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Environmental and Social Factors in Supplier Assessment: Fuzzy-Based Green Supplier Selection

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Abstract: Supplier selection is a key process that entails selecting suppliers who provide high-quality, cost-effective products or services with predetermined schedules and quantities. Organisations are currently reconsidering their supply chain strategies in order to incorporate environmental and ecological issues into their operations. This involves a shift towards environmentally conscientious providers as well as the incorporation of environmental requirements into daily practises. This research paper investigates supplier evaluation strategies and selection criteria in depth. This study presents a novel methodology for assessing supply chain risk management in the setting of supplier management. This study's focuses are cost, quality, delivery time, environmental performance, and social responsibility. The incorporation of administrative observation into supplier selection is illustrated, with the results compared to those of traditional methods. Our findings highlight the synergies between administrative observation and quantitative metrics, providing crucial insights into supplier sustainability performance and improving decision making. Finally, this study emphasises the importance of managerial observation in sustainable supplier selection, emphasising the relevance of subjective ratings to improve awareness of suppliers' sustainability practises and minimise risks associated with weak quantitative assessments.

Keywords: supply chain management; resilience; supply chain risk; sustainability; Fuzzy TOPSIS

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1. Introduction

Across all industries, supply chain management (SCM) is essential to the success and long-term viability of organisations. The choice of suppliers is an important component of SCM since it has a direct impact on the effectiveness, price, and quality of the goods and services that a company offers. The significance of choosing a sustainable supplier—one that takes into account environmental, social, and economic factors—has recently come to be well understood. By incorporating sustainability concepts into the decision-making process, sustainable supplier selection strives to ensure that suppliers are in line with an organization's values and long-term goals. Historically, choosing a supplier has been largely based on quantitative factors like price, quality, delivery time, and reliability [1–3]. However, as organisations and society at large grow more conscious of the environmental and social effects of their operations, there is a need to go beyond just economic considerations when choosing suppliers. Organisations are becoming aware of how unsustainable supply chain practises can eventually result in cost increases, reputational harm, and legal problems. As a result, there is an increasing need for techniques and frameworks that make it possible to incorporate sustainability factors into supplier selection procedures [4–6]. Supplier qualification is critical in the supply chain management process to ensuring that selected suppliers meet particular criteria, such as requirements for quality and sustainability practises, in order to meet consumer demand successfully. Later-stage supplier monitoring is as crucial for maintaining continuous supplier compliance, efficiency, and responsiveness, allowing organisations to react to changing market conditions and mitigate possible hazards. Supplier qualification and monitoring processes work together to create a strong and dependable supply chain. This ensures the timely and high-quality distribution

of goods and services to satisfy client needs efficiently. Figure 1 below shows the supply chain management process.

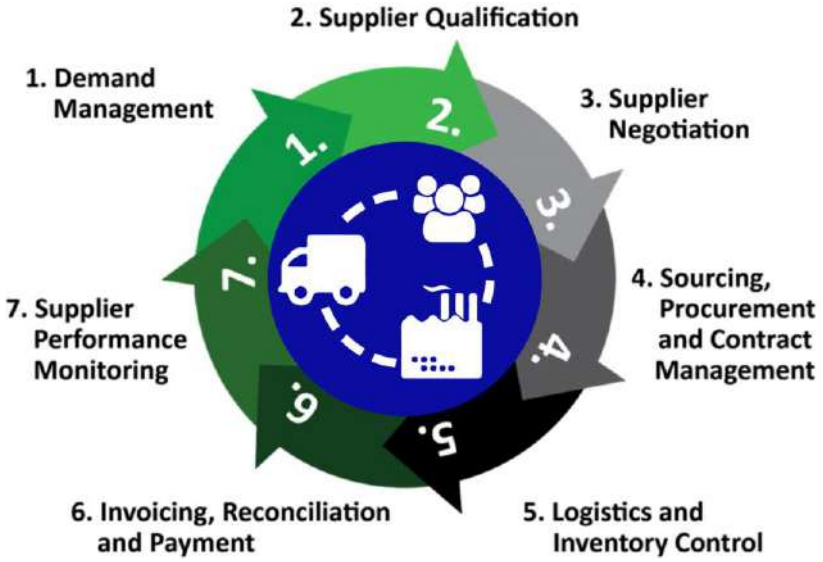

Figure 1. Supply chain management process.

The incorporation of administrative observation into supplier selection procedures is one strategy with a lot of potential in this context. The direct examination and evaluation of prospective suppliers depending on their operational practises, including their performance in terms of sustainability, is accomplished through administrative observation [7,8]. Organisations can acquire useful information about the suppliers' adherence to environmental laws, labour standards, health and safety procedures, as well as their general commitment to sustainable business practises by performing on-site visits and inspections. Organisations may make better decisions and ensure that their supply chains support their sustainability objectives by using this first-hand knowledge [9–12]. This research paper's goal is to investigate how management observation can be added to SCM's sustainable supplier selection process. This research paper attempts to highlight the key difficulties and opportunities associated with incorporating management observation by performing a thorough analysis of the existing literature on sustainable supplier selection. Additionally, it aims to build a framework that businesses may utilise to successfully integrate administrative observation into their supplier selection procedures. The suggested framework takes into account a number of factors, including the selection criteria, evaluation techniques, data gathering, and decision-making procedures.

This study acknowledges the growing importance of considering environmental and social factors alongside traditional quantitative criteria for supplier selection. We used a mixed-methods approach to accomplish this, integrating quantitative data from questionnaires and secondary sources with qualitative information from case studies as well as interviews. The main emphasis is on learning from businesses that have effectively included administrative observation into their supplier selection procedures and evaluating the results of these initiatives [13–15]. By emphasising the role of management monitoring as a useful tool for assessing suppliers' sustainability performance, this research article ultimately aims to add to the body of knowledge on sustainable supplier selection in SCM. This article will assist organisations in selecting suppliers more wisely and sustainably by offering useful guidance through the suggested framework, thereby enhancing the overall sustainability and resilience of their supply chains.

