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A COMBINED FUZZY MULTI-CRITERIA DECISION MAKING APPROACH FOR GREEN SUPPLIER SELECTION IN BUILDING MATERIAL INDUSTRY

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ABSTRACT

With the growing awareness of environmental protection and increasingly demanding customers, the integration of green practices into supply chain management has become an important issue for companies in different industry sectors. It is now essential for managers to review their strategies and improve the performance of their decision-making systems if they want to maintain their competitiveness. This paper proposes a green supplier selection and evaluation model for material building sector that takes into account both traditional and ecological characteristics. This hybrid model incorporates two well-known decision-making approaches, Fuzzy Analytic Hierarchical Process (Fuzzy AHP) and Fuzzy Technique for Order Preference by Similarity to Ideal Solution (Fuzzy TOPSIS). The selection criteria are determined on the basis of a detailed analysis of the existing literature and a series of interviews with the expert team members, taking into account the characteristics of the studied sector. These criteria are evaluated and weighted by the Fuzzy AHP method and subsequently, based on the Fuzzy AHP weights, Fuzzy TOPSIS is applied to rank the potential suppliers. In order to prove the efficiency and the applicability of the suggested approach a real-world case study is conducted to evaluate three green suppliers of a Moroccan ceramic tile company. And finally a sensitivity study is performed to assess the impact of criterion weights on the supplier ranking order.

Keywords: *Green supplier selection, Multi criteria decision-making, Fuzzy set theory, Fuzzy AHP, Fuzzy TOPSI*

1. INTRODUCTION

Knowing the fact that environment deterioration is mainly caused by human activity and especially industrial activity, the environment preservation becomes a shared concern for all; politicians, professionals and the general public. Managers need to be more responsible and take action in order to reduce their company's environmental impact. Profit maximization is no longer the only focus of managers. Thus the integration of green practices and the challenge of transitioning from the traditional SCM to the Green SCM is nowadays a necessity and no more a luxury(1). Supplier selection and evaluation is a classic problem in the supply chain management, it has been widely covered by authors from many different perspectives. Indeed, our bibliography lists several publications that address this issue. The earliest work is published in the 1960s by Dickson(2) he is recognized as a pioneer in this particular research area. On the other hand, the literature on the evaluation and selection of green suppliers is very limited and only emerged after the early 1990s. Green Supplier Selection has become an issue of great importance recently due to the global awareness of environmental issues (3–6). In a SCM concept, that is based on cooperation and collaboration principles, suppliers are considered as partners playing an important role in the global performance of the company. Selecting the right supplier is a very high priority decision (7), managers must be very vigilant when choosing their partners. This decision depends on several factors, both qualitative and quantitative (8), and when it comes to selecting a green supplier, ecological factors are also taken into account. Indeed, it is a complex decision and researchers are contributing a great deal of effort in this area by providing decision makers with various models for the selection of green suppliers. this paper falls within the framework of the same problematic where we attempt through this work to enrich the literature in this field of study and propose a model of ecological supplier selection and evaluation in an industrial sector that is often neglected by researchers.

The building materials manufacturing sector is of major importance because of the relationships it has with the rest of the economy, particularly construction, tourism, and infrastructure works moreover it has a pivotal role in improving human settlements(9). Building material industry includes mainly, ceramic, marble, steel and cement industry. On the other hand, it is considered as one of the most environmental unfriendly sectors(10). With regard to the manufacture of ceramic tiles, for example, the main source of primary energy is non-renewable fossil fuel, which is why this sector in particular requires special attention with regard to the integration of environmental practices(11).

The human mind excels at comparing two objects based on a single criterion. However, when comparing several objects based on multiple criteria, our brain becomes confused. Researchers are attempting to assist managers in their decision-making by developing several selection models utilizing various methods and techniques. Researchers have proved the effectiveness of Multi criteria decision-making (MCDM) methods for supplier evaluation and selection(4,12,13). These methods, which are typically relied on expert opinion, are frequently linked with a high level of uncertainty. In this paper, we propose a model that uses fuzzy theory to overcome ambiguity and fuzziness in human judgment (14). The proposed model uses FAHP to weight the criteria and then the alternatives are ranked based on FAHP weights using FTOPSIS.

The rest of the paper is structured as follows: Section 2 present a literature review on different method and relevant selection criteria used in evaluating green suppliers. Section 3 present the proposed methodology with a description of the Fuzzy AHP and Fuzzy TOPSIS calculation steps. Section 4 gives a brief introduction to the Moroccan building material sector followed by a case study conducted in a Moroccan tile ceramic company. discussion of the results obtained from the model implementation as well as the research findings are in section 5. A sensitive analysis is conducted in section 6 and finally, in section 7 a conclusion and further research orientation.

2. LITERATURE REVIEW

In this section a brief presentation is given of the findings from the literature review concerning the most common methods used in Green Supplier selection as well as the relevant selection criteria. There are various studies in the literature that deal with the problem of supplier selection. (2) was a pioneer in addressing the vendor selection problem. He examined a set of 23 criteria that were subsequently exploited by researchers. Now with the global rise of environmental awareness, studies on green supplier selection are attracting more attention and are becoming more and more numerous. Today any company that wants to keep its place among its competitors must adopt the concept of GSCM by integrating green practices and working in collaboration with its external partners (1). this competitiveness pushes managers to look for the most efficient green supplier. Choosing the right supplier is a strategic decision that depends on different factors.

The identification of the selection criteria is a very important step in the process of selecting suppliers (3), a step that must be carried out carefully and responsibly. It is a determining factor of the model efficiency and the relevance of the results obtained (15). In the literature we can classify the criteria under two categories; the traditional or economic criteria and the green criteria. (2) is considered to be a leading researcher in analyzing selection criteria in vendor evaluation. In his study he presented a list of the most relevant factors that should be considered in every selection model. 23 criteria are ranked by degree of importance; quality is the most important one followed by delivery, performance history, warranties & claims policies, production facilities and capacity, price, technical capability and financial position. Currently with the growing global awareness, managers are more involved in evaluating the environmental performance of their partners and integrating green criteria in the decision making process (14,16). (17) conducted a literature review to determine the most relevant factors for a strong and successful long-term relationship in Green Supplier selection. He constructed a hierarchy composed of eight main criteria and thirty-one sub-criteria. Cost, delivery, quality, service, strategic alliance, pollution control, green product, environmental management. Table 2 highlights the selection criteria and sub-criteria that have been widely known and followed in the literature.

Since supplier selection is considered as complex decision, researchers are trying to support managers in their decision making through the development of green supplier selection models using different approaches and techniques. The most commonly used methods are: MCDM methods, Mathematical Programming (MP) and Artificial Intelligence Technology (AIT) (14). The question that arises is which of these methods to use. Govindan et al (4) tried to answer this question in a systematic literature review. According to his study, AHP is the most widely used one. Currently, researchers tend to combine several methods and propose hybrid approaches to improve the robustness of their models. Hybrid methods are based on combining several methods to solve a multi-criteria decision making problem. According to (18) they can be grouped in 4 categories: 1 using more than one method. 2- combining the use of MCDM with another weighting method. 3- integration of fuzzy theory. 4- using another optimization method with MCDM. In their review those authors found that recent studies have demonstrated the advantages of using hybrid models over individual methods, and concluded that it improves decision making (18).

