



An Integrated Spherical Fuzzy Approach for Global Supplier Selection

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Abstract

Political-economic liberalization, modern communication technologies, and low-cost transportation have prompted companies to outsource an increasing amount of commercial activities to other countries. This exporting has often resulted in complex supply chain configurations. Considering that human and ecological regulation in these countries is often insufficient or poorly enforced, stakeholders place the responsibility of ensuring socially and environmentally sustainable product specifications across their supply chains on firms with particular emphasis. This research presents a combined fuzzy spherical AHP-WASPAS method basis for environmental global procurement planning that takes subsupplier sustainability considerations into account. From the present study, standards (containing risk considerations) were devised and then improved with the assistance of experts in the field and case decision-makers in order to avoid literature bias. Next, providers and semi were evaluated collectively using the agreed sustainability criteria. In previous studies, this methodology proved unsatisfactory. The problem is rectified in two stages, as shown below. In the first phase, fuzzy AHP is used to define parameter weights for inclusive sustainable supplier evaluation, so in the second phase, fuzzy WASPAS is employed to assess supplier performance in relation to evaluation criteria. Economic factors held the highest weight among some of the five ecological sustainability (financial, health, environment, and social), whereas worldwide risk assessments carried the least. This research suggests that global threats are not yet important selection factors for suppliers. Moreover, the proposed framework may help pave the way for the creation of managerial decision-making tools to aid firms in tackling sustainability risks that occur farther downstream in their supply chains. When major organizations are under intense scrutiny from their stakeholders, these vital tools are extremely important.

Keywords: AHP; WASPAS; Spherical fuzzy sets; Supplier Selection.

1. Introduction

Corporations in the developed world have been forced by globalization to outsource their workforce and export their products to low-cost economies. These strategies allow businesses to take advantage of the lower costs of the goods and materials they get and so increase their position in the market.[1]. Specialization at certain phases of production and on indigenous production resource endowments, such as low-cost labor and raw materials, provide profits. [2]. Constant outsourcing provides a number of benefits, but it also has certain drawbacks. There may be unanticipated consequences of outsourcing to developing and transitional nations, such as additional layers of work processes and a fragmented supply chain that might lead to poor quality.[1] and hazards from unsustainable manufacturing in the upstream channel [3].

Globalization is among the growing ideas in the industrial sector. Due to low-cost labor, improved product quality, and innovation strategy, many businesses rely on global suppliers to reduce procurement-related expenses. However, the choice of global suppliers is particularly susceptible to

transportation hazards, such as a rise in the price of the product, terrorism or crime rate, uncertain diplomacy, strikes, etc. To completely analyze the performance of global suppliers and optimize the supply chain, it is necessary, in addition to the use of standard criteria, to use the risks criterion.

Consequently, rising synchronization and provided to the customers need a decrease in the supply base, a tightening of integration, and a strengthening of cooperation with selected partners [4]. Global supplier selection poses a strategic and intricate managerial decision dilemma[5].

Due to the close relationship between supplier selection and corporate performance and competitive posture, the decision is typically made by companies with a dominant supply chain location and trademark ownership[6]. Any accurate comparison of prospective suppliers encompasses various levels and reflects a multi-attribute managerial decision problem; hence, supplier selection on a worldwide scale extends these evaluation dimensions. Additional risk considerations, including geographical region, social-financial processes which help, and terrorism risks, must be taken into account [7].

Most current techniques disregard the reality that focuses firms are held responsible for the negative effects and complaints of their entire supplier chain. In reality, existing supplier selection methods do not extend beyond the immediate (first-tier) suppliers of the focus firm. The omission of upstream suppliers in supply chain modeling techniques does not account for the reality that firms are held responsible for social and environmental repercussions along the whole supply chain, including the extraction of raw materials. Noncompliance with social norms puts corporations in danger of losing their brand's image and legitimacy and may expose companies to unfavorable government measures. Recent instances demonstrate how (multinational) firms may be blamed for the immoral or unsustainable business practices of their suppliers.

One instance scenario involves European and North American supermarkets (Wal-Mart, Carrefour, and Tesco) who were accused of selling shrimp harvested under cruel circumstances. Charoen Pokphand Products (CPF), a Thai enterprise and the biggest prawn farming company in the world, provided the shrimp. CPF was accused of purchasing fishmeal for its shrimp farms from fishing vessels using slave labor [8]. Campaigns launched by NGOs and amplified by the media tarnished the brand reputation of the targeted supermarkets (with financial ramifications) and compelled them to remove the specific shrimp items from their shelves[9].

