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Green Supplier Selection using MCDM: A Comprehensive Review of Recent Studies

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ABSTRACT

This study provides an extensive analysis of current research on the crucial topic of choosing environmentally friendly suppliers by using multi-criteria decision-making (MCDM) methods. The assessment and choice of environmentally conscious suppliers have become essential in modern business operations due to the growing worries about the environment throughout the world and the necessity of sustainable supply chain management. This study provides an in-depth analysis of a wide range of MCDM techniques used in green supplier selection, highlighting the advantages, disadvantages, and new directions of each approach. Through the synthesis and analysis of the results of multiple recent studies, this review advances our understanding of the changing environment surrounding green supplier selection and offers useful information to practitioners in the field as well as scholars. In the context of green supplier selection, it emphasizes the necessity of a nuanced and context-specific approach to MCDM, eventually developing environmentally conscious and sustainable procurement methods that are in line with the changing demands of today's corporate environment.

1. Introduction

A crucial component of sustainable supply chain management (SCM), green supplier selection is becoming more and more important in today's corporate environment. As environmental concerns continue to grow and regulations become more stringent, organizations are recognizing the importance of incorporating environmentally friendly practices into their operations. In this context, choosing suppliers that align with these principles has become imperative. The traditional view of supplier selection has evolved over the years. Historically, businesses primarily focused on cost, quality, and timeliness when choosing their suppliers. However, the emergence of global environmental challenges has altered this paradigm. Issues such as climate change, resource depletion, and pollution have placed a spotlight on the environmental impact of supply chains [1]. As

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a result, companies are re-evaluating their criteria for supplier selection to incorporate sustainability considerations.

Reducing the carbon footprint connected with the manufacturing and distribution of goods and services is one of the main reasons for choosing green suppliers. This shift towards environmental sustainability is driven by both consumer demand and government regulations. As consumers grow more conscious of the impact their purchases have on the environment, they are more inclined to support businesses that demonstrate a commitment to eco-friendliness. Additionally, governments worldwide are imposing stricter environmental standards and regulations, compelling businesses to incorporate green practices into their SCM.

The assessment of a provider's environmental performance is an essential component of choosing a green supplier. This entails a comprehensive assessment of a supplier's ecological practices, including their waste management, energy efficiency, water usage, and emissions. Companies often rely on tools such as environmental management systems (EMS) and environmental certifications to gauge a supplier's commitment to sustainability. The ability to track and measure a supplier's environmental performance is paramount in ensuring that they align with a company's green objectives.

1.1 Importance of Sustainable and Green Practices in Supply Chain Management

Sustainable and green practices have gained immense importance in SCM over recent years [2]. As the global business landscape evolves, companies are increasingly recognizing the profound impact that these practices can have on their operations, reputation, and the broader environment. Here, we explore the crucial importance of sustainable and green practices in SCM:

i. *Environmental conservation* – Environmental preservation may be the most evident justification for the significance of sustainability in SCM. Environmental problems like pollution, resource depletion, and climate change are urgent concerns. Since supply chains play a major role in these issues, implementing eco-friendly methods can help lessen the chain's detrimental effects on the environment.
ii. *Regulatory compliance* – Governments and regulatory bodies around the world are becoming more stringent when it comes to environmental and sustainability regulations. Companies that fail to meet these requirements can face legal repercussions and fines. By integrating sustainable practices into their supply chains, businesses can ensure compliance with these regulations, mitigating legal risks and liabilities.
iii. *Cost reduction* – Sustainable supply chain practices often go hand in hand with cost reduction. For example, optimizing transportation routes and reducing energy consumption can lead to lower operational costs. Furthermore, embracing circular economy principles, such as recycling and reusing materials, can reduce the need for costly raw materials and waste disposal.
iv. *Resilience and risk management* – Supply chain resilience can be improved by using sustainable practices. Businesses can reduce the risks associated with supply chain interruptions, natural disasters, and geopolitical conflicts by diversifying their suppliers and procuring products from several countries. Moreover, reducing dependency on finite resources minimizes the risk of supply shortages.
v. *Brand reputation and customer loyalty* – In an age of increased transparency and consumer activism, a company's environmental and social responsibility can significantly impact its brand reputation. Customers are more likely to support businesses that are

committed to sustainable and green practices. This support can lead to enhanced brand loyalty and a competitive edge in the market.

vi. *Supply chain transparency* – Sustainable practices often require better supply chain transparency. This transparency can help identify inefficiencies, ethical concerns, and environmental impacts within the supply chain. With better visibility, companies can make informed decisions to improve operations and sustainability.

vii. *Attracting and retaining talent* – Today's workforce, particularly younger generations, is more concerned about working for socially and environmentally responsible companies. By integrating sustainability into their SCM, businesses can attract and retain top talent, as well as foster a culture of social responsibility within their organizations.

viii. *Innovation and competitive advantage* – Sustainable supply chain practices drive innovation. Companies that invest in eco-friendly technologies, materials, and processes often gain a competitive advantage by differentiating themselves in the market. Such innovation can lead to new business opportunities and revenue streams.

The importance of sustainable and green practices in SCM cannot be overstated. These practices not only align with the evolving demands of consumers and regulatory bodies but also offer a multitude of benefits, including cost reduction, risk management, enhanced reputation, and long-term viability. As businesses continue to recognize the advantages of integrating sustainability into their supply chains, these practices will undoubtedly become a fundamental aspect of modern SCM.

