ISSN: 1648-6897 / eISSN: 1822-4199

JOURNAL of ENVIRONMENTAL ENGINEERING & LANDSCAPE MANAGEMENT

2025
Volume 33
Issue 4
Pages 415–427
https://doi.org/10.3846/jeelm.2025.25194

A HYBRID FUZZY AHP-TOPSIS APPROACH FOR GREEN SUPPLIER SELECTION: A CASE STUDY IN SRI LANKA

Sulaksha WIMALASENA✉, Zenonas TURSKIS, Jūratė ŠLIOGERIENĖ

Institute of Sustainable Construction, Vilnius Gediminas Technical University, Vilnius, Lithuania

Highlights:

- a hybrid Fuzzy AHP-TOPSIS framework enhances green supplier selection accuracy;
- environmental compliance is identified as the most critical selection criterion;
- case study in Sri Lanka validates the model's applicability in the construction sector;
- Supplier A ranked highest, excelling in sustainability and technological competence;
- the proposed method supports data-driven, systematic green procurement decisions.

Article History:

- received 4 March 2025
- accepted 2 June 2025

Abstract. Green supplier selection is an important component of sustainable supply chain management, particularly in emerging markets where environmental rules and institutional support may be inadequate. This study addresses the need for a structured, sustainability-focused decision-making strategy by presenting a novel hybrid framework that merges the Fuzzy Analytic Hierarchy Process (Fuzzy AHP) with the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). The suggested methodology enables systematic evaluation of suppliers by including both subjective expert judgment and objective performance data under conditions of uncertainty. A case study conducted inside the Sri Lankan construction sector demonstrates the practical applicability of the concept. Suppliers were evaluated on four important criteria: environmental, economic, social, and technological. The data reveal that Supplier A is the most suited choice, excelling mainly in environmental and social dimensions. Environmental compliance emerged as the most relevant element in the selection process. By merging fuzzy language assessments with quantitative analysis, the hybrid Fuzzy AHP–TOPSIS method promotes the accuracy, transparency, and consistency of supplier evaluation. The results give valuable insights for industry practitioners, procurement managers, and legislators aiming to connect purchasing choices with long-term sustainability goals. Additionally, the framework gives an accurate platform for future research and application in similar scenarios, helping the growth of green purchasing practices in developing nations.

Keywords: green supplier selection, multi-criteria decision making, fuzzy AHP, TOPSIS, green procurement, construction industry.

✉Corresponding author. E-mail: *dcvsw39@gmail.com*

1. Introduction

Green supplier selection has become a critical part of supply chain management as firms increasingly attempt to incorporate environmental, economic, and social issues into their procurement procedures. The heightened emphasis on sustainability has pushed organizations to use multi-criteria decision-making (MCDM) procedures that systematically analyze and rank suppliers based on a combination of qualitative and quantitative considerations (Aal, 2024). The major issue that many enterprises face during the process is the conflict between affordability and sustainability they need to choose during procurement to ensure sustainability in their supply chain. Traditional supplier selection strategies, which largely stressed cost and quality, have proved ineffective in tackling the intricacies of current supply chain sustainability concerns. Consequently, decision-makers are resorting to sophisticated analytical frameworks to verify that their suppliers fit with sustainability goals while retaining operational efficiency (Parvaneh & Hammad, 2024). Among these, hybrid methods such as the Fuzzy Analytical Hierarchy Process (Fuzzy AHP) paired with the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) have demonstrated tremendous potential in optimizing procurement choices.

The move toward sustainable procurement has been heavily affected by growing environmental concerns, severe regulatory rules, and corporate social responsibility programs. Governments and international organizations have introduced sustainability frameworks, such as the Leadership in Energy and Environmental Design (LEED) and the Building Research Establishment Environmental

Assessment Method (BREEAM), to encourage industries to adopt greener practices (Alimova & Perkova, 2023). Despite the availability of these criteria, adopting sustainability in supplier selection remains a substantial problem, particularly in emerging countries like Sri Lanka. Challenges such as insufficient regulatory enforcement, high costs associated with implementing green practices, and opposition from suppliers owing to financial limitations or lack of understanding have prevented the mainstream implementation of sustainability-focused procurement methods (Ashoka et al., 2023). Therefore, companies demand an efficient decision-making strategy that analyzes suppliers based not just on conventional economic variables but also integrates sustainability criteria in an organized and objective way.

The Analytical Hierarchy Process (AHP) has been extensively utilized in supplier assessment owing to its structured decision-making method, which allows for prioritizing based on pairwise comparisons. AHP decomposes complicated decision-making situations into a hierarchy, where criteria and sub-criteria are methodically reviewed to establish their relative relevance (Stofkova et al., 2022). However, a significant limitation of the traditional AHP model is its reliance on precise numerical values, which may not fully capture the uncertainty and subjectivity inherent in human judgment, especially when dealing with qualitative factors such as environmental impact or ethical business practices (Agarwal et al., 2023). To solve this constraint, the Fuzzy AHP technique has been created, combining fuzzy logic to enable decision-makers to express their preferences using language phrases rather than set numerical values. This innovation is especially important in green supplier selection, where subjective judgments typically impact evaluations of sustainability performance.

While AHP and its fuzzy extension aid in evaluating the relative relevance of multiple supplier assessment criteria, they do not offer a ranking system for picking the best suited provider. To solve this, the TOPSIS technique is applied, which evaluates alternatives by calculating their relative proximity to an ideal positive answer while concurrently analyzing their distance from an anti-ideal negative solution (Chen et al., 2023). The strength of TOPSIS rests in its capacity to offer a clear rating of providers, making it a helpful tool for decision-makers who need to pick the most sustainable and cost-effective choice. By merging Fuzzy AHP with TOPSIS, companies may benefit from a hybrid model that combines the systematic weighing of criteria with a strong ranking mechanism, eventually leading to better informed supplier selection choices (Wang et al., 2023).

The Hybrid Fuzzy AHP-TOPSIS model has been successfully utilized in many sectors to boost decision accuracy and efficiency in supplier selection. In the construction sector, where sustainability is becoming a key focus, this method enables companies to assess suppliers based on a balanced set of criteria, including environmental regulations, cost competitiveness, quality assurance, and technological innovation (Sequeira et al., 2022). Pourjavad and Shahin (2018) illustrated the integration of fuzzy inference and fuzzy DEMATEL for assessing sustainability performance in supply chains, hence underscoring the efficacy of fuzzy hybrid models in intricate decision-making contexts. Shahin et al. (2019) similarly discovered significant barriers to the implementation of green supply chain management with fuzzy TOPSIS-DEMATEL, hence reinforcing the necessity for methodical, multi-criteria methodologies in sustainability assessment.

Studies have indicated that MCDM models incorporating fuzzy logic with multi-criteria assessment approaches are especially successful in addressing the uncertainties and complexity of supply chain decision-making. In nations like Sri Lanka, where green practices are still not extensively adopted, the absence of institutional sustainability frameworks and uneven assessment techniques have contributed to difficulty in identifying dependable suppliers that comply to sustainability norms (Wimalarathna et al., 2023). Pourjavad and Shahin (2020a) emphasize the advantages of hybrid fuzzy models in mitigating green supply chain risks, whereas Pourjavad and Shahin (2020b) establish a robust framework for the selection of green supplier development programs utilizing Fuzzy AHP-TOPSIS-DEMATEL. Shahin et al. (2020) further underscore the significance of structured decision frameworks in prioritizing eco-innovation, hence reinforcing the pertinence of our integrated approach.

