

Research Article

Sustainable Vendor Selection under Multi-Criteria Decision Framework using Fuzzy-AHP and TOPSIS: An Electronics Sector Case Study with 22 Sustainability Criteria

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Abstract

Vendor selection under sustainable supply chain criteria presents a complex multi-criteria decision problem involving incommensurable performance dimensions, interdependent criteria, and inherent subjectivity in expert preference elicitation. This study develops and applies an integrated Fuzzy Analytic Hierarchy Process (Fuzzy-AHP) and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) framework for sustainable vendor selection in the printed circuit board (PCB) manufacturing supply chain of a Tier-1 electronics OEM. Twenty-two sustainability criteria spanning economic, environmental, and social dimensions were identified through structured literature review and validated through expert panel consultation. Fuzzy-AHP triangular membership functions were used to capture expert opinion uncertainty in pairwise criterion comparisons. TOPSIS was applied with Fuzzy-AHP-derived weights to rank 12 candidate PCB suppliers. The environmental criteria dimension received the highest aggregate weight (0.391). Vendor V1 achieved the highest TOPSIS Closeness Coefficient of 0.784, substantially exceeding the second-ranked supplier (0.743). Sensitivity analysis confirmed the robustness of top-two and bottom-two rankings across alternative weighting scenarios.

Keywords: Sustainable Vendor Selection; Fuzzy-AHP; TOPSIS; Multi-Criteria Decision Making; Supply Chain Sustainability; Electronics Manufacturing; Green Procurement

1. Introduction

Sustainable supply chain management has evolved from a peripheral corporate responsibility concern to a central strategic imperative for manufacturing organisations. Vendor selection, as the primary mechanism through which organisations determine the composition of their supply networks, represents a critical leverage point for implementing sustainable supply chain objectives. Traditional vendor selection approaches predominantly employed economic criteria such as cost, quality, and delivery performance, treating environmental and social performance as qualifying criteria or secondary considerations.

The limitations of this approach have become apparent as regulatory pressure under frameworks such as the EU Corporate Sustainability Due Diligence Directive, the UK Modern Slavery Act, and SEC climate disclosure rules extends corporate accountability for supplier environmental and social performance throughout multi-tier supply chains.

Multi-Criteria Decision Making (MCDM) methods provide the theoretical and methodological foundation for multi-dimensional vendor evaluation. The Analytic Hierarchy Process (AHP) developed by Saaty (1980) enables structured pairwise comparison of criteria, producing relative importance weights through eigenvalue analysis. TOPSIS, developed by Hwang and Yoon (1981), provides an intuitive alternative ranking method based on simultaneous minimisation of distance from a positive ideal solution and maximisation of distance from a negative ideal solution.

2. Literature Review

2.1 Sustainable Vendor Selection Criteria Frameworks

The Triple Bottom Line framework organises criteria into economic, environmental, and social pillars. Within the environmental pillar, commonly evaluated criteria include carbon footprint, energy efficiency, waste management, water consumption, environmental management system certification (ISO

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14001), and green product design capability. The social pillar encompasses labour rights and working conditions, health and safety performance, community impact, supplier diversity, and ethical sourcing compliance. Govindan, Rajendran, Sarkis, and Murugesan (2015) conducted a systematic review of green supplier selection, synthesising 98 criteria from 55 studies.

2.2 Fuzzy-AHP and TOPSIS Integration

The integration of Fuzzy-AHP for criteria weight determination with TOPSIS for alternative ranking represents the most widely adopted methodological framework in the recent sustainable vendor selection literature. Fuzzy-AHP addresses the recognised limitation of crisp AHP that expert pairwise judgments are inherently imprecise. Triangular fuzzy numbers (TFNs) of the form (l, m, u) capture this imprecision while remaining computationally tractable. The Chang (1996) extent analysis method for defuzzification converts TFNs to crisp weights through geometric mean synthesis and normalisation.

3. Methodology

3.1 Criteria Identification and Expert Panel

Twenty-two sustainability criteria were identified through a structured literature review of sustainable vendor selection publications in electronics manufacturing contexts (2010 to 2020, n=47 papers), supplemented by interviews with six supply chain sustainability managers at the case study organisation. Criteria were validated through a two-round Delphi process with an expert panel of 12 members. The final 22 criteria were organised into three dimensions: Economic (8 criteria including cost performance, quality score, delivery reliability, supplier financial stability, technology capability, responsiveness, lead time consistency, and risk management maturity); Environmental (8 criteria including carbon footprint, CO2 per unit, waste management, water consumption, renewable energy use, environmental certifications, green product design, and packaging sustainability); and Social (6 criteria including labour practices, worker health and safety, community engagement, supplier diversity, ethical sourcing compliance, and human rights performance).

3.2 Fuzzy-AHP Weight Derivation

Pairwise comparisons of all 22 criteria were performed by each expert panel member using a nine-point fuzzy linguistic scale with TFN equivalents. Individual judgments were aggregated by geometric mean. Consistency Ratio (CR) was checked for all comparison matrices; all matrices achieved CR less than 0.10, satisfying the Saaty consistency threshold.