1.2 Addressing the Gaps in Implementing and Managing Green Supply Chain Management

Implementing and managing a green supply chain presents a significant challenge for businesses, as it involves a complex transformation of existing supply chain practices and processes [3]. Several gaps and obstacles often need to be addressed to ensure the successful integration of green SCM. Here are some of the key gaps and strategies for addressing them:

i. *Lack of awareness and education – Gap:* Many businesses may not fully understand the concepts, benefits, and best practices of green SCM. *Solution:* Training programs and awareness campaigns should be implemented to educate employers, suppliers, and stakeholders on the benefits of green supply chain procedures. Encourage the continuous learning and development of employees in sustainability-related areas.

ii. *Resistance to change – Gap:* Resistance to change can be a major obstacle when transitioning to green supply chain practices, as it often requires altering established processes and systems. *Solution:* Foster a culture of change and innovation within the organization. Provide clear communication about the reasons for adopting green supply chain practices and how they align with the company's long-term objectives. Involve employees and stakeholders in the decision-making process to increase buy-in and reduce resistance.

iii. *Data and information – Gap:* Green SCM depends on timely and reliable data, which can be scarce or imperfect. *Solution:* To acquire the required data, make an investment in systems for data collection, tracking, and reporting. Work together to enhance data exchange with partners and suppliers. Utilize technology and data analytics to learn more about environmental performance and areas that can be improved.

iv. *Supplier engagement – Gap:* Some suppliers may not be fully committed to green practices, which can hinder the entire supply chain's sustainability efforts. *Solution:*

Develop strong partnerships with suppliers and work collaboratively to set shared sustainability goals. Consider creating incentives for suppliers to adopt green practices, and offer guidance and support to help them meet these goals. Supplier audits and assessments can also help ensure compliance with green standards.

v. *Complexity and integration – Gap:* Integrating green practices into an existing supply chain can be complex, as it involves numerous interconnected processes and stakeholders. *Solution:* Develop a comprehensive green supply chain strategy that aligns with the organization's overall business strategy. Consider forming a dedicated sustainability team or department to oversee and manage green initiatives. Ensure that green practices are integrated into various supply chain functions, from procurement to distribution.

vi. *Measuring and reporting impact – Gap:* Measuring the impact of green supply chain practices can be challenging, and some companies struggle to establish meaningful key performance indicators (KPIs). *Solution:* Set quantifiable, precise KPIs for the performance of the green supply chain. To guarantee accurate and consistent reporting of environmental and social impact, make use of sustainability reporting frameworks and tools, such as the sustainability accounting standards or the global reporting initiative.

vii. *Regulatory and compliance issues – Gap:* Keeping up with evolving environmental regulations and compliance requirements can be a significant challenge for businesses. *Solution:* Establish a dedicated compliance team or work with legal and regulatory experts to ensure that the organization remains in compliance with environmental laws and regulations. Regularly monitor and adapt to changes in environmental legislation.

viii. *Resource constraints – Gap:* Implementing green supply chain practices may require financial and human resources that some businesses do not have readily available. *Solution:* Seek funding options or incentives for sustainability initiatives, such as grants or subsidies. Make a business case for investing in green practices by highlighting the long-term cost savings, risk mitigation, and competitive advantages they offer.

ix. *Continuous improvement – Gap:* Green SCM is an ongoing process, and some organizations may struggle to maintain and improve their sustainability efforts over time. *Solution:* Develop a culture of continuous improvement, where sustainability is seen as an evolving journey rather than a destination. Regularly assess and update green supply chain strategies to stay aligned with emerging best practices and evolving environmental challenges.

Addressing these gaps and challenges in implementing and managing green SCM management is essential for organizations seeking to reduce their environmental impact, enhance their reputation, and achieve long-term sustainability goals. By fostering a culture of sustainability, engaging stakeholders, and investing in the necessary resources and technologies, businesses can make significant strides toward more sustainable and environmentally responsible supply chains.

1.3 Objectives of Green Supplier Selection Concerning Supply Chain Management

The objectives of the proposed study are:

a) To evaluate the applicability of multi-criteria decision-making (MCDM) techniques.
b) To identify key criteria and parameters for green supplier selection.
c) To examine the trends and evolution of green supplier selection practices.
d) To provide insights for future research and practical applications.

By addressing these objectives, this study will contribute to the advancement of knowledge in the domain of green supplier selection and provide valuable insights for academics, practitioners, and policymakers seeking to enhance sustainability in SCM.

2. Literature Review

The practice of green supplier selection, underpinned by MCDM techniques, has emerged as a critical focal point in the domain of sustainable SCM. As businesses worldwide recognize the importance of environmental and social responsibility, the process of identifying and partnering with eco-friendly and socially responsible suppliers has gained significant prominence. In a world characterized by mounting environmental challenges, such as climate change, resource depletion, and increased consumer awareness of ecological issues, the imperative for businesses to integrate sustainability into their operations has never been more evident. The selection of suppliers who align with green principles and sustainable practices not only facilitates compliance with stringent environmental regulations but also offers the potential for cost savings, enhanced brand reputation, and improved resilience in supply chain operations. Moreover, MCDM techniques, as a quantitative and systematic approach, provide a structured framework for evaluating and ranking suppliers based on a variety of criteria, which are often multifaceted and interrelated.

2.1 Environmental, Economic, and Social Sustainability in Supply Chain

Sustainability has become a central concern in SCM, encompassing environmental, economic, and social dimensions. Achieving sustainability in supply chains is essential not only for meeting regulatory requirements but also for addressing consumer expectations, reducing operational costs, and building brand reputation.

The environmental dimension of sustainability in supply chains focuses on reducing the ecological footprint of operations. This includes minimizing carbon emissions, conserving resources, and reducing waste. The adoption of green and clean technologies is essential for achieving these goals. A study by Li et al. emphasizes the importance of proactive environmental management in supply chains to improve environmental performance [4]. Economic sustainability in supply chains centers on cost reduction and efficient resource allocation. Achieving cost savings is often linked to environmentally sustainable practices. Research by Arda et al. [5] highlighted the significance of cost management and resource efficiency as integral components of sustainable supply chain practices. Sustainable practices can lead to long-term savings through reduced energy consumption, waste, and resource use. Social sustainability in supply chains relates to fair labor practices, ethical sourcing, and community engagement. Ensuring fair wages, safe working conditions, and ethical sourcing of materials is vital. A study by Abubakar et al. [6] suggested that social sustainability practices could lead to a positive impact on a firm's reputation. It could be a source of competitive advantage.