Despite its potential, there remains minimal implementation of this hybrid model in emerging economies, and few research give context-specific validations. Moreover, many extant research lack transparency in identifying their methodological contributions from past efforts. To overcome these deficiencies, this study suggests a unique hybrid Fuzzy AHP–TOPSIS model suited for green supplier selection in Sri Lanka's construction industry. The study contributes in three important ways:

1. It utilizes the hybrid concept in a developing nation environment, proving practical application where regulatory infrastructure is poor.
2. It clearly specifies the original contribution by refining the integration process and directly connecting sustainability criteria with localized industry demands.
3. It builds on prior hybrid approaches by comparing performance with recent models such as the q-Rung Orthopair Fuzzy TOPSIS by Pınar et al. (2021) and the interval-valued Pythagorean fuzzy AHP–COPRAS method by Erdebilli et al. (2023), thereby positioning this work within the current scholarly dialogue.

The rising emphasis on sustainability in supplier selection underlines the need for systematic, data-driven decision-making techniques that can assess vendors based on numerous factors. This research intends to examine the Hybrid Fuzzy AHP-TOPSIS model as a technique to optimize purchase choices while guaranteeing sustainability compliance. By harnessing the qualities of both techniques, companies may systematically assess suppliers in a manner that corresponds with long-term sustainability goals while retaining cost-effectiveness and operational efficiency (Khulud et al., 2023). The study contributes to the growing body of knowledge on multi-criteria decision-making frameworks, particularly in the context of emerging economies, where sustainability remains a challenge due to weak regulatory frameworks and a lack of standardized supplier evaluation processes (Oubrahim & Sefiani, 2024). By applying the Hybrid Fuzzy AHP-TOPSIS strategy, organizations may make more informed supplier selection choices, decrease environmental effects, and contribute to a greener and more sustainable supply chain.

In addition to the results, subsequent research has further proven the usefulness of hybrid MCDM techniques in green supplier selection. For instance, research by Safavi et al. (2025) proposed a three-stage strategy incorporating fuzzy AHP and fuzzy TOPSIS for green supplier selection and order allocation, showing the model's usefulness in real-world settings. Similarly, study by Ramadhanti and Pulansari (2022) proposed a new framework integrating AHP and TOPSIS inside a fuzzy environment, highlighting the need of flexibility and good communication in supplier assessment. These studies, among others, underline the usefulness and applicability of hybrid MCDM models in tackling the challenges of green supplier selection across multiple sectors.

2. Materials and methods

This section discusses the methodology employed for analyzing green supplier selection using the Fuzzy AHP-TOPSIS hybrid approach. The research blends qualitative and quantitative assessments to offer a full review of supplier performance across multiple variables. The approach comprises two basic phases: criterion weight determination using Fuzzy AHP and supplier ranking using TOPSIS. Scholars the most widely use the AHP and TOPSIS methods to solve multi-criteria decision-making problems (Zavadskas et al., 2016). These methodologies allow decision-makers to use both subjective expert judgments and objective data-driven analysis to increase the accuracy and dependability of supplier selection.

Data gathering was accomplished using a mix of expert interviews and secondary data analysis. A systematic questionnaire was constructed to elicit expert views on pairwise comparisons of criteria and sub-criteria, which were then processed using Fuzzy AHP to evaluate the relative relevance of each element. The supplier performance data were acquired through company sustainability reports, supplier assessments, and industry standards, guaranteeing a solid and trustworthy dataset for the TOPSIS ranking process. By integrating expert insights with actual performance data, the research guarantees a balanced and impartial approach to green supplier assessment.

2.1. Hierarchical structure of Fuzzy AHP and TOPSIS analysis

The research applies the Analytical Hierarchy Process (AHP) paradigm to systematically examine and prioritize aspects impacting green supplier selection. The Analytic Hierarchy Process (AHP), introduced by Saaty (1977), is recognised as a modern tool for dealing with complex decision-making that may help the decision-maker to set priorities to make the best decision. AHP, a widely used Multi-Criteria Decision-Making (MCDM) approach, allows decision-makers to break down complicated issues into hierarchical components, allowing for pairwise comparisons and ranking based on overall performance. The approach starts with developing a decision tree, putting the primary aim of green supplier selection at the top, followed by dimensions and sub-dimensions that specify essential assessment criteria. These dimensions identify key variables, whereas sub-dimensions and influencing components handle particular issues. For this research, the hierarchical structure contains the fundamental purpose of choosing a green supplier, significant aspects essential to green supplier evaluation, and influencing components beneath each dimension. Table 1 gives a full description of the evaluation criteria and contributing elements in the context of green supplier selection.

To develop a structural hierarchy for complicated decision-making, the decision is broken down into a tiered

Table 1. Influencing dimensions and factors for best green supplier selection

Goal	Main criteria		Sub criteria	Description
Selection of factors for the best green supplier selection	Environmental (EN)	EN1	Compliance with Environmental Regulations	Supplier adheres to national and international environmental laws and standards
		EN2	Use of Eco-Friendly Materials	Use of recyclable, biodegradable, or non-toxic materials in the production process
		EN3	Waste Management Practices	Proper handling, recycling, and disposal of waste materials during production and delivery
		EN4	Energy Efficiency	Adoption of energy-efficient practices and technologies to reduce environmental impact
		EN5	Carbon Footprint Reduction	Implementation of practices aimed at reducing greenhouse gas emissions

End of Table 1

Goal	Main criteria		Sub criteria	Description
	Economical (EC)	EC1	Cost Competitiveness	Competitive pricing of products or services compared to other suppliers
		EC2	Delivery Performance	Suitability and reliability in delivering goods or services
		EC3	Financial Stability	Financial health of the supplier, ensuring consistent and long-term performance
		EC4	Quality Assurance	Supplier provides high-quality materials and adheres to industry quality standards
	Social (S)	S1	Labor Practices	Compliance with labor laws, provision of fair wages, and maintaining safe working conditions
		S2	Community Engagement	Contribution to local communities through social responsibility initiatives
		S3	Ethical Business Practices	Commitment to transparency, honesty, and adherence to anti-corruption standards
		S4	Stakeholder Satisfaction	Positive feedback and relationships with stakeholders, including contractors and other partners in the supply chain
	Technological (T)	T1	Technological Capability	Use of advanced technologies to enhance efficiency and sustainability
		T2	Innovation in Green Practices	Introduction of innovative methods or products that contribute to environmental sustainability
		T3	Maintenance and Support	Availability of after-sales support and assistance for products or services provided
		T4	Infrastructure and Resources	Adequate infrastructure and resources to meet supply demands while maintaining environmental standards

structure, beginning with the overall goal or objective at the top level. Beneath this top level, numerous key criteria are defined, followed by sub-criteria and other layers, falling to the most comprehensive and precise parts at the bottom. The summit of the hierarchy indicates the ultimate objective of the decision-making process. For instance, in the context of picking the most appropriate green supplier, the hierarchy (see Figure 1) starts with the key goal – choosing the best green supplier – at the top. Below this, major decision considerations such as economic, environmental, social and technological performance evaluation comprise the primary criterion at the next level. Further down, these criteria are backed by intermediate sub-criteria, which add to the decision-making process. This organized method guarantees that every element impacting the choice is thoroughly evaluated.