According to table1 we notice that fuzzy set theory has become very popular and much used to deal with uncertainty and to improve the performance and robustness of the decision system. (19) is among the first researchers to address the GSS problem under interval type-2 fuzzy (IT2F) environment by extending the classic AHP to IT2FAHP. He found that his model can cope with ambiguity more effectively than other FAHP. (12) evaluated green suppliers by proposing a model that combines 3 popular MCDM methods and fuzzy theory. In order to evaluate the criteria, a new approach based on fuzzy ANP and fuzzy DEMATEL is proposed. Taking into consideration the interdependence between the criteria, it provides more accurate results. FTOPSIS is subsequently applied to rank the suppliers (12). By analyzing the literature, we found that AHP and TOPSIS are the most widely used methods in supplier selection problem and that in hybrid models AHP is highly beneficial for weighting the criteria(1), and TOPSIS is more commonly used to rank the alternatives (4,20). Recently (21) combined AHP and TOPSIS to develop a sustainable supplier selection models in a constructive supply chain. The model is validated by conducting a case study in a real construction project in Egypt. Some aspects of their study can be improved. The uncertainty of their model was not considered, especially regarding the ambiguity and vagueness of expert judgment. This drawback can be overcome by integrating fuzzy theory into the model and use Fuzzy AHP and Fuzzy TOPSIS instead of AHP-TOPSIS. we cite another recent study carried out in the Indian automotive industry to select the best green supplier (14). The proposed model managed to reach the same ranking of alternatives by integrating three different MCDM method WASPAS, MABAC and TOPSIS, with FEAHP. the robustness of the proposed approach is tested and confirmed. Another comparative study of selection methods is carried out in the agri-food sector under a fuzzy environment (22). three widely used methods TOPSIS, VIKOR and GRA are applied and the results show that all three methods yield the same result and that GRA is the most efficient in terms of complexity time. (13) proposed a green supplier selection approach based on GSCM practices by improving the conventional TOPSIS through the integration of the fuzzy theory. In order to validate his approach, he compared the results obtained with another two existing versions of FTOPSIS. Although his method is innovative, the imprecision in his proposed model still persists since the evaluation of the suppliers is based on criteria weights assigned by the experts rather than being computed. This drawback in this approach can be overcome by combining this model with a criteria weighting method.

Although TOPSIS is a very efficient method in terms of ranking alternatives, it still represents some limitations. It did not consider any weights or preferences between the criteria, the criteria weights are assigned by the experts and not calculated. This makes us wonder how anyone could establish valid weights using it. on the other hand, AHP is a pairwise comparison based method. The powerful of AHP is that you can incorporate both quantitative and qualitative scores in the model and check the inconsistency. this method can be easily combined with topsis. indeed, the AHP can assist TOPSIS in determining the weights of the criteria through pairwise comparison.

This paper aims to overcome the shortcomings of the previously mentioned works and proposes a model that combines the use of Fuzzy AHP and Fuzzy TOPSIS for green supplier selection and evaluation considering both environmental and economic aspects in the material construction industry. Therefore, the proposed work is a unique topic in the literature.

From the literature and as shown in the table 1, the problem of supplier selection is addressed in several industrial areas, and the automotive industry is the most concerned one. We found that there are only few works that are interested in the construction industry, and none of them are interested in the building materials industry. Through this contribution we attempt to fill this gap by addressing an adequate model of green supplier selection and presenting a set of criteria and sub-criteria that consider the characteristics of the sector.

Table 1 Summary of studies on green supplier selection methods in different industries

Author	**Year**	**MCDM method applied**	**Industry**
(23)	2022	AHP TOPSIS	electronics supply chain
(24)	2022	fuzzy (BWM-WASPAS-COPRAS)	renewable energy
(21)	2021	AHP TOPSIS	Construction supply chain
(25)	2020	BWM+ Fuzzy TOPSIS	Steel industry
(26)	2020	(Fuzzy AHP, Fuzzy TOPSIS, and fuzzy ELECTRE) + ANN	Textile
(19)	2020	interval type-2 fuzzy AHP	Home appliance manufacturer
(27)	2020	Intuitionistic Fuzzy TOPSIS and Two-phase fuzzy goal programming	Air filter industry
(14)	2019	Fuzzy(AHP+TOPSIS),Fuzzy(AHP+WASPAS), Fuzzy(AHP+MABAC)	Automotive industry
(28)	2019	AHP and Fuzzy AHP	Plastic industry
(29)	2019	Choquet integral and type-2 fuzzy uncertainty	Electric vehicle charging facility
(30)	2019	Fuzzy Extended AHP	Manufacturing
(31)	2019	interval type-2 fuzzy BWM and VIKOR	Manufacturing industry
(16)	2018	DEMATEL+ ANP+ Fuzzy VIKOR	Retail industry
(32)	2017	DEMATEL, QFD and COPRAS	Dairy company
(33)	2017	Relative Preference Relation (RPR) with interval type-2 number	Construction industry
(34)	2017	Fuzzy TOPSIS and AHP	--
(35)	2016	Fuzzy TOPSIS, Fuzzy VIKOR and Fuzzy GRA	Agri-Food Industry
(36)	2017	TODIM and interval type-2 fuzzy sets (IT2FS)	Automobile industry

(37)	2017	AHP and VIKOR	Automobile
(3)	2016	(DEA) data envelopment analysis and genetic programming (GP)	Sample company
(38)	2016	Fuzzy VIKOR	Automobile industry
(39)	2015	ANP and improved Grey relational analysis	Automotive industry
(40)	2017	Fuzzy(ANP – DEMATEL- MOLP)	Illustrative example
(41)	2015	Fuzzy axiomatic design (FAD)	Plastic manufacturing
(13)	2014	Fuzzy TOPSIS	Electronics industry
(12)	2012	fuzzy DEMATEL, fuzzy ANP and fuzzy TOPSIS	Automotive industry
(42)	2010	ANN- MADA	Manufacturing industry
(20)	2010	Fuzzy TOPSIS	Logistics
(1)	2009	DELPHI method and Fuzzy EAHP	High-tech electronics industry

Table 2 Literature review of existing criteria

	Main criteria	Sub criteria/ attribute	references
Classic criteria	**Cost/price**	Product cost, production cost, freight cost, price performance value, logistic cost, ordering cost, inventory cost, maintenance cost, purchasing price, compliance with sectoral price value, transportation cost, storage cost, cost reduction capability, fluctuation on costs, indirect cost	(1,37,39,42,43)
	Quality	Customer satisfaction, reject rate, quality assurance, low defect rate, warranties and claim policies, capability of handling abnormal quality, repair and return rate, product performance, process capability, process improvement, quality certification, quality management practices and systems,	(1,12,37,39,42)
	Delivery	Lead time, on-time delivery, order fulfill rate, flexibility of the supplier, suppling capability, number of shipments to arrive on time, order frequency, distance, geographical condition, delivery conditions, delivery efficiency, delivery reliability, delivery performance	(7,37,41–44)
	Service	Rate of processing order form, rate of delivery in time, punctuality, service quality, standard of services, responsiveness, service quality, ease of communication, degree of information modernized, stock management, design capability, guarantee, preventive action, after-sales service	(1,7,12,35,44)
	Flexibility	short setup time, using flexible machines, product volume changes, design flexibility, conflict resolution, technological change and equipment up-gradation	(45–47)
	Technology capability	Technology level, capability of R&D, capability of design, technological compatibility, informatisation level of the enterprise, product performance	(1,12,39,41,43,44)