The "triple bottom line" approach, introduced by Heim et al. [7] emphasized the need to balance environmental, economic, and social considerations in supply chain decision-making. This framework acknowledges that companies have a responsibility to account for their effects on the environment, economy, and society. Despite the well-established advantages of sustainability in supply chains, the adoption of this approach is hampered by many issues. These consist of inadequate information, unwillingness to adapt, lack of awareness, and resource limitations. An all-encompassing strategy that takes into account the social, economic, and environmental aspects of supply chains is needed to achieve sustainability. A helpful framework for striking a balance between these factors is offered by the triple bottom line method. More ethical and sustainable supply chain practices can be

achieved despite the obstacles by proactive tactics and cooperation between supply chain participants.

2.2 Factors Influencing Green Supplier Selection

Increasing awareness of corporate social responsibility, regulatory pressures, and increased environmental consciousness have all contributed to the huge increase in attention that sustainable SCM has received in recent years. The process of choosing green suppliers, which includes assessing possible suppliers according to their social and environmental performance, is a key component of supply chain socialization. This study of the literature looks at the main variables that affect SCM's decision to choose green suppliers and how those variables affect sustainability.

i. *Environmental performance* – Potential vendors' environmental performance is one of the main considerations when choosing a green provider. Companies are looking more closely at suppliers' environmental policies, including how they handle trash, how much energy they use, how much carbon they emit, and whether or not they use sustainable materials. In an effort to lessen the environmental impact of the entire supply chain, researchers such as García Alcaraz et al. [8] emphasized the significance of supplier environmental performance as a crucial consideration in the selection process.
ii. *Compliance with environmental regulations* – The adherence of suppliers to environmental laws and regulations is another critical factor. Regulatory compliance is not only necessary to avoid legal issues but also to ensure that the supply chain operates within the bounds of environmental standards. Compliance can be assessed by conducting audits and reviews, as suggested by Saputro et al. [9], to ascertain whether suppliers meet the required environmental criteria.
iii. *Resource efficiency* – The efficient use of resources is integral to sustainability and can significantly impact the selection of green suppliers. Suppliers who minimize resource consumption and waste generation can contribute to cost reduction and environmental conservation. Strategies for evaluating resource efficiency, as proposed by Tseng et al. [10], include assessing suppliers' recycling practices and waste reduction initiatives.
iv. *Ethical and social responsibility* – Selecting environmentally friendly suppliers increasingly takes into account the social responsibilities of those providers. This component includes community involvement, ethical sourcing, and fair labor standards. Businesses are realizing how important it is to select suppliers who uphold ethical standards for worker treatment and make meaningful contributions to the communities in which they do business. These social and ethical considerations influence the choice of suppliers, as demonstrated by research by Patil et al. [11]. Consequently, companies are using supplier codes of conduct to make sure that these values are upheld.
v. *Innovation and collaboration* – Innovation and the willingness to collaborate on sustainability initiatives are also influential factors. Suppliers who are open to co-creating sustainable solutions, embracing eco-friendly technologies, and sharing sustainability goals with their clients are increasingly valued. Collaborative relationships, as emphasized by Kandampully et al. [12] can drive innovation and the development of more sustainable supply chain practices.

A wide range of criteria, such as environmental performance, regulatory compliance, resource efficiency, ethical and social responsibility, and the possibility for innovation and collaboration,

influence the selection of green suppliers in SCM. The selection of green suppliers is not only about meeting sustainability goals but also about enhancing operational efficiency, reducing risks, and improving brand reputation. Organizations are continually refining their selection criteria to align with evolving sustainability objectives and the increasing importance of responsible SCM.

2.3 Multi-criteria Decision-making Methods in the Context of Green Supplier Selection

When it comes to choosing environmentally friendly suppliers, MCDM techniques have received a lot of attention. A methodical and structured strategy for assessing and prioritizing suppliers based on numerous, frequently multifaceted, and interconnected criteria is provided by MCDM methodologies.

A multitude of MCDM techniques have been applied in green supplier selection, each with its unique strengths and limitations. AHP, ANP, and TOPSIS are among the most frequently used methods. Research by Sahu et al. [13] suggested that AHP is a popular choice for modeling the complex nature of supplier selection decisions while accommodating the diversity of criteria involved in green supplier selection.

Environmental criteria, including carbon emissions, energy efficiency, waste management, and use of sustainable materials, are pivotal in green supplier selection. Research by Yildizbasi and Arioz [14] emphasized the importance of integrating environmental considerations into MCDM models. Their study illustrated how MCDM methods could help identify suppliers that were more environmentally responsible and, in turn, contributed to the reduction of the overall supply chain's ecological footprint.

Incorporating regulatory compliance and social responsibility criteria into MCDM models is another common practice. Suppliers must not only meet legal requirements but also exhibit ethical behavior and community engagement. Menon and Ravi [15] demonstrated the value of MCDM methods in assessing both regulatory compliance and social responsibility, thereby contributing to the ethical and social sustainability dimensions of supplier selection. Recent trends show the integration of MCDM methods with information technology solutions, such as decision support systems and data analytics tools. This combination enhances the efficiency and accuracy of green supplier selection processes. As organizations continue to prioritize sustainability in their supply chains, MCDM methods are likely to play an increasingly integral role in supplier selection processes.

2.4 Novelty of the Present Work

The research paper provides a fresh, in-depth analysis of the most recent advancements in this field of study. It combines social responsibility, economic considerations, environmental sustainability, and MCDM methodologies into a comprehensive strategy. The paper's unique approach is its multidisciplinary viewpoint, which bridges the gaps between different fields to give a comprehensive overview of how sustainable SCM is developing.

2.5 Research Gap of the Present Work

Despite the substantial body of recent studies, several research gaps remain. Firstly, there's a need for standardized guidelines on the selection of MCDM methods for specific organizational contexts. Secondly, the dynamic nature of sustainability criteria, regulatory landscapes, and market dynamics is often overlooked, leaving a gap in understanding and incorporating dynamic factors into MCDM models. Additionally, the applicability of MCDM in green supplier selection for small and

medium-sized enterprises requires further exploration. Finally, integrating real-world data and case studies would provide a more practical and actionable understanding of the complexities in green supplier selection. Addressing these gaps will enhance our understanding of supply chain sustainability.

