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Sustainable Procurement and Green Supplier Selection using Multi-Criteria Decision Making (MCDM) Methods

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ABSTRACT - Sustainable procurement has become a central pillar of supply chain management, driven by resource depletion, climate change, and rising social and ethical expectations. Where procurement decisions once turned almost entirely on cost, quality, and delivery reliability, organisations today must reconcile financial performance with environmental stewardship, social responsibility, and ethical governance. This has made supplier selection one of the most demanding decisions in supply chain management, requiring planners to weigh multiple, frequently conflicting, criteria at once. Thus, the present research, "Sustainable Procurement and Green Supplier Selection Using Multi-Criteria Decision Making (MCDM) Methods," attempts to design a structured, quantitatively validated decision-support model that ranks suppliers against economic, environmental, social, and ethical criteria.

The study employed a quantitative, cross-sectional research design built entirely around the hybrid Analytic Hierarchy Process (AHP) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) methods. Twelve procurement and supply-chain experts from the Indian manufacturing sector supplied pairwise comparisons of four sustainability pillars: Economic, Environmental, Social, and Ethical, using Saaty's 1–9 scale, and scored eight candidate suppliers against each criterion. All data were processed and validated using Microsoft Excel, with the AHP eigenvector weights, TOPSIS closeness coefficients, and weight- perturbation sensitivity analysis computed and cross-checked manually. No structural equation modelling, hypothesis testing, or PLS-SEM analysis was used at any stage; validation rests solely on AHP consistency checking and TOPSIS sensitivity analysis.

The research results indicated that Social (weight = 0.507) and Economic (weight = 0.338) criteria dominate supplier-selection decisions in this expert panel, together accounting for 84.5% of the total decision weight, with a Consistency Ratio of 0.050 confirming the reliability of the aggregated expert judgments. The TOPSIS analysis ranked Supplier C as the top-performing supplier (Closeness Coefficient = 0.932), a result that remained unchanged across sixteen weight-perturbation scenarios (±10% and ±20%) and compared favourably against an earlier, smaller pilot dataset from the same expert pool. The study also identifies the practical barriers cost sensitivity, limited supplier awareness, rigid procurement cultures, and long lead times that slow the adoption of sustainable procurement in the Indian context.

4 **Overall, the study demonstrates the applicability of a hybrid AHP–TOPSIS framework to sustainable supplier selection, offering a repeatable, decision-support tool intended to bridge the gap between sustainability theory and industrial procurement practice.**

Keywords: Sustainable Procurement; Green Supplier Selection; Multi-Criteria Decision Making; Analytic Hierarchy Process; TOPSIS; Sustainable Supply Chain Management

1. INTRODUCTION

1.1 Introduction Sustainable procurement is the integration of ethical, social, economic, and environmental considerations into supplier selection and purchasing decisions. It recognises the growing importance of ethical governance in supply-chain decision-making while emphasising the triple bottom line economic viability, environmental stewardship, and social responsibility. Supplier selection has become an increasingly complex decision process due to globalisation, diverse stakeholder expectations, stricter regulatory frameworks, and dynamic market demands. Companies are increasingly required to ensure that suppliers observe human rights, comply with laws, provide safe and decent working conditions, and maintain transparency in operations. However, due to competing cost pressures, inconsistent supplier disclosure, limited monitoring capacity, and other factors, sustainable supplier selection is becoming increasingly difficult. So, in order to select suppliers more objectively and reliably, this

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study uses Multi-Criteria Decision-Making (MCDM) techniques specifically the Analytic Hierarchy Process (AHP) and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) which combine expert judgement with quantitative ranking to give more structured, defensible, and transparent results than unaided managerial judgement alone.

This chapter gives a brief introduction to sustainable procurement and green supplier selection through AHP and TOPSIS. This chapter discusses the current industry scenario, limitations, gaps in research, motivation, research objectives and specifications, and the schedule of the project.

1.2 Introduction to the Area of Work The supply chain management process is regarded as one of the main processes that relate to planning, procurement, production, inventory management, logistics, and delivering goods to consumers. All these processes require supplier selection decisions that are vital to strategic and operational performance alike. These decisions become significantly more difficult once sustainability is added as a formal requirement rather than a secondary preference.

Traditionally, supplier selection has been carried out using largely cost-driven approaches: lowest bid, fastest delivery, and highest historical quality score. Nevertheless, cost-based approaches are good for simple transactional buying, but poorly suited to reflecting non- quantifiable, qualitative aspects like ethical behaviour, social responsibility, and environmental performance, and they do not scale to a number of conflicting dimensions simultaneously.

Recent innovations in multi-criteria Decision-Making have radically shifted approaches to supplier assessment, since structured decision-analysis tools have appeared that provide the decision-maker with the ability to integrate expert judgement, quantitative scoring, and formal consistency checking. 10 Analytic Hierarchy Process, created by Saaty (1980), allows decision-makers to use the concept of structured pairwise comparison to calculate the relative significance of criteria, and TOPSIS ranks alternatives by their geometric closeness to an ideal solution. This hybrid framework of these two approaches can capture the multi-dimensional aspect of sustainable supplier selection decisions.

This project is aimed at designing a hybrid AHP-TOPSIS model to facilitate comparative analysis of the candidate suppliers based on the economic, environmental, social and ethical measures to ensure that Indian manufacturing organisations can select suppliers who are not only operationally competent, but also aligned with the sustainability objectives.

1.3 Present Day Scenario The increasing trend in e-commerce, globalisation, digitalisation, and the change in the expectations of stakeholders has increased the complexities involved in managing sustainable procurement programmes. Companies must adjust to sustainability requirements while remaining cost-competitive and capable of delivery. Inadequate supplier selection has resulted in reputational loss, supply interruptions, regulatory non-compliance and a lack of trust by stakeholders.

The scale of this change is measurable. A survey of 1,000 global multinational purchasers and almost 2,000 suppliers in 20 industries and three geographic areas, the Sustainable Procurement Barometer 2026, which is published by EcoVadis in cooperation with Accenture, reveals that the most successful organisations are those that have internalised sustainability intelligence directly into sourcing decisions and supplier relationships as opposed to operating a separate programme (EcoVadis, 2026). Nonetheless, there remains an execution gap: according to industry surveys, only approximately 17 per cent of businesses currently have implemented efficient real-time systems to monitor supplier ESG performance, so that most procurement functions still lack the operational transparency required to respond to sustainability criteria at the supplier-selection stage (KPMG, cited in Procurement Tactics, 2026).

In today's world, modern organisations are increasingly using structured decision-support tools, sustainability disclosures, and supplier audits to build defensible, criteria-based supplier- evaluation models. However, despite the development of these advanced tools, most organisations, particularly in emerging economies such as India, are still using largely informal or cost-only methods for supplier selection, which are not well suited to balancing environmental, social, and ethical requirements alongside economic performance. There is, therefore, an increasing demand for intelligent, criteria-based, and quantitatively validated supplier-selection systems of the kind developed in this study.

Motivation for the Project Shortcomings in Previous Work

- The majority of prior studies have considered only cost, quality, and delivery as supplier-selection criteria.
- Few studies combine economic, environmental, social, and ethical criteria within a single, unified evaluation model.
- Ethical criteria transparency, conflict of interest, code of conduct are particularly underrepresented in existing supplier-evaluation frameworks. • Very few hybrid AHP TOPSIS studies have been empirically validated within Indian manufacturing

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specifically. • Most existing studies do not validate their supplier ranking against an earlier or smaller prior dataset, or test the ranking's robustness through formal sensitivity analysis.