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Green criteria	**Pollution control**	Pollution control capability, wastewater, solid waste, air emission, remediation, energy consumption, use of harmful materials, hazardous wastes	(20,41,43,48–51)
	Green product	green packaging, reuse, use of recycled and nontoxic materials, re-manufacture, recycle, disposal,	(1,12,39,45,48,51)
	Green image	ratio of green customers to total customers, green materials coding, and recording, stakeholder's relationship, social responsibility, green customer's market share	(1,20,41,42,49–51)
	Eco-design	Design of products for reduction or elimination of hazardous materials, design of products for resource efficiency, design of products for reuse, recycle, recovery of material	(7,44,48,51)
	Environmental management system EMS	environmental certificates such as ISO14000, environmental policies, green process planning, regulatory compliance	(1,7,20,42,44,45,48,51,52)
	Environmental performance	Use of environment-friendly technology and materials, partnership with green organizations, training supplier employees on environmental issues, supplier environmental evaluation and feedback, auditing suppliers	(7,20,50,51)
	Green competencies	Green material selection, cleaner production technologies, technical transformation ability, ability to change process and product for reducing the impact on natural resources, reverse logistics, availability of clean technologies, pollution reduction capability, reduced green packaging	(1,12,20,39,43,50)
	Green technology innovation	Recycling product design, redesign of product, renewable product design, green process planning, green R&D project	(1,7,12,20,49,51)
	Green purchasing	Trained purchase and supply chain managers, purchasing environmentally friendly raw materials, Ensuring suppliers environmental management system	(39,41,44,48)

3. METHODS

The proposed research framework for the selection and evaluation of green suppliers in Moroccan material construction sector is based on a hybrid approach employing fuzzy AHP and fuzzy TOPSIS includes three phases:

- Phase 1: Data collection: The first phase of our model is to identify the most relevant selection criteria based on the literature and the specific characteristics of the considered sector. After identifying the suppliers to be evaluated and a set of traditional and ecological criteria, the hierarchical structure of the problem is established.
- Phase 2: criteria weighting: After approving the hierarchical structure of the problem, we apply the FEAHP method to determine the weight of the criteria and sub criteria already selected.
- Phase 3: Supplier selection: Ranking the green suppliers by applying the fuzzy TOPSIS method and using as input the weight of the criteria obtained by FEAHP

In order to fully understand this model, a brief presentation of the methods used in the proposed approach is given in figure 1:

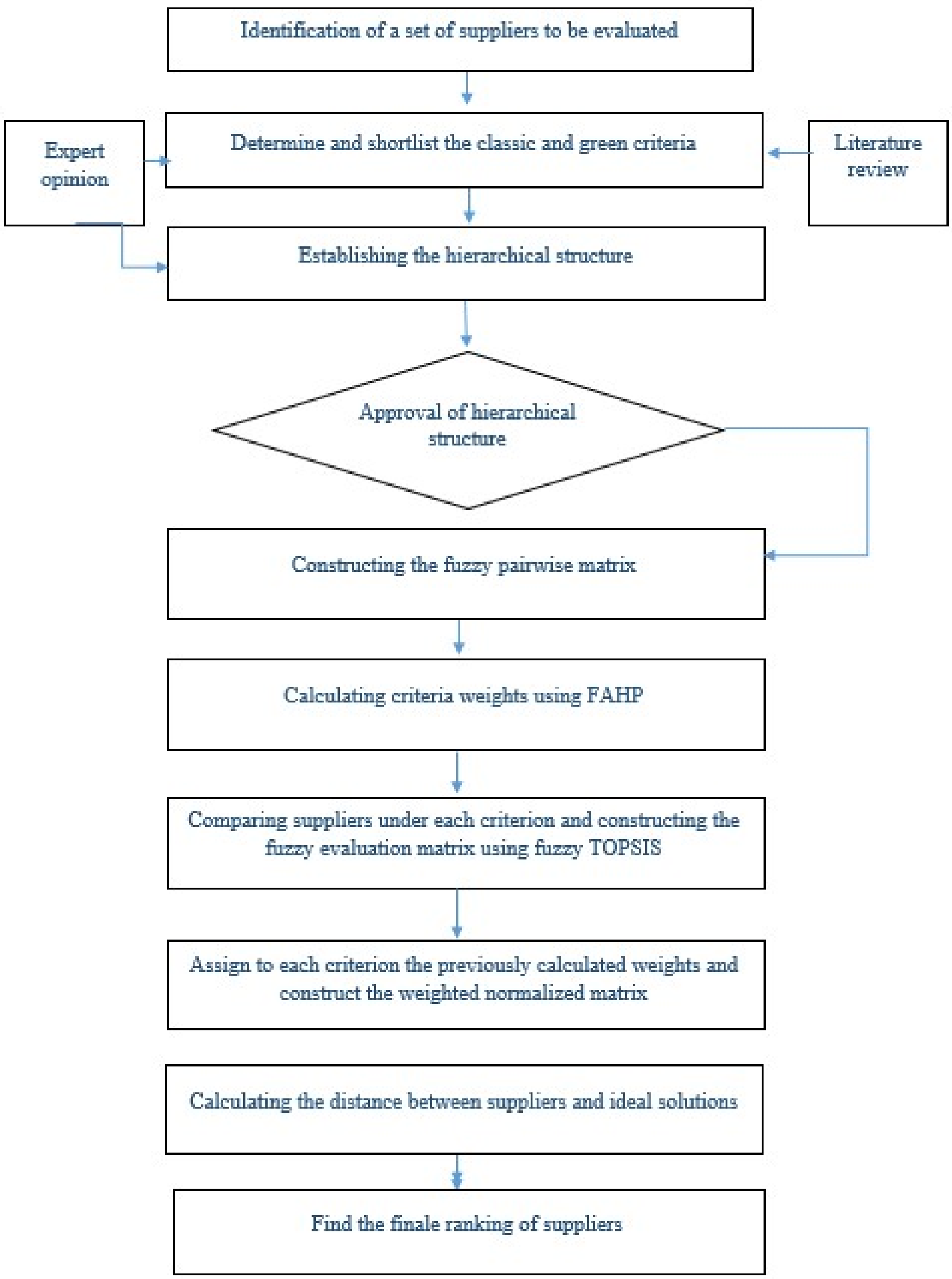

Figure 1 The Overall Flow Chart Of The Proposed Model

3.1. Fuzzy Set Theory

Generally, in most cases of multi-criteria decision problems (MCDM), the criteria are heterogeneous and cannot be compared on the same scale. For qualitative criteria, it is difficult to express the preference or comparison by an exact number(20,52). in order to deal with this problem Fuzzy set theory (FST) is integrated. FST was first introduced by (53) in 1965. It is known for its ability to take into account the uncertainty and the vagueness in expert's judgement and thus improve the performance and robustness of the decision system. In 1970 (53) present their first attempt at constructing a conceptual framework for MCDM problem in a fuzzy environment. The ratings and weights of the attributes in FMCDM problems are expressed in linguistic terms and then transformed to fuzzy numbers(13). A fuzzy number is a generalized version of regular real numbers that refers to a connected collection of potential values rather than a single value. The trapezoidal fuzzy number and triangular fuzzy number are the most popular one.

Triangular fuzzy number is represented as a triplet (l, m, u) where l, m, u are three real numbers. The parameters l, m, and u show the three judgment values: l is the smallest possible value, m the most probable value, and u the highest possible value. A triangular fuzzy number (TFN), M, is shown in Figure 2.