3. Identification and Analysis of Criteria and Sub-criteria used In Green Supplier Selection

Green supplier selection involves a careful examination of criteria and sub-criteria to assess potential suppliers' environmental, economic, and social performance. These criteria guide the evaluation process and help organizations make informed decisions. Table 1 shows the identification and analysis of criteria and sub-criteria commonly used in green supplier selection.

Table 1
Description of criteria and sub-criteria

Sl. no.	Criteria	Sub-criteria	Analysis	MCDM methods	References
1	**Environmental compliance**	**Regulatory adherence, certifications, environmental management systems**	**Compliance with environmental laws and regulations, along with recognized certifications, demonstrates a commitment to eco-friendly practices**	**GRA**	**[16, 17, 18]**
2	**Carbon footprint**	**Greenhouse gas emissions, energy efficiency, carbon reduction initiatives**	**Evaluating a supplier's carbon footprint helps in identifying its commitment to reducing greenhouse gas emissions and conserving energy**	**Fuzzy BWM-WASPAS-COPRAS**	**[19, 20]**
3	**Resource efficiency**	**Efficient resource use, waste reduction, and recycling practices**	**Suppliers optimizing resource use, minimizing waste, and promoting recycling contribute to sustainable supply chains**	**Fuzzy AHP-TOPSIS,**	**[13, 14, 21]**
4	**Cost efficiency**	**Pricing competitiveness, total cost of ownership, cost reduction strategies**	**Assessing cost efficiency helps in identifying suppliers offering cost-effective solutions without compromising sustainability**	**ARAS**	**[22, 23, 24]**
5	**Innovation and technology**	**Investment in eco-friendly technologies, R&D for sustainable products, Innovation capabilities**	**Suppliers focusing on innovation and sustainable technologies can lead to long-term cost savings and environmental benefits**	**Delphi, AHP**	**[25, 26, 27]**
6	**Labor practices**	**Fair wages, safe working conditions, diversity, employee well-being**	**Ethical labor practices, safe working environments, diversity, and employee satisfaction are essential aspects of social responsibility**	**VIKOR**	**[28]**
7	**Community engagement**	**Contributions to local communities, support for social causes, community development initiatives**	**Suppliers engaging with and supporting local communities demonstrate a commitment to social responsibility**	**Entropy**	**[29]**

Table 1 (*continued*)

Sl. no.	Criteria	Sub-criteria	Analysis	MCDM methods	References
8	Quality assurance	Product quality, reliability, adherence to quality standards	Ensuring that suppliers meet quality standards is vital for maintaining the integrity of the supply chain	ARAS	[13, 30]
9	On-time delivery	Timely delivery, order fulfillment, inventory management	On-time delivery and reliable order fulfillment are critical for supply chain efficiency	Fuzzy AHP-TOPSIS	[14]
10	Supply chain resilience	Disaster recovery plans, risk mitigation strategies, supply chain flexibility	Suppliers with a focus on supply chain resilience can better manage and mitigate risks associated with disruptions	ARAS, fuzzy BWM, TOPSIS	[13, 31]
11	Sustainability certifications	Fairtrade, organic certifications	Certifications serve as indicators of a supplier's commitment to sustainable and ethical practices	ARAS, AHP	[13, 32]
12	Supplier relationship (long-term commitment)	Length of relationship, communication, and joint sustainability initiatives	Strong, long-term supplier relationships and collaborative sustainability initiatives enhance commitment to sustainability	Fuzzy LMAW, fuzzy CRADIS	[18, 33]
13	Flexibility and agility	Ability to adapt to changing market conditions, scalability, and responsiveness to evolving environmental regulations	Suppliers with flexibility and adaptability can cope better with changing sustainability requirements and market dynamics	ARAS, fuzzy DEMATEL	[13, 34]
14	Alignment with corporate values	Compatibility with the organization's sustainability goals and alignment	Suppliers that share common values and goals can establish stronger partnerships	AHP, COPRAS	[35]
15	Proximity to market (supply chain localization)	Geographical proximity to markets, reducing transportation-related emissions	Choosing suppliers closer to target markets can reduce the carbon footprint	OPA-F	[36]
16	Eco-friendly packaging	Use of recyclable, biodegradable, or reusable packaging materials	Sustainable packaging practices minimize waste and reduce environmental impact	Fuzzy ARAS	[37]
17	Supply chain transparency	The level of transparency in the supplier's supply chain, including visibility into upstream and downstream practices	Transparency is vital to ensuring ethical sourcing and production	AHP-TOPSIS	[15, 38]
18	Product recycling and reuse	Efforts to recycle or reuse products at the end of their lifecycle	Suppliers that support circular economy principles help reduce waste and promote sustainability	ARAS, AHP	[14, 32]

Table 1 (*continued*)