1.4.2 Importance of the Present Work • Increasing stakeholder and regulatory pressure for sustainable sourcing. • Better-informed, defensible supplier-selection decisions. • Reduction in reputational and compliance risk from poor supplier choices. • Improved balance between cost competitiveness and sustainability performance. • Faster, more transparent, and more consistent decision-making. • Stronger alignment between procurement practice and organisational sustainability goals.

1.4.3 Uniqueness of the Proposed Methodology • Implementation of a first-level AHP pairwise comparison across four sustainability pillars: Economic, Environmental, Social, and Ethical. • Implementation of TOPSIS supplier ranking using AHP-derived criteria weights. • Explicit weight-perturbation sensitivity analysis (±10% and ±20%) across sixteen scenarios to test ranking robustness.

- Explicit comparison of the current dataset against an earlier, smaller pilot dataset from the same expert pool. • A literature review structured around explicit Finding-then-Gap analysis for each thematic stream. • No PLS-SEM, structural equation modelling, or hypothesis testing at any stage validation rests solely on AHP consistency checking and TOPSIS sensitivity analysis.

1.4.4 Significance of the Expected Results Expected outcomes include:

- A validated, four-pillar weighted criteria framework for sustainable supplier selection. • A robust, sensitivity-tested ranking of candidate suppliers. • Identification of the single most impactful sustainability criterion in supplier selection. • Practical insight into the barriers slowing sustainable procurement adoption in India. • A repeatable decision-support framework applicable across manufacturing sectors.

1.5.1 Main Objective

To identify the factors relevant to sustainable green supplier selection, and to develop a hybrid AHP–TOPSIS framework that weights these factors and ranks candidate suppliers accordingly.

1.6 Target Specifications The proposed system aims to:

- Achieve a Consistency Ratio below 0.10 for the aggregated AHP pairwise-comparison matrix. • Produce a clear, well-separated TOPSIS supplier ranking. • Maintain a stable top-3 supplier ranking across ±10% and ±20% weight-perturbation scenarios. • Identify the single most impactful sustainability criterion for supplier selection. • Support strategic, sustainability-aligned procurement decisions. • Provide a scalable, repeatable framework applicable beyond the current expert panel and supplier set.

1.7 Research Questions In line with the objectives above, this study addresses the following research questions:

RQ1: What are the key economic, environmental, social, and ethical factors influencing sustainable green supplier selection?

RQ2: How can these factors be weighted using the Analytic Hierarchy Process?

RQ3: How can candidate suppliers be analysed and ranked using TOPSIS on the basis of these weighted factors?

1.8 Problem Statement Current supplier-evaluation practice still prioritises economic factors over thorough environmental, social, and ethical consideration, and barriers such as cost sensitivity, limited supplier awareness, rigid procurement cultures, and long lead times hinder the adoption of sustainable procurement. In the Indian context, there remain few organised and empirically validated models that combine social, ethical, environmental, and economic considerations when evaluating suppliers.

2. LITERATURE REVIEW

2.1 Introduction A literature review is an integral part of any research work since it helps gain a detailed insight into the current state of knowledge, methods, and progress achieved within the research field. This enables scholars to examine past literature, identify gaps in research, evaluate different methods, and provide a strong theoretical foundation for their work. In the framework of supply chain management, sustainable supplier selection is a controversial topic of discussion due to its direct interconnection

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with procurement risk, corporate reputation, compliance with regulations, and long-term supply-chain resilience. The development of sustainability reporting and the maturity of the MCDM methods have made it possible to move beyond purely cost- based supplier selection to multi-dimensional evaluation.

In this chapter, an extensive review of the available literature on sustainable supply chain management, MCDM techniques, and hybrid AHP TOPSIS applications is provided. It covers the history of supplier-selection approaches, modern progress in sustainability-related decision- making, and the theoretical foundations of AHP and TOPSIS. In addition, this chapter provides a critical review of past research studies, pointing out their strengths and weaknesses, identifying the knowledge gaps that form the motivation for this study, and providing the theoretical and mathematical basis of the proposed methodology.

2.2 Introduction to the Project Title Title: Sustainable Procurement and Green Supplier Selection Using Multi-Criteria Decision Making (MCDM) Methods

In this current competitive and ever-evolving business world, sustainable supplier selection is essential in order to manage the supply chain process effectively. The organisation needs to be able to evaluate candidate suppliers against a broad set of criteria so that it can maintain operational performance, reduce risk, and align with sustainability commitments. Nevertheless, it is not always easy to use conventional cost-based methods to evaluate suppliers in view of the growing importance of environmental, social, and ethical considerations. Hence, many organisations are turning towards Multi-Criteria Decision-Making approaches.

MCDM refers to a family of structured decision-analysis techniques that allow decision-makers to evaluate alternatives against multiple, often conflicting, criteria simultaneously. The Analytic Hierarchy Process, a subset of MCDM developed by Saaty (1980), allows decision-makers to structure a decision hierarchically and derive priority weights from pairwise comparisons. The Technique for Order Preference by Similarity to Ideal Solution, developed by Hwang and Yoon (1981), ranks alternatives according to their geometric distance from a positive-ideal and a negative-ideal solution.

14 The advent of hybrid AHP–TOPSIS models has revolutionised the practice of supplier evaluation through structured, criteria-weighted, and quantitatively validated decision-making.

The process of sustainable supplier selection in this study involves identifying relevant economic, environmental, social, and ethical criteria; deriving their relative importance through AHP; and ranking candidate suppliers against those criteria using TOPSIS. With the help of this framework, organisations can select suppliers who are both operationally competent and sustainability-aligned, while minimising the risk of over-reliance on a single dominant criterion such as cost.

In this research work, a hybrid framework is developed using only AHP and TOPSIS no structural equation modelling, hypothesis testing, or PLS-SEM analysis is used at any stage. The effectiveness of the criteria weights and supplier ranking derived is validated against the Consistency Ratio (in AHP) and weight-perturbation sensitivity analysis (in TOPSIS). The overall objective of the research work is to determine the most effective sustainability criteria, as well as the suppliers that are in the best position to address operational and sustainability needs.

2.3 Literature Review

2.3.1 Foundations of Sustainable Supply Chain Management Seuring and Müller (2008) undertook a literature review as a foundational step to provide a conceptual framework for sustainable supply chain management (SSCM) synthesising a substantial amount of previous literature into a structured framework that connects triggers of sustainability (legal demands and stakeholder pressure) to the strategies adopted by organisations in response and the resulting supply-chain outcomes. Their model formalized the three intertwined pillars of economic, environmental, and social performance as the foundational elements of SSCM, and is one of the most referenced conceptual pillars in the field. The authors proved that sustainability in supply chains could not be treated as a single add-on but should be considered throughout the process of selecting suppliers and entering contracts, as well as monitoring their performance.

Research Gap: This review, although highly influential in exerting its conceptual vocabulary on the field, is intentionally conceptual, and it does not provide any quantitative or criteria- weighting procedure for implementing the triple-bottom-line framework into practice at the level of an individual supplier-selection decision. The current study is a continuation of this work, constructing the triple bottom line, which is further expanded to four pillars such as ethics, a quantitative AHP-TOPSIS model.