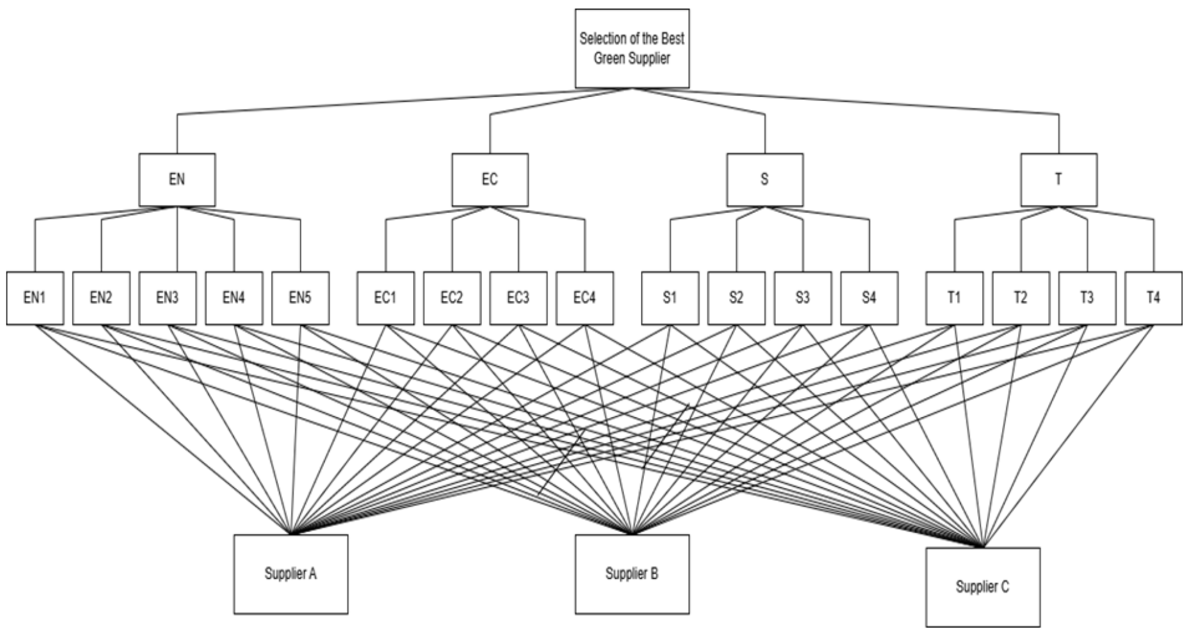

Figure 1. AHP hierarchical structure for decision-making factors influencing best green supplier selection (source: developed by the authors)

2.2. Using the fuzzy AHP technique to determine the criterion weights

Van Laarhoven and Pedrycz (1983). extended hierarchical analysis to the case where the participants can employ fuzzy ratios instead of exact ratios.

If $\tilde{A}_1 = (l_1, m_1, u_1)$ and $\tilde{A}_2 = (l_2, m_2, u_2)$ represent two fuzzy triangular numbers (TFN), then algebraic operations can be expressed as follows:

$$\tilde{A}_1 + \tilde{A}_2 = (l_1, m_1, u_1) + (l_2, m_2, u_2) = (l_1 + l_2, m_1 + m_2, u_1 + u_2); \quad (1)$$

$$\tilde{A}_1 - \tilde{A}_2 = (l_1, m_1, u_1) - (l_2, m_2, u_2) = (l_1 - l_2, m_1 - m_2, u_1 - u_2); \quad (2)$$

$$\tilde{A}_1 \text{ x } \tilde{A}_2 = (l_1, m_1, u_1) \text{ x } (l_2, m_2, u_2) = (l_1 l_2, m_1 m_2, u_1 u_2); \quad (3)$$

$$\tilde{A}_1 \text{ x } \tilde{A}_2 = \frac{(l_1, m_1, u_1)}{(l_2, m_2, u_2)} = \left(\frac{l_1}{l_2}, \frac{m_1}{m_2}, \frac{u_1}{u_2}\right); \quad (4)$$

$$\tilde{A}_1^{-1} = (l_1, m_1, u_1) = \left(\frac{1}{u_1}, \frac{1}{m_1}, \frac{1}{l_1}\right). \quad (5)$$

Accurate pairwise comparisons are essential to traditional AHP. On the other hand, expert opinions are often vague and unclear. We use TFNs to encode linguistic judgments in order to address this (Chang, 1992).

$$M_{gi}^1, M_{gi}^2, M_{gi}^3, \ldots, M_{gi}^n \quad i = (1, 2, 3, 4, \ldots n), \quad (6)$$

where all $M_{gi}^i \left(j = 1, 2, 3, 4, \ldots, n \right)$ are triangular fuzzy numbers which are shown in Table 2.

Table 2. TFN of linguistic comparison matrix

Linguistic variable	Assigned TFN
Equal importance	(1, 1, 1)
Slightly more importance	(1, 2, 3)
Moderately more importance	(2, 3, 4)
Strongly more importance	(3, 5, 7)
Very strongly importance	(5, 7, 9)

With this, we construct the pairwise comparison matrix for the selected criteria as:

$$\tilde{A} = \begin{bmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ \tilde{a}_{21} & 1 & & \tilde{a}_{2n} \\ \vdots & & \ddots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \cdots & 1 \end{bmatrix}. \quad (7)$$

The fuzzy synthetic extents (S_i) value in regard to i^{th} criterion is then determined using Chang's (1992) extent analysis approach as:

$$S_i = \sum_{j=1}^{m} M_{gi}^j \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^j \right]^{-1};$$

$$\sum_{j=1}^{m} M_{gi}^j = \left(\sum_{j=1}^{m} l_{ij}, \sum_{j=1}^{m} m_{ij}, \sum_{j=1}^{m} u_{ij} \right);$$

$$\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^j \right]^{-1} = \left(\frac{1}{\sum_n^{i=1} \sum_m^{i=1} u_{ij}}, \frac{1}{\sum_n^{i=1} \sum_m^{i=1} m_{ij}}, \frac{1}{\sum_n^{i=1} \sum_m^{i=1} l_{ij}} \right). \quad (8)$$

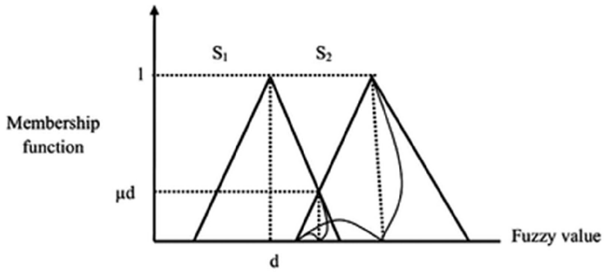

Figure 2. The intersection of fuzzy numbers (Iqbal et al., 2021)

In this case, m is the significant number, u is the upper limit value, and i is the lower limit value. Then the degree of possibility of $S_2 = (l_2, m_2, u_2) \geq (l_1, m_1, u_1)$ can be defined as:

$$\left[V(S_2 \geq S_1 \right] = \sup_{y \geq x} \left[\min\left(\mu_{s1}(x), \mu_{s2}(y) \right) \right]. \quad (9)$$

As seen in Eq. (10) where x and y interpret the value in each axis of the membership function of each criterion:

$$V(S_2 \geq S_1) = \begin{cases} 1 \\ 0 \\ \dfrac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} \end{cases}$$

if $m_2 > m_1$; *if* $l_1 \geq l_2$; *otherwise.* (10)

Figure 2 shows the intersection of fuzzy numbers graphically (where μ_d is the highest point where μ_{s1} and μ_{s2} cross).