4. Results

4.1 Criteria Weight Analysis

Figure 1 presents the normalised Fuzzy-AHP weights for the top 10 criteria from the full 22-criterion set. The environmental dimension received the highest aggregate weight (0.391), reflecting the case study organisation carbon neutrality commitment and EU environmental compliance requirements. Carbon Footprint (0.094) and CO2 per Unit (0.091) received the highest environmental criterion weights. Cost Performance (0.082) and Quality Score (0.078) were the highest-weighted economic criteria, while Labour Practices (0.088) was the most heavily weighted social criterion.

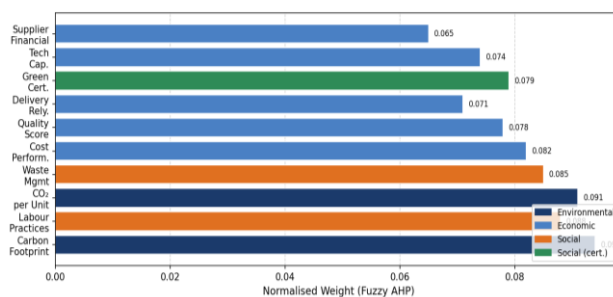


Figure 1: Top 10 Criteria Weights from Fuzzy-AHP Analysis (22 Criteria Total, Three Sustainability Dimensions)

4.2 TOPSIS Vendor Ranking

Figure 2 presents the TOPSIS Closeness Coefficients (CCs) for all 12 candidate PCB suppliers. Vendor V1 achieved the highest CC of 0.784, substantially exceeding V2 (0.743) and the recommended minimum threshold of 0.65 for Tier-1 preferred supplier classification. Vendors V1 through V5 all exceeded the threshold, with vendors V6 through V12 falling below. The bottom-three vendors demonstrated particularly poor environmental performance, failing ISO 14001 certification.

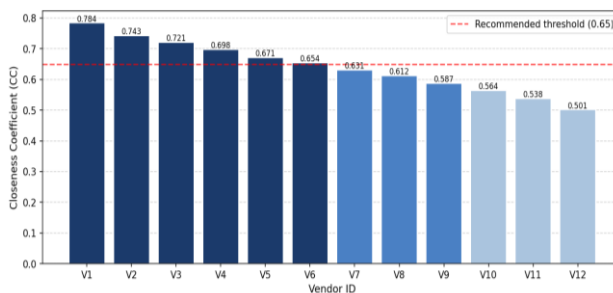


Figure 2: TOPSIS Closeness Coefficient Ranking of 12 PCB Suppliers Against 22-Criterion Sustainable Vendor Framework

Table 1: TOPSIS Vendor Ranking Summary (Selected Vendors)

Vendor	Cost Rank	Environ. Score	Social Score	TOPSIS CC	Final Rank
V1 (Taipei, TW)	3	0.841	0.812	0.784	1st
V2 (Shenzhen, CN)	1	0.798	0.776	0.743	2nd
V3 (Penang, MY)	4	0.812	0.798	0.721	3rd
V4 (Suwon, KR)	2	0.774	0.754	0.698	4th
V5 (Tokyo, JP)	5	0.768	0.821	0.671	5th
V9 (Guangzhou, CN)	7	0.631	0.612	0.564	9th
V12 (Jakarta, ID)	9	0.481	0.534	0.501	12th

4.3 Sensitivity Analysis

Sensitivity analysis was performed by systematically varying the relative weights of the three sustainability dimensions across 18 alternative weighting scenarios. The top-two (V1, V2) and bottom-two (V11, V12) vendor rankings remained stable across all 18 scenarios, confirming robustness of the selection recommendation to reasonable variation in stakeholder weight preferences. Middle-ranking vendors (V5 to V8) showed ranking sensitivity to dimension weight variations, reflecting competitive trade-offs between cost and sustainability performance in this group.

5. Discussion

The results demonstrate that Fuzzy-AHP-TOPSIS provides a methodologically rigorous, practically implementable framework for sustainable vendor selection that successfully integrates economic, environmental, and social performance dimensions. The selection of V1 as the top-ranked vendor, despite ranking 3rd on cost performance, reflects the higher aggregate weight assigned to environmental and social criteria consistent with the organisation sustainability strategy. This result would not have emerged from traditional cost-focused vendor evaluation frameworks.

The sensitivity analysis findings provide important practical guidance. The stability of top-two and bottom-two rankings across diverse weight scenarios increases confidence in the core selection recommendation.

For middle-ranking vendors where sensitivity is higher, the framework correctly signals that selection decisions require explicit deliberation about dimensional priorities rather than automatic acceptance of the central-weight ranking.

6. Conclusions

This paper has presented and validated an integrated Fuzzy-AHP-TOPSIS framework for sustainable vendor selection applied to 12 PCB suppliers across 22 criteria spanning economic, environmental, and social dimensions. Vendor V1 achieved the highest Closeness Coefficient of 0.784, with rankings stable to weight sensitivity analysis for top-two and bottom-two positions. Future research will extend this framework to incorporate dynamic multi-period vendor performance tracking, blockchain-enabled real-time criterion data collection, and machine learning-based prediction of vendor sustainability performance trajectory.

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