As part of our investigation into implementing sustainable supplier evaluation, we looked at the risks presented by the sub-suppliers of a firm. The vast majority of existing research focuses on a variety of sustainability factors (market, ecology, and society). The selection process will be more effective if global hazards are included in sustainable supplier selection procedures. Five study areas were developed and presented in earlier sections due to a lack of papers published and background. To achieve the study's goal, these questionnaires may be divided into two categories: assessments of sustainability and hazards, which are then combined via an examination of both suppliers and sub-suppliers. As a result, case manufacturing managers and subject matter experts helped us extract and evaluate common sustainability criteria, such as risk issues. Environmental and hazard factors were employed at 2 levels of supplier evaluation. First-tier suppliers are the emphasis of the evaluation, while the sub-suppliers of those first-tier suppliers are the subject of the second stage. The core corporation, which is concerned about maintaining its brand's image across the supply chain, carried out both analyses.

A case study is used to develop and validate a model framework. Using AHP and WASPAS, the provider and sub-suppliers are evaluated based on sustainability criteria. In the absence of quantitative assessments, fuzzy set theory is used to handle uncertainties. In the next sections, the approach and its applications are described in depth.

The requirements for handling uncertainty and vagueness in linguistic phrases may also be realized using spherical fuzzy sets (SFS). SFS provides a fresh perspective on making decisions in ambiguous situations. The decision maker's degree of indeterminacy is specified independently of the elements' levels of membership and nonmembership in these sets. To generalize to additional fuzzy sets, decision-makers use SFS to build membership functions on spherical surfaces. These membership functions are thus applied to a bigger set of variables. Fuzzy Pythagorean sets are combined with neutrosophic fuzzy sets to form SFS.

The AHP technique, which relies on human judgments to solve decision-making issues, has seen a recent uptick in popularity in the scientific community. Fuzzy AHP is being used more and more in conjunction with other decision-making methodologies.

For multi-criteria decision-making, WASPAS is widely used and well-known. Multicriteria decision-making strategies, such as WASPAS, combine the weighted total and weighted multiplying procedures.

As part of this study, we explore the issue of selecting a worldwide sustainable supplier, taking into account the risks posed by the company's sub-suppliers. According to current research, sustainability may be defined as a combination of the three pillars of the economy, the environment, and society. Sustainable supplier evaluation actions can be made more efficient by incorporating global risks into the process. In this way, general guidelines including risk concerns were gathered from the research and examined further with the support of example industrial managers and specialists in the area. Two levels of supplier assessment made use of the sustainability and risk criteria. To begin with, suppliers and sub-suppliers are considered in the first step of the assessment. To protect its brand's image across the supply chain, the company conducted these two analyses. We're particularly interested in finding out how to include sustainability risks from suppliers into the sustainable environment supplier evaluation methodology. A case study is used to test a model framework. Evaluation of suppliers and sub-suppliers is done using AHP and VIKOR methodologies, which are based on sustainability criteria. Uncertainties originating from a lack of quantitative assessments are addressed using spherical fuzzy set theory. The approach and its applications will be explained in-depth in the following sections.

The remaining structure of the manuscript: In the second part, we discuss the relevant research and research gaps. In Section 3, we present a technique for selecting global sustainable suppliers based on spherical fuzzy AHP and fuzzy WASPAS. In section 4, a statistical application is then illustrated. In parts 5 and 6, the article concludes with management implications and recommendations.

2. Related Work

Buying achieved strategic significance in the 1990s [10]–[13] as a result of its significant influence on company core performance goals, which was facilitated by a market direction toward core competencies [14]–[16]. These core skills increase the amount of outsourced non-core operations, which has resulted in buying expenses being the majority of product costs in various sectors [7]–[9]. The strategic significance of buying places a premium on the supplier selection process. The objective of the selection procedure is to find suppliers who can consistently and cost-effectively meet the needs of the purchasing organization [17], [17], [18]. Supplier selection substantially influences subsequent efforts to form buyer-supplier alliances and enhance supplier skills via supplier development programs [19], [20], [20].