2.3.2 MCDM Approaches for Green Supplier Evaluation: A Review Govindan, Rajendran, Sarkis, and Murugesan (2015) carried out an extensive literature review of the multi-criteria decision-making techniques applied specifically in the context of green

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supplier evaluation and selection. The authors provided a list of the most and least common

15 criteria in the studies reviewed most commonly the environmental management systems, pollution control, and resource consumption and the most used MCDM techniques, such as AHP, ANP, TOPSIS, and various fuzzy variants of each.

They identified that combinations of two or more MCDM approaches were becoming progressively more popular than individual methodologies since they take the advantages of criteria-weighting methods (like AHP) with the advantages of ranking methods (like TOPSIS).

Research Gap: The review's own criteria catalogue is dominated by environmental criteria, with social and ethical dimensions comparatively underrepresented across the studies reviewed a pattern this study's own literature review (see Theme 2, Section 2.4) confirms persists a decade later. This research paper fills this gap by providing the Social and Ethical pillars with equal structural weight compared to Economic and Environmental criteria in the AHP hierarchy.

2.3.3 An Integrated Framework for Sustainable Supplier Selection and Evaluation Luthra, Govindan, Kannan, and Mangla (2017) put forward a combined system of fuzzy AHP and fuzzy TOPSIS to assess and choose sustainable suppliers, which was used in an Indian automobile manufacturing case. Their model included 22 sub-criteria clustered into economic, environmental, and social dimensions, and the authors showed that a fuzzy hybrid MCDM model could be effective for ranking suppliers even in situations where expert judgements are described using linguistic uncertainty.

Research Gap: The ethical aspect of the framework is focused on a few sub-criteria nested in social sustainability, rather than being an independent pillar, and the study has been implemented in only one industry (automobile manufacturing) without running the robustness of the rankings in a formal sensitivity analysis. The current work brings ethical standards to a specific, first-level pillar and introduces explicit weight-perturbation sensitivity testing, which is not done in the study by Luthra et al.

2.3.4 A Framework of Sustainable Supply Chain Management: Moving Toward New Theory The theoretical framework proposed by Carter and Rogers (2008) proposes a location of sustainability at the centre of economic, social, and environmental performance, and suggests that sustainability initiatives in the supply chain are best pursued when tied to, instead of independent of, core supply-chain strategy. The authors determined 4 facilitating elements- transparency, risk management, strategy, and culture- are needed for real SSCM implementation.

Research Gap: As with Seuring and Müller (2008), the framework is conceptual rather than operational, and it does not specify how an organisation should weight or trade off the three sustainability dimensions when making an individual sourcing decision. This study translates the framework's triple-bottom-line logic into the quantitative AHP weight vector reported in Chapter 4.

16 2.3.5 Hybrid AHP–TOPSIS for Sustainable Supplier Selection in Electronics Supply Chains Menon and Ravi (2021) used a hybrid AHP-TOPSIS model for the sustainable selection of suppliers within one of the electronics supply chains, computing the weights of the criteria using AHP, and ranking eight potential suppliers using TOPSIS. The study found the hybrid approach effective at balancing sustainability, quality, and cost criteria, and reported strong internal consistency in the AHP judgments obtained from their expert panel.

Research Gap: The study is confined to the electronics sector and does not report a sensitivity analysis of the derived ranking, nor does it compare its results against any earlier or smaller dataset.

This paper addresses both gaps by using the identical hybrid AHP-TOPSIS framework for Indian manufacturing in general, and through the inclusion of sensitivity testing of sixteen scenarios and comparison with an earlier pilot dataset.

2.3.6 Sustainable Supplier Selection in Construction Using Hybrid AHP Methods As applied by Al Hazza et al. (2023) in their construction procurement sustainable supplier selection analysis, AHP is demonstrated as an effective tool for balancing sustainable performance and cost-efficiency in a sector with a low sustainability maturity history. The expert panel of the study emphasised cost and delivery reliability more than environmental aspects, which represents the sector's classic purchasing culture.

Research Gap: The study employed AHP, but without a complementary ranking strategy like TOPSIS, that is, candidate suppliers were not formally streamlined to an ideal solution that had been computed. This study's hybrid AHP–TOPSIS structure closes that gap by pairing AHP's criteria-weighting strength with TOPSIS's alternative-ranking strength.

2.3.7 Triple Bottom Line-Based Sustainable Supplier Selection Using Integrated AHP- TOPSIS Choudhary et al. (2021) developed an integrated AHP-TOPSIS framework explicitly structured around the triple bottom line, applying it to supplier evaluation with a strong emphasis on digitalisation as an enabler of real-time supplier-performance tracking. Their findings confirmed that AHP-TOPSIS hybrids give more consistent, auditable results than unaided managerial judgement.

Research Gap: Despite an explicit sustainability focus, the study confirms that cost and quality criteria still dominate the final AHP weight vector in practice, and ethical criteria such as conflict of interest and code of conduct remain comparatively underrepresented in the criteria set used. This study addresses the gap by including Ethical as a distinct, equally weighted first-level pillar in the AHP hierarchy.

17 2.3.8 Supplier Evaluation Considering Ethics and Sustainability in Indian Automotive Supply Chains Garg and Sharma (2021) examined supplier evaluation practices in the Indian automotive sector, finding that tighter international requirements have made ethical compliance and transparency increasingly important supplier-selection criteria. Their study documented specific instances where conflicts of interest and a lack of transparency undermined supplier- selection processes in practice.

Research Gap: The study is limited to the automotive sector and relies primarily on qualitative interview evidence rather than a quantitative, criteria-weighted ranking model.

This study builds on Garg and Sharma's (2021) finding that ethical criteria are under-formalised by giving Ethical criteria an explicit AHP weight (0.097) within a broader manufacturing context, rather than treating ethics as a qualitative afterthought.

2.3.9 Ethical Procurement in Indian Supply Chains: Drivers, Barriers, and Outcomes

Mishra et al. (2022) studied ethical procurement practices across Indian supply chains, finding that supplier compliance with social norms, ethical procurement, and transparency directly affects organisational reputation and stakeholder trust. The study also found that lax regulatory enforcement in emerging economies frequently undermines ethical sourcing commitments in practice, regardless of formal supplier-selection policy.

Research Gap: The results of the study are based on survey and interview data, instead of an MCDM ranking exercise, and thus do not imply how ethical criteria must be weighted in comparison to the economic, environmental and social criteria of an actual sourcing decision. This paper quantifies that trade-off directly in the weight vector of AHP as shown in Section 4.2.3.

2.3.10 A Multi-Criteria Framework for Assessing Social Sustainability in Supplier Selection Ali et al. (2024) designed a multi-criteria framework with a specific focus on evaluating supplier practices in community development, human rights, and worker health and safety, highlighting the increased research and practitioner attention to social sustainability as a unique pillar of supplier assessment, separate from and equally significant to environmental sustainability.

Research Gap: The framework is developed exclusively regarding the social aspect and fails to combine it with economic, environmental, and ethical evaluations within the same model; it does not compare the model with the working alternatives of suppliers. The work, which incorporates social criteria into a four-pillar framework, discovers, as the focus of Ali et al. (2024) suggests, that social sustainability has the highest weight in AHP among all four pillars (0.507) in this professional sample.

18 2.3.11 Sustainable Supplier Selection Using Fuzzy MCDM Approaches Kannan et al. (2021) argued that fuzzy extensions of MCDM methods are needed to properly handle the linguistic uncertainty inherent in expert judgement when evaluating sustainable suppliers, and demonstrated a fuzzy AHP-based model that outperformed a crisp (non-fuzzy) equivalent on a small validation sample.

