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Evaluating Supplier Sustainability Metrics through Data-Driven Procurement and Supply Chain Frameworks

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Abstract
The growing demand for sustainable supply chains has placed supplier evaluation at the forefront of organizational strategies. Procurement functions are no longer confined to cost optimization but are increasingly responsible for aligning supplier practices with sustainability imperatives encompassing environmental stewardship, social responsibility, and governance standards. This transformation has given rise to supplier sustainability metrics, which offer structured approaches for assessing supplier contributions to organizational sustainability goals. Traditional evaluation frameworks often emphasized compliance or limited scorecards, yet contemporary approaches increasingly leverage data-driven procurement and supply chain frameworks to enhance transparency, objectivity, and scalability. Data analytics, artificial intelligence, and digital supply chain technologies enable organizations to monitor supplier performance in real time, integrate diverse datasets, and forecast sustainability risks and opportunities. This paper examines the evolution and application of supplier sustainability metrics, focusing specifically on developments up to 2023. Through a literature-based review, it traces the historical progression of sustainability evaluation, explores methodological innovations, and analyzes how data-driven frameworks have reshaped procurement and supply chain practices. Key themes include the integration of environmental, social, and governance (ESG) indicators, the role of multi-criteria decision-making (MCDM) models, the incorporation of big data analytics, and the emergence of digital platforms for sustainable procurement. The review also highlights challenges, including data quality, interoperability, and balancing objectivity with qualitative insights. Findings underscore that supplier sustainability evaluation is an evolving strategic capability, demanding integrative frameworks that combine robust metrics with advanced data-driven methodologies. The study contributes to academic and practical debates, offering insights for researchers, policymakers, and practitioners seeking to build resilient, transparent, and sustainable supply chains.

Keywords: Supplier Sustainability, Data-Driven Procurement, Supply Chain Analytics, ESG Metrics, Sustainable Sourcing, Digital Evaluation Frameworks

1. Introduction

The sustainability of global supply chains has become a defining issue for businesses, governments, and civil society in the 