To compare S_1 and S_2 both $V(S_2 \geq S_1)$ and $V(S_1 \geq S_2)$ are required. Then the degree of possibility for a convex fuzzy number S to be greater than k convex fuzzy number $S_i = (i = 1, 2, 3, 4,\ldots, k)$ can be defined as:

$$V(S \geq S_1, S_2, \ldots, S_k) = V\left[(S \geq S_1), (S \geq S_2), \ldots\ldots, (S \geq S_k) \right] = \min V(S \geq S_i), \quad i = 1, 2, 3, \ldots, k.$$

Assume that $d'(A_i) = \min V(S_i \geq S_k)$.

For $k = 1, 2, 3,\ldots, n$ $k \neq i$, the weight vectors are given in Eq. (11), and the normalized weight vector is given in Eq. (12):

$$W' = \left(d'\left(A_1\right), d'\left(A_2\right), \ldots\ldots, d'\left(A_n\right)\right)^T; \tag{11}$$

$$W = d\left(A_1\right), d\left(A_2\right), \ldots\ldots, d\left(A_n\right)^T. \tag{12}$$

2.3. Ranking alternatives by TOPSIS

The TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) (Hwang & Yoon, 1981) technique ranks alternatives based on how similar they are to an ideal answer. The ideal solution reflects greatest advantages and least costs, whereas the negative ideal solution increases expenses and decreases benefits. The optimal alternative is the one closest to the ideal solution and furthest from the negative ideal, assessed using Euclidean distance. This approach permits trade-offs between criteria, making it suited for multi-criteria decision-making (MCDM) situations. The decision matrix employed in TOPSIS consists of m choices and n criteria, providing an organized evaluation of possibilities.

$$X = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix}_{m \times n}. \tag{13}$$

This section's equations all use $j = 1, \ldots, n$, and $i = 1, \ldots, m$. The following equation (Equation (14)) must be satisfied by the vector for criterion weights, which may alternatively be included in the question as $W = (w_1, \ldots, w_n)$:

$$\sum_{j=1}^{n} w_j = 1. \tag{14}$$

The following six major phases outline the process of selecting the optimal option using the TOPSIS technique:

Step 1: Normalizing the decision matrix

Each MCDM issue has a variety of criteria with various units. The normalizing procedure makes it feasible for those criteria to be dimensionless, or unit-free, for comparison. This may be accomplished in a number of ways. A typical approach is provided here, but Shih et al. (2006) mentioned other linear and non-linear normalizing techniques. For instance, the vector normalization technique's normalized values for each x_i in the decision matrix are shown as follows:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}. \tag{15}$$

Step 2: Calculating the weighted normalized matrix

The weighted normalized decision matrix (V) can be calculated as:

$$V = \left(v_{ij}\right)_{n \times m}, \tag{16}$$

where $v_{ij} = w_j\, r_{ij}$.

Step 3: Determining the positive ideal and negative ideal solutions

This stage calculates the negative ideal solution, also referred to as the Nadir or anti-ideal (A^-) solutions, and the positive ideal solution, also known as Zenith (A^*).

$$A^* = \left\{v_1^*, v_2^*, \ldots\ldots v_n^*\right\} \text{maximum values}, \tag{17}$$

where $v_i^* = \left\{\max\left(v_{ij}\right)\right\}$ *if* $j \in J$; $\min\left(v_{ij}\right)$ *if* $j \in J^-$.

$$A^* = \left\{v_1^*, v_2^*, \ldots\ldots v_n^*\right\} \text{ minimum values}, \tag{18}$$

where $v^- = \left\{\min\left(v_{ij}\right)\right\}$ *if* $j \in J$; $\max\left(v_{ij}\right)$ *if* $j \in J^-$.

Step 4: Calculate the separation measures of each alternative from PIS and NIS

This step involves calculating the distance between the alternatives with A^* and A^- after identifying the positive and negative solutions.

$$D_i^* = \sqrt{\sum_{j=1}^{n}\left(v_{ij} - v_j^*\right)^2}; \tag{19}$$

$$D_i^- = \sqrt{\sum_{j=1}^{n}\left(v_{ij} - v_j^-\right)^2}. \tag{20}$$

Step 5: Calculating relative closeness

The following formula is used to determine the relative closeness factor, which has a range of 0 to 1:

$$C_i^* = \frac{D_i^*}{D_i^* + D_i^-}. \tag{21}$$

Step 6: Ranking the alternatives

The closeness coefficient's diminishing values are used to rank the choices from best to worst. The option with the highest closeness coefficient (C_i^*) is chosen.

3. Results

A case study was undertaken to show the implementation of the Fuzzy Analytical Hierarchy Process (FAHP) in the supplier selection process. The research concentrated on a Sri Lankan multinational firm situated in Colombo, Sri Lanka. For this research, three local vendors – designated as Supplier A, Supplier B, and Supplier C – were selected from the organization list of authorized suppliers. These vendors were prequalified based on their capacity to deliver different components needed by the firm. The major purpose of the research was to determine the best acceptable supplier among the three, highlighting their commitment to green manufacturing standards. This emphasis on environmentally friendly methods coincided with the organization commitment to sustainability and offered a framework for assessing supplier performance beyond typical procurement criteria.

A case study was performed to illustrate the use of the Hybrid Fuzzy AHP-TOPSIS approach in the supplier selection process. The study focused on a Sri Lankan multinational corporation situated in Colombo, Sri Lanka, analyzing three prequalified local vendors – Supplier A, Supplier

Table 3. Summary table of characterizations

Supplier	Strengths	Weaknesses	Ideal for
Supplier A	Balanced performer; excels in Environmental and Social aspects; strong technical base	Slightly weaker in Economic efficiency	Organizations valuing sustainability, social responsibility, and reliability
Supplier B	Cost-efficient with strong Economic performance and decent social engagement	Weaker in Environmental and Technical areas	Budget-conscious projects prioritizing cost and reliability over sustainability
Supplier C	Technically innovative with moderate Environmental focus	Higher costs and weaker social engagement	Projects requiring technical expertise and moderate sustainability

B, and Supplier C – selected from the organization's list of approved suppliers. The suppliers were evaluated on their capacity to provide crucial components in accordance with the company's dedication to sustainable manufacturing standards. The research sought to find the most appropriate supplier by prioritizing sustainability in conjunction with conventional procurement criteria, therefore offering a systematic method for assessing supplier performance beyond just cost and efficiency.

To do this, industry specialists evaluated the three providers (refer to Table 3) via a systematic Hybrid Fuzzy AHP-TOPSIS study. Each supplier displayed varied strengths and limits, making them ideal for diverse organizational requirements. Supplier A emerged as a well-rounded performer, excelling in environmental compliance, social responsibility, and technical skills. Conversely, Supplier B had robust economic performance and cost efficiency, although fell short in sustainability and innovation. Supplier C distinguished itself by its technical proficiency and modest environmental commitment, although lacked competition in pricing and social responsibility. This expert review offered a strategic framework, allowing decision-makers to match supplier selection with the organization's overarching business and sustainability objectives.

In summary, the classification of these providers, founded in expert contributions, indicates the greatest match for specific business aims. Supplier A is appropriate for individuals emphasizing sustainability and well-rounded performance. Supplier B is advised for cost-conscious projects, whereas Supplier C is better suited for efforts needing significant technical competence.

3.1. Application of Fuzzy AHP

The fuzzy AHP (Laarhoven & Pedrych, 1983) methodology was employed to determine the weights of both the main criteria and sub-criteria based on expert inputs. A total of 17 experts assessed the primary criteria and sub-criteria using the Triangular Fuzzy Numbers (TFN) outlined in Table 2. The fuzzy pairwise comparisons and the corresponding weights for the primary criteria and sub-criteria are presented in Tables 4 to 8.