By providing a more holistic and nuanced view of supplier sustainability, the proposed model of administrative observation tackles the constraints and limits of standard quantitative assessment approaches. While quantitative methods frequently concentrate on numerical data, administrative observation supplements these metrics by offering quali-

tative insights into a supplier's practices and behaviour. Organizations may ensure that the identified supplier selection variables are applied consistently and reliably by defining the criteria and guidelines within their supply chain management and procurement processes. This could include creating standardized assessment processes, performing regular audits, and encouraging supplier engagement. Organizations might apply weights or rankings according to their specific aims to align these factors with sustainability goals. Typically, this is accomplished using a multi-criteria decision-making technique in which experts or stakeholders give importance to each variable based on the organization's sustainability priorities. This methodical approach assists in ensuring that supplier selection matches with an organization's sustainability goals and objectives while preserving its dependability and consistency.

The remaining sections of the paper are organized as follows: Section 2 provides an overview of related works that have been conducted in the field. Section 3 delves into the Materials and Methods employed in this research study, encompassing the Fuzzy TOPSIS approach and the hierarchy for the selection process. Section 4 presents the findings that have emerged from this study, highlighting the outcomes and results obtained. In Section 5, a comprehensive discussion is presented, analysing and interpreting the findings in the context of the research objectives. Finally, in Section 6, the paper concludes by summarizing the key findings, discussing any limitations encountered during the study, and proposing avenues for future research and study in the subject area.

2. Related Works

The related works section provides a thorough analysis of the literature and research on sustainable supplier selection in supply chain management. This section highlights notable studies, methodologies, and frameworks that have aided in the comprehension of sustainable supplier selection practises. We intend to acquire insight into the many approaches, challenges, and possibilities within this sector by delving into the existing body of knowledge, while also identifying gaps for future research. The subsections that follow provide a detailed examination of relevant studies, categorising them according to their emphasis on sustainable criteria and decision-making processes, as well as practical implications.

Luthra et al. [16] introduced an integrated strategy that combined the analytical hierarchy process (AHP) and ViseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) to evaluate sustainable supplier selection. Their work began by identifying 22 sustainable supplier selection factors across economic, environmental, and social dimensions. The framework was illustrated using a real-world case study in the Indian automobile industry, emphasizing the top five factors influencing sustainable supplier selection. This research provides valuable insights for managers and professionals seeking to differentiate critical supplier selection factors and identify the most effective and sustainable suppliers. Tavana et al. [17] introduced an innovative integrated multi-criteria decision-making approach to address the challenges of selecting sustainable suppliers. Their model systematically analysed the interplay of sustainable factors, creating a hierarchical structure for these variables. It weighted choice criteria based on customer requirements, followed by a ranking of suppliers through a multi-objective optimization process. This research paper highlights the adaptability of this approach for businesses with similar characteristics.

Hashemi et al. [18] presented a comprehensive strategy for selecting green suppliers, addressing both economic and environmental factors. They employed the analytic network process (ANP) to handle criteria dependencies and an enhanced grey relational analysis (GRA) to address the inherent uncertainty in supplier selection decisions. This unique approach actively involves decision makers and integrates linguistic evaluations into the supplier selection process, as demonstrated in an automotive sector case study. Badri Ahmadi et al. [19] designed a structured decision approach for assessing sustainable suppliers in the telecommunications sector. Their integration of the analytical hierarchy process (AHP) with an enhanced grey relational analysis (IGRA) allowed for the determination of

sustainability criteria importance and supplier ranking. The model's sensitivity analysis tested its robustness in the context of sustainable supplier selection in Southern Iran.

Freeman and Chen [20] emphasized the creation of a model for green supplier selection, balancing traditional selection criteria with environmental concerns. Their approach aligns with green supply chain management (GSCM) principles, offering a systematic method for integrating eco-friendly suppliers while complying with environmental regulations. Zimmer et al. [21] conducted an extensive review of research on sustainable supplier management (SSM), emphasizing formal models for the selection, monitoring, and improvement of sustainable suppliers. This content analysis of 143 peer-reviewed publications from 1997 to 2014 reveals increased academic interest, particularly in methodologies like the analytic hierarchy process, analytic network process, and fuzzy-based methods. It underscores the significance of the evaluation and decision process and the potential for the further exploration of social and quantitative variables.

Wang et al. [22] introduced a supplier selection paradigm emphasizing information integration for supply chain management, integrating building information modelling (BIM) and geographic information systems (GIS) to create a resilient building supply chain. The framework combines the analytic hierarchy process (AHP) and grey relational analysis (GRA) for supplier evaluation with a sensitivity analysis to identify key factors impacting supplier selection preferences. Fallahpour et al. [23] explored the use of hybrid artificial-intelligence-based systems for supplier evaluations, introducing a model combining a data envelopment analysis (DEA) with genetic programming (GP). This innovative approach overcame the limitations of traditional DEA-AI models, offering a potent tool for supplier efficiency assessments.

Song et al. [24] developed a comprehensive methodology combining rough numbers, the pairwise contrast method, the decision-making trial and evaluation laboratory (DEMATEL), and pairwise comparative procedures for assessing relative importance. A case study in the solar air conditioner industry demonstrated the effectiveness of this methodology. Yazdani et al. [25] proposed an integrated method for selecting green suppliers, utilizing the decision-making trial and evaluation laboratory (DEMATEL) approach to establish a relationship structure. Quality function deployment (QFD) determined the degree of connection among the supplier selection criteria and customer requirements, followed by a complex proportional assessment (COPRAS) for ranking and prioritizing alternative suppliers.

These studies collectively contribute to the evolving field of sustainable supplier selection by introducing innovative approaches and addressing various facets of sustainability in supplier management. Several other authors [26–29] have employed MCDM approaches to address intricate problems in recent years. It is also important to highlight that the Fuzzy Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method is used in our research to choose suppliers. For decision-making issues, particularly in complex and unpredictable situations, the Fuzzy TOPSIS technique is widely acknowledged and used. This approach can manage confusing and inaccurate data by incorporating fuzzy logic, which is frequently encountered while evaluating sustainability criteria in supplier selection. The Fuzzy TOPSIS method has been successfully used in numerous studies to rank suppliers according to sustainability criteria such as price, quality, and environmental performance, as well as social responsibility. By incorporating administrative observation into the Fuzzy TOPSIS technique, our research expands on this basis by improving the thoroughness and precision of the supplier selection procedure. Our research adds to the literature by putting the benefits of the Fuzzy TOPSIS method and management observation together to propose a novel strategy that helps organisations to choose sustainable suppliers efficiently and make decisions based on many factors.