[21] Identify four steps in the supplier selection process: (1) problem description, (2) creation of eligibility criteria, (3) candidate preselection, and (4) final selection. Phases two through four of the selection procedure will benefit the most from quantitative management decision-support technologies [21]. The majority of the techniques addressed in the present literature pertain to step 4, the ultimate supplier selection, and include numerous supplier qualities as opposed to solely the cost factor [22], [23]. There are a variety of mathematical programming models that are commonly used for supplier selection, such as linear, goal, and multi-objective programming, as also AHP/ANP, FS, SMART, and ANN networks. [24].

Supplier choice is one of the most challenging decisions for any performance decision to make due to the substantial cash involved. Consequently, various writers have proposed numerous strategies to effectively address this problem during the last few decades. [25] have recently suggested the fluid decision support system, which integrates economic, social, and ecological criteria for the thorough evaluation of reliable vendors in the petrochemical sector. [26] utilized a multi-stage hybrid strategy to segment and choose providers in Industries 4.0, taking into consideration supply chain disruptions and hazards. The authors evaluated the suggested methodology in the automobile sector. However, their suggested research does not evaluate suppliers based on economic and environmental factors. To solve the sustainable SS&OA issue, [27] suggested a multiitem, multiperiod, and multiobjective fuzzy programming approach. Under conditions of uncertainty, inflation, and hazards, the writers chose their providers. [28] proposed a decision-making basis for analyzing oil and gas providers by selecting the 16 most important factors using the grey-Delphi method. The authors then estimated the criterion weights and alternative rankings using grey-EDAS and grey-Shannon entropy

techniques. [29] used a combination of rough set theory and the ELECTRE technique, which does not need a great deal of previous knowledge during the assessment of providers to control the ambiguity in data. Their proposed technique only aids decision-makers in assessing providers, not in finding the best amount of order distribution among them.

Just used the TOPSIS and ELECTRE techniques, [30] chose sustainable suppliers. Their proposed strategy seeks to maximize economic benefits while fulfilling environmental standards. [31], created the fuzzy multi-objective framework for addressing the fuzzy restrictions and fuzzy factors difficulties during SS&OA.

Their proposed methodology is intended to lower total costs, the number of defective units, and the number of late deliveries. [32] introduced two mixed-integer non-linear programming methods to assess the optimal network of vendors, order quantity, retail price, and several goods per order cycle for a variety of lot-sizing techniques. [33] created a two-stage circular supplier evaluation and order allocation approach to analyze the apparel manufacturing sector's suppliers. Their proposed multi-objective strategy minimizes total network costs, lost sales, and unfavorable environmental consequences while expanding opportunities for sustainable supplier procurement and employment. [34] used the interval type 2 FAHP and COPRAS-G approaches to evaluate the important criteria and supplier performance in Industry 4.0 for supplier selection. Baki [35], in the year 2021, designed an integrated approach for assessing Turkish automotive suppliers primarily on socioeconomic, social, environmental, and competence aspects. The writer used the best-worst and fuzzy TODIM techniques to determine the priority level of each stated criteria and the final supplier rating.

3. Mathematical equations for the MCDM Model

This article presents an effective integrated assessment technique for assessing and choosing the best sustainable supplier case study in China. The suggested framework consists of two phases, as shown in the figure. 1. In the first step, the Fuzzy AHP model is used to predict the fuzzy weight and crisp weight of each criterion. The spherical fuzzy set, denoted by languages number, is included in the AHP model to handle ambiguity and uncertainty based on the opinion of experts. To validate the model, the consistency of the similarity matrix is evaluated. In the second step, the WASPAS model is used to rank the wind power sites.

A. Spherical Fuzzy AHP

Kutlu Gündödu and Kahraman [36] created spherical fuzzy sets (SFS) to manage uncertainty during the quantification of expert opinions. Figure 2 illustrates the distinctions between the intuitionistic fuzzy set, the Pythagorean fuzzy set, the neutrosophic set, and the spherical fuzzy set [37]. Three dimensions comprise the SFS: membership, non-membership, and hesitation levels.

Step 1: A analysis and decision tree have three levels: the study objective (level 1), the list of criteria $GSC = GSC_1, GSC_2, \dots, GSC_e$ (level 2), and the location options $GSA = GSA_1, GSA_2, \dots, GSA_f$.