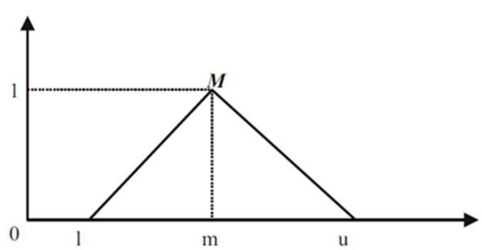

Figure 2 a triangular fuzzy number

Let $\widetilde{A} = (l_1, m_1, u_1)$ and $\widetilde{B} = (l_2, m_2, u_2)$ two triangular fuzzy numbers. The four main operations of Triangular Fuzzy Number are presented below.

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

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

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

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

3.2. Fuzzy Extended AHP

The AHP method, proposed by Saaty (53) in 1980, is an MCDM method, known for its ability to structure a complex and multi-criteria problem in order to compare several elements (53). The large number of works using the AHP method, especially in industrial application, proves its success and efficiency. this popularity is primarily due to its simplicity and flexibility (4,54,55). Despite its many advantages, the authors have demonstrated its limitations. The traditional AHP does not take into account the imprecision in expert's judgment. this weakness required the integration of the fuzzy set theory. In 1983, (56) was first to propose a fuzzy AHP by representing the pairwise comparisons by triangular fuzzy numbers. In the following years, several FAHPs have been proposed by researchers having in common the combination of traditional AHP and fuzzy numbers. In this work, we will use the FEAHP introduced by Chang in 1996 (57). This method is based on the calculation of fuzzy synthetic extent and the comparison of the degree of possibility. among all the FAHP methods the extended form appears to be the most widely used one, where the fuzzy pairwise comparison matrix FPCM is expressed by the fuzzy triangular number. In 2009, (1) in their paper proposed a model to select the most suitable green supplier in high-tech industry using the EFAHP. In 2019 (30) used the FEAHP to select the best green supplier demonstrated by a case study in an Indian manufacturing organizations. In the same year (14) in his research presents a novel framework for green supplier selection under fuzzy environment in automotive industry. They used the extended form of AHP to weight criteria and then applied 3 different MCDM methods to rank supplier fuzzy-TOPSIS, fuzzy- MABAC, and fuzzy-WASPAS. (28) evaluate supplier of Plastic Manufacturing Sector taking into consideration both traditional and green criteria. They compared the result obtained from the application of the classic AHP and FAHP. (26) A recent study Emphasize the importance of green supplier selection by proposing an application of FAHP, FTOPSIS, and FELECTRE combined with the artificial neural networks ANN. (58) In order to purchase the necessary materials for the production of pre-insulated pipes authors applied the FEAHP to select the best supplier. (58) proposed a hybrid model based on the Fuzzy TOPSIS method and FEAHP to select the most suitable supplier for a construction company.

The steps of fuzzy Extended AHP according to chang1996(57):

Step1: The comparisons of criteria are done in linguistic terms by decision makers using table 1 and a fuzzy pairwise comparison matric is created.

Step2: calculation of the Value of fuzzy synthetic extent with respect to each alternative using the following formula:

$$\widetilde{S_\iota} = \sum_{j=1}^{m} M_{gi}^{j} \times \left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} \quad (5)$$

Step3: calculate the degree of possibility

Suppose we have 2 TFN M1 and M2. The degree of possibility of one TFN to be greater than another TFN is calculated using the following formula:

$$V(M_2 > M_1) = hgr(M_2 > M_1) = \quad (6)$$

$$\mu_{M_2}(d) =$$

$$\begin{cases} 1 & if\ m_2 \geq m_1 \\ 0 & if\ l_1 \geq u_2 \\ \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} & otherwise \end{cases}$$

We can visualize this phenome in the figure3:

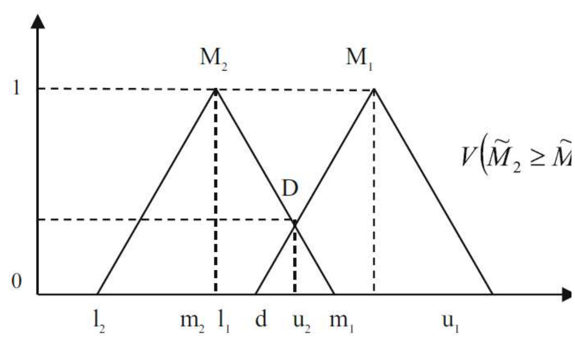

Figure 3 interaction between 2 TFN M1 and M2

Step4: calculate the degree of possibility for a convex fuzzy number to be greater than k convex fuzzy numbers. The result is given according to the following expression:

$$V(\widetilde{M} > \widetilde{M_1}, \widetilde{M_2}, \ldots, \widetilde{M_k}) = V(\widetilde{M} > \widetilde{M_1}) \text{ and } V(\widetilde{M} > \widetilde{M_2}) \ldots \text{ And } V(\widetilde{M} > \widetilde{M_k}) = \min V(\widetilde{M} > \widetilde{M_{1k}}),\ i = 1,2,\ldots,k \quad (7)$$

And then the weight vector is given:

$$d_i'(A_1) = \min V(S_i > S_k), \qquad k = 1,2,\ldots,n, k \neq i$$

$$W' = (d'(A_1), d'(A_2), \ldots, d'(A_n))^T \quad (8)$$

Step5: weight normalization

the weight of each criterion need to be normalized using the following equation:

$$N_i = \frac{M_i}{\sum_{i=1}^{n} M_i} \quad (9)$$

3.3. Fuzzy TOPSIS

TOPSIS is the acronym of: Technique for Order Preference by Similarity to Ideal Solution, is an MCDM method first introduced by (59) in 1981. TOPSIS is a very noun and commonly used method. 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, (60) proposed an extension of the classical TOPSIS method for collaborative decision-making in a fuzzy context. By analyzing the literature, we found that AHP and TOPSIS are the most widely used methods in supplier selection problem and that in hybrid models AHP is highly beneficial for weighting the criteria (1), and TOPSIS is more commonly used to rank the alternatives (4,20). (25) suggested three-phase approach to assist decision makers of Khouzestan Steel Company in ranking their suppliers based on their green innovation abilities. this approach uses the Best-Worst Method to weight criteria and determine the most important one then the fuzzy TOPSIS is applied to rank alternatives. (14) proposed an integrated framework based on fuzzy MCDM applied in the Indian automotive industry. The criteria weight is obtained by applying FEAHP and then three MCDM methods: fuzzy-TOPSIS, fuzzy-MABAC, and fuzzy-WASPAS are used to evaluate suppliers. (27) present a study on the green supplier selection problem in a multi-item/multi-supplier and multi-period environment. Authors utilizes the Intuitionistic fuzzy TOPSIS to obtain the classic and green scores of alternatives. (34) proposed a novel model for supplier selection that offers decision maker more flexibility in determining the importance of the environmental factor. The model use AHP to weight criteria end fuzzy TOPSIS to rank suppliers and then applied multi-objective optimization approaches to choose the best suppliers and allocate orders. In 2010 an interesting study on supplier environmental performance evaluation is done by (20) using Fuzzy TOPSIS. In order to improve GSCM initiatives (12) proposed a novel hybrid MCDM approach combining the fuzzy DEMATEL, fuzzy ANP and fuzzy TOPSIS methods to evaluate green suppliers. (13) proposed an improvement of the fuzzy TOPSIS method to solve green supplier selection problem and compared the results of two other types of fuzzy TOPSIS.