3. Materials and Methods

This section used a hierarchical structure and the Fuzzy Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) to assist with sustainable supplier selection in supply chain management. The term "fuzzy" signifies the presence of uncertainty as

well as imprecision in decision making. When reviewing and ranking suppliers by considering environmental and social factors, this strategy handles ambiguous or imprecise information. The supplier assessment criteria's inherent uncertainties and ambiguity were addressed using the Fuzzy TOPSIS approach, and the hierarchical structure offered a structured framework for managing the decision-making process [26–30]. This study aims to make informed decisions by leveraging the experience of 55 managerial-level professionals, including top-level managers, business analysts, and senior researchers. Expert profiles were created to collect raw data based on their qualifications, expertise, and relevance to the research subject. We conducted structured interviews with these experts, utilizing a pre-determined list of questions covering major parts of the research issue. To gain expert opinions, we conducted in-depth interviews with each professional, allowing us to tap into their significant knowledge and experience in the field. The process for using the Fuzzy TOPSIS approach within the hierarchical structure is described in this part, including the selection of criteria, criteria weighting, fuzzy evaluation, and final supplier ranking.

3.1. Fuzzy TOPSIS Approach

Due to its capacity to deal with the inherent uncertainty as well as imprecision involved with decision-making processes, the Fuzzy TOPSIS technique has drawn substantial interest in the context of supplier selection in supply chain management. The Fuzzy TOPSIS method offers a methodical process for assessing and ranking potential suppliers based on a variety of factors, taking into account both their positive and negative performance characteristics [31–34]. An overview of the Fuzzy TOPSIS approach and a mathematical model of the steps are given in this section. Fuzzy normalisation, fuzzy similarity measurements, and the computation of Fuzzy TOPSIS scores are some of the mathematical operations included in the Fuzzy TOPSIS technique. Fuzzy set theory, aggregation operators, and weighted average methods serve as the foundation for these calculations. This research article will derive and explain in detail the particular mathematical formulas and equations utilised in the Fuzzy TOPSIS approach, ensuring a thorough comprehension of the system's mathematical foundation and implementation.

This research study intends to give a strong and efficient technique for integrating administrative observation into sustainable supplier selection in supply chain management by utilising the Fuzzy TOPSIS method and its mathematical model. Organisations will be able to use the mathematical framework to make defensible judgements based on ambiguous and unclear data, taking into account a variety of factors including environmental dimensions [35–40]. This scale is composed of a standard group of expressions that have been organised in a certain sequence. These expressions serve to depict specific phenomena, states as expressions that are equally spaced from the determined value. Making a comprehensive list of selection criteria for the sustainable supplier is the first stage in the process. Choosing criteria for a model is one of the major challenges. As a result, by reading the literature and utilising the findings of earlier studies, the standards for evaluating sustainable suppliers are created. In accordance with the organization's strategy and requirements, local experts' opinions are considered to identify the most efficient criteria for choosing suppliers among the examined criteria. Five criteria for the sustainable suppliers were chosen from the predetermined criteria after the requisite interviews. The best sustainable supplier was then chosen using an evaluation based on the fuzzy scale. The Fuzzy TOPSIS-based supply chain management strategy for sustainable supplier selection is depicted in Figure 2.

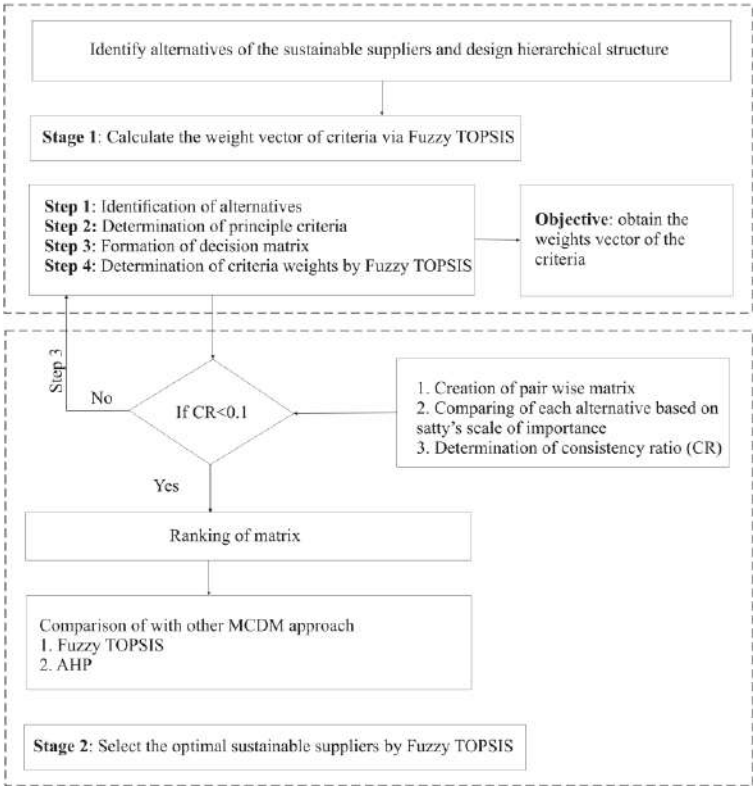

Figure 2. Fuzzy-TOPSIS-based framework for sustainable supplier selection in supply chain management.

