0,772	0,705	0,607
Vercolor	DM1	0,859	0,667	0,818	0,771	0,889	0,889	0,333	0,855	0,818	0,548	0,579	0,548	0,667	0,543
	DM2	0,667	0,667	0,818	0,771	0,556	0,556	0,833	0,478	0,818	0,548	0,579	0,548	0,471	0,914
	DM3	0,474	0,667	0,364	0,458	0,556	0,556	0,833	0,667	0,364	0,905	0,842	0,905	0,863	0,543
Ivonic	DM1	0,587	0,494	0,667	0,757	0,667	0,667	0,545	0,667	0,725	0,667	0,385	0,667	0,933	0,725
	DM2	0,825	0,494	0,667	0,757	0,667	0,667	0,727	0,471	0,725	0,667	0,71	0,667	0,533	0,725
	DM3	0,587	1,013	0,667	0,486	0,667	0,667	0,727	0,863	0,55	0,667	0,905	0,667	0,533	0,55
Plexint	DM1	0,963	0,757	0,852	0,852	0,667	0,833	0,222	0,933	0,863	0,863	0,863	0,373	0,374	0,863
	DM2	0,621	0,757	0,296	0,296	0,667	0,583	0,889	0,533	0,863	0,863	0,863	1,013	0,703	0,863
	DM3	0,416	0,486	0,852	0,852	0,667	0,583	0,889	0,533	0,275	0,275	0,275	0,613	0,923	0,275
Criteria weights	DM1	0,383	0,387	0,388	0,389	0,027	0,791	0,788	0,304	0,306	0,307	0,307	0,541	0,545	0,383
	DM2	0,606	0,607	0,608	0,608	0,953	0,201	0,205	0,682	0,682	0,688	0,689	0,455	0,453	0,614
	DM3	0,728	0,777	0,779	0,779	0,064	0,406	0,414	0,616	0,616	0,617	0,617	0,913	0,908	0,768

In this situation, the decision makers agreed to assign the consensus threshold value to be at 0.70. This consensus threshold value is obtained based on the negotiation between the decision makers.

If the consensus threshold value > 0.7, it implies a higher degree of consistency among the decision makers' opinions.

Table 11 presents the calculation of the CI using (4), (5), (6) and (7).

Table 11*. The CI of individual decision makers.*

Alternatives	Decision-Maker (DM)	CI
Itelyum Regeneration Spa	DM1	0,907
	DM2	0,954
	DM3	0,913
Galco	DM1	0,855
	DM2	0,953
	DM3	1,013
Dutch2 B. V	DM1	0,98
	DM2	0,953
	DM3	0,913
Wanhua	DM1	0,876
	DM2	0,953
	DM3	1,037
Vercolor	DM1	0,889
	DM2	0,953
	DM3	0,913
Ivonic	DM1	0,933
	DM2	0,953
	DM3	1,013
Plexint	DM1	0,963
	DM2	1,013
	DM3	0,923

Then, we determine the utility degrees of all alternatives according to the criteria to create the complete pre-order in Table 12.

Table 12*. The complete pre-order.*

Alternatives \Distance	Ci	Ranking
Itelyum Regeneration Spa	0,375	6
Galco	0,862	1
Dutch2 B. V	0,157	7
Wanhua	0,380	5
Vercolor	0,665	3
Ivonic	0,622	4
Plexint	0,689	2

5. Discussion

The proposed methodology for classifying green suppliers depends on the number of suppliers, decision makers, and evaluation criteria. In our application, we focus on selecting suppliers of chemical products worldwide based on specific criteria. The weights for these criteria were determined using fuzzy SWARA, which revealed that the most significant criterion was Q, followed by TS, CS, and EMS.

Subsequently, the selection of green suppliers for chemical products was carried out using H-FTOPSIS, incorporating a consensus process. The analysis identified "Itelyum Regeneration Spa" as the top-ranked supplier, followed by Galco, Dutch2 B.V, Wanhua, Vercolor, Ivonic, and Plexint.