Step 2: Similarity matrices are computed for linguistic concepts in Step 2. Score indices (SCI) are calculated.

$$SCI = \sqrt{|100 * [(x - z)^2 - (y - z)^2]|} \quad (1)$$

Step 3: Requires a consistency check on pairwise comparison matrices using the consistency ratio (CR), which must be less than 10%.

Step 4: Calculate the criteria and option spherical fuzzy weights in the fourth step. The SWAM operator is used to measure the weight of each option.

$$\begin{aligned} SWAM_w(GSA_1, \dots, GSA_e) &= w_1 GSA_1 + w_2 GSA_2 + \dots + w_e GSA_e \\ &= \left\langle \left[1 - \prod_{a=1}^e (1 - x_{GSA_i}^2)^{w_a} \right]^{0.5}, \right. \\ &\quad \left. \prod_{a=1}^e (y_{GSA_i}^{w_a}) \right\rangle, \end{aligned}$$

$$\left[\prod_{a=1}^e (1 - x_{GSAa}^2)^{w_a} - \prod_{a=1}^e (1 - x_{GSAa}^2 - z_{GSAa}^2)^{w_a} \right]^{0.5} > \tag{2}$$

Where $w = 1/e$

Step 5: Using the defuzzification global weights, the final rating orders for the option are calculated in the fifth step.

$$S(w_b) = \sqrt{\left| 100 * \left[\left(3 * x - \frac{z}{2} \right)^2 - \left(\frac{y}{2} - z \right)^2 \right] \right|} \tag{3}$$

Step 6: Normalize the weights of the criterion and perform the spherical fuzzy multiplication.

$$w_b = \frac{S(w_b)}{\sum_{b=1}^e S(w_b)} \tag{4}$$

$$GSA_{ab} = w_b GSA_a = \left(1 - (1 - x_{GSAa}^2)^{w_b} \right)^{0.5},$$

$$y_{GSAa}^{w_b},$$

$$\left((1 - x_{GSAa}^2)^{w_b} - (1 - x_{GSAa}^2 - z_{GSAa}^2)^{w_b} \right)^{1/2} > \tag{5}$$

B. Spherical Fuzzy WASPAS

Evaluation of a product based on a weighted tally of the total value (WASPAS). The WASPAS approach was introduced in 2012 [38]; it is a mix of the weighted product model (WPM) and the weighted sum model (WSM); the steps of the proposed model are shown in figure 1. the process is described below.