3.2. Hierarchical Model for the Selection of Sustainable Supplier

In order to properly organize the selection process of sustainable supplier, a hierarchical model is proposed, taking into account the multi-faceted character of sustainable supplier selection. The introduction of an innovative and thorough supplier selection framework based on five important aspects—cost, quality, delivery time, environmental performance, and social responsibility—is intended to revolutionize long-term supply chain management. This specific framework includes cutting-edge approaches and adheres to sustainability, ethical, and efficiency principles. The first element, cost, goes beyond the traditional method of focusing exclusively on purchasing price. Instead, it incorporates total cost of ownership (TCO) assessment, which includes procurement, shipping, inventory keeping, and other pertinent costs. Organizations can make better-informed choices that match with their financial objectives as well as long-term profitability by evaluating suppliers via this holistic cost lens. Quality remains an essential criterion in the framework, emphasising the consistency and dependability of suppliers' products or services. Using sophisticated quality management approaches such as Six Sigma and Statistical Process Control, suppliers with a solid track record of regularly delivering high-quality goods and services can be identified. Delivery time, in addition to cost and quality, appears to be a critical element in the framework. For efficiency in operations, meeting customer demand, and lowering lead times, timely delivery is critical. The hierarchical model employs performance data and cutting-edge delivery tracking tools to find suppliers who can consistently meet tight deadlines.

The innovative supplier selection framework is also the first to incorporate environmental performance as a critical factor. The environmental impact of suppliers is thoroughly analysed through life cycle analyses and environmental certifications, including greenhouse gas emissions, water usage, and waste generation. Suppliers who exhibit a strong commitment to sustainability and have embraced eco-friendly practises can be prioritised by organisations. Additionally, the framework prioritises social responsibility, emphasising suppliers' ethical behaviour and social impact. Labour practises, human rights compliance,

diversity and inclusion activities, and interaction with local communities are all evaluated. Organisations may cultivate a positive reputation, increase their brand value, and positively contribute to society by cooperating with socially responsible suppliers. This specific supplier selection framework's incorporation of cost, quality, delivery time, environmental performance, and social responsibility as the main pillars symbolises an innovation in supply chain management. Organisations can accomplish sustainable procurement practises, make responsible decisions, and form long-term partnerships with suppliers that align with their ethical as well as business goals by adopting this comprehensive strategy. Furthermore, this novel approach ushers in the next phase of supply chain sustainability by empowering organisations to set the standard for corporate social responsibility as well as environmental stewardship. The hierarchy makes it possible to evaluate suppliers holistically, ensuring that all pertinent criteria are taken into account and given the proper weighting during the decision-making process. The hierarchical representation for choosing a sustainable supplier is shown in Figure 3 below.

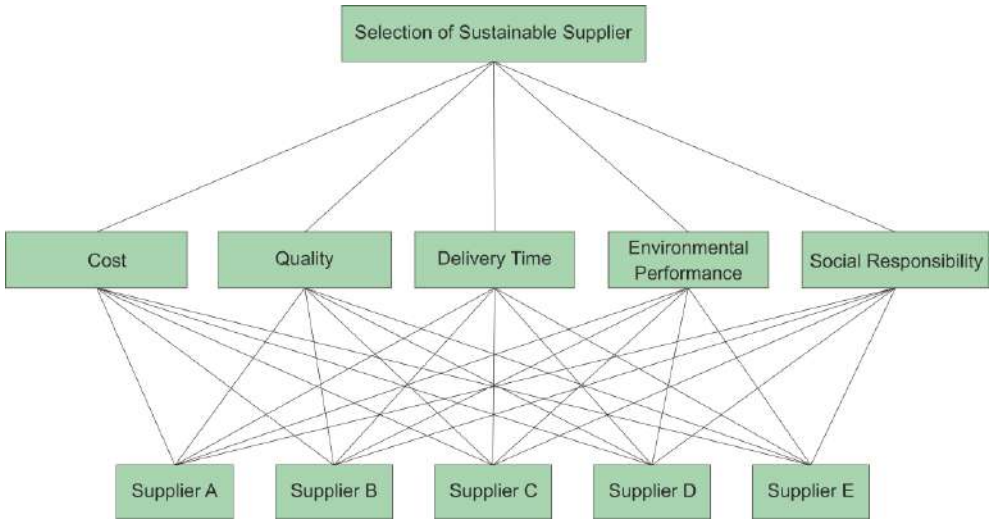

Figure 3. Hierarchy model for the selection of sustainable suppliers.

3.2.1. Criteria Identification

The main goals of this part were to develop and define the essential standards for assessing suppliers' sustainability performance in supply chain management. Given the importance of taking into account many sustainability-related factors, a methodical approach was used to identify the pertinent standards. The process used to determine the criteria is described in this section, which included a thorough assessment of the literature, discussions with business professionals, and consideration of organisational goals. This section establishes the groundwork for a rigorous and inclusive evaluation framework by defining a thorough set of criteria, ensuring that all pertinent sustainability-related factors are taken into account during the supplier selection process. The five criteria that were determined for this research study are listed below.

Cost: This criterion evaluates each supplier's price strategy, total cost of ownership, and overall financial impact. It takes into account things like the cost of the product, the conditions of payment, discounts, and any supplemental expenses like shipping or customisation.

Quality: The capacity of the supplier to consistently supply goods or services which satisfy or go above the predetermined standards is referred to as quality. This criterion assesses elements including product dependability, compliance with quality control procedures, certifications, and customer satisfaction scores.

Delivery Time: The primary concern of delivery time is the supplier's capacity to fulfil orders promptly and adhere to established delivery schedules. It takes into account things like lead times, production capacity, effective order processing, and delivery performance.

Environmental Performance: This criterion assesses the supplier's dedication to eco-friendly business practises. It evaluates elements including carbon footprint, waste management, energy efficiency, reliance on renewable resources, and adherence to environmental laws.

Social Responsibility: The supplier's ethical as well as social practises are evaluated by the social responsibility criterion. It takes into account elements like working conditions, ethical business practices, diversity and inclusion strategies, health and safety regulations, and community involvement programmes.

3.2.2. Identification of Alternatives

The selection and identification of potential supplier alternatives to be considered during the sustainable supplier selection process were the main objectives of this section. This section covers the methodical process used to find and shortlist the alternatives because it is crucial to take into account a wide range of options. To create a complete list of potential suppliers, this approach involved market research, supplier databases, and cooperation with important parties. In order to ensure that only the alternatives with the greatest potential for sustainable performance are taken into consideration for further review, the section also discusses the criteria used to filter and prioritise the alternatives. This part carefully identifies and chooses the alternatives, laying the groundwork for a thorough and efficient supplier evaluation procedure. The recognised options for this examination and selection are listed below.