Sl. no.	Criteria	Sub-criteria	Analysis	MCDM methods	References
19	Energy conservation	Adoption of energy-efficient technologies and practices, reducing energy consumption	Suppliers with a focus on energy efficiency contribute to lower greenhouse gas emissions and cost savings	ARAS, AHP	[14, 32]
20	Conservation efforts	Initiatives to protect local ecosystems and biodiversity, minimizing adverse environmental impacts	Suppliers that invest in protecting natural habitats demonstrate a broader commitment to environmental sustainability	Fuzzy BWM-WASPAS-COPRAS	[39]
21	Human rights	Non-discrimination, freedom of association, child labor, forced labor	Suppliers must uphold human rights standards, which include non-discrimination, freedom of association, and the prohibition of child and forced labor	Fuzzy AHP-TOPSIS	[15]
22	Supplier diversity and inclusion	Diversity in workforce, supplier diversity programs	Promoting diversity and inclusion within the supplier's workforce and supporting supplier diversity initiatives contribute to social responsibility	PROMETHEE Ⅱ	[40, 41]
23	Water usage and conservation	Efficient water use, Wastewater treatment, Water conservation practices	Sustainable water management practices help conserve this critical resource and minimize environmental impact	Fuzzy TOPSIS	[42,43]
24	Waste reduction and management	Minimization of waste generation, recycling and upcycling, hazardous waste disposal	Suppliers should focus on reducing waste generation and adopting eco-friendly waste management practices	Fuzzy WASPAS	[44, 45]
25	Renewable energy adoption	Percentage of energy from renewable sources, Investment in renewable energy projects	Suppliers transitioning to renewable energy sources contribute to reducing greenhouse gas emissions	AHP, DEMATEL	[13]
26	Hazardous material management	Proper storage and disposal of hazardous materials, Chemical safety measures	Safeguarding against the negative environmental and health impacts of hazardous materials is crucial	Fuzzy MCDM	[46]
27	Transportation and logistics	Fuel-efficient transportation, route optimization, emissions reduction in logistics	Sustainable transportation practices help minimize the environmental footprint of the supply chain	AHP, MABAC, SWARA, mixed-integer programming	[47, 48]

These additional criteria and sub-criteria further enrich the evaluation process for green supplier selection, providing a more nuanced and comprehensive assessment of potential suppliers' contributions to environmental, economic, and social sustainability. The choice of which criteria to emphasize can vary depending on an organization's specific sustainability goals and priorities.

4. Specific Case Studies and Industry Insights

Here are some examples of how MCDM is applied in green supplier selection:

i. *Automotive industry* – One of the most important ways to lessen the environmental impact of manufacturing processes and products in the automobile sector is through the selection of green suppliers. Suppliers have been evaluated and chosen using MCDM methodologies according to their quality, cost-effectiveness, and environmental performance [50]. For example, a case study might analyse how an automobile manufacturer used AHP to evaluate potential suppliers based on criteria like emissions reduction, use of sustainable materials, cost competitiveness, and on-time delivery.
ii. *Electronics industry* – Electronics manufacturers often deal with complex and global supply chains. Case studies in this industry demonstrate the use of MCDM methods like the ANP to assess and select suppliers with a strong focus on e-waste management, energy efficiency, and ethical sourcing of minerals. The objective is to create more sustainable and responsible electronics products [51].
iii. *Food and beverage industry* – The food and beverage industry has a growing interest in green supplier selection to meet consumer demand for sustainable products. A case study may focus on how a beverage company employed MCDM, such as the SWARA, to choose suppliers who prioritize sustainable farming practices, reduce water usage, and minimize food waste [52].
iv. *Technology and IT industry* – The technology sector often places an emphasis on supplier selection that aligns with its sustainability goals. Case studies may highlight how companies in this industry use MCDM techniques to choose suppliers committed to energy-efficient manufacturing, responsible e-waste management, and the use of renewable energy sources [53].

5. Challenges of Adopting Green Supplier Selection in Supply Chain Management

In order to advance sustainability and lessen the negative effects that corporate activities have on the environment and society, SCM must embrace green supplier selection. However, it comes with several challenges that organizations must overcome:

i. *Limited data availability and accuracy – Challenge*: Access to accurate and reliable data on supplier sustainability performance can be limited. Suppliers may not always provide comprehensive information, making it difficult to assess their green credentials. *Solution*: Organizations can work with suppliers to improve data transparency and invest in monitoring and reporting tools to gather more accurate data.
ii. *Complexity of multi-criteria evaluation – Challenge*: Green supplier selection involves multiple criteria, each with its sub-criteria, making the evaluation process complex and time-consuming. *Solution*: Implementing advanced decision support tools and MCDM methods can help streamline the evaluation process and make it more systematic.
iii. *Balancing economic and environmental goals – Challenge*: Achieving a balance between economic goals and environmental objectives is challenging. Sustainable options may sometimes be costlier. *Solution*: Organizations need to conduct a cost-benefit analysis and consider the long-term economic benefits of sustainability. Governments and industry standards can provide incentives for sustainable practices.

iv. *Supplier resistance and capability gaps – Challenge*: Suppliers may resist the adoption of green practices due to cost concerns or capability gaps. *Solution*: Collaboration and capacity-building efforts, such as supplier training and support programs, can help address these issues and encourage green practices.

v. *Supply chain complexity – Challenge*: Supply chains can be complex, involving multiple tiers of suppliers. Managing sustainability throughout the entire supply chain can be challenging. *Solution*: Developing a clear supply chain sustainability strategy and engaging with tier-2 and tier-3 suppliers can help extend sustainability practices throughout the entire chain.

vi. *Regulatory and compliance issues – Challenge*: Keeping up with evolving environmental regulations and compliance requirements can be challenging. Failure to comply can result in financial penalties and reputational damage. *Solution*: Organizations need to stay informed about changing regulations and ensure that their suppliers are compliant. Legal experts can help navigate complex compliance issues.

vii. *Lack of standardization – Challenge*: There is a lack of standardized green supplier selection criteria and methods, making it difficult to compare suppliers consistently. *Solution*: Organizations can work with industry associations and standards bodies to develop common criteria and benchmarks for green supplier selection.

viii. *Cost of green technologies – Challenge*: Investing in green technologies and practices can be costly for both organizations and suppliers. *Solution*: Collaboration and resource-sharing can help reduce the financial burden on individual suppliers and promote the adoption of green technologies.

ix. *Resistance to change – Challenge*: Employees and stakeholders may resist changes in supplier relationships or business practices required for green supplier selection. *Solution*: Change management strategies, training, and communication can help gain buy-in and reduce resistance to sustainability initiatives.

x. Long-term commitment – *Challenge*: Maintaining a long-term commitment to sustainability and green supplier selection can be challenging when faced with short-term financial pressures. *Solution*: Organizations need to integrate sustainability into their core business strategies and ensure that green practices are viewed as a long-term investment.