Research Gap: The improvement in accuracy from fuzzification came at the cost of substantially greater computational and data-collection complexity, and the study did not test whether a well-validated crisp AHP–TOPSIS model checked through consistency ratio and sensitivity analysis could achieve comparably robust results without fuzzy logic. This study uses a crisp AHP–TOPSIS model precisely because its CR = 0.050 and its ranking's complete stability across sixteen perturbation scenarios (Section 4.2.7) demonstrate that fuzzification is not strictly necessary to obtain a robust result in this context, though it remains a valid avenue for future refinement (Section 5.3).

2.3.12 Evaluating Sustainable Procurement Adoption in Indian SMEs Using AHP- TOPSIS

Kumar and Routroy (2023) applied AHP-TOPSIS to evaluate sustainable procurement adoption specifically within Indian small and medium manufacturing enterprises (SMEs), finding that managers in this segment still prioritise cost and delivery over sustainable procurement criteria, though global supply-chain pressure is gradually raising awareness of environmental and ethical issues.

Research Gap: The study focuses on SMEs and therefore might not be applicable in general to larger manufacturing organisations

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with more developed procurement functions and better ability to absorb sustainability-related costs. This research expands the hybrid AHP-TOPSIS method to a broader panel of Indian manufacturing experts not limited to the SME segment.

2.3.13 Barriers to Sustainable Supplier Selection: Evidence from Indian Manufacturing A survey of procurement professionals, conducted by Ahmed et al. (2021), revealed that the most pronounced and recurring barriers to sustainable supplier selection in Indian manufacturing organisations were high implementation cost, limited supplier capacity, and lack of awareness among procurement managers.

Research Gap: The study quantifies the barriers qualitatively but fails to relate these barriers to a formal exercise of criteria-weighting to explain how these barriers may be translated into which criteria managers actually prioritize in practice. The AHP weight vector of this study, where Environmental sustainability has the lowest weight of all four pillars (0.058), provides a quantitative equivalent to the Ahmed et al. (2021) qualitative barrier results.

2.3.14 Hybrid MCDM Methods for Supplier Evaluation in Uncertain Environments Awasthi and Kannan (2022) affirmed that MCDM methods provide reproducibility and

19 transparency in supplier assessment, a property the authors argue is particularly valuable in industries subject to compliance audits and third-party sustainability certification, where the rationale for a supplier decision must be defensible after the fact.

Research Gap: The study is largely methodological and does not apply its argument to a specific Indian manufacturing dataset with real expert judgments and real candidate suppliers. This study operationalises Awasthi and Kannan's (2022) reproducibility argument directly, by documenting every AHP and TOPSIS calculation step in full (Sections 2.7 and 4.2) so that the entire ranking is independently auditable.

2.3.15 Sustainable Supplier Selection in Bangladesh's E-Commerce Sector: An Integrated TOPSIS-AHP Approach Shahriar et al. (2026) applied an integrated AHP TOPSIS framework with sensitivity analysis to sustainable supplier selection within Bangladesh's e-commerce sector, one of the most recent hybrid-MCDM applications in the literature, confirming that the combined approach remains a leading methodology for this class of problem as of 2026.

Research Gap: The study is set in the e-commerce sector of a neighbouring economy rather than Indian manufacturing, and its four-pillar structure does not treat ethics as a distinct pillar.

This study confirms the continuing relevance of the hybrid AHP TOPSIS-with-sensitivity- analysis approach identified by Shahriar et al. (2026), while extending it to Indian manufacturing with an explicit ethical pillar.

2.3.16 Integrating AHP and SAW for Sustainable Supplier Selection: A Post-Pandemic ESG Perspective Kaluku, Gienardy, Purnama, and Ariwijaya (2026) integrated AHP with the Simple Additive Weighting (SAW) method for sustainable supplier selection in green supply chains, adopting an explicit post-pandemic ESG (Environmental, Social, Governance) lens that treats governance-related criteria as a first-class concern alongside environmental and social criteria.

Research Gap: The study pairs AHP with SAW rather than TOPSIS, and SAW's simpler additive-weighting logic does not account for a supplier's distance from a negative-ideal (worst- case) solution the way TOPSIS does. This study retains TOPSIS specifically for its ability to reward suppliers who are simultaneously close to the best-case and far from the worst-case profile across all four criteria.

2.3.17 Sustainable Supplier Selection Based on a Comparative Decision-Making Approach Under Uncertainty Dehshiri (2026) compared several MCDM approaches for sustainable supplier selection under conditions of uncertainty, concluding that the choice of MCDM method can materially affect the resulting supplier ranking, and recommending that studies report sensitivity or robustness checks alongside their primary ranking result.

20 Research Gap: The study is a methodological comparison rather than an applied case study with a specific expert panel and supplier set. This study responds directly to Dehshiri's (2026) recommendation by reporting a full sixteen-scenario sensitivity analysis (Section 4.2.7) alongside the primary TOPSIS ranking.

2.3.18 A Cloud-Based MCDM Framework for Green-Resilient Supplier Selection in Manufacturing Yang, Geng, and Zhang (2026) proposed a cloud-based multi-criteria decision-making framework for green-resilient supplier selection in manufacturing, integrating real-time supplier data feeds into a continuously updated MCDM ranking, and demonstrating the feasibility of moving MCDM-based supplier evaluation from a periodic exercise to a continuous monitoring process.

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Research Gap: The cloud-based, real-time architecture proposed is a substantial digital- infrastructure undertaking not attempted in this study, which uses a single-round expert survey rather than continuous data feeds. The integration of real-time supplier information with formal AHP-TOPSIS ranking mechanism as conceptualized by Yang et al. (2026) is recognized as a particular direction for future work in this study (Section 5.3).

2.4 Summarized Outcome of the Literature Review The overall impression gained from the reviewed literature is that sustainability has become firmly established as a necessary consideration in supplier selection, and that hybrid MCDM techniques particularly AHP paired with TOPSIS are now recognised as the leading methodology for translating sustainability priorities into a defensible, ranked supplier decision.

The literature has verified that a combination of a criteria-weighting method (AHP) and an alternative-ranking method (TOPSIS) yields more accurate and auditable results than a single- criteria cost-based method of selecting or a manual managerial method of selecting.

In addition, the examined articles continuously indicate that Economic and, more often, Social criteria dominate the weight vectors of supplier selection in practice, whereas Environmental and, particularly, Ethical criteria are under-weighted in comparison to their declared strategic significance (Choudhary et al., 2021; Garg & Sharma, 2021; Mishra et al., 2022). This trend is also reflected in the AHP outcomes of this study (Chapter 4), in which Social and Economic criteria contain 84.5% of the overall decision weight.

However, the literature review identified a number of unresolved research gaps. First, most papers reviewed consider ethics as a sub-criterion nested within social sustainability rather than a first-level pillar. Second, some studies use AHP or TOPSIS as individual tools rather than as a validated hybrid pair. Third, very few studies formally test the robustness of their supplier ranking through weight-perturbation sensitivity analysis, and fewer still compare their results against an earlier or smaller dataset from the same context. Fourth, empirical hybrid-MCDM

21 applications are still confined to the Indian automotive industry and Indian SMEs, when more extensive Indian manufacturing is yet to be experimented with. Fifth, digitalisation and real- time information integration with official MCDM ranking is an emerging but not an established practice.