Table 4. Pairwise comparison and weight of main criteria

Criteria	EN	EC	S	T	Weight
EN	(1, 1, 1)	(2, 3, 4)	(4, 5, 6)	(6, 7, 8)	(0.321, 0.333, 0.345)
EC	(1/4, 1/3, 1/2)	(1, 1, 1)	(2, 3, 4)	(4, 5, 6)	(0.225, 0.23, 0.238)
S	(1/6, 1/5, 1/4)	(1/4, 1/3, 1/2)	(1, 1, 1)	(2, 3, 4)	(0.168, 0.172, 0.176)
T	(1/8, 1/7, 1/6)	(1/6, 1/5, 1/4)	(1/4, 1/3, 1/2)	(1, 1, 1)	(0.093, 0.095, 0.098)

Table 5. Pairwise comparison and weight of environmental criteria

Sub-criteria	EN1	EN2	EN3	EN4	EN5	Weight
EN1	(1, 1, 1)	(2, 3, 4)	(4, 5, 6)	(6, 7, 8)	(8, 9, 10)	(0.35, 0.36, 0.37)
EN2	(1/4, 1/3, 1/2)	(1, 1, 1)	(2, 3, 4)	(4, 5, 6)	(6, 7, 8)	(0.21, 0.22, 0.23)
EN3	(1/6, 1/5, 1/4)	(1/4, 1/3, 1/2)	(1, 1, 1)	(2, 3, 4)	(4, 5, 6)	(0.14, 0.15, 0.16)
EN4	(1/8, 1/7, 1/6)	(1/6, 1/5, 1/4)	(1/4, 1/3, 1/2)	(1, 1, 1)	(2, 3, 4)	(0.1, 0.11, 0.12)
EN5	(1/10, 1/9, 1/8)	(1/8, 1/7, 1/6)	(1/6, 1/5, 1/4)	(1/4, 1/3, 1/2)	(1, 1, 1)	(0.07, 0.08, 0.09)

Table 6. Pairwise comparison and weight of economical criteria

Sub-criteria	EC1	EC2	EC3	EC4	Weight
EC1	(1, 1, 1)	(2, 3, 4)	(4, 5, 6)	(6, 7, 8)	(0.39, 0.4, 0.41)
EC2	(1/4, 1/3, 1/2)	(1, 1, 1)	(2, 3, 4)	(4, 5, 6)	(0.26, 0.27, 0.28)
EC3	(1/6, 1/5, 1/4)	(1/4, 1/3, 1/2)	(1, 1, 1)	(2, 3, 4)	(0.18, 0.19, 0.2)
EC4	(1/8, 1/7, 1/6)	(1/6, 1/5, 1/4)	(1/4, 1/3, 1/2)	(1, 1, 1)	(0.12, 0.13, 0.14)

Table 7. Pairwise comparison and weight of social criteria

Sub-criteria	S1	S2	S3	S4	Weight
S1	(1, 1, 1)	(2, 3, 4)	(4, 5, 6)	(6, 7, 8)	(0.4, 0.41, 0.42)
S2	(1/4, 1/3, 1/2)	(1, 1, 1)	(2, 3, 4)	(4, 5, 6)	(0.25, 0.26, 0.27)
S3	(1/6, 1/5, 1/4)	(1/4, 1/3, 1/2)	(1, 1, 1)	(2, 3, 4)	(0.2, 0.21, 0.22)
S4	(1/8, 1/7, 1/6)	(1/6, 1/5, 1/4)	(1/4, 1/3, 1/2)	(1, 1, 1)	(0.15, 0.16, 0.17)

Table 8. Pairwise comparison and weight of technological criteria

Sub-criteria	T1	T2	T3	T4	Weight
T1	(1, 1, 1)	(2, 3, 4)	(4, 5, 6)	(6, 7, 8)	(0.605, 0.601, 0.591)
T2	(1/4, 1/3, 1/2)	(1, 1, 1)	(2, 3, 4)	(4, 5, 6)	(0.249, 0.253, 0.259)
T3	(1/6, 1/5, 1/4)	(1/4, 1/3, 1/2)	(1, 1, 1)	(2, 3, 4)	(0.102, 0.103, 0.107)
T4	(1/8, 1/7, 1/6)	(1/6, 1/5, 1/4)	(1/4, 1/3, 1/2)	(1, 1, 1)	(0.045, 0.043, 0.044)

The consistency check (CI and CR) findings demonstrate that all pairwise comparisons done in the AHP hierarchy are consistent and dependable for decision-making. The consistency ratio (CR) for the key criteria is 0.0506, which is significantly below the acceptable level of 0.10, showing that the judgments made in assessing the environmental, economic, social, and technical factors are logically sound. Similarly, the CR values for all sub-criteria matrices – environmental (0.0536), economic (0.0382), social (0.0798), and technical (0.0708) – are all within the acceptable range, showing that the subjective judgments offered by decision-makers correspond properly with AHP's logical framework. These findings guarantee that the weight computations and rankings obtained by AHP remain accurate and impartial, providing a stable platform for future research in the fuzzy AHP-TOPSIS hybrid technique.

3.2. Ranking suppliers using TOPSIS

To ensure comparability across all assessment criteria, the decision matrix was first normalized using the vector normalization approach, which standardizes performance ratings across multiple units. This transition permitted a fair and impartial comparison of supplier performance. Following normalization, the Weighted Normalized Decision Matrix was created by multiplying each normalized value by its associated Fuzzy AHP-derived weight. This ensured that factors of greater relevance, as assessed by expert judgments, had a commensurate influence on the final ranking. The combined results of normalization and weighted normalization for all criterion and sub-criteria. The normalized values, Ideal and Negative-Ideal Solutions for all key criteria and sub-criteria are shown in Table 9 to Table 13.

The Euclidean distance approach was utilized to estimate the separation of each provider from both the

Table 9. Weighted normalized matrix and ideal solutions of main criteria

Main criteria	Weighted normalized matrix			Ideal Solution (A^+)	Negative-Ideal Solution (A^-)
	Supplier A	Supplier B	Supplier C		
EN	0.2624	0.1968	0.2296	0.2624	0.1968
EC	0.1722	0.1968	0.1476	0.1968	0.1722
S	0.1348	0.1048	0.1196	0.1348	0.1048
T	0.0492	0.0574	0.0656	0.0656	0.0492

Table 10. Weighted normalized matrix and ideal solutions of environmental criteria

Sub-criteria	Weighted normalized matrix			Ideal Solution (A^+)	Negative-Ideal Solution (A^-)
	Supplier A	Supplier B	Supplier C		
EN1	0.2296	0.1722	0.2009	0.2296	0.1722
EN2	0.1435	0.164	0.123	0.164	0.123
EN3	0.1348	0.1048	0.1196	0.1348	0.1048
EN4	0.059	0.0689	0.0787	0.0787	0.059
EN5	0.0328	0.0394	0.0459	0.0459	0.0328

Table 11. Weighted normalized matrix and ideal solutions of economical criteria

Sub-criteria	Weighted normalized matrix			Ideal Solution (A^+)	Negative-Ideal Solution (A^-)
	Supplier A	Supplier B	Supplier C		
EC1	0.2048	0.1843	0.1539	0.1722	0.1435
EC2	0.1532	0.1634	0.1238	0.164	0.1394
EC3	0.1436	0.1324	0.1187	0.1348	0.1048
EC4	0.1182	0.1389	0.1492	0.1196	0.0898