Supplier A: A reputable supplier with a competitive pricing structure, a proven track record of supplying high-quality items, and a solid track record of completing orders on time. They have put in place strategies for environmental sustainability and operate active social responsibility initiatives.

Supplier B: A reasonable provider with reasonable prices; however, they need to enhance their quality control procedures and delivery performance. They have already begun putting environmental sustainability practises into practise and are currently working to improve their social responsibility programmes.

Supplier C: A high-end source with more expensive prices, but outstanding product quality as well as prompt delivery. They actively take part in social responsibility initiatives and have a strong environmental sustainability policy in place.

Supplier D: A reasonable in terms of pricing, quality, and timeliness of delivery performance source. They have few social responsibility programmes, and they are just starting to apply environmental sustainability initiatives.

Supplier E: A provider whose low prices are accompanied by variable product quality and lengthy delivery windows. They make only modest efforts to uphold social responsibility and implement minimal environmental sustainability practises.

In Fuzzy-TOPSIS-based multiple criteria decision-making (MCDM) analysis, identifying criteria and alternatives is critical. The selection of proper criteria is critical since it establishes the dimensions or traits that will be used to evaluate the options. These criteria constitute guiding principles that match with the decision making process's aims and requirements. A thorough investigation and precise criteria specification guarantee that all essential parts of the problem are considered, resulting in a more comprehensive and accurate review. In a comparable manner, proper alternative determination is critical since they provide prospective solutions or possibilities to be evaluated against the established criteria. A well-defined set of alternatives guarantees that the decision-making process covers a wide range of possible consequences, providing a thorough review of prospective options. This, in turn, enables decision makers to make informed and sound decisions by taking into account a variety of viable options. In general, methodical identification of criteria as well as alternatives in Fuzzy-TOPSIS-based MCDM analysis improves decision-making objectivity and rigour. It enables a more thorough and inclusive review of various alternatives, enabling the selection of the best option that matches with the decision makers' interests and values. As an outcome, in complicated and unpredictable decision-making contexts, this technique assists in making well-informed choices.

4. Results

The evaluation and analysis of the supply chain management's sustainable supplier selection procedure are presented in this section along with the conclusions and results that were reached. This section emphasises the quantitative and qualitative findings from the use of the chosen evaluation methodology, offering insightful information on the effectiveness of the examined suppliers. An overview of the data gathered and the precise statistical or analytical methods used are included in the section's opening paragraph. The results are then organised in accordance with the predetermined evaluation criteria and presented in a clear and plain manner. The analysis of the results offers a thorough understanding of the performance of the sustainable providers and makes it easier to make comparisons between various suppliers. Furthermore, any important trends, patterns, or findings are emphasized and count towards the research study's final results and ramifications.

4.1. Statistical Outcome

The goal of this research was to use the knowledge of 55 managerial-level specialists to make educated judgements in this area. The Fuzzy TOPSIS approach was used to collect and analyse their data in order to identify the best vendors. The research technique includes identifying five important factors that were thought to be essential for choosing sustainable suppliers. Five potential solutions were assessed and compared using these criteria. The ranking of the most advantageous providers was generated using the Fuzzy TOPSIS approach based on their performance in accordance to the defined criteria. Table 1 is included in the report to provide the characteristics of different criteria used in this investigation. The various criteria used in the evaluation process are shown in this table along with the associated weights given to each criterion. The relative weights of each criterion in the supplier selection process were determined by these weights, which were very important.

Table 1. Characteristics of criteria.

	Name	Type	Weight
1	Cost	+	(0.200, 0.200, 0.200)
2	Quality	+	(0.200, 0.200, 0.200)
3	Delivery Time	+	(0.200, 0.200, 0.200)
4	Environmental Performance	+	(0.200, 0.200, 0.200)
5	Social Responsibility	+	(0.200, 0.200, 0.200)

Table 2 provided below illustrates the specific fuzzy scale employed within the model.

Table 2. Fuzzy Scale.

Code	Linguistic Terms	L	M	U
1	Very low	1	1	3
2	Low	1	3	5
3	Medium	3	5	7
4	High	5	7	9
5	Very high	7	9	9

The outcomes of the decision matrix's examination of the options using different criteria are shown in Table 3 below. It should be taken into account that the matrix below represents the arithmetic mean of all the experts' evaluations in situations in which numerous experts participated in the evaluation process.

Table 3. Decision matrix.

	Cost	Quality	Delivery Time	Environmental Performance	Social Responsibility
Supplier A	(4.600, 6.600, 8.000)	(4.600, 6.600, 7.600)	(3.600, 5.600, 7.200)	(3.800, 5.800, 7.200)	(4.000, 6.000, 7.400)
Supplier B	(3.600, 5.600, 7.200)	(4.000, 6.000, 7.200)	(4.800, 6.800, 7.800)	(4.200, 6.200, 7.600)	(2.800, 4.600, 6.200)
Supplier C	(5.600, 7.600, 8.200)	(4.400, 6.400, 7.800)	(4.600, 6.600, 8.000)	(3.400, 5.400, 7.000)	(3.200, 5.200, 7.200)
Supplier D	(3.600, 5.600, 7.400)	(3.800, 5.800, 7.400)	(3.200, 5.200, 7.000)	(4.000, 5.800, 7.400)	(3.600, 5.600, 7.000)
Supplier E	(2.400, 4.400, 6.400)	(3.200, 5.200, 6.600)	(3.000, 5.000, 6.600)	(4.400, 6.400, 7.600)	(3.200, 5.200, 7.000)

The expression that follows can be used to compute a normalised decision matrix using the positive and negative ideal solutions:

$$\widetilde{r}_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*} \right) \quad ; \quad c_j^* = \boldsymbol{max}_i \, c_{ij}; \textit{ Positive ideal solution} \tag{1}$$

$$\widetilde{r}_{ij} = \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}} \right) \quad ; \quad a_j^- = \boldsymbol{min}_i \, a_{ij}; \textit{ Negative ideal solution} \tag{2}$$

Table 4 below presents the normalized decision matrix.