Table 3 Saaty scale and corresponding triangular fuzzy numbers (26)

scale	Numerical value	Fuzzy triangular scale
Equally important (EI)	1	(1,1,1)
Weakly important (WI)	3	(2,3,4)
Fairly important (FI)	5	(4,5,6)
Strongly important (SI)	7	(6,7,8)
Very Strongly important (VSI)	9	(8,9,9)
intermittent values between Two adjacent scales	2, 4, 6, 8	(1,2,3) (3,4,5) (5,6,7) (7,8,9)

Table 4 Linguistic terms for alternative evaluations and their corresponding triangular fuzzy numbers

scale	Numerical value	Fuzzy triangular scale
Very low (VL)	1	(1,1,1)
Low (L)	3	(2,3,4)
Medium (M)	5	(4,5,6)
High (H)	7	(6,7,8)
Very High (VH)	9	(8,9,9)

The steps of fuzzy TOPSIS according to Balwinder Sodhi and Prabhakar (61) :

Step1: construction of the fuzzy decision matrix D by converting linguistic variables using table2

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

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

For k different decision maker, the global rating of all decision maker is obtained using:

$$\tilde{X}ij = \begin{Bmatrix} a_{ij} = & \min a_{ij}^k \\ b_{ij} = & \frac{\sum b_{ij}^k}{k} \\ c_{ij} = & \max c_{ij}^k \end{Bmatrix} \quad (10)$$

Step2: Normalization of the fuzzy decision matrix

Identify cost and benefit criteria from our set of green and classic criteria and construct the matrix

$$\tilde{R} = [\widetilde{r_{ij}}]_{mxn}, \quad i=1, 2,\dots,m ; \quad j=1,2,\dots,n$$

where:

$$\widetilde{r_{ij}} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right) \quad \text{and} \quad c_j^* = \max_i c_{ij} \quad (11)$$

(benefit criteria)

$$\widetilde{r_{ij}} = \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}}\right) \quad \text{and} \quad a_j^- = \min_i a_{ij} \quad (12)$$

(cost criteria)

Step3: construction of the weighted normalized fuzzy decision matrix

It's the result of multiplying the normalized matrix by the weights assigned to each selection criterion.

Step4: finding the Fuzzy positive ideal FPIS (A+) and Fuzzy negative ideal FNIS (A-). They are calculated as follows:

$$A^+ = (v_1^+, v_2^+ \dots, v_n^+) \quad (13)$$

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

Where:

$$v_j^+ = \max(\widetilde{v_{ij}}) \quad (15)$$

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

Calculating the distance of each alternative from (FPIS) and (FNIS) according to the following equations:

$$d_i^+ = \left\{\sum_{j=1}^{n} (v_{ij} - v_{ij}^+)^2\right\}^{1/2}, i = 1 \dots m \quad (17)$$

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

Step5: the closeness coefficient it represents de distance to both (FPIS) and (FNIS).

It is found according to the following equation:

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

4. CASE STUDY

Because of the relationships it has with the rest of the economy, particularly construction, tourism, and infrastructure works, the building materials sector is of considerable importance in the Moroccan industry. The construction materials industry has witnessed exceptional growth in recent years, thanks to sectoral policies implemented by the Moroccan government to make housing, tourism, and industry engines of growth (MCINET). Building material industry includes mainly, ceramic, marble, steel and cement industry. The ceramics industry in particular plays an important role in the Moroccan construction industry with a related market expected to grow from US$1.5 billion in 2015 to US$2.4 billion by 2024.

In order to test the effectiveness of the proposed model in a real situation, a case study will be conducted in a Moroccan company manufacturing construction materials located in the industrial zone of Berrechid. For confidentiality reasons, the identity of the company will not be declared; instead, we refer to the company as ABC. Leader in its field, ABC is a company in full expansion existing since 2008 and specialized in the manufacture of tiles and ceramics. It proposes a wide and diversified range of products; we count more than 3,000 references. The company ABC is committed to a quality approach that allows it to build an environmental management system in order to get ISO 14001 certification, as well as an occupational health and safety management system in compliance with OHSAS 18001 certification. The company works with a significant number of suppliers, which totaled 3000 in 2019.These suppliers provide the company with packaging, raw materials, spare parts, energy, consumable materials, Machinery and industrial equipment and technical services. Ceramic tiles are generally produced from a mixture of clays and other inorganic materials. Since more than 80% of the raw material is obtained from the extraction of clay, the energy suppliers will be considered as the most important ones. For this study three potential suppliers are selected, designated S1, S2 and S3 respectively. It is important to note that thermal energy contributes for over 80% of total energy consumption in the ceramic sector, while electricity accounts for 20%. Because the main source of primary energy is nonrenewable fossil fuel, it requires special attention regarding the integration of environmental practices(11).

The expert group is composed of four decision makers from the company ABC. This group includes the Chief Executive Officer CEO of the company, the head of the purchasing department, a purchasing manager and an expert in the field representing the Professional Association of Ceramic Industries (APIC). according to R. Handfield et al. (48) in their study, they concluded that in green supplier selection problem the expert team should include purchasing managers who may not be directly familiar with environmental metrics to achieve better results.

Criteria selection

The different selection criteria were determined after a detailed and thorough review of literature, taking into consideration the characteristics of the Moroccan building materials sector and the particularity of the company under study. A large number of green and traditional criteria is selected from the literature. In order to determine the most relevant criteria, questionnaires were distributed to the experts to evaluate the criteria and only those with highest scores were retained. After various meetings where we discussed the survey results. The sub criteria were then defined. In this study 8 main criteria and 17 sub-criteria are considered. Cost, quality, delivery & service, pollution control, green product, green image, EMS, green performance as main criteria and Purchasing price, Cost reduction capability, Quality Management, Reject rate, Responsiveness, Lead time, Air emission, Waste water, Use of harmful materials, Green packaging, Recycle, Green market share, Customer retention, ISO 14001 certification, Env. Management Information System, Waste management and Green design as sub-criteria. Figure4 illustrates the hierarchical structure of the problem.