Table 12. Weighted normalized matrix and ideal solutions of main criteria

Sub-criteria	Weighted normalized matrix			Ideal Solution (A^+)	Negative-Ideal Solution (A^-)
	Supplier A	Supplier B	Supplier C		
S1	0.2158	0.1865	0.1594	0.2296	0.1968
S2	0.172	0.1628	0.1402	0.1722	0.1476
S3	0.1487	0.1305	0.1208	0.1348	0.1048
S4	0.1205	0.1103	0.1049	0.1196	0.0898

Table 13. Weighted normalized matrix and ideal solutions of main criteria

Sub-criteria	Weighted normalized matrix			Ideal Solution (A^+)	Negative-Ideal Solution (A^-)
	Supplier A	Supplier B	Supplier C		
T1	0.2456	0.1904	0.1689	0.2624	0.1968
T2	0.1895	0.1703	0.1524	0.1722	0.1476
T3	0.1728	0.1482	0.1325	0.1348	0.1048
T4	0.1509	0.1426	0.1208	0.1196	0.0898

Ideal Solution (A^+) and the Negative-Ideal Solution (A^-), measuring how near or distant each option is from the greatest and worst potential performance. The estimated separation distances (S^+ and S^-) for all providers across the main and sub-criteria are provided in Table 14. Building upon these distances, the TOPSIS score (C_i) for each provider was derived by assessing the relative proximity to the Ideal Solution. This score is determined by dividing the separation from the Negative-Ideal Solution by the total separation distance, where a larger score implies a better ranking. The final Euclidean distances and TOPSIS scores are shown in a combined results Table 15, which offers a clear ranking of providers and forms the foundation for the final choice in the supplier selection process.

The final ranks of the suppliers were decided based on their TOPSIS scores, which represent their relative proximity to the Ideal Solution (A^+) and distance from the Negative-Ideal Solution (A^-). The calculated scores, provided in Figure 3 reveal that Supplier A obtained the highest TOPSIS score, exhibiting the greatest overall performance across the examined categories. Supplier B and Supplier C

Table 14. Euclidean distances for sub criteria

Supplier	Separation from Ideal (S^+)				Separation from Negative-Ideal (S^-)			
	Environmental	Economical	Social	Technological	Environmental	Economical	Social	Technological
Supplier A	0.0296	0.0412	0.0387	0.0423	0.0762	0.0856	0.0812	0.0843
Supplier B	0.0726	0.0698	0.0654	0.0685	0.0499	0.0567	0.0529	0.0552
Supplier C	0.0611	0.0593	0.0572	0.0601	0.0395	0.0451	0.0417	0.0463

Table 15. Euclidean distances for main criteria and TOPSIS Scores

Supplier	Separation from Ideal (S^+)	Separation from Negative-Ideal (S^-)	CC_i score	Ranking
Supplier A	0.0396	0.0824	0.7014	1
Supplier B	0.0678	0.0543	0.4450	2
Supplier C	0.0587	0.0428	0.4401	3

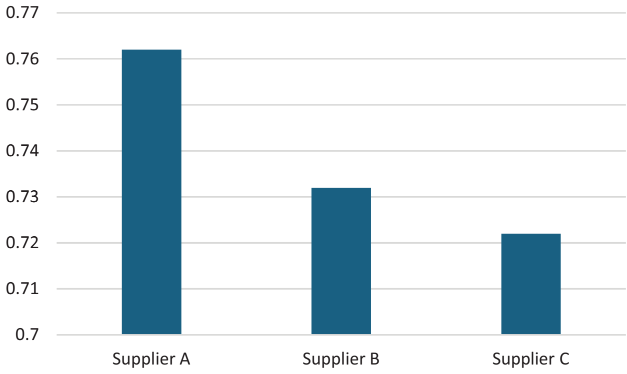

Figure 3. TOPSIS scores of suppliers

followed in second and third place, respectively, with lower relative closeness coefficients.

The ranking findings show that Supplier A is the best viable alternative for green supplier in the Sri Lankan construction industry, as it aligns most well with the priority environmental, economic, social, and technological criteria. These results give an organized and data-driven approach to supplier selection, ensuring that the choice is both objective and linked with strategic sustainability objectives.

4. Discussion

The results of this research indicate the efficiency of the hybrid Fuzzy AHP-TOPSIS strategy in green supplier selection, notably in the Sri Lankan construction sector. The combination of Fuzzy AHP for weight determination and TOPSIS for assessing suppliers enables a balanced and rigorous decision-making process. This dual-method approach promotes decision quality by addressing both subjective judgments and measurable performance indicators – an essential prerequisite for sustainability-oriented procurement. This correlates with earlier research demonstrating that multi-criteria decision-making (MCDM) techniques, especially hybrid approaches, offer a systematic and dependable framework for supplier assessment (Lahdhiri et al., 2022).

One of the most significant outcomes of the research is the predominance of environmental compliance as the most essential element in supplier selection. The result is consistent with prior study, where environmental restrictions and carbon footprint reduction were recognized as the primary factors of sustainable supplier selection (Singh et al., 2022). The Sri Lankan construction sector, like many developing nations, is increasingly moving towards sustainable procurement, but problems like as regulatory compliance and supplier preparation remain substantial (Wimalarathna et al., 2023). The study's findings underline that organizations need to link their procurement strategies with global green standards, including ISO 14001 certification and waste management best practices, to achieve long-term sustainability (Singh & Chan, 2022).

The ranking of suppliers further illustrates the trade-offs between environmental, economic, social, and technological factors. Supplier A emerged as the best-balanced alternative, excelling in environmental and social elements while keeping strong technical skills. Supplier B proved cost effectiveness, making it a favored alternative for budget-conscious projects. However, its lower sustainability performance underscores a typical difficulty in green supplier selection – organizations often confront an issue between financial viability and environmental responsibility (Utama, 2021). Supplier C, although technologically sophisticated, lacked competition in cost and social responsibility, emphasizing that innovation alone is insufficient in green procurement if it is not matched with social and environmental responsibilities. From a managerial standpoint, the findings give numerous actionable implications:

- Procurement managers should favor suppliers with consistent performance across all sustainability pillars rather than relying just on cost or technical excellence.
- Decision-makers can use hybrid fuzzy models to eliminate personal bias and make more consistent and defensible decisions, especially in uncertain or resource-limited contexts.
- Policymakers could incentivise sustainable behavior through tax relief or subsidies for certified green providers and mandate sustainability disclosures in public auctions.

The findings reinforce the emerging agreement that hybrid fuzzy models increase decision accuracy in supplier selection. Compared to classic MCDM techniques, such as solo AHP or TOPSIS, the Fuzzy AHP-TOPSIS model lowers the influence of subjective bias and boosts decision-maker confidence (Rouyendegh & Savalan, 2022). This correlates with results by Sahoo et al. (2024), who emphasized the advantages of fuzzy-based MCDM approaches in Industry 4.0 supplier selection owing to their capacity to manage ambiguity and linguistic variations. Moreover, similar studies in the steel, automotive, and textile sectors have showed that combining fuzzy logic with TOPSIS resulted in more consistent and accurate supplier rankings (Tronnebati et al., 2024; Bas, 2024). This research adds to this evidence by showing that the strategy remains effective and flexible even in emerging nations with legislative and infrastructure limitations.