Compared to the model to that proposed by Gupta et al, [6] the proposed approach is able to effectively deal with the involvement of multiple decision-makers and the presence of subjectivity and imprecision in the group multi-criteria decision-making problem. Indeed, the application of this approach helps to improve the effectiveness of the consensus building process in solving the multi-criteria group decision-making problem and is applicable to efficiently solve the general multi-criteria group decision-making problem in real-world situations.

6. Conclusion

Achieving consensus in multicriteria group decision making is a complex and demanding task due to the involvement of multiple decision makers, the presence of various selection criteria, and the inherent subjectivity and imprecision associated with assessments during the group decision-making process.

Consideration of a new green strategy could generate a competitive advantage for an organization and this requires a change in the capabilities and resources provided. This study proposed an MCGDM (Multicriteria group decision making) approach based on consensus process and hierarchical Fuzzy TOPSIS to support such an assessment in order to achieve sustainable economic and environmental performance. The Fuzzy SWARA method is indeed utilized to calculate the criteria weights and the H-FTOPSIS approach based on consensus process, on the other hand, is used to rank the options. The implementation of this method to select the green supplier who respects the conditions of sale indicates the rate of danger when using its products. Among the advantages of our model: it is a structural technique compared to others such as AHP, ELECTRE and that it is based on the utility which compares each supplier directly according to the data in the evaluation matrix and weights.

Abbreviations

GSSP	Green Suppliers‘Selection Problem
H-FTOPSIS	Hierarchical Fuzzy Technique for Order of Preference by Similarity to Ideal Solution
H-FTOPSIS-CP	Hierarchical Fuzzy TOPSIS Based on Consensus Process
DM	Decision Maker
MCGDM	Multicriteria Group Decision Making
SWARA	Stepwise Weight Assessment Ratio Analysis
CoCoSo	Combined Compromise Solution
IT2TrFNs	Interval Type-2 Trapezoidal Fuzzy Numbers
PF	Pythagorean Fuzzy
AHP	Analytic Hierarchy Process
VIKOR-MRM	VIKOR Median Ranking Method
EDAS	Evaluation Based on Distance from Average Solution
PLTs	Probabilistic Linguistic Term sets
CI	Consistency Index
C	Criteria
W_j	Weight
P	Individual Assessment of D
TFN	Triangular Fuzzy Number
$\boldsymbol{M}(\mathrm{V}\boldsymbol{ij})$	Generalized Mean

Author Contributions

Hichem Brahmi: Conceptualization, Investigation, Methodology, Visualization, Writing – review & editing

Taicir Moalla Loukil: Formal Analysis, Methodology, Validation, Visualization

Maroua Ghram: Conceptualization, Formal Analysis, Methodology

Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] Ateş N. Y., Çevik S., Kahraman C., Gülbay M. & Erdoğan S. A. (2006). Multi Attribute Performance Evaluation Using a Hierarchical Fuzzy TOPSIS Method. Studies in Fuzziness and Soft Computing, Vol 537–572. https://doi.org/10.1007/3-540-33517-x_22

[2] Brahmi H. and Loukil M. T, (2021), A New multicriteria decision support tool based on fuzzy SWARA and TOPSIS, Multiple Criteria Decision Making (16), Vol 16, pp. 5-22.

[3] Cabrerizo F., Ureña R., Pedrycz W., & Herrera-Viedma E. (2014). Building consensus in group decision making with an allocation of information granularity. Fuzzy Sets and Systems, 255, Vol 115–127. https://doi.org/10.1016/j.fss.2014.03.016

[4] Dos-Santos B. M., Godoy L. P., & Campos L. M. S. (2018). Performance Evaluation of Green Suppliers using Entropy-TOPSIS-F. Journal of Cleaner Production. https://doi.org/10.1016/j.jclepro.2018.09.235

[5] Gao H., Ju Y., Santibanez Gonzalez E. D. R., & Zhang W. (2019). Green supplier selection in electronics manufacturing: An approach based on consensus decision making. Journal of Cleaner Production, 118781. https://doi.org/10.1016/j.jclepro.2019.118781

[6] Gupta S., Soni U., & Kumar G. (2019). Green supplier selection using multi-criterion decision making under fuzzy environment: A case study in automotive industry. Computers & Industrial Engineering. https://doi.org/10.1016/j.cie.2019.07.038

[7] Herrera-Viedma E., Martínez L., Mata F. & Chiclana F. (2005). A consensus support systems model for group decision making problems with multigranular linguistic preference relations. IEEE Transactions on Fuzzy Systems, 13, Vol 644–658.