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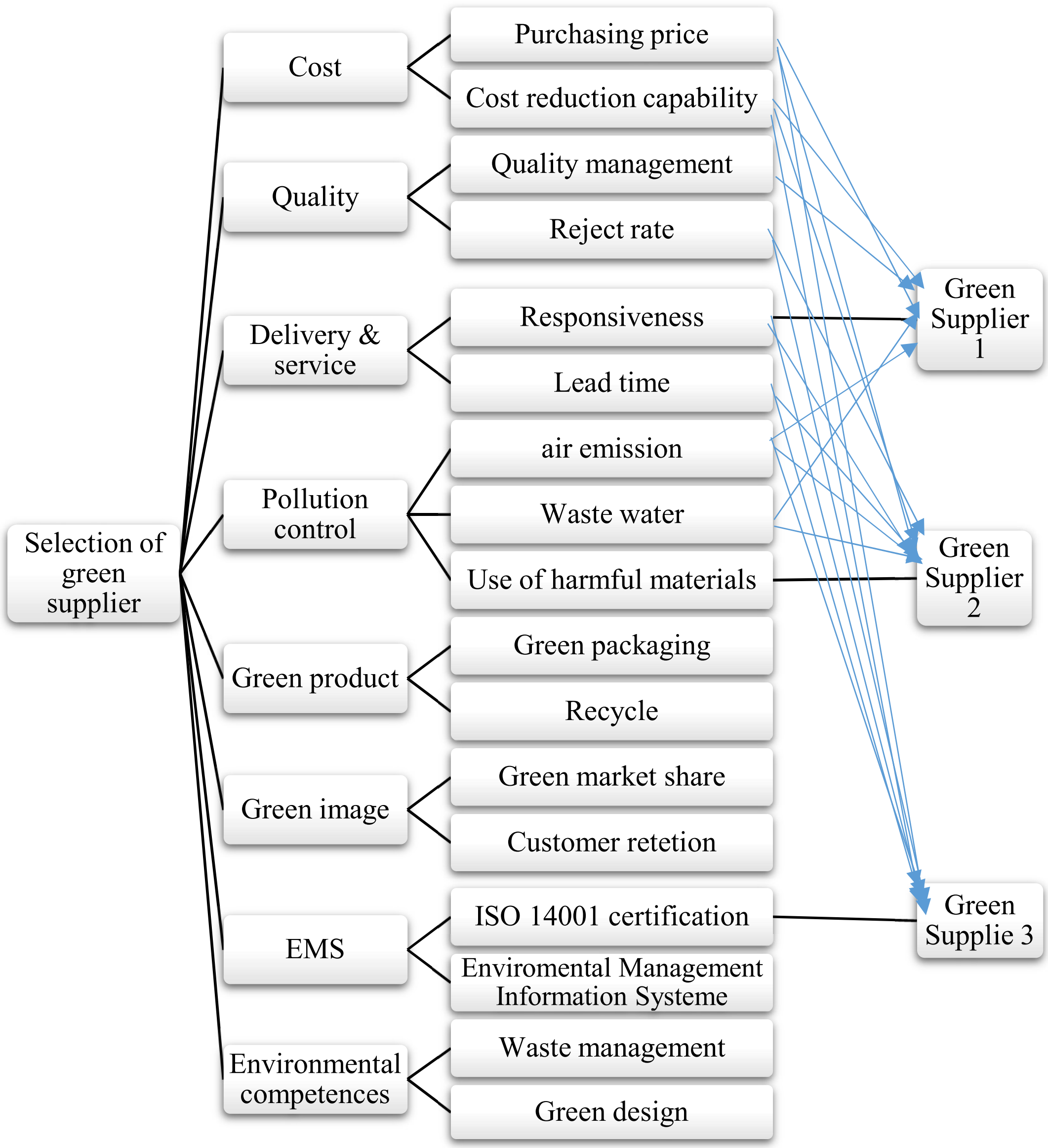

Figure 4 The hierarchy for green supplier selection

Criteria weighting using FEAHP

After approving the hierarchical structure of the problem the criteria's weight is calculated using FEAHP. Experts are asked to rate the importance of each criterion on Satty's scale given in table 3 and the fuzzy pairwise comparison matrix is constructed.

The different steps of the application of FEAHP have already been explained in section 3. the same procedure will be performed for the comparison of the sub-criteria against their main criterion The product of the weight of the sub criteria and the weight of their corresponding main criterion gives the final weight of the sub criteria. the final weights of each criterion and sub-criteria using the FEAHP method are shown in table 6.

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Table 5the fuzzy pairwise comparison matrix

	cost	quality	Service & delivery	Pollution control	Green product	Green image	EMS	Green perform
Cost	(1,1,1)	(1,1,1)	(2.33, 3.00, 3.67)	(7.00, 8.00, 8.50)	(6.00, 7.00, 7.67)	(8.00, 9.00, 9.00)	(5.00, 6.00, 7.00)	(7.33, 8.33, 8.67)
Quality	(1,1,1)	(1,1,1)	1.50, 2.00, 2.50)	(6.67, 7.67, 8.33)	(6.00, 7.00, 7.67)	(7.00, 8.00, 8.50)	(4.67, 5.67, 6.67)	(6.67, 7.67, 8.33)
Service &delivery	(0.27, 0.33, 0.43)	(0.40, 0.50, 0.67)	(1,1,1)	2.75, 3.50, 4.25)	(5.00, 6.00, 7.00)	(5.33, 6.33, 7.33)	(1.33, 1.67, 2.00)	(5.33, 6.33, 7.33)
Pollution control	(0.12, 0.13, 0.14)	(0.12, 0.13, 0.15)	(0.24, 0.29, 0.36)	(1,1,1)	(1.67, 2.33, 3.00)	(3.50, 4.50, 5.50)	(0.27, 0.33, 0.43)	(4.00, 5.00, 6.00)
Green product	(0.13, 0.14, 0.17)	(0.13, 0.14, 0.17)	(0.14, 0.17, 0.20)	(0.33, 0.43, 0.60)	(1,1,1)	(2.25, 3.00, 3.75)	(0.27, 0.33, 0.43)	(1.00, 1.33, 1.67)
Green image	(0.11, 0.11, 0.13)	(0.12, 0.13, 0.14)	(0.14, 0.16, 0.19)	(0.18, 0.22, 0.29)	(0.27, 0.33, 0.44)	(1,1,1)	(0.15, 0.18, 0.22)	(0.24, 0.29, 0.36)
EMS	(0.14, 0.17, 0.20)	(0.15, 0.18, 0.21)	(0.50, 0.60, 0.75)	(2.33, 3.00, 3.67)	(2.33, 3.00, 3.67)	(4.50, 5.50, 6.50)	(1,1,1)	(5.00, 6.00, 7.00)
Green performance	(0.12, 0.12, 0.14)	(0.12, 0.13, 0.14)	(0.14, 0.16, 0.19)	(0.18, 0.22, 0.29)	(0.60, 0.75, 1.00)	(2.75, 3.50, 4.25)	(0.14, 0.17, 0.20)	(1,1,1)

Table 6criteria and sub-criteria weights using FEAHP

criteria	**Main criteria weight**	**Sub criteria**	**Sub criteria weight**	**Final weight**
Cost	0.27	Purchasing price	0.87	0.234
		Cost reduction capability	0.13	0.035
Quality	0.25	Quality management	0.2	0.05
		Reject rate	0.8	0.200
Service & delivery	0.16	Responsiveness	0.4	0.064
		Lead time	0.6	0.096
Pollution control	0.09	Air emission	0.15	0.013
		Waste water	0.15	0.013
		Use of harmful materials	0.7	0.063
Green product	0.04	Green packaging	0.81	0.032
		Recycle	0.19	0.007
Green image	0.02	Green market share	0.14	0.002
		Customer retention	0.86	0.017
EMS	0.12	ISO 14001 certification	0.75	0.09
		Env. Mang. Information System	0.25	0.03
Green performance	0.04	Waste management	0.75	0.03
		Green design	0.25	0.01

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Green supplier ranking using FTOPSIS:

Based on the final weights of the criteria obtained by the application of the FEAHP method. the Fuzzy TOPSIS method is then applied to rank the three potential green suppliers. Each member of the expert group is asked to give individually his own linguistic rating of each potential supplier's performance against each criterion. The judgment of the decision makers is then converted into a triangular fuzzy number according to the table 4. According to equation (10), we combine all the experts' judgments into a single decision matrix in which all the experts agreed. To normalize the decision matrix, first we have to identify the beneficial and non-beneficial criteria; Purchasing price, Reject rate, Lead time, Air emission, Waste water and Use of harmful materials are considered as cost criteria and the others as benefit criteria. After applying equation (11) and (12) the normalized matrix is then obtained. The weighted normalized fuzzy decision matrix is obtained by multiplying the normalized matrix by the FEAHP weights assigned to each criterion. This matrix is showed in table 7. Next we compute FPIS and FNIS for all criteria in table 9.