Based on these gaps, the current study designs a hybrid AHP–TOPSIS framework that (1) treats Economic, Environmental, Social, and Ethical criteria as four equally structured first-level pillars; (2) validates the AHP weights through a Consistency Ratio check; (3) validates the TOPSIS ranking through sixteen-scenario weight-perturbation sensitivity analysis; (4) explicitly compares the resulting ranking against an earlier, smaller pilot dataset from the same expert pool; and (5) applies the framework within Indian manufacturing more broadly, rather than being confined to the automotive sector or the SME segment alone.

3. RESEARCH GAP

However, the literature review identified a number of unresolved research gaps. First, most papers reviewed consider ethics as a sub-criterion nested within social sustainability rather than a first-level pillar. Second, some studies use AHP or TOPSIS as individual tools rather than as a validated hybrid pair. Third, very few studies formally test the robustness of their supplier ranking through weight- perturbation sensitivity analysis, and fewer still compare their results against an earlier or smaller dataset from the same context. Fourth, empirical hybrid-MCDM

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4. OBJECTIVES

1.5.1 Main Objective

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To identify the factors relevant to sustainable green supplier selection, and to develop a hybrid AHP–TOPSIS framework that weights these factors and ranks candidate suppliers accordingly.

5. METHODOLOGY

3.1 Introduction This chapter describes the methodology used for the development of the proposed hybrid AHP TOPSIS framework for sustainable supplier selection. The methodology consists of the entire research process, beginning with the research approach and study design, data collection, instrument development, sample design, and the statistical tools and methods used for AHP weighting, TOPSIS ranking, and sensitivity-based validation. To be explicit: this study does not use PLS-SEM, structural equation modelling, or formal hypothesis testing at any stage all validation is carried out through AHP consistency checking and TOPSIS sensitivity analysis alone.

3.2 Research Approach The study adopts a quantitative, cross-sectional research design to develop and validate a hybrid AHP TOPSIS framework for sustainable supplier selection. The choice of a quantitative design is justified by the nature of the study, which involves numerical pairwise-comparison data, structured supplier scoring, and formal statistical validation (Consistency Ratio and sensitivity analysis) rather than open-ended qualitative inquiry. The study draws on expert judgment from procurement and supply-chain professionals to derive criteria weights (via AHP) and to score candidate suppliers (via the TOPSIS decision matrix), and it validates the resulting ranking through weight-perturbation sensitivity analysis and comparison with an earlier dataset.

3.3 Study Design This research is conducted in stages: identification of the criteria, AHP-based criteria weighting, TOPSIS-based supplier ranking, and validation, which is done with sensitivity analysis and comparisons with a previous dataset. Each stage is informative and contributes toward developing a reliable, decision-relevant supplier-evaluation framework.

The first stage involved identifying the economic, environmental, social, and ethical criteria relevant to sustainable supplier evaluation, drawing on the literature review (Chapter 2) and consultation with procurement experts. The second stage involved collecting pairwise- comparison judgments from twelve procurement and supply-chain experts and aggregating them into a single AHP weight vector, checked for consistency. The third stage involved collecting supplier scores from the same expert panel for eight candidate suppliers against each of the four criteria, and applying the AHP weights within a TOPSIS ranking model. The fourth and final stage involved validating the resulting ranking through weight-perturbation sensitivity analysis (±10% and ±20%, sixteen scenarios in total) and comparison against an earlier, smaller pilot dataset collected from the same expert pool at an earlier stage of the research.

27 3.4 Data Collection Method The data used for this research were collected through structured expert surveys administered to twelve procurement and supply-chain managers within the Indian manufacturing sector.

Primary Data: collected through organised surveys with procurement and supply-chain managers; sustainability criteria refined using the Delphi method; pairwise comparisons of the four sustainability pillars gathered through structured AHP surveys using Saaty's 1–9 scale; supplier scores collected on a 1–10 scale against each of the four criteria for eight candidate suppliers.

Secondary Data: sustainability disclosures, supplier performance and audit reports (where available), and published case studies and industry reports on supplier evaluation in India, used to inform the criteria-identification stage and to contextualise the results.

3.5 Instrument Development The main instrument used for this study is a structured pairwise-comparison and supplier- scoring survey, developed and administered using Microsoft Excel, with all subsequent computation normalisation, eigenvector weight derivation, Consistency Ratio calculation,

TOPSIS ranking, and sensitivity analysis performed and cross-checked using Python (Pandas and NumPy).

3.5.1 AHP Pairwise-Comparison Instrument The AHP instrument presented each expert with all six pairwise comparisons among the four sustainability pillars (Economic vs. Environmental, Economic vs. Social, Economic vs. Ethical, Environmental vs. Social, Environmental vs. Ethical, Social vs. Ethical), using Saaty's standard 1–9 verbal-numerical scale. Individual expert judgments were aggregated using the geometric mean prior to weight derivation.

3.5.2 TOPSIS Supplier-Scoring Instrument The TOPSIS instrument presented each expert with eight candidate suppliers (labelled Supplier A through Supplier H) and asked them to score each supplier on a 1–10 scale against each of the four criteria, based on the expert's knowledge of the supplier's operational and sustainability performance. Individual expert scores were averaged to produce the final decision matrix used in the TOPSIS ranking.

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3.5.3 Software and Tools

Software / Tool Purpose Microsoft Excel Survey administration, pairwise-comparison and supplier-scoring data capture Microsoft Word Documentation and reporting of results

28 3.6 Sample Design

3.6.1 Study Population Description The study population includes the professionals in procurement and supply-chain management in the Indian manufacturing industry, along with the candidate suppliers that they assess. This involves the professionals charged with the role of selecting suppliers, managing suppliers and ensuring sustainability in their respective organisations.

3.6.2 Availability of Sampling Frame The sampling frame consisted of procurement and supply-chain professionals available through professional and industry contacts within Indian manufacturing organisations, along with a candidate set of eight suppliers familiar to the expert panel due to previous business interactions.

3.6.3 Selection of Sampling Method The research was purposively sampled by selecting expert respondents, as the AHP and TOPSIS both demand respondents with adequate domain knowledge to make meaningful pairwise comparisons and supplier evaluations. The respondents were selected according to their immediate professional work related to supplier selection or sustainability compliance decisions.

3.6.4 Sample Size The last sample comprised twelve procurement and supply-chain professionals who gave AHP pairwise comparisons, and TOPSIS supplier scores, comparing eight candidate suppliers to four sustainability criteria. This sample size is consistent with existing AHP practice whereby expert panels comprising 8-15 respondents are considered adequate for deriving stable, consistent priority weights.

3.6.5 Sample Unit The sample unit for the AHP component was a single expert's complete set of six pairwise comparisons among the four sustainability pillars. The sample unit for the TOPSIS component was a single expert's complete set of scores for one supplier across all four criteria.

3.7 Statistical Tools Used The following statistical tools and techniques were used in this study.

Saaty's AHP Methodology: used to derive criteria priority weights from pairwise- comparison judgments and to check the internal consistency of those judgments via the Consistency Ratio.

TOPSIS: used to rank candidate suppliers by their Closeness Coefficient to a computed positive-ideal and negative-ideal solution.

29 Weight-Perturbation Sensitivity Analysis: used to test whether the TOPSIS ranking remains stable when each AHP criterion weight is varied by ±10% and ±20%.

Geometric Mean Aggregation: used to combine the twelve individual experts' pairwise- comparison judgments into a single aggregated AHP matrix.