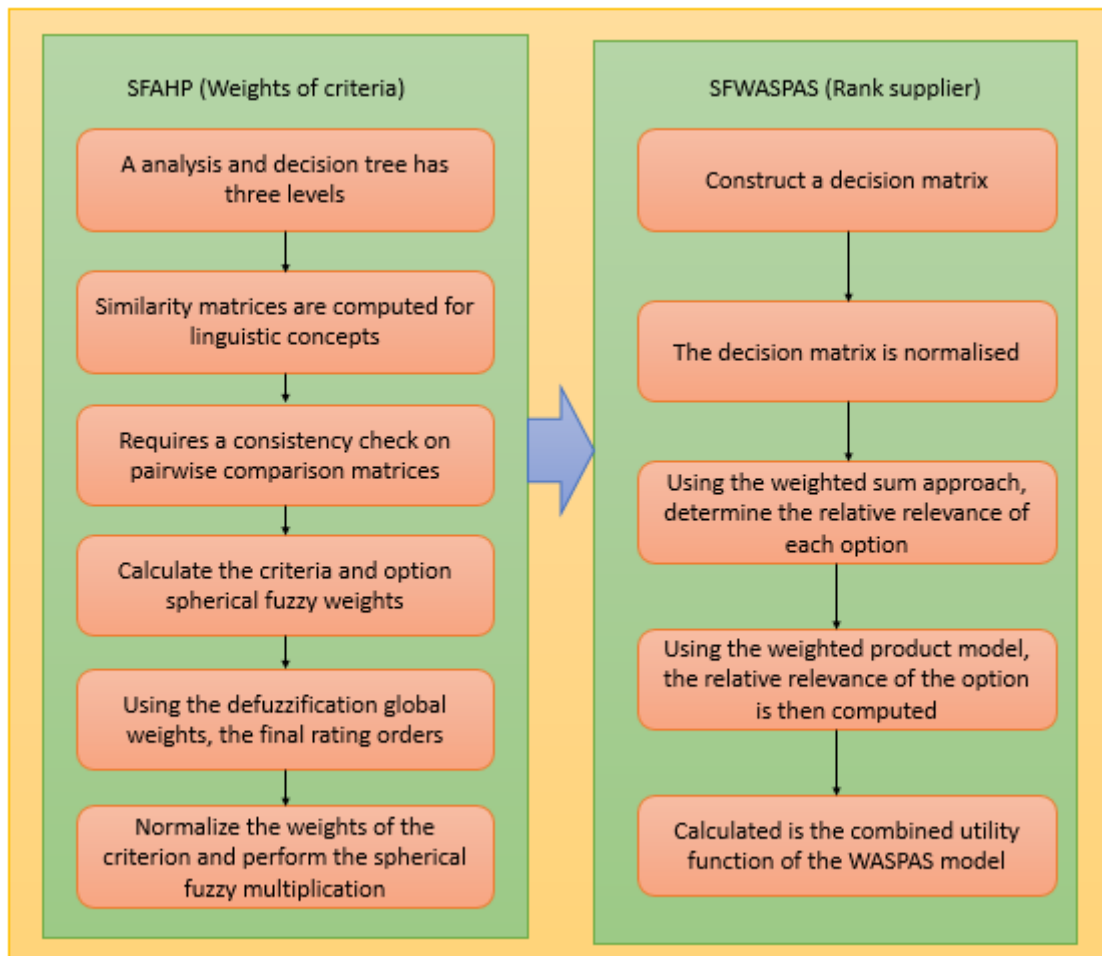


Figure 1: The framework of the paper.

Step 1: Construct a decision matrix $O = [o_{ab}]_{ef}$, where o_{ab} represents the performance of the a th option to the b th criterion, f represents the number of choices, and e represents the number of criteria.

Step 2: The decision matrix is normalized for benefit and cost criteria as:

$$O_{ab} = \frac{o_{ab}}{\max_a o_{ab}} \quad (6)$$

$$O_{ab} = \frac{o_{ab}}{\min_a o_{ab}} \quad (7)$$

Where $a = 1, 2, 3, \dots, f$; $b = 1, 2, 3, \dots, e$

Step 3: Using the weighted sum approach, determine the relative relevance of each option

$$R_a^{(1)} = \sum_{b=1}^e o_{ab} w_b \quad (8)$$

Step 4: Using the weighted product model, the relative relevance of the option is then computed.

$$R_a^{(2)} = \prod_{b=1}^e (o_{ab})^{w_b} \quad (10)$$

Step 5: Calculated is the combined utility function of the WASPAS model.

$$R_a = \lambda R_a^{(1)} + (1 - \lambda) R_a^{(2)} \quad (11)$$

$$\lambda = \frac{\sum_{a=1}^f R_a^{(1)}}{\sum_{a=1}^f R_a^{(1)} + \sum_{a=1}^f R_a^{(2)}} \quad (12)$$

4. Application

In this part, we illustrate the numerical application of the suggested technique for a manufacturer of electronic products interested in assessing its worldwide suppliers from a holistic sustainability standpoint.

To determine their priorities, the decision-making committee undertakes pairwise assessments of criteria. Using the average method technique aggregate pairwise scores are calculated for the different criteria and sub-criteria. The aggregate pairwise judgment matrix of the decision committee members for the stage I criterion is shown in Table 1. The C.R is less than 0.1; hence, the assessments are consistent.

After running pairwise comparison matrices and verifying consistencies, the priority of sub-criteria linked with stage I are also displayed. The local and global weights of the different sub-criteria connected with stage I are shown in Table 2. The global weights are calculated by multiplying the local weights by the weight associated with each criterion. For example, the local weight of sub-criteria is 0.5, while the local weight of criterion is 0.3; consequently, the global weight of sub-criteria is $0.5 * 0.3 = 0.15$. Figure 2 shows the weights of the main criteria. The main, sub-criteria and alternatives in below