Table 7The weighted normalized fuzzy decision matrix

	Weighted Normalized fuzzy decision matrix																										
Weight	0,234	0,234	0,234	0,035	0,035	0,035	0,05	0,05	0,05	0,2	0,2	0,2	0,064	0,064	0,064	0,096	0,096	0,096	0,135	0,135	0,135	0,135	0,135	0,135	0,063	0,063	0,063
	COST						***QUALITY***						***DELIVERY AND SERVICE***						***POLLUTION CONTROL***								
	Purchasing price			**Cost reduction capability**			**Quality management**			**Reject rate**			**Responsiveness**			**Lead time**			**Air emission**			**Waste water**			**Use of harmful materials**		
GS1	0,0585	0,072	0,0936	0,0094	0,0121	0,01481	0,0423	0,0481	0,05	0,1333	0,16	0,2	0,0512	0,0589	0,064	0,072	0,0823	0,096	0,0049	0,006	0,0077	0,0042	0,0049	0,006	0,0118	0,0145	0,0189
GS2	0,0374	0,0407	0,0468	0,0054	0,0067	0,00808	0,0192	0,025	0,0308	0,032	0,0348	0,04	0,0077	0,0077	0,0077	0,0262	0,0303	0,036	0,009	0,0108	0,0135	0,009	0,0108	0,0135	0,063	0,063	0,063
GS3	0,156	0,1872	0,234	0,0296	0,0337	0,035	0,0077	0,0096	0,0115	0,0296	0,0296	0,0333	0,0102	0,0128	0,0154	0,0222	0,023	0,0262	0,003	0,0077	0,0045	0,003	0,0036	0,0045	0,0118	0,0145	0,0189
A+	0,156	0,1872	0,234	0,0296	0,0337	0,035	0,0423	0,0481	0,05	0,1333	0,16	0,2	0,0512	0,0589	0,064	0,072	0,0823	0,096	0,009	0,0108	0,0135	0,009	0,0108	0,0135	0,063	0,063	0,063
A-	0,0374	0,0407	0,0468	0,0054	0,0067	0,00808	0,0077	0,0096	0,0115	0,0296	0,0296	0,0333	0,0077	0,0077	0,0077	0,0222	0,023	0,0262	0,003	0,006	0,0045	0,003	0,0036	0,0045	0,0118	0,0145	0,0189

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Table 8 (table7 continued)

W	0,032	0,032	0,032	0,007	0,007	0,007	0,002	0,002	0,002	0,017	0,017	0,017	0,09	0,09	0,09	0,03	0,03	0,03	0,03	0,03	0,03	0,01	0,01	0,01
	GREEN PRODUCT						**GREEN IMAGE**						**EMS**						**Environmental competences**					
	Green packaging			**Recycle**			**Green market Share**			**Customer retention**			**ISO 14001 certification**			**Env.Man Information System**			**Waste management**			**Green design**		
GS1	0,0174	0,0212	0,0249	0,0014	0,0017	0,0024	0,0009	0,0011	0,0013	0,003	0,0037	0,0044	0,0554	0,0658	0,0762	0,0092	0,0127	0,0161	0,0185	0,0219	0,0254	0,0067	0,0083	0,01
GS2	0,0274	0,0312	0,0324	0,0055	0,0066	0,0076	0,0025	0,0028	0,0028	0,0133	0,0155	0,017	0,0762	0,0865	0,09	0,0231	0,0265	0,03	0,0231	0,0265	0,03	0,0067	0,0083	0,01
GS3	0,005	0,0062	0,0075	0,001	0,001	0,001	0,0004	0,0005	0,0006	0,0022	0,0022	0,0022	0,0173	0,0242	0,0312	0,0057	0,0081	0,0104	0,015	0,0173	0,0185	0,0022	0,0028	0,0033
A+	0,0274	0,0312	0,0324	0,0055	0,0066	0,0076	0,0025	0,0028	0,0028	0,0133	0,0155	0,017	0,0762	0,0865	0,09	0,0231	0,0265	0,03	0,0231	0,0265	0,03	0,0067	0,0083	0,01
A-	0,005	0,0062	0,0075	0,001	0,001	0,001	0,0004	0,0005	0,0006	0,0022	0,0022	0,0022	0,0173	0,0242	0,0312	0,0057	0,0081	0,0104	0,015	0,0173	0,0185	0,0022	0,0028	0,0033

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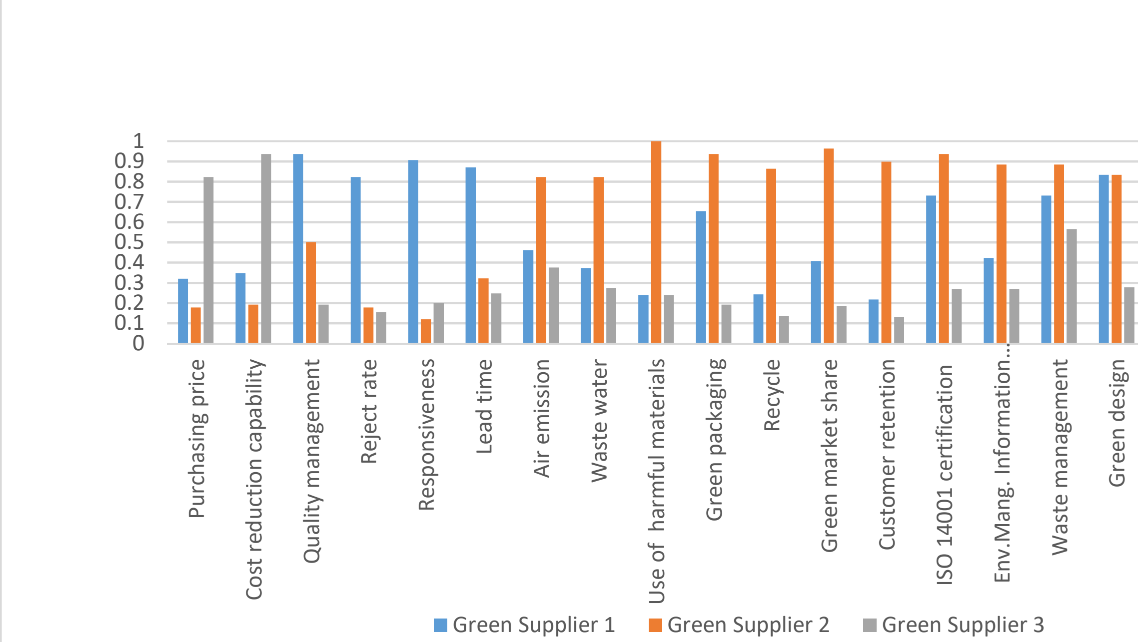

Figure 3 performance of green suppliers against each criterion

Table 9 FPIS and FNIS

	GREEN SUPPLIER 1		GREEN SUPPLIER 2		GREEN SUPPLIER 3	
	FPIS	**FNIS**	**FPIS**	**FNIS**	**FPIS**	**FNIS**
Purchasing price	0,119	0,035	0.153	0.00	0.00	0.153
Cost reduction capability	0.021	0,005	0.026	0.00	0.00	0.026
Quality management	0,00	0.037	0.022	0.016	0.037	0.00
Reject rate	0,00	0.136	0.131	0.005	0.136	0.00
Responsiveness	0,00	0.051	0.051	0.00	0.045	0.006
Lead time	0,00	0,060	0.053	0.007	0.060	0.00
Air emission	0,005	0,002	0.00	0.007	0.006	0.001
Waste water	0.006	0.001	0.00	0.008	0.008	0.00
Use of harmful materials	0,048	0.00	0.00	0.048	0.048	0.00
Green packaging	0,009	0.015	0.0	0.024	0.024	0.00
Recycle	0,005	0.001	0.00	0.006	0.006	0.00
Green market share	0,002	0.001	0.00	0.002	0.002	0.00
Customer retention	1.00	0.002	1.00	0.013	1.00	0.00
ISO 14001 certification	0,019	1.00	0.00	1.00	0.060	1.00
Env.Mang. Information system	0,014	0.005	0.00	0.018	0.018	0.000
Waste management	0,005	0.005	0.00	0.010	0.010	0.000
Green design	0.00	0.006	0.00	0.006	0.006	0.00