Vector Normalisation: used to normalise the TOPSIS decision matrix so that supplier scores across criteria with different scales become comparable.

3.8 Statistical Method The statistical method used in this research consists of a defined sequence of steps:

aggregation of expert pairwise comparisons, derivation of AHP priority weights, consistency checking, construction and normalisation of the TOPSIS decision matrix, computation of the weighted normalised matrix and ideal solutions, computation of separation distances and closeness coefficients, final supplier ranking, and validation through sensitivity analysis and comparison with an earlier dataset. The complete calculation sequence, including all intermediate matrices, is presented step by step in Section 4.2, so that the entire result is independently verifiable.

All twelve experts' pairwise-comparison judgments were first aggregated into a single 4×4 matrix using the geometric mean, from which priority weights were derived using the eigenvector method and checked for consistency using Saaty's Consistency Ratio. These weights were then applied within the TOPSIS ranking model to the averaged supplier-scoring data collected from the same twelve experts. Finally, the robustness of the resulting ranking was tested by perturbing each of the four AHP weights by ±10%

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and ±20% in turn, re- normalising the remaining three weights proportionally, and re-computing the TOPSIS ranking under each of the sixteen resulting scenarios.

3.9 Conclusions This chapter described the research methodology used to develop a hybrid AHP–TOPSIS framework for sustainable supplier selection. The study adopted a quantitative, cross-sectional research design, collecting primary data from twelve procurement and supply-chain experts within Indian manufacturing through structured AHP pairwise-comparison and TOPSIS supplier-scoring instruments. The chapter described the software and tools used, the sampling method and sample size, and the statistical method through which AHP weights and TOPSIS rankings were derived and validated. The next chapter presents the detailed results of this methodology, including the full AHP and TOPSIS calculations, the sensitivity analysis, and the comparison with an earlier dataset.

30 CHAPTER 4

RESEARCH FINDINGS AND ANALYSIS

6. RESULTS

The results are presented using the AHP criteria-weighting stage followed by TOPSIS supplier evaluation and sensitivity validation.

6.1 AHP Criteria Weights

Criteria	Weight	Rank
Social (SS)	0.507	1
Economic (ES)	0.338	2
Ethical (ET)	0.097	3
Environmental (EN)	0.058	4

Social sustainability is the most impactful criterion in the final AHP weighting, followed by Economic, Ethical and Environmental criteria.

6.2 AHP Consistency Ratio

The consistency check is used to verify whether the pairwise comparisons are logically acceptable. The calculated Consistency Ratio (CR) is approximately 0.050, which is below the commonly accepted threshold of 0.10. Therefore, the aggregated expert judgments are considered acceptably consistent for subsequent TOPSIS analysis.

6.3 TOPSIS Supplier Ranking

Rank	Supplier	Closeness Coefficient
1	Supplier C	0.932
2	Supplier A	0.875
3	Supplier G	0.788
4	Supplier B	0.662
5	Supplier F	0.470
6	Supplier D	0.417
7	Supplier E	0.287

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8	Supplier H	0.021

Supplier C achieved the highest closeness coefficient and was therefore identified as the best-performing supplier overall.

6.4 Sensitivity Analysis

Sensitivity analysis was conducted by perturbing the AHP criterion weights by ±10% and ±20% in turn and recomputing the TOPSIS ranking. The supplier order remained C > A > G > B > F > D > E > H across the tested scenarios, indicating that the final ranking is robust to reasonable changes in criterion weights.

6.5 Results Narrative

4.1 Introduction This chapter presents the results of applying the hybrid AHP TOPSIS methodology described in Chapter 3 to the data collected from twelve procurement and supply-chain experts within Indian manufacturing. The purpose of this chapter is to report the aggregated AHP pairwise-comparison matrix and derived criteria weights, the TOPSIS decision matrix and supplier ranking, the weight-perturbation sensitivity analysis, and the comparison against an earlier, smaller pilot dataset. Tables and figures are used throughout to present the results transparently and to allow the full calculation sequence to be independently verified.

4.2 Result Analysis

4.2.1 Expert Panel and Dataset Overview Twelve procurement and supply-chain experts from the Indian manufacturing sector completed both the AHP pairwise-comparison survey and the TOPSIS supplier-scoring survey. Eight candidate suppliers (Supplier A through Supplier H) were evaluated against four sustainability criteria: Economic (ES), Environmental (EN), Social (SS), and Ethical (ET). This is a first-level comparison: the four pillars are compared directly against one another as top-tier criteria, with no intermediate sub-criteria layer in the current model (a second-level comparison of sub-criteria within each pillar e.g., cost vs quality within Economic is identified as future scope; see Section 5.3).

4.2.2 AHP Pairwise-Comparison Matrix and Normalisation The pairwise-comparison ratios collected from all 12 experts for each of the six first-level criterion pairs were combined using the geometric mean and arranged into the 4×4 pairwise- comparison matrix below (rows/columns ordered ES, EN, SS, ET). A reciprocal value $a_{ji} = 1/a_{ij}$ is used below the diagonal, and every diagonal entry equals 1.

ES EN SS ET ES 1.000 5.942 0.442 5.076 EN 0.168 1.000 0.161 0.438 SS 2.265 6.205 1.000 4.762

ET 0.197 2.281 0.210 1.000 Table 4.1: Aggregated AHP Pairwise-Comparison Matrix (First-Level)

Each column is divided by its column sum (column sums: ES = 3.630, EN = 15.427, SS = 1.813, ET = 11.277), so every normalised column sums to 1, producing the normalised matrix below.

31 ES EN SS ET ES 0.275 0.385 0.244 0.450 EN 0.046 0.065 0.089 0.039 SS 0.624 0.402 0.552 0.422

ET 0.054 0.148 0.116 0.089 Table 4.2: Normalised AHP Pairwise-Comparison Matrix

4.2.3 AHP Criteria Weights and Consistency Check Averaging each normalised row gives the approximate priority weight of that criterion: w(ES) = (0.275+0.385+0.244+0.450)/4 = 0.339, w(EN) = 0.060, w(SS) = 0.500, w(ET) = 0.102. These row-average weights are an approximation; the exact eigenvector solution used for all subsequent TOPSIS calculations refines this approximation, and the two agree to within rounding. The weighted sum vector A·w was computed and each entry divided by the corresponding weight to estimate the principal eigenvalue: $\lambda_{max} \approx 4.14$ (average of 4.22, 4.05, 4.24, 4.03). The Consistency Index is $CI = (\lambda_{max} - n)/(n - 1) = (4.14 - 4)/3 = 0.046$, and with the Random Index for n = 4 (RI = 0.90), the Consistency Ratio is $CR = CI/RI = 0.046/0.90 \approx 0.050$. Since CR < 0.10, the aggregated first-level expert judgments are acceptably consistent, and the derived weights below are reliable for use in TOPSIS.

Rank Criteria Weight 1 Social (SS) 0.507 2 Economic (ES) 0.338 3 Ethical (ET) 0.097 4 Environmental (EN) 0.058 Table 4.3: AHP Criteria Weights and Ranking (Consistency Ratio = 0.050)

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Figure 4.1: AHP Criteria Weights (First-Level Comparison)

32 As Figure 4.1 shows, Social and Economic criteria together account for 84.5% of the total decision weight, identifying Social sustainability as the single most impactful criterion in this expert panel, while Ethical and Environmental criteria carry comparatively little weight.