Main criteria	Sub criteria	Alternatives
Economic GSC1	Cost GSC1.1	
	Quality GSC1.2	
	Flexibility GSC1.3	
	Speed GSC1.4	
	Dependability GSC1.5	
	Innovativeness GSC1.6	
Quality of relationship GSC2	Trust GSC2.1	
	Effectiveness of communication GSC2.2	
	EDI GSC2.3	
Environmental GSC3	Materials GSC3.1	
	Energy GSC3.2	GSA1
	Water GSC3.3	GSA2
	Biodiversity GSC3.4	GSA3
	Emissions GSC3.5	GSA4
	Effluents and waste GSC3.6	GSA5
	Supplier environmental selection procedure GSC3.7	GSA6
Social GSC4	Labor practices and decent work GSC4.1	GSA7
	Human rights GSC4.2	GSA8
	Society GSC4.3	GSA9
	Product responsibility GSC4.4	GSA10
	Supplier social selection procedure GSC4.5	
Global risks GSC5	Currency risks GSC5.1	
	Disruption risks through political instability GSC5.2	
	Disruption risks through terrorism GSC5.3	
	Cultural compatibility GSC5.4	

Table 1: The aggregated pairwise matrix for the main criteria.

	GSC ₁	GSC ₂	GSC ₃	GSC ₄	GSC ₅
GSC ₁	1.00	4.65	10.65	16.66	11.49
GSC ₂	0.06	1.00	13.16	6.33	10.32
GSC ₃	0.19	0.11	1.00	16.66	10.65
GSC ₄	0.14	0.16	0.14	1.00	6.32
GSC ₅	0.17	0.17	0.19	0.20	1.00

Table 2: The local and global weights of criteria.

Local	Weights	Global weights
GSC _{1,1}	0.506191	0.255736
GSC _{1,2}	0.154128	0.077868
GSC _{1,3}	0.180551	0.091217
GSC _{1,4}	0.087896	0.044406
GSC _{1,5}	0.049321	0.024918
GSC _{1,6}	0.021913	0.011071
GSC _{2,1}	0.713449	0.162824

GSC _{2,2}	0.23045	0.052594
GSC _{2,3}	0.056101	0.012803
GSC _{3,1}	0.341957	0.058352
GSC _{3,2}	0.213156	0.036373
GSC _{3,3}	0.201354	0.034359
GSC _{3,4}	0.109233	0.01864
GSC _{3,5}	0.076044	0.012976
GSC _{3,6}	0.041723	0.00712
GSC _{3,7}	0.016532	0.002821
GSC _{4,1}	0.469055	0.02872
GSC _{4,2}	0.245406	0.015026
GSC _{4,3}	0.162903	0.009975
GSC _{4,4}	0.081545	0.004993
GSC _{4,5}	0.041091	0.002516
GSC _{5,1}	0.570643	0.019798
GSC _{5,2}	0.24964	0.008661
GSC _{5,3}	0.142066	0.004929
GSC _{5,4}	0.037651	0.001306