Table 4. A normalized decision matrix.

	Cost	Quality	Delivery Time	Environmental Performance	Social Responsibility
Supplier A	(0.561, 0.805, 0.976)	(0.590, 0.846, 0.974)	(0.450, 0.700, 0.900)	(0.500, 0.763, 0.947)	(0.541, 0.811, 1.000)
Supplier B	(0.439, 0.683, 0.878)	(0.513, 0.769, 0.923)	(0.600, 0.850, 0.975)	(0.553, 0.816, 1.000)	(0.378, 0.622, 0.838)
Supplier C	(0.683, 0.927, 1.000)	(0.564, 0.821, 1.000)	(0.575, 0.825, 1.000)	(0.447, 0.711, 0.921)	(0.432, 0.703, 0.973)
Supplier D	(0.439, 0.683, 0.902)	(0.487, 0.744, 0.949)	(0.400, 0.650, 0.875)	(0.526, 0.763, 0.974)	(0.486, 0.757, 0.946)
Supplier E	(0.293, 0.537, 0.780)	(0.410, 0.667, 0.846)	(0.375, 0.625, 0.825)	(0.579, 0.842, 1.000)	(0.432, 0.703, 0.946)

The weighted normalised decision matrix can be calculated by multiplying every criterion's weight with the value it corresponds to in the normalised fuzzy decision matrix using the method given below, taking into consideration the different weights allocated to each criterion.

$$\widetilde{v}_{ij} = \widetilde{r}_{ij}.\widetilde{w}_{ij} \tag{3}$$

where $\widetilde{w}_{ij}$ represents the weight of criterion c_j.

The weighted normalized decision matrix is displayed in Table 5 below.

Table 5. The weighted normalized decision matrix.

	Cost	Quality	Delivery Time	Environmental Performance	Social Responsibility
Supplier A	(0.112, 0.161, 0.195)	(0.118, 0.169, 0.195)	(0.090, 0.140, 0.180)	(0.100, 0.153, 0.189)	(0.108, 0.162, 0.200)
Supplier B	(0.088, 0.137, 0.176)	(0.103, 0.154, 0.185)	(0.120, 0.170, 0.195)	(0.111, 0.163, 0.200)	(0.076, 0.124, 0.168)
Supplier C	(0.137, 0.185, 0.200)	(0.113, 0.164, 0.200)	(0.115, 0.165, 0.200)	(0.089, 0.142, 0.184)	(0.086, 0.141, 0.195)
Supplier D	(0.088, 0.137, 0.180)	(0.097, 0.149, 0.190)	(0.080, 0.130, 0.175)	(0.105, 0.153, 0.195)	(0.097, 0.151, 0.189)
Supplier E	(0.059, 0.107, 0.156)	(0.082, 0.133, 0.169)	(0.075, 0.125, 0.165)	(0.116, 0.168, 0.200)	(0.086, 0.141, 0.189)

The first positive ideal solution (FPIS) and first negative ideal solution (FNIS) for the alternatives can be defined as follows:

$$A^* = \{\widetilde{v}_1^*, \widetilde{v}_2^*, \ldots, \widetilde{v}_n^*\} = \left\{ \left(\max_j v_{ij} | i \in B \right), \left(\min_j v_{ij} | i \in C \right) \right\} \tag{4}$$

$$A^- = \{\tilde{v}_1^-, \tilde{v}_2^-, \ldots, \tilde{v}_n^-\} = \left\{\left(\min_j v_{ij} | i \in B\right), \left(\max_j v_{ij} | i \in C\right)\right\} \quad (5)$$

where $\tilde{v}_i^*$ is the max value of i for all the alternatives and $\tilde{v}_1^-$ is the min value of i for all the alternatives. B and C represent the positive and negative ideal solutions, respectively.

Table 6 below showcases the positive and negative ideal solutions.

Table 6. The positive and negative ideal solutions.

	Positive Ideal	Negative Ideal
Cost	(0.137, 0.185, 0.200)	(0.059, 0.107, 0.156)
Quality	(0.118, 0.169, 0.200)	(0.082, 0.133, 0.169)
Delivery Time	(0.120, 0.170, 0.200)	(0.075, 0.125, 0.165)
Environmental Performance	(0.116, 0.168, 0.200)	(0.089, 0.142, 0.184)
Social Responsibility	(0.108, 0.162, 0.200)	(0.076, 0.124, 0.168)

The calculation of the distance between each alternative and the first positive ideal solution (FPIS) and the distance between each alternative and the first negative ideal solution (FNIS) is performed as follows:

$$S_i^* = \sum_{j=1}^n d\left(\tilde{v}_{ij}, \tilde{v}_j^*\right) \qquad i = 1, 2, \ldots, m \quad (6)$$

$$S_i^- = \sum_{j=1}^n d\left(\tilde{v}_{ij}, \tilde{v}_j^-\right) \qquad i = 1, 2, \ldots, m \quad (7)$$

where d is the distance between two fuzzy numbers. When given two triangular fuzzy numbers (a_1, b_1, c_1) and (a_2, b_2, c_2), the distance between the two can be calculated as follows:

$$d_v\left(\tilde{M}_1, \tilde{M}_2\right) = \sqrt{\frac{1}{3}\left[(a_1 - a_2)^2 + (b_1 - b_2)^2 + (c_1 - c_2)^2\right]} \quad (8)$$

Note that $d\left(\tilde{v}_{ij}, \tilde{v}_j^*\right)$ and $d\left(\tilde{v}_{ij}, \tilde{v}_j^-\right)$ are crisp numbers.

The distances from the positive and negative ideal solutions are presented in Table 7 below.

Table 7. Distance from positive and negative ideal solutions.

	Distance from Positive Ideal	Distance from Negative Ideal
Supplier A	0.064	0.141
Supplier B	0.099	0.105
Supplier C	0.05	0.157
Supplier D	0.117	0.088
Supplier E	0.164	0.04

The calculation of the closeness coefficient for each alternative is performed using the following formula:

$$CC_i = \frac{S_i^-}{S_i^+ + S_i^-} \quad (9)$$

Table 8 below displays the closeness coefficient of each alternative, along with their corresponding ranking order. It is important to note that the best alternative is the one that is closest to the first positive ideal solution (FPIS) and farthest from the first negative ideal solution (FNIS).