4.2.4 TOPSIS Decision Matrix and Normalisation Eight candidate suppliers were scored on a 1–10 scale against each of the four criteria by the same expert panel, producing the decision matrix below.

Supplier ES EN SS ET Supplier A 8 7 9 7 Supplier B 9 8 7 7 Supplier C 9 8 9 7 Supplier D 7 5 6 6

Supplier E 7 8 5 6 Supplier F 5 4 7 5 Supplier G 8 6 8 9 Supplier H 5 5 4 5 Table 4.4: TOPSIS Decision Matrix (Supplier Scores)

The decision matrix was normalised using vector normalisation, $r_{ij} = x_{ij} / \sqrt{\Sigma x^2_j}$. The column norms are

$\sqrt{\Sigma(ES^2)} = 20.928$, $\sqrt{\Sigma(EN^2)} = 18.520$, $\sqrt{\Sigma(SS^2)} = 20.025$, and $\sqrt{\Sigma(ET^2)} = 18.708$.

4.2.5 TOPSIS Weighted Normalised Matrix and Ideal Solutions The normalised matrix was multiplied by the AHP-derived weights (ES 0.338, EN 0.058, SS 0.507, ET 0.097) to obtain the weighted normalised matrix. Since all four criteria are benefit criteria (higher is better), the positive-ideal solution V^+ takes the maximum of each weighted column, and the negative-ideal solution V^- takes the minimum, as shown for selected rows below.

Supplier ES EN SS ET Supplier C 0.145 0.025 0.228 0.036 (top) Supplier A 0.129 0.022 0.228 0.036

Supplier H 0.081 0.016 0.101 0.026 (bottom) Positive Ideal 0.145 0.025 0.228 0.047 (V+) Negative

0.081 0.013 0.101 0.026 Ideal (V−) Table 4.5: TOPSIS Weighted Normalised Matrix (Selected Rows)

33 4.2.6 Supplier Ranking Results The Euclidean separation distance of each supplier from the positive-ideal (D+) and negative-ideal (D -) solutions was computed, and the Closeness Coefficient CC
= D - / (D+ + D -) was derived for each supplier, as shown below.

Supplier D+ D− CC Supplier A 0.019 0.136 0.875 Supplier B 0.052 0.101 0.662 Supplier C 0.010

0.143 0.932 Supplier D 0.085 0.060 0.417 Supplier E 0.107 0.043 0.287 Supplier F 0.086 0.076 0.470

Supplier G 0.031 0.114 0.788 Supplier H 0.144 0.003 0.021 Table 4.6: TOPSIS Separation Distances and Closeness Coefficients

Rank Supplier Closeness Coefficient 1 Supplier C 0.932 2 Supplier A 0.875 3 Supplier G 0.788 4

Supplier B 0.662 5 Supplier F 0.470 6 Supplier D 0.417 7 Supplier E 0.287 8 Supplier H 0.021 Table

4.7: Final Supplier Ranking

34 Figure 4.2: TOPSIS Supplier Ranking by Closeness Coefficient Supplier C achieved the highest closeness coefficient (0.932) and is therefore the best- performing supplier overall, followed by Supplier A (0.875) and Supplier G (0.788). Supplier C and Supplier A score strongly on both Social

and Economic criteria the two most heavily weighted pillars confirming Social sustainability as the most impactful criterion identified in the AHP results, while Supplier H trails the field (0.021), scoring weakly across all four criteria.

4.2.7 Sensitivity Analysis of Criteria Weights Because criteria weights are estimates from expert judgement, the ranking's credibility depends on whether it holds up when those weights shift. Each of the four AHP criteria weights was perturbed by ±10% and ±20% in turn, with the remaining three weights re- normalised proportionally, and the TOPSIS ranking was recomputed for each of the 16 resulting scenarios.

Figure 4.3: Sensitivity Analysis - Ranking Stability Under Weight Perturbation

35 The complete eight-supplier ranking (C > A > G > B > F > D > E > H) was reproduced identically in all 16 perturbation scenarios, with no reversal at any rank and, in particular, no change to the top-3 order (Supplier C, Supplier A, Supplier G), as

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illustrated in Figure 4.3. This indicates that the ranking is not an artefact of a single, fragile weight estimate and can be relied upon even allowing for reasonable disagreement among experts about the exact relative importance of each pillar directly answering the third secondary objective set out in Section 1.5.2.

4.2.8 Comparison with Earlier Findings As a further robustness check, the current dataset (12 experts, 8 supplier alternatives) was compared against an earlier finding from this study a smaller pilot dataset (5 experts, 3 supplier alternatives) collected at an earlier stage to confirm that the larger dataset produces a more decisive and dependable ranking rather than a materially different one.

Diagnostic Earlier / Smaller Dataset Current Dataset Number of experts 5 12 Number of supplier 3 8 alternatives Consistency Ratio (CR) 0.073 0.050 Range of TOPSIS closeness 0.132 – 0.898 0.019 – 0.936 coefficients Table 4.8: Comparison with Earlier (Pilot) Findings

The larger, current dataset yields a lower (better) Consistency Ratio and a wider spread of closeness coefficients than the earlier finding, indicating a more decisive, better-separated, and less outlier-sensitive supplier ranking than the earlier pilot data produced.

4.3 Significance of the Results Obtained The proposed hybrid AHP–TOPSIS framework demonstrated its efficiency in ranking sustainable suppliers against four weighted criteria within Indian manufacturing. The AHP Consistency Ratio of 0.050 indicates that the aggregation of the expert judgments that form the criteria weights is credible, and the stability of the TOPSIS ranking under sixteen weight-perturbation cases indicates that the supplier ranking obtained is not overly sensitive to any of the weight estimates. The criteria weights by themselves are strategically important: when combined with the Social (0.507) and Economic (0.338) criteria, taking 84.5 per cent of the overall weight of the decision, this panel of experts can target the procurement teams to adopt the criteria that have the most significant impact on supplier selection. The comparison with the previous, smaller pilot dataset further proves that the

36 larger current dataset leads to a more accurate ranking, which confirms the confidence in the current findings as the sample of experts and suppliers increased.

4.4 Deviations from the Expected Results and Justification Although the overall strength of the results is high, there are some deviations from the initial expectations. To start with, the Environmental criteria had a significantly lower weight in the AHP (0.058) than it should have been under the conditions of the global focus on environmental sustainability as observed in the literature review (Chapter 2). This deviation is best explained by the specific priorities of this expert panel, who appear to weight social compliance and cost/quality performance more heavily than environmental performance when forced into a direct pairwise trade-off a pattern that is, in fact, consistent with several of the reviewed Indian studies (Garg & Sharma, 2021; Kumar & Routroy, 2023), even though it runs against the sustainability literature's normative emphasis on environmental criteria.

Second, while the TOPSIS ranking proved completely stable across all sixteen sensitivity scenarios, the closeness-coefficient gap between the lowest-ranked supplier (Supplier H, CC = 0.021) and the next-lowest (Supplier E, CC = 0.287) is unusually wide. This reflects Supplier H's consistently weak scores across all four criteria rather than any computational anomaly, and it is consistent with the wider overall spread of closeness coefficients observed in the current (larger) dataset relative to the earlier pilot dataset (Section 4.2.8).

Overall, the deviations observed were limited in scope and readily explained by the specific composition and stated priorities of the twelve-expert panel, rather than indicating any flaw in the AHP–TOPSIS methodology itself.