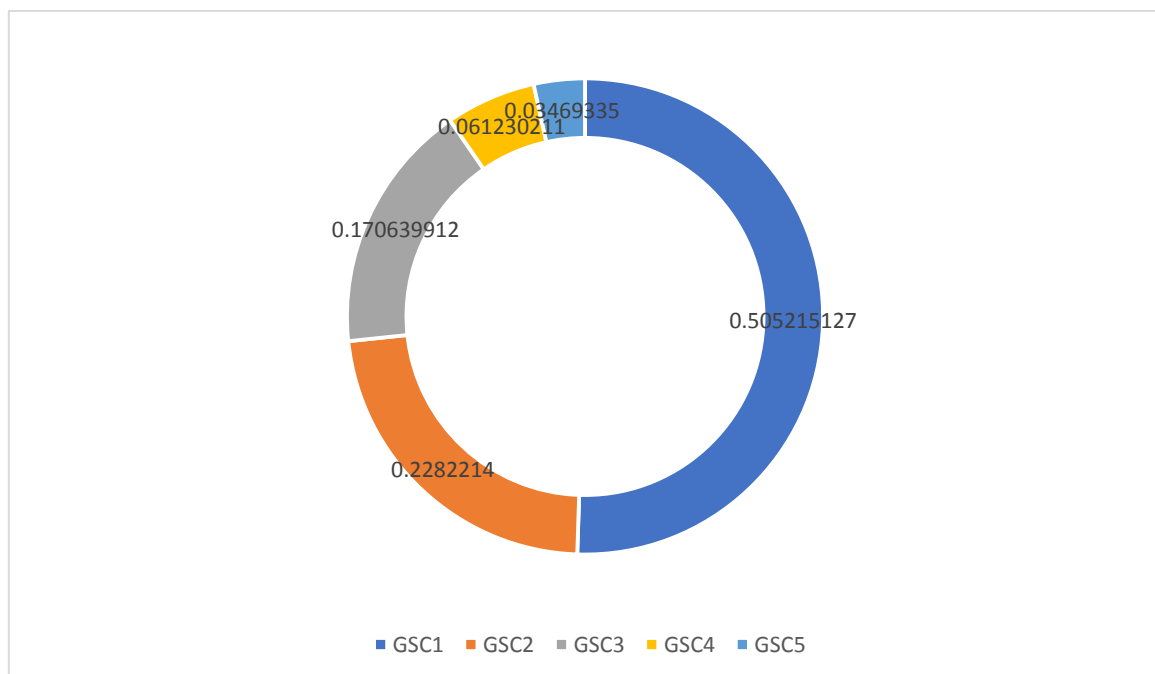


Figure 2: The weights of the main criteria.

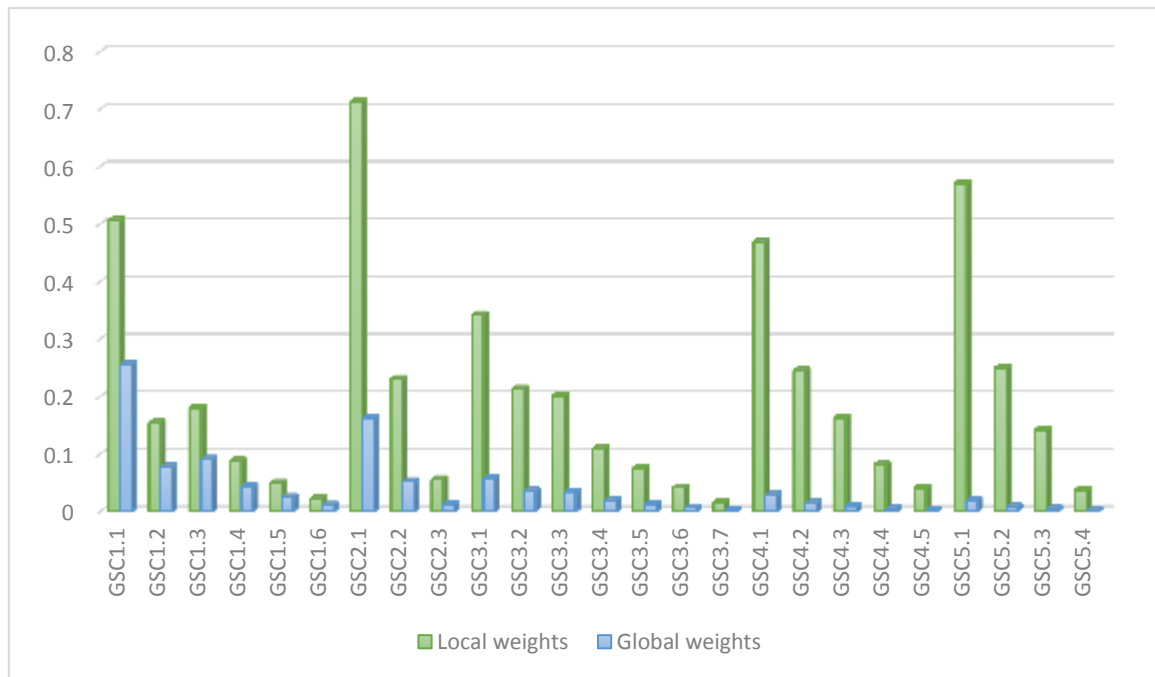


Figure 3: The local and global weights of criteria.

Fuzzy WASPAS is used to choose the sustainable supplier and sub-supplier(s) based on the weighted criteria derived by fuzzy AHP (stages I and II). A committee of three decision-makers is created to assess the alternatives (ten suppliers) using qualitative (linguistic) evaluations based on the stated criteria in tables 3.1-3.3. The aggregated acquired ratings are shown in Table 3.