Table 8. Closeness coefficient.

	Ci	Rank
Supplier A	0.686	2
Supplier B	0.515	3
Supplier C	0.76	1
Supplier D	0.43	4
Supplier E	0.197	5

The graph below in Figure 4 illustrates the closeness coefficient of each alternative.

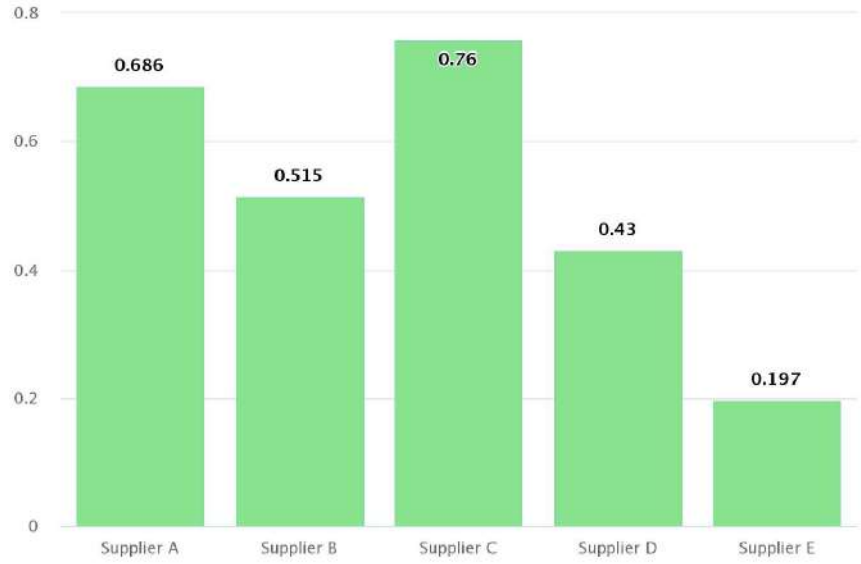

Figure 4. Sustainable supplier selection results in supply chain management.

Based on the evaluation criteria, Supplier C is identified as the top-ranked alternative. In addition to its competitive price, outstanding product quality, and dependable on-time delivery, Supplier C provides all three. The strong environmental sustainability practises that they have put in place show their dedication to waste reduction, carbon footprint reduction, and resource efficiency. Additionally, Supplier C actively engages in social responsibility programmes, demonstrating moral workplace policies, fair trade initiatives, and neighbourhood involvement projects. They are the best option for the choice of a sustainable supplier due to their high performance across all categories. Additionally, Supplier A exhibits competitive pricing and a proven track record of supplying high-quality goods. Although they have made considerable improvements in cost effectiveness and quality, their social responsibility initiatives and environmental sustainability measures might not be as extensive as those of Supplier C. Supplier A is still an excellent choice, especially for businesses that give more weight to cost effectiveness and quality but less to sustainability and social responsibility.

Cost effectiveness and a demonstrated commitment to putting environmental sustainability practises into practise are offered by Supplier B. However, Supplier B lags behind in terms of their delivery performance and quality control procedures, which may affect their suitability as a supplier in general for sustainability. Nevertheless, their initiatives to advance environmental sustainability and launch social responsibility programmes show promise, making them a potential option for businesses that prioritise sustainable practices and are prepared to collaborate with suppliers who are proactively raising their game. Supplier D has products of average cost and mediocre quality, as well as average delivery performance. Their efforts may not be as far along as those of higher-ranked alternatives, despite the fact that they are still in the early phases of putting environmental sustainability

measures into practice. Additionally, they have made few social responsibility efforts. Organizations looking for reasonable pricing and performance with the possibility for improvement in sustainability and social responsibility practises might find Supplier D to be a good fit. Supplier E offers a competitive price; however they fall short in terms of erratic product quality and protracted delivery timeframes. Additionally, their social responsibility initiatives are modest and their environmental sustainability practises are scant. For businesses that put a premium on quality, dependability, and sustainability when choosing their suppliers, Supplier E might be viewed as less appealing.

4.2. Comparative Analysis

The research paper's comparative evaluation contrasts the Fuzzy TOPSIS and the analytic hierarchy process (AHP) approaches in order to validate the study's findings. This comparison serves several functions, including determining the consistency, dependability, and robustness of the produced data. This study compares the ranks produced from these two independent evaluation procedures in order to detect any discrepancies or similarities. This assessment is critical because it demonstrates the sensitivity of the results to the chosen assessment method. Furthermore, the reliability and validity of the conclusions are increased by closely studying the discrepancies in the rankings and examining the underlying criteria as well as weighting the variables used in each approach. The comparison analysis sheds light on the environmental feasibility of the alternatives under consideration. It promotes a more thorough grasp of the research findings, improves decision making, and promotes an improved understanding of the analysed options. This research paper aims to improve the overall reliability of the findings by scrutinising the rankings and examining the fundamental criteria and weighting variables, which is critical for ensuring their practical applicability and significance in sustainable supplier selection within supply chain management. Table 9 below shows the comparative analysis findings in this study.

Table 9. Comparative analysis findings.

Rank Order	**1**	**2**	**3**	**4**	**5**
AHP	Supplier C	Supplier D	Supplier A	Supplier B	Supplier E
Fuzzy TOPSIS	Supplier C	Supplier A	Supplier B	Supplier D	Supplier E

The results of this investigation suggest some discrepancies in the order of supplier rankings depending on the supplied rankings from the comparative evaluation of the AHP and Fuzzy TOPSIS techniques. Supplier C is the top-ranked supplier in the AHP technique, followed by Supplier D, Supplier A, Supplier B, and Supplier E, in that order. The Fuzzy TOPSIS technique, on the other hand, rates Supplier C as the top supplier as well, but it places Supplier A second, followed by Supplier B, Supplier D, and Supplier E. The comparison analysis reveals that the ranks produced by the two approaches are not totally consistent. While both approaches agree that Supplier C is the top-ranked supplier, the rankings of the other suppliers differ. Supplier A and Supplier B, in particular, take opposing stances in the two different strategies. This disparity in ranks highlights the sensitivity of findings to the evaluation approach used. It implies that the methodology chosen can have a major impact on the supplier selection decision. To make educated and trustworthy conclusions, decision makers must carefully analyse the approach utilised and comprehend the underlying criteria and weighting elements. This research study improves the credibility and validity of its conclusions by completing this comparison analysis. It emphasises the significance of assessing and comprehending various assessment approaches, their ramifications, and the impact they might have on supplier selection decisions in supply chain management.