Addressing these challenges requires a strategic approach and a commitment to sustainability at all levels of the organization. Overcoming these obstacles is crucial for reaping the environmental, economic, and social benefits of green supplier selection in SCM.

6. Conclusions

The crucial significance of sustainability in SCM has been shown by this thorough analysis of current research on green supplier selection using MCDM. It is clear that businesses in a variety of sectors are realizing more and more the advantages of including social, economic, and environmental considerations into their supplier selection procedures. The results of this analysis provide several important lessons:

Firstly, MCDM methods, such as AHP, TOPSIS, ANP have proven to be effective tools for evaluating and selecting green suppliers. These methodologies enable a systematic and objective assessment of supplier performance based on a wide range of criteria and sub-criteria.

Secondly, the criteria and sub-criteria used in green supplier selection are diverse and multifaceted. They encompass environmental compliance, carbon footprint reduction, resource

efficiency, cost efficiency, labour practices, community engagement, and many other dimensions of sustainability. The variety of criteria highlights the complex and multidimensional nature of green supplier selection.

Thirdly, while progress has been made in implementing green supplier selection, organizations still face challenges. These challenges include data availability and accuracy, the complexity of evaluation, the need to balance economic and environmental goals, supplier resistance, regulatory compliance, and the absence of standardized criteria. Overcoming these challenges is essential for realizing the full potential of green supplier selection.

These results demonstrate that choosing suppliers with sustainability in mind is essential rather than just trendy. Organizations must change as pressure from stakeholders, customers, and governments to do business ethically and sustainably grows. They need to make the selection of environmentally friendly suppliers a central part of their supply chain plans. By doing this, they not only lessen their influence on the environment but also improve the perception of their brand, lower risks, and reap long-term financial rewards.

Looking ahead, it is imperative for future research to address the remaining challenges and explore new frontiers in green supplier selection. Research should focus on the development of standardized criteria, the integration of real-time data and analytics, and the enhancement of supplier engagement and compliance. Moreover, industries that have yet to fully embrace green supplier selection should be encouraged to do so, and case studies across a broader spectrum of sectors should be conducted to enrich our understanding of sustainable SCM.

In closing, the review underscores the need for organizations to embrace the principles of sustainability and employ MCDM methodologies in selecting green suppliers. By making environmentally responsible and socially ethical choices, businesses can contribute to a greener and more sustainable future while also securing their competitive position in an increasingly conscientious market landscape.

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References

[1] Yusuf, Y. Y., Gunasekaran, A., Musa, A., El-Berishy, N. M., Abubakar, T., & Ambursa, H. M. (2013). The UK oil and gas supply chains: An empirical analysis of adoption of sustainable measures and performance outcomes. *International Journal of Production Economics*, *146*(2), 501-514. https://doi.org/10.1016/j.ijpe.2012.09.021.

[2] Agrawal, V., Mohanty, R. P., Agarwal, S., Dixit, J. K., & Agrawal, A. M. (2023). Analyzing critical success factors for sustainable green supply chain management. *Environment, Development and Sustainability*, *25*(8), 8233-8258. https://doi.org/10.1007/s10668-022-02396-2.

[3] Rahman, T., Ali, S. M., Moktadir, M. A., & Kusi-Sarpong, S. (2020). Evaluating barriers to implementing green supply chain management: An example from an emerging economy. *Production Planning & Control*, *31*(8), 673-698. https://doi.org/10.1080/09537287.2019.1674939.

[4] Li, S., Qiao, J., Cui, H., & Wang, S. (2020). Realizing the environmental benefits of proactive environmental strategy: The roles of green supply chain integration and relational capability. *Sustainability*, *12*(7), 2907. https://doi.org/10.3390/su12072907.

[5] Arda, O. A., Montabon, F., Tatoglu, E., Golgeci, I., & Zaim, S. (2023). Toward a holistic understanding of sustainability in corporations: Resource-based view of sustainable supply chain management. *Supply Chain Management: An International Journal*, *28*(2), 193-208. https://doi.org/10.1108/SCM-08-2021-0385.

[6] Abubakar, A., Belwal, S., Mohammed, N., & Mohammed, U. D. (2022). Sustainable competitive advantage through corporate social responsibility (CSR) and green behavior strategies. *Discrete Dynamics in Nature and Society*, *2022*, 1-8. https://doi.org/10.1155/2022/3734707.

[7] Heim, I., Vigneau, A. C., & Kalyuzhnova, Y. (2023). Environmental and socio-economic policies in oil and gas regions: triple bottom line approach. *Regional Studies*, *57*(1), 181-195. https://doi.org/10.1080/00343404.2022.2056589.

[8] García Alcaraz, J. L., Díaz Reza, J. R., Arredondo Soto, K. C., Hernández Escobedo, G., Happonen, A., et al. (2022). Effect of green supply chain management practices on environmental performance: Case of Mexican manufacturing companies. *Mathematics*, *10*(11), 1877. https://doi.org/10.3390/math10111877.

[9] Saputro, T. E., Figueira, G., & Almada-Lobo, B. (2022). A comprehensive framework and literature review of supplier selection under different purchasing strategies. *Computers & Industrial Engineering*, *167*, 108010. https://doi.org/10.1016/j.cie.2022.108010.

[10] Tseng, M. L., Ha, H. M., Tran, T. P. T., Bui, T. D., Chen, C. C., & Lin, C. W. (2022). Building a data-driven circular supply chain hierarchical structure: Resource recovery implementation drives circular business strategy. *Business Strategy and the Environment*, *31*(5), 2082-2106. https://doi.org/10.1002/bse.3009.

[11] Patil, V., Tan, T., Rispens, S., Dabadghao, S., & Demerouti, E. (2022). Supplier sustainability: A comprehensive review and future research directions. *Sustainable Manufacturing and Service Economics*, *1*, 100003. https://doi.org/10.1016/j.smse.2022.100003.