Another significant feature of the research is its practical applicability in a growing country like Sri Lanka, unlike wealthy nations where green supply chain management (GSCM) is widely used, Sri Lankan enterprises typically suffer with economic constraints, regulatory inadequacies, and supplier contradiction to change (Ashoka et al., 2023). In such situations, firms confront extra problems like cash limits and supplier reluctance. The Fuzzy AHP–TOPSIS framework provides a reproducible approach for systematically evaluating providers in spite of these constraints. The decision-making framework offered in this article offers a systematic technique that can be reproduced across sectors, allowing organizations to assess suppliers beyond standard cost and quality indicators. The results indicate the need for governmental measures to incentivise green procurement, such as tax rewards for ecologically complying suppliers and required sustainability reporting (Shi & Ge, 2025).

Furthermore, the Fuzzy AHP-TOPSIS model's capacity to include expert opinion while keeping objective numerical analysis offers a flexible but organized review process. This work adds to the expanding body of information supporting fuzzy decision-making models as a critical tool for sustainable procurement. Future research may build on this by adding big data analytics and artificial intelligence into the review process, as recommended by Rashid et al. (2025), to further boost decision accuracy and automation in green supplier selection.

The research confirms the Fuzzy AHP-TOPSIS technique as a viable, data-driven, and adaptable alternative for green supplier selection. It provides insightful information for both procurement managers and policymakers, reinforcing the necessity for structured, multi-criteria frameworks in advancing sustainability and operational efficiency across supply chains.

5. Conclusions

5.1. Key findings

The research effectively applied a Hybrid Fuzzy AHP–TOPSIS methodology to identify and rank green suppliers in the Sri Lankan construction sector. The combination of Fuzzy AHP and TOPSIS provides a systematic, structured, and impartial methodology for evaluating suppliers across four important sustainability pillars: environmental, economic, social, and technological. This dual-stage hybrid methodology permitted the integration of subjective expert opinion with objective numerical analysis, so improving both consistency and transparency in decision-making.

The findings revealed that environmental compliance is the most influential parameter in green supplier selection, underscoring the increased relevance of integrating procurement strategies with sustainability principles. This is particularly crucial in developing nations like Sri Lanka, where environmental legislation are continually updating and enterprises may lack internal sustainability monitoring mechanisms. Among the supplier alternatives, Supplier A was chosen as the most balanced and best choice, displaying strong performance across all four evaluation dimensions. It notably excelled in environmental and social parameters while still maintaining competitive technological competence and economic acceptability.

Supplier B delivered cost efficiency but lagged in environmental and social elements, indicating a common trade-off enterprises confront between affordability and sustainability. Supplier C displayed technological strength but fell short on economic and social responsibility parameters. These rankings emphasize the complicated and frequently contradictory requirements encountered by procurement managers when seeking to balance financial performance with environmental stewardship and ethical considerations.

Overall, the study validates the Hybrid Fuzzy AHP–TOPSIS strategy as an effective tool for supplier evaluation under uncertainty, capable of minimizing decision-maker bias and boosting judgment accuracy in sustainability-focused procurement.

5.2. Research limitations

While the model has tremendous potential, certain limitations must be addressed. First, the research is based on a single case study inside the Sri Lankan construction sector, which may limit the external validity of the conclusions across different industries or nations. More diversified example applications would provide a broader grasp of the model's adaptability.

Second, although fuzzy logic provides for better management of linguistic uncertainty and ambiguous criteria, the model still depends on expert judgment, which can add bias and variability depending on the background and experience of the decision-makers. This subjectivity, while controlled, is not totally eradicated.

Third, the study's static nature – relying on a one-time evaluation – does not account for evolving supplier performance over time or the influence of market and regulatory changes. The existing model also does not employ dynamic or real-time data streams, which could further refine responsiveness and predictive decision-making in volatile procurement contexts.

5.3. Recommendations for future research

Future studies can build on this work in various relevant directions. One essential route is to test the proposed hybrid model across multiple sectors, such as manufacturing, energy, or healthcare, and in distinct geographic regions. This would assist assess the model's robustness and contextual flexibility. Another interesting path is the integration of modern technologies – including artificial intelligence (AI), machine learning (ML), and big data analytics – to automate data processing and continuously monitor supplier performance. This could enable real-time decision-making and improve the adaptability of supplier selection processes in fast-paced global markets.

Furthermore, adopting multi-actor or stakeholder-based review models – involving regulators, customers, local communities, and sustainability auditors – would strengthen the comprehensiveness and validity of green procurement decisions. These models could fit better with larger sustainability goals such as circular economy, social equality, and climate resilience. Longitudinal research could track how supplier rankings and organizational procurement habits evolve over time when led by fuzzy MCDM-based frameworks. This would provide useful insights into long-term sustainability consequences and assist refine key supplier partnerships.

References

Aal, S. I. A. (2024). A multi-criteria decision making model for sustainable and resilient supplier selection and management. *Neutrosophic Systems with Applications*, *15*, 33–45. https://doi.org/10.61356/j.nswa.2024.1513956

Agarwal, A., Pant, A., & Agarwal, M. (2023). Green supplier selection for manufacturing organization using a hybrid MCDM approach. *Journal of Statistics and Management Systems*, *26*(2), 341–355. https://doi.org/10.47974/jsms-1050

Alimova, D., & Perkova, M. (2023). Comparative analysis of international standards for green building. *Bulletin of Belgorod State Technological University Named After V G Shukhov*, *8*(4), 55–66. https://doi.org/10.34031/2071-7318-2023-8-4-55-66

Ashoka, A. N. D., Jayasooriya, S. D., & Galahitiyawe, N. (2023). *Awareness of green supply chain management practices of Sri Lankan SMEs* [Conference presentation]. 6th International Conference on Business Research (ICBR 2023), Business Research Unit. https://doi.org/10.31705/icbr.2023.22

Bas, S. A. (2024). A hybrid approach based on consensus decision making for green supplier selection in the automotive industry. *Sustainability*, *16*(7), Article 3096. https://doi.org/10.3390/su16073096

Chang, D. (1992). *Extent analysis and synthetic decision, optimization techniques and applications* (Vol. 1). World Scientific.

Chen, X., Zhou, B., Štilić, A., Stević, Ž., & Puška, A. (2023). A fuzzy–rough MCDM approach for selecting green suppliers in the furniture manufacturing industry: A case study of eco-friendly material production. *Sustainability*, *15*(13), Article 10745. https://doi.org/10.3390/su151310745

Erdebilli, B., Yilmaz, İ., Aksoy, T., Hacıoglu, U., Yüksel, S., & Dinçer, H. (2023). An interval-valued Pythagorean Fuzzy AHP and COPRAS hybrid methods for the supplier selection problem. *International Journal of Computational Intelligence Systems*, *16*(1), Article 124. https://doi.org/10.1007/s44196-023-00297-4

Hwang, C., & Yoon, K. (1981). Multiple attribute decision making. In *Lecture notes in economics and mathematical systems* (Vol. 186). Springer. https://doi.org/10.1007/978-3-642-48318-9

Iqbal, M., Ma, J., Ahmad, N., Ullah, Z., & Ahmed, R. I. (2021). Uptake and adoption of sustainable energy technologies: Prioritizing strategies to overcome barriers in the construction industry by using an integrated AHP-TOPSIS approach. *Advanced Sustainable Systems*, *5*(7), Article 2100026. https://doi.org/10.1002/adsu.202100026

Khulud, K., Masudin, I., Zulfikarijah, F., Restuputri, D. P., & Haris, A. (2023). Sustainable supplier selection through multi-criteria decision making (MCDM) approach: A bibliometric analysis. *Logistics*, *7*(4), Article 96. https://doi.org/10.3390/logistics7040096