5. Discussion

Incorporating administrative observation into sustainable supplier selection has various advantages. For instance, it supplements quantitative evaluations by offering subjective observations and qualitative data on suppliers' sustainability performance. This provides decision makers with a more comprehensive insight of a supplier's practises than simply numerical indicators. Additionally, administrative observation improves decision making by providing significant insights that quantitative evaluations alone may not uncover. Subjective judgements and direct observations help to clarify a supplier's commitment to sustainability, social responsibility, and ethical practices. This extra information enables decision makers to make better-educated supplier selections that match with the organization's sustainability objectives and values. Incorporating administrative observation also helps to mitigate the limits of quantitative evaluations. Quantitative measurements may not capture the entire scope of a supplier's sustainable practices, or they may neglect intangible variables that are critical in evaluating sustainability performance. Administrative observation closes these discrepancies by providing context, indicating potential hazards or opportunities for improvement, and providing a comprehensive picture of a supplier's overall sustainability profile. Organisations can mitigate the risks linked to insufficient quantitative assessments by utilizing managerial observation. It enables them to find suppliers who not only match the quantitative standards but also display a true commitment to environmental preservation and sustainability.

The results of this study shed a spotlight on how crucial it is to incorporate management observation into the process of choosing sustainable suppliers within the framework of supply chain management. The incorporation of observation enables a thorough evaluation of suppliers' performance that goes beyond conventional quantitative metrics and takes into account elements like social responsibility and environmental sustainability. Any further debate will centre on the most important ramifications of this study's findings and how important it is to encourage supply chains to use sustainable practises.

The established criteria first offer a comprehensive framework for assessing prospective suppliers' costs, quality, delivery times, environmental performance, and social responsibility. These requirements are in line with the fundamentals of sustainable supply chain management, which take economic, environmental, and social concerns into account. The inclusion of social accountability as well as environmental performance criteria illustrates the growing importance of sustainability in modern supply chains and confirms the premise that businesses should consider suppliers' whole environmental and societal impacts. Based on the given criteria, the ranked alternatives provide information about the relative performance of the suppliers. When it comes to reasonable pricing, outstanding product quality, on-time delivery, strong environmental sustainability measures, and active involvement in social responsibility programmes, Supplier C stands out as the best option. Despite operating well, Supplier A does not have the same level of social responsibility and environmental sustainability measures as Supplier C. These findings highlight the necessity for organisations to prioritise suppliers with excellent sustainability practises and ethical standards in addition to traditional performance indicators.

Despite being cost-effective and dedicated to environmental sustainability, Supplier B falls short when it comes to quality control procedures and delivery performance. However, their initiatives to advance sustainability and social responsibility show a promising trajectory, indicating room for development and the possibility of future cooperation. With average pricing and performance, Supplier D has few social responsibility programmes and is just starting to develop sustainability measures. They are a decent option for organisations looking for a compromise between cost effectiveness and sustainability. Supplier E, on the other hand, offers inexpensive prices but displays variable product quality, delayed deliveries, and few socially responsible or sustainable practises. This emphasises the dangers that could arise from suppliers who are only concerned with cutting costs because they might forego standards of quality, dependability, and ethics. The long-term effects on an organization's reputation and sustainability objectives should be carefully considered

by organisations looking for sustainable supply chains. These results highlight the significance of including sustainability factors in supplier selection procedures. By considering environmental as well as social factors in addition to traditional issues, businesses can make well-informed decisions which promote their objectives for sustainability and build sustainable supply chains. This report stresses the importance of businesses prioritising suppliers who have a demonstrated track record of delivering high-quality items on time and with excellent environmental performance.

6. Conclusions

This study looked into how to use management observation in the setting of supply chain management to choose sustainable suppliers. Organizations can make decisions that are in line with their sustainability goals by factoring in factors including cost, quality, delivery time, environmental performance, and social responsibility. This study shows how important it is to take into account suppliers' entire social and environmental impacts in addition to traditional performance indicators. A thorough framework for assessing and rating alternatives according to the specified criteria has been supplied by our research. With their low pricing, outstanding product quality, on-time delivery, strong environmental sustainability measures, and enthusiastic involvement in social responsibility programmes, Supplier C won the top spot among the alternatives. This underlines how crucial it is to choose vendors who uphold high moral and ethical standards. Suppliers A, B, D, and E all showed different levels of performance and sustainability initiatives, allowing organizations to choose wisely depending on their unique priorities.

It is crucial to recognize the limits of this study, though. First of all, the hypothetical weights given to the criteria may change depending on the various sectors, organizations, and sustainability objectives. Our theoretical-framework-supported results would be bolstered by empirical validations employing actual case studies or data analyses. Furthermore, while our research focuses on a specific set of criteria, there may be other relevant variables that must be taken into consideration when selecting suppliers. Future research should examine the incorporation of new criteria and the validation of the suggested framework in various business environments. Future studies in this area should investigate how to implement administrative observation in supplier selection procedures and the practical issues that come with that. It would be beneficial to look at the specific processes and equipment for gathering and processing information on environmental performance and social responsibility. Additionally, it would be beneficial to undertake longitudinal studies to evaluate the long-term effects of supplier selection choices on supply chain sustainability and performance. Furthermore, given the ongoing evolution of sustainability practises and stakeholder expectations, future research must focus on integrating flexible and adaptable supplier selection methods. This would entail creating frameworks that can adapt to changes in societal needs, environmental regulations, and technological breakthroughs. Investigating how supply chain stakeholders might work together and share ideas to promote sustainable supplier selection would also add to the body of knowledge in this field.

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