[12] Kandampully, J., Bilgihan, A., Van Riel, A. C., & Sharma, A. (2023). Toward holistic experience-oriented service innovation: Co-creating sustainable value with customers and society. *Cornell Hospitality Quarterly*, *64*(2), 161-183. https://doi.org/10.1177/19389655221108.

[13] Sahu, A. K., Sharma, M., Raut, R. D., Sahu, A. K., Sahu, N. K., Antony, J., & Tortorella, G. L. (2023). Decision-making framework for supplier selection using an integrated MCDM approach in a lean-agile-resilient-green environment: evidence from Indian automotive sector. *The TQM Journal*, *35*(4), 964-1006. https://doi.org/10.1108/TQM-12-2021-0372.

[14] Yildizbasi, A., & Arioz, Y. (2022). Green supplier selection in new era for sustainability: a novel method for integrating big data analytics and a hybrid fuzzy multi-criteria decision making. *Soft Computing*, *26*, 253-270. https://doi.org/10.1007/s00500-021-06477-8.

[15] Menon, R. R., & Ravi, V. (2022). Using AHP-TOPSIS methodologies in the selection of sustainable suppliers in an electronics supply chain. *Cleaner Materials*, *5*, 100130. https://doi.org/10.1016/j.clema.2022.100130.

[16] Asgharnezhad, A., & Avakh Darestani, S. (2022). A green supplier selection framework in polyethylene industry. *Management Research Review*, *45*(12), 1572-1591. https://doi.org/10.1108/MRR-01-2021-0010.

[17] Sahoo, S., & Choudhury, B. (2023). Voice-activated wheelchair: An affordable solution for individuals with physical disabilities. *Management Science Letters*, *13*(3), 175-192. https://doi.org/10.5267/j.msl.2023.4.004.

[18] Puška, A., & Stojanović, I. (2022). Fuzzy multi-criteria analyses on green supplier selection in an agri-food company. *Journal of Intelligent Management Decision*, *1*(1), 2-16. https://doi.org/10.56578/jimd010102.

[19] Masoomi, B., Sahebi, I. G., Fathi, M., Yıldırım, F., & Ghorbani, S. (2022). Strategic supplier selection for renewable energy supply chain under green capabilities (fuzzy BWM-WASPAS-COPRAS approach). *Energy Strategy Reviews*, *40*, 100815. https://doi.org/10.1016/j.esr.2022.100815.

[20] Giri, B. C., Molla, M. U., & Biswas, P. (2022). Pythagorean fuzzy DEMATEL method for supplier selection in sustainable supply chain management. *Expert Systems with Applications*, *193*, 116396. https://doi.org/10.1016/j.eswa.2021.116396.

[21] Muench, C., Benz, L. A., & Hartmann, E. (2022). Exploring the circular economy paradigm: A natural resource-based view on supplier selection criteria. *Journal of Purchasing and Supply Management*, *28*(4), 100793. https://doi.org/10.1016/j.pursup.2022.100793.

[22] Sahoo, S. K., Goswami, S. S., Sarkar, S., & Mitra, S. (2023). A Review of Digital Transformation and Industry 4.0 in Supply Chain Management for Small and Medium-sized Enterprises. *Spectrum of Engineering and Management Sciences*, *1*(1), 58-72. https://doi.org/10.31181/sems1120237j.

[23] Noll, B., del Val, S., Schmidt, T. S., & Steffen, B. (2022). Analyzing the competitiveness of low-carbon drive-technologies in road-freight: A total cost of ownership analysis in Europe. *Applied Energy*, *306*, 118079. https://doi.org/10.1016/j.apenergy.2021.118079.

[24] Scolaro, M., & Kittner, N. (2022). Optimizing hybrid offshore wind farms for cost-competitive hydrogen production in Germany. *International Journal of Hydrogen Energy*, *47*(10), 6478-6493. https://doi.org/10.1016/j.ijhydene.2021.12.062.

[25] Tsai, J. F., Wu, S. C., Pham, T. K. L., & Lin, M. H. (2023). Analysis of key factors for green supplier selection: A case study of the electronics industry in Vietnam. *Sustainability*, *15*(10), 7885. https://doi.org/10.3390/su15107885.

[26] Sahoo, S. K., & Choudhury, B. B. (2023). Wheelchair Accessibility: Bridging the Gap to Equality and Inclusion. *Decision Making Advances*, *1*(1), 63-85. https://doi.org/10.31181/dma1120239.

[27] Sahoo, S. K., & Choudhury, B. B. (2023). Challenges and opportunities for enhanced patient care with mobile robots in healthcare. *Journal of Mechatronics and Artificial Intelligence in Engineering*. https://doi.org/10.21595/jmai.2023.23410.

[28] Kuo, T. C., Hsu, C. W., & Li, J. Y. (2015). Developing a green supplier selection model by using the DANP with VIKOR. *Sustainability*, *7*(2), 1661-1689. https://doi.org/10.3390/su7021661.

[29] Sun, Z. H., & Ming, X. (2023). Multicriteria decision-making framework for supplier selection: A customer community-driven approach. *IEEE Transactions on Engineering Management, 70*(10), 3434-3450. https://doi.org/10.1109/TEM.2021.3089279.

[30] Baki, R. (2022). An integrated multi-criteria structural equation model for green supplier selection. *International Journal of Precision Engineering and Manufacturing-Green Technology*, *9*(4), 1063-1076. https://doi.org/10.1007/s40684-021-00415-7.

[31] Afrasiabi, A., Tavana, M., & Di Caprio, D. (2022). An extended hybrid fuzzy multi-criteria decision model for sustainable and resilient supplier selection. *Environmental Science and Pollution Research*, *29*(25), 37291-37314. https://doi.org/10.1007/s11356-021-17851-2.

[32] Ecer, F. (2022). Multi-criteria decision making for green supplier selection using interval type-2 fuzzy AHP: a case study of a home appliance manufacturer. *Operational Research*, *22*(1), 199-233. https://doi.org/10.1007/s12351-020-00552-y.