Lahdhiri, M., Babay, A., & Jmali, M. (2022). Multi-criteria decision making using hybrid methods for supplier selection in the clothing industry. *Fibres and Textiles in Eastern Europe*, *30*(2), 23–34. https://doi.org/10.2478/ftee-2022-0004

Oubrahim, I., & Sefiani, N. (2025). An integrated multi-criteria decision-making approach for sustainable supply chain performance evaluation from a manufacturing perspective. *International Journal of Productivity and Performance Management*, *74*(1), 304–339. https://doi.org/10.1108/ijppm-09-2023-0464

Parvaneh, F., & Hammad, A. (2024). Application of multi-criteria decision-making (MCDM) to select the most sustainable power-generating technology. *Sustainability*, *16*(8), Article 3287. https://doi.org/10.3390/su16083287

Pınar, A., Daneshvar, R. B., & Özdemir, Y. S. (2021) Q-Rung Orthopair Fuzzy TOPSIS method for green supplier selection problem. *Sustainability*, *13*(2), Article 985. https://doi.org/10.3390/su13020985

Pourjavad, E., & Shahin, A. (2018). Hybrid performance evaluation of sustainable service and manufacturing supply chain management: An integrated approach of fuzzy DEMATEL and fuzzy inference system. *Intelligent Systems in Accounting, Finance and Management*, *25*(3), 134–150. https://doi.org/10.1002/isaf.1431

Pourjavad, E., & Shahin, A. (2020a). A hybrid model for analyzing the risks of green supply chain in a fuzzy environment. *Journal of Industrial and Production Engineering*, *37*(8), 422–433. https://doi.org/10.1080/21681015.2020.1833995

Pourjavad, E., & Shahin, A. (2020b). Green supplier development programmes selection: A hybrid fuzzy multi-criteria decision-making approach. *International Journal of Sustainable Engineering*, *13*(6), 463–472. https://doi.org/10.1080/19397038.2020.1773569

Ramadhanti, V., & Pulansari, F. (2022). Integration of fuzzy AHP and fuzzy TOPSIS for green supplier selection of mindi wood raw materials. *Jurnal Sistem dan Manajemen Industri*, *6*(1), 1–13. https://doi.org/10.30656/jsmi.v6i1.4332

Rashid, A., Baloch, N., Rasheed, R., & Ngah, A. H. (2025). Big data analytics-artificial intelligence and sustainable performance through green supply chain practices in manufacturing firms of a developing country. *Journal of Science and Technology Policy Management*, *16*(1), 42–67. https://doi.org/10.1108/jstpm-04-2023-0050

Rouyendegh, B. D., & Savalan, Ş. (2022). An integrated Fuzzy MCDM hybrid methodology to analyze agricultural production. *Sustainability*, *14*(8), Article 4835. https://doi.org/10.3390/su14084835

Saaty, T. L. (1977). A scaling method for priorities in hierarchical structures. *Journal of Mathematical Psychology*, *15*(3), 234–281. https://doi.org/10.1016/0022-2496(77)90033-5

Safavi, A., Bigham, B. S., & Zahedi-Seresht, M. (2025). Supplier selection utilizing AHP and TOPSIS in a fuzzy environment based on KPIs. *Contemporary Mathematics*, 574–593. https://doi.org/10.37256/cm.6120256152

Sahoo, S. K., Goswami, S. S., & Halder, R. (2024). Supplier selection in the age of Industry 4.0: A review on MCDM applications and trends. *Decision Making Advances*, *2*(1), 32–47. https://doi.org/10.31181/dma21202420

Sequeira, M., Adlemo, A., & Hilletofth, P. (2022). A hybrid fuzzy-AHP-TOPSIS model for evaluation of manufacturing relocation decisions. *Operations Management Research*, *16*(1), 164–191. https://doi.org/10.1007/s12063-022-00284-6

Shahin, A., Imanipour, N., & Wood, L. C. (2020). An integrative approach for structuring and prioritizing eco-innovation determinants with a survey in knowledge-based companies. *Journal of Manufacturing Technology Management*, *31*(4), 799–824. https://doi.org/10.1108/JMTM-03-2019-0110

Shahin, A., Masoomi, B., & Shafiei, M. A. (2019). Ranking the obstacles of green supply chain management using fuzzy approaches of TOPSIS and DEMATEL with a case study in a pharmaceutical industry. *International Journal of Logistics Systems and Management*, *33*(3), 404–419. https://doi.org/10.1504/IJLSM.2019.101163

Shi, Y., & Ge, J. (2025). The role of government fiscal and tax incentives in green technology innovation and enterprise development: Implications for human health and hygiene. *Frontiers in Public Health*, *12*, Article 1502856. https://doi.org/10.3389/fpubh.2024.1502856

Shih, H., Shyur, H., & Lee, E. S. (2006). An extension of TOPSIS for group decision making. *Mathematical and Computer Modelling*, *45*(7–8), 801–813. https://doi.org/10.1016/j.mcm.2006.03.023

Singh, A., Kumar, V., Verma, P., & Ramtiyal, B. (2022). Can suppliers be sustainable in construction supply chains? Evidence from a construction company using best worst approach. *Management of Environmental Quality an International Journal*, *34*(4), 1129–1157. https://doi.org/10.1108/meq-03-2022-0057

Singh, P. K., & Chan, S. W. (2022). The impact of electronic procurement adoption on green procurement towards sustainable supply chain performance-evidence from Malaysian ISO organizations. *Journal of Open Innovation Technology Market and Complexity*, *8*(2), Article 61. https://doi.org/10.3390/joitmc8020061

Stofkova, J., Krejnus, M., Stofkova, K. R., Malega, P., & Binasova, V. (2022). Use of the analytic hierarchy process and selected methods in the managerial decision-making process in the context of sustainable development. *Sustainability*, *14*(18), Article 11546. https://doi.org/10.3390/su141811546

Tronnebati, I., Jawab, F., Frichi, Y., & Arif, J. (2024). Green supplier selection using Fuzzy AHP, Fuzzy TOSIS, and Fuzzy WASPAS: A case study of the Moroccan automotive industry. *Sustainability*, *16*(11), Article 580. https://doi.org/10.3390/su16114580

Utama, D. M. (2021). AHP and TOPSIS integration for green supplier selection: A case study in Indonesia. *Journal of Physics*: *Conference Series*, *1845*(1), Article 012015. https://doi.org/10.1088/1742-6596/1845/1/012015

Van Laarhoven, P. J., & Pedrycz, W. (1983). A fuzzy extension of Saaty's priority theory. *Fuzzy Sets and Systems*, *11*(1–3), 229–241. https://doi.org/10.1016/S0165-0114(83)80082-7

Wang, C., Pan, C., Nguyen, H., & Fang, P. (2023). Integrating Fuzzy AHP and TOPSIS methods to evaluate operation efficiency of daycare centers. *Mathematics*, *11*(8), Article 1793. https://doi.org/10.3390/math11081793

Wimalarathna, W. H. P., De Silva, L., & Dissanayake, D. (2023). Challenges in implementing sustainable construction practices in Sri Lanka. *Built Environment Project and Asset Management*, *13*(1), 91–108. https://doi.org/10.31705/wcs.2023.51

Zavadskas, E. K., Mardani, A., Turskis, Z., Jusoh, A., & Nor, K. M. (2016). Development of TOPSIS method to solve complicated decision-making problems – an overview on developments from 2000 to 2015. *International Journal of Information Technology* & *Decision Making*, *15*(03), 645–682. https://doi.org/10.1142/S0219622016300019