In the final step. we determine the distance of each alternative from (FPIS) and (FNIS). and calculate the closeness coefficient

Table 10Closeness coefficient(CCi) and final ranking of suppliers

	d+	d-	CC	Ranking
GS1	1	1	0,521056727	1
GS2	1,435911991	1,169398849	0,448851949	2
GS3	1,466557565	1,185943031	0,447103775	3

5. RESULTS AND DISCUSSION

In this case study we evaluated the suppliers of a Moroccan company manufacturing ceramic tiles. A panel of specialists from the firm under investigation recommended and selected three potential suppliers, 8 criteria and 17 sub-criteria. The FEAHP method is applied to weight the criteria while the FTOPSIS method is applied to rank the suppliers. Analyzing the results of the application of the FEAHP method, allowed us to classify the selection criteria and to determine the importance of each one. In table 6 we can see that the *purchasing price* criterion is ranked in first position followed by *Reject rate* and *lead time* having respectively the following weights 0.234 0.20 and 0.096. The Professional Association of Ceramic Industries in Morocco (APIC) states that the main handicap of the ceramic tile industry in Morocco is the high cost of thermal energy. It appears logical that the proposed model considers the *cost* criterion as the most important criteria. Given that all the manufacturing process of ceramic tiles is based on the consumption of thermal energy, any delay in the delivery of energy can cause a production stop; an enormous financial loss for the company. The *lead time* is a very important factor in supplier selection for building material manufacturers and especially for energy suppliers. concerning the environmental criteria, *Ems, use of harmful,* and *the green packaging* are regarded as the most important among the ecological criteria. *Green market share, recycle* and *green design* are at the bottom of the rankings. As the main source of energy consumed in ceramic tile manufacturing is a non-renewable energy with serious environmental impacts, it is important to give more attention to the integration of green practices in the supply chain and to prospect new environmentally friendly suppliers. Several ecological factors can be taken into consideration when choosing a future green supplier. Eco-labels and certifications are the first criteria to be taken into account. The fact to have an EMS shows the environmental commitment of the company and its ability to control its footprint on the environment. The application of the Fuzzy TOPSIS method allowed us to rank the green suppliers based on the FEAHP weights. Upon interpretation of the results, it can be seen that **GS**2 performs very well in terms of ecological criteria and is the most environmentally friendly among its competitors. Despite this high environmental performance, this supplier is not the first choice of decision makers because of its low score in classic criteria. Although this supplier is environmentally friendly, it is more expensive than its competitors, which makes it worthwhile. The fact that companies are willing to collaborate with green suppliers does not necessarily mean that they have to neglect the other classic criteria. The proposed model shows that the integration of green practices should not be at the expense of traditional criteria, both of them should be considered in green supplier selection problem.

Naturally, as with any research project, there were some obstacles that hindered the successful completion of this project. Firstly, good and fluid communication is required. Lack of clarity about the company's requirements can bias the results and lead to selecting the wrong supplier. Furthermore, the collection of data from suppliers and the identification of selection criteria are decisive steps in this model. Secondly, some quantitative criteria and also in some cases, qualitative criteria are known to be unstable and time-varying, which makes the evaluation of suppliers even more complex. For the Cost criteria for example the purchase price as well as the discounts offered by the supplier are not stable and vary according to the market demand.

6. SENSITIVITY ANALYSIS

In this section, a sensitivity analysis is carried out to assess the robustness of the proposed model. The purpose of this analysis is to create different scenarios by varying the weight of the selection criteria and then evaluate the impact of these changes on the final ranking of the alternatives. If the obtained ranking order is modified, we can conclude

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that the results are sensitive; otherwise, they are robust. In order to identify the criterion most likely to influence the decision making process 28 experiments were performed by interchanging the weights of each criterion with another one and keeping the remaining weights unchanged. For each experiment, the closeness coefficient CCi is calculated using the fuzzy TOPSIS method in order to rank the suppliers. Within the 28 experiences, we find that GS1's closeness coefficient value remains the highest over 25 tests and GS3 ranked at the bottom in more than 80% of all cases, which means that the results are relatively insensitive to criteria weight. Thus, we can conclude that the proposed model is robust in nature. The findings of the analysis are presented in the radar plot figure 6.

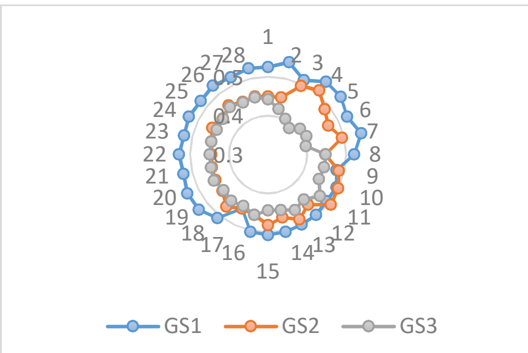

Figure 6 Results of sensitivity analysis

7. CONCLUSION

In this paper we propose a green supplier selection model considering both traditional and green criteria in material building industry. This hybrid model combines 2 famous decision making methods AHP and TOPSIS and the fuzzy set theory to get the advantage of each approach. The effectiveness and usefulness of the proposed model was demonstrated by a reel case study where 3 suppliers of a Moroccan ceramic tile company were evaluated on the basis of ecological and classic criteria. The study demonstrated that both green and traditional criteria must be taken into account in the selection process of green suppliers and that neither should be at the expense of the other.

The proposed model presents different advantages first of all, it is important to choose the right criteria and the best approach to evaluate them. A wrong weighting of the selection criteria can lead to a wrong choice of supplier. In this study 8 main criteria and 17 sub-criteria are selected after a detailed and thorough literature review and based on experts' opinion. For the evaluation of the criteria, the proposed model uses the widely known AHP method. AHP adequately handles the inconsistency in multi-criteria decision making, and provides the flexibility necessary to better interpret the decision problem(4). And to improve the robustness of the model FST is integrated to deal with the uncertainty and the vagueness in expert judgment. Then the Fuzzy TOPSIS method is applied to classify the green potential suppliers. Fuzzy TOPSIS is very efficient in terms of ranking the alternatives, moreover it gives the practitioner a clear view of the problem as it shows the performance of a supplier against each criterion. In this paper either the applicability and the robustness of the model was tested by conducting a real case study and a sensitivity analysis.

8. LIMITATIONS AND FUTURE WORK

While this study presents an added value to the existing literature on green supplier selection issues, there are several improvements that can be made to this contribution. Identifying selection criteria is a crucial and critical stage in the supplier selection process. the set of criteria proposed in this paper are selected based on a comprehensive literature review as well as through a series of interviews conducted with the Company's experts they are specific to the studied case. they take into consideration the Company's particular needs and its internal requirements. Researchers have to put more effort into identifying the appropriate selection criteria for different sectors of activity. Furthermore, in future research the interrelation between selection factors can be taken into consideration. First introduced by Saaty (1996), nalytic network process (ANP) it is a very interesting method and among the most popular one. It is known for its ability to handle interdependencies and outer-dependencies between elements of different levels of the hierarchy. In the future studies, this method can be used instead of AHP and then compare the results obtained with the results of our model.

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