[8] Huang J., Jiang N., Chen J., Balezentis T., & Streimikiene D. (2021). Multi-criteria group decision-making method for green supplier selection based on distributed interval variables. Economic Research-Ekonomska Istraživanja, Vol 1–16. https://doi.org/10.1080/1331677x

[9] Li H., Wu P., Zhou L., & Chen H. (2021). A new multi-criteria group decision-making method based on consensus mechanism in an interval type-2 fuzzy environment. Journal of Intelligent & Fuzzy Systems, 40(6), 10935–10953. https://doi.org/10.3233/jifs-201979

[10] Liang R., & Chong H.-Y. (2019). A hybrid group decision model for green supplier selection: a case study of megaprojects. Engineering, Construction and Architectural Management. https://doi.org/10.1108/ecam-10-2018-0462

[11] Lu JP, Wei C, Wu J & Wei GW (2019). TOPSIS method for probabilistic linguistic MAGDM with entropy weight and its application to supplier selection of new agricultural machinery products. Entropy 21: 953.

[12] Mousavi S. M., Foroozesh N., Zavadskas E. K., & Antucheviciene J. (2020). A new soft computing approach for green supplier selection problem with interval type-2 trapezoidal fuzzy statistical group decision and avoidance of information loss. Soft Computing, 24(16), Vol 12313–12327. https://doi.org/10.1007/s00500-020-04675-4

[13] Perçin Selçuk (2019), An Integrated Fuzzy SWARA and Fuzzy AD Approach for Outsourcing Provider Selection, Journal of Manufacturing Technology Management, https://doi.org/10.1108/JMTM-08-2018-0247

[14] Roshandel, J., Miri-Nargesi S. S. & Hatami-Shirkouhi L. (2013). Evaluating and selecting the supplier in detergent production industry using hierarchical fuzzy TOPSIS. Applied Mathematical Modelling, 37(24), Vol 10170–10181. https://doi.org/10.1016/j.apm.2013.05.043

[15] Wei G., Wei C. & Guo Y. (2021). EDAS method for probabilistic linguistic multiple attribute group decision making and their application to green supplier selection. Soft Computing, 25(14), Vol 9045–9053. https://doi.org/10.1007/s00500-021-05842-x

[16] Wen Z., Liao H., Ren R., Bai C., Zavadskas E. K., Antucheviciene J. & Al-Barakati, A. (2019). Cold chain logistics management of medicine with an integrated multi-criteria decision- making method. International Journal of Environmental Research and Public Health, 16(23), 4843. https://doi.org/10.3390/ijerph16234843

[17] Wibowo S. & Deng, H. (2013). Consensus-based decision support for multicriteria group decision making. Computers & Industrial Engineering, 66(4), Vol 625–633. https://doi.org/10.1016/j.cie.2013.09.015

[18] Xu D., Cui X. & Xian, H. (2020). An Extended EDAS Method with a Single-Valued Complex Neutrosophic Set and Its Application in Green Supplier Selection. Mathematics, 8(2), 282. https://doi.org/10.3390/math8020282

[19] Zamora Y. (2020). Consensus building in a group decision-making process. Pesquisa Operacional (2020) 40: e235350 p. 1-15 https://doi.org/10.1590/0101-7438.2020.040.00235350

[20] Zhou F. & Chen T.-Y. (2020). An Integrated Multicriteria Group Decision-Making Approach for Green Supplier Selection Under Pythagorean Fuzzy Scenarios. IEEE Access, 8, Vol 165216–165231. https://doi.org/10.1109/access.2020.3022377

[21] Zouggari A.& Benyoucef L. (2011), "Une approche couplant logique floue et capitalisation des connaissances pour la résolution du problème de choix des fournisseurs", Mathématiques générales [math. GM], Université Paul Verlaine – Metz, https://hal.univ-lorraine.fr/tel01749069