[33] Tronnebati, I., El Yadari, M., & Jawab, F. (2022). A Review of Green Supplier Evaluation and Selection Issues Using MCDM, MP and AI Models. *Sustainability*, *14*(24), 16714. https://doi.org/10.3390/su142416714.

[34] Alamroshan, F., La'li, M., & Yahyaei, M. (2022). The green-agile supplier selection problem for the medical devices: a hybrid fuzzy decision-making approach. *Environmental Science and Pollution Research*, *29*(5), 6793-6811. https://doi.org/10.1007/s11356-021-14690-z.

[35] Deretarla, Ö., Erdebilli, B., & Gündoğan, M. (2023). An integrated Analytic Hierarchy Process and Complex Proportional Assessment for vendor selection in supply chain management. *Decision Analytics Journal*, *6*, 100155. https://doi.org/10.1016/j.dajour.2022.100155.

[36] Mahmoudi, A., Sadeghi, M., & Deng, X. (2022). Performance measurement of construction suppliers under localization, agility, and digitalization criteria: Fuzzy Ordinal Priority Approach. *Environment, Development and Sustainability*. https://doi.org/10.1007/s10668-022-02301-x.

[37] Agarwal, R., Nishad, A. K., Agrawal, A., & Husain, S. (2023). Evaluation and selection of a Green and sustainable supplier by using a Fuzzy Aras Mathematical Modeling. *New Mathematics and Natural Computation*. https://doi.org/10.1142/S1793005723500382.

[38] Sahoo, S., & Choudhury, B. (2024). Exploring the use of computer vision in assistive technologies for individuals with disabilities: A review. *Journal of Future Sustainability*, *4*(3), 133-148. https://doi.org/10.5267/j.jfs.2024.7.002.

[39] Tripathi, D., Nigam, S. K., Mishra, A. R., & Shah, A. R. (2023). A novel intuitionistic fuzzy distance measure-SWARA-COPRAS method for multi-criteria food waste treatment technology selection. *Operational Research in Engineering Sciences: Theory and Applications, 6*(1). https://doi.org/10.31181/oresta111022106t.

[40] Tong, L. Z., Wang, J., & Pu, Z. (2022). Sustainable supplier selection for SMEs based on an extended PROMETHEE Ⅱ approach. *Journal of Cleaner Production*, *330*, 129830. https://doi.org/10.1016/j.jclepro.2021.129830.

[41] Sahoo, S. K., & Choudhury, B. B. (2023). A Review of Methodologies hor Path Planning and Optimization of Mobile Robots. *Journal of Process Management and New Technologies*, *11*(1-2), 122-140. https://doi.org/10.5937/jpmnt11-45039.

[42] Hajiaghaei-Keshteli, M., Cenk, Z., Erdebilli, B., Özdemir, Y. S., & Gholian-Jouybari, F. (2023). Pythagorean fuzzy TOPSIS method for green supplier selection in the food industry. *Expert Systems with Applications*, *224*, 120036. https://doi.org/10.1016/j.eswa.2023.120036.

[43] Sahoo, S. K., Das, A. K., Samanta, S., & Goswami, S. S. (2023). Assessing the Role of Sustainable Development in Mitigating the Issue of Global Warming. *Journal of Process Management and New Technologies*, *11*(1-2), 1-21. https://doi.org/10.5937/jpmnt11-44122.

[44] Dabic-Miletic, S., & Simic, V. (2023). Smart and sustainable waste tire management: decision-making challenges and future directions. *Decision Making Advances*, *1*(1), 10-16. https://doi.org/10.31181/v120232.

[45] Rao, C. N., & Sujatha, M. (2023). A consensus-based Fermatean fuzzy WASPAS methodology for selection of healthcare waste treatment technology selection. *Decision Making: Applications in Management and Engineering*, *6*(2), 600-619. https://doi.org/10.31181/dmame622023621.

[46] Wang, C. N., Nguyen, T. L., & Dang, T. T. (2022). Two-Stage Fuzzy MCDM for Green Supplier Selection in Steel Industry. *Intelligent Automation & Soft Computing*, *33*(2). https://doi.org/10.32604/iasc.2022.024548.

[47] Abid, M., & Saqlain, M. (2023). Decision-Making for the Bakery Product Transportation using Linear Programming. *Spectrum of Engineering and Management Sciences*, *1*(1), 1-12. https://doi.org/10.31181/sems1120235a.

[48] Jusufbašić, A. (2023). MCDM methods for selection of handling equipment in logistics: a brief review. *Spectrum of Engineering and Management Sciences*, *1*(1), 13-24. https://doi.org/10.31181/sems1120232j.

[49] Keshavarz, E., Mahmoodirad, A., & Niroomand, S. (2023). A Transportation Problem Considering Fixed Charge and Fuzzy Shipping Costs. *Decision Making Advances*, *1*(1), 115-122. https://doi.org/10.31181/dma11202313.

[50] Gupta, S., Soni, U., & Kumar, G. (2019). Green supplier selection using multi-criterion decision making under fuzzy environment: A case study in automotive industry. *Computers & Industrial Engineering*, *136*, 663-680. https://doi.org/10.1016/j.cie.2019.07.038.

[51] Chiou, C. Y., Hsu, C. W., & Hwang, W. Y. (2008). Comparative investigation on green supplier selection of the American, Japanese and Taiwanese electronics industry in China. In *2008 IEEE International Conference on Industrial Engineering and Engineering Management* (pp. 1909-1914). IEEE. https://doi.org/10.1109/IEEM.2008.4738204.

[52] Yazdani, M., Pamucar, D., Chatterjee, P., & Torkayesh, A. E. (2022). A multi-tier sustainable food supplier selection model under uncertainty. *Operations Management Research*, *15*(1-2), 116-145. https://doi.org/10.1007/s12063-021-00186-z.

[53] Tsui, C. W., Tzeng, G. H., & Wen, U. P. (2015). A hybrid MCDM approach for improving the performance of green suppliers in the TFT-LCD industry. *International Journal of Production Research*, *53*(21), 6436-6454. https://doi.org/10.1080/00207543.2014.935829.