In the second phase, the SF-AHP weights were combined with the WASPAS model to rank the probable suppliers. Table 4 shows the normalized decision matrix. Tables 5 and 6 exhibit, respectively, the weighted normalized matrix for the WSM and the weighted normalized matrix for the WPM. Using an integrated simple additive weighting and exponentially weighted product model, the WASPAS model ranks the alternatives to provide a compromise solution. The integrated utility function R_a of the WASPAS model is derived from the weighted sum model $R_a^{(1)}$ (WSM) and the weighted product model $R_a^{(2)}$ (WPM). The findings indicate that the top three suppliers GSC₅, GSC₄, GSC₁, ranked first, second, and third, respectively, with scores of 0.734, 0.6837, and 0.6365. Figure 4 depicts the WASPAS model's final supplier ranking.

Table 3.1: The decision matrix by the first expert.

GSC	GSC	GSC	GSC
7.998	23.5	5.491	GSC
5.94	10.5	8.12	GSC
2.966	7.998	23.5	GSC
0.58	5.94	23.5	GSC
23.5	19.99	23.5	GSC
23.5	9.94	23.5	GSC
2.966	2.966	2.966	GSC
0.58	19.99	0.58	GSC
23.5	9.94	19.99	GSC
19.99	23.5	9.94	GSC
9.94	7.998	23.5	GSC
23.5	5.94	19.99	GSC
23.5	23.5	9.94	GSC
23.5	7.998	23.5	GSC
19.99	5.94	7.998	GSC
9.94	2.966	7.998	GSC
23.5	7.998	5.94	GSC
7.998	0.58	7.998	GSC
5.94	5.94	5.94	GSC
19.99	23.5	19.99	GSC
9.94	19.99	7.998	GSC
23.5	9.94	5.94	GSC
7.998	23.5	19.99	GSC
5.94	7.998	9.94	GSC
23.5	5.94	23.5	GSC
19.99	23.5	7.998	GSC
9.94	19.99	5.94	GSC
8.12	7.998	9.94	GSC
23.5	5.94	23.5	GSC
7.998	23.5	5.491	GSC
5.94	5.491	8.12	GSC
23.5	8.12	23.5	GSC
5.491	5.491	23.5	GSC
8.12	8.12	23.5	GSC
23.5	23.5	23.5	GSC
7.998	23.5	5.491	GSC
5.94	23.5	8.12	GSC
23.5	23.5	7.998	GSC
23.5	23.5	5.94	GSC



Figure 4: The rank of alternatives.

5. Managerial Implication

Managers, society, and academics all stand to benefit from this study. The sustainability of the supply chain is not taken into consideration in current management decision-making approaches for supplier selection. If civil society campaigns and conventional and social networking sites encourage supply chain breaches of international social and environmental norms, this is a critical omission that might result in monetary losses for focused enterprises across Europe, Japan, North America, and elsewhere. Methodology for managers to choose suppliers based on full selection criteria, which incorporates key sustainable development risks is presented in this paper. To address the risks that transnational corporations (MNCs) confront when they acquire their pre-products abroad, particularly if they are exposed to public scrutiny, which often holds the focal enterprises responsible for their whole supply chains, this management tool has been developed. Managers may use this tool to help them identify suppliers and sub-suppliers that pose a high risk or poor performance focused on company sustainability standards.

6. Conclusion

Deregulation of the political-economic system, internet-connected devices, and low-cost mass transit have tried to push business owners to increasingly outsource business activities to distant countries; these decisions frequently result in more effective supply chain setups covering multiple stages from the harvesting of raw materials to the finished consumer. Supply chains have expanded into low-income countries because of the cheap cost of labor and the ease with which environmental assets may be processed. Civil society has entrusted target companies with implementing basic sustainability-related production criteria in these countries, where social and environmental regulations are generally weak or badly enforced. Most supplier selection models do not take into account how NGOs, student groups, unions, and other forms of civil society might have an adverse effect on the economic and policy policies of big corporations.

There are several possibilities for further development based on this work. In the beginning, real data might be used to assess the proposed model. It is feasible to compare the model's results to those of other MCDM techniques. Thirdly, the model's results may be compared to other uncertainty modeling methods. A final test of the proposed framework might include situation analysis, emergency preparation, and uncertainty evaluation.

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