7. DISCUSSION

Viewed alongside the studies reviewed in Chapter 2, the results of this study confirm a pattern noted across much of the earlier literature: Economic and, increasingly, social criteria dominate the weight vectors derived from expert judgement, while Environmental and Ethical criteria are comparatively under-weighted (Choudhary et al., 2021; Garg & Sharma, 2021; Mishra et al., 2022; Kumar & Routroy, 2023). Earlier hybrid AHP–TOPSIS studies such as Menon and Ravi (2021) and Choudhary et al. (2021) demonstrated that the hybrid approach yields more consistent results than unaided managerial judgement but stopped short of testing whether their rankings would hold up under sensitivity analysis or against an independent dataset. Similarly, studies focused specifically on ethical and social dimensions (Ali et al., 2024; Garg & Sharma, 2021) treated these pillars in isolation rather than integrating them into a single weighted framework alongside economic and environmental criteria.Set against this backdrop, this paper gives the following exact contributions: (1) a four- pillar AHP weight vector: Economic, Environmental, Social, and Ethical, treated as equally structured, first-level criteria, rather than nesting Ethical within Social as in Luthra et al. (2017); (2) a validated TOPSIS ranking of eight candidate suppliers, with Supplier C identified as the top-performing supplier (Closeness Coefficient = 0.932); (3) a sixteen- scenario weight-perturbation sensitivity

analysis confirming that this ranking is not an artefact of a single fragile weight estimate, directly responding to Dehshiri's (2026) call for more robustness-checked studies; and (4) an explicit comparison against an earlier, smaller pilot dataset, confirming that the larger dataset produces a more decisive and dependable ranking. Together, these four contributions extend the reviewed literature from a largely single-shot, unvalidated weighting-and-ranking exercise to a fully validated, auditable decision-support framework for Indian manufacturing.

4.6 Conclusions The chapter outlined the findings from using the hybrid AHP-TOPSIS tool on the twelve- expert data set (eight suppliers) collected in this study. The AHP analysis yielded a consistent vector of criteria weight led by Social (0.507) and Economic (0.338) criteria and the TOPSIS analysis ranked Supplier C as the most performing supplier (CC = 0.932), which was completely stable over sixteen sensitivity-analysis conditions and compared well to a smaller pilot dataset done earlier. The importance of these results was also discussed in the chapter, and a reason was given for the slight differences that were found compared to initial expectations. The final chapter provides a summary of the study, general conclusions, and further directions for this research.

8. CONCLUSION

5.2.1 General Conclusions The proposed hybrid AHP–TOPSIS framework was successful in meeting the research objectives by identifying and weighting the criteria relevant to sustainable supplier selection and by producing a robust, sensitivity-validated supplier ranking. The literature review (Chapter 2) showed that sustainable supply chain management has developed into a multifaceted field requiring the joint evaluation of social, ethical, environmental, and economic factors, even though cost and quality still dominate practical supplier-selection criteria in much of the reviewed literature a pattern this study's own AHP results reproduce, with Social and Economic criteria together carrying 84.5% of the total decision weight.

The twelve-expert, eight-supplier Indian manufacturing dataset using the hybrid AHP- TOPSIS model resulted in a Consistency Ratio of 0.050, a criteria-weight order with Social (0.507) and Economic (0.338) sustainability first, and a Supplier ranking topped by Supplier C (Closeness Coefficient = 0.932).

This ranking held unchanged across sixteen weight-perturbation scenarios and compared favourably against an earlier, smaller pilot dataset from the same expert pool, confirming that the framework's output is both decision-relevant and methodologically robust.

Despite these findings, there are a number of limitations. Social and ethical factors, even though central to actual sustainable procurement are under-weighted in comparison to economic performance in much of the wider literature, and restraints to adoption, such as cost sensitivity, lack of supplier information, entrenched procurement cultures and long lead times, remain to slow the translation of sustainability theory into Indian industrial practice.

5.2.2 Significance of the Results Obtained The research findings are important because they indicate that a hybrid AHP-TOPSIS model can be used to create a credible, accountable and auditable foundation of sustainable supplier selection in Indian manufacturing - one founded on expert judgement, and formally verified by consistency checking and sensitivity analysis. The framework is not sector-specific in its logic and could theoretically be used in other manufacturing and service settings where supplier selection has to weigh economic, environmental, social and ethical factors. The finding that Social sustainability is the most influential criterion among this expert panel is a tangible, practical message to procurement teams to develop or update their own supplier scorecard.

5.3 Future Scope of Work

5.3.1 Fuzzy Extensions of AHP and TOPSIS The present crisp AHP-TOPSIS framework can be extended to Fuzzy AHP and Fuzzy TOPSIS to formally manage linguistic uncertainty in expert judgment in future studies, following the fuzzy MCDM literature discussed in Section 2.3.11 (Kannan et al., 2021).

5.3.2 Second Level (Sub-Criteria) Comparison The AHP model that is currently used is merely a first-level comparison of the four major sustainability pillars. A second level of pillar comparison of sub-criteria (such as cost versus quality in Economic, eco-design versus pollution control in Environmental) may be added to future work to provide a more detailed criteria-weighting structure.

5.3.3 ANP and DEMATEL for Criteria Interdependencies Further studies may investigate the Analytic Network Process (ANP)

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and the Decision- Making Trial and Evaluation Laboratory (DEMATEL) technique to model interdependencies between criteria that cannot be modeled in a strict AHP hierarchy such as where the environmental performance of a supplier affects its social reputation, or vice versa.

5.3.4 Real-Time Data Integration Building on the cloud-based MCDM framework proposed by Yang, Geng, and Zhang (2026) (Section 2.3.18), future work can explore integrating real-time supplier performance data drawn from ERP systems, sustainability disclosure platforms, or supplier audit databases into a continuously updated AHP–TOPSIS ranking, rather than relying on a single-round expert survey.

5.3.5 Cross-Sector and Cross-Regional Expansion A further study can expand the experts and candidates to include more Indian manufacturing sub-sectors than those discussed in this study, and can contrast outcomes across regions within India or other emerging economies to confirm whether the present observation, Social sustainability as the most impactful criterion, can be extrapolated to other expert panels.

5.4 Limitations While the framework performed reliably, the study is subject to the following limitations:

- The expert panel was limited to twelve procurement and supply-chain professionals, purposively sampled, which may not capture the full diversity of the Indian manufacturing sector. • Only eight candidate suppliers were evaluated; findings may not generalise directly to a larger or differently composed supplier pool. • Data were collected through a single-round survey, so supplier and criteria assessments reflect a single point in time rather than continuously updated information. • The AHP model uses only a first-level comparison of the four sustainability pillars, without a second level of sub-criteria within each pillar. • Ethical and Environmental criteria, while formally included, remain comparatively under-weighted relative to Economic and Social performance in this expert panel, reflecting the panel's stated priorities rather than a normative ideal. • Findings are specific to Indian manufacturing and would require further validation before being generalised to other sectors or regions.

Overall Conclusion This study has shown that a hybrid AHP-TOPSIS Multi-Criteria Decision-Making model can be used to conduct sustainable supplier selection in sustainable manufacturing in India. The criteria weight comparison further verified that the expert decision-making process is now led by Social and Economic aspects, whereas the TOPSIS ranking proved, and sensitivity testing showed, Supplier C as the most likely strong candidate overall.

41 This technique of structured pairwise comparison, consistency checking, weighted supplier ranking and formal sensitivity analysis provides a practical, defensible and repeatable procurement team tool to bridge sustainability theory and Indian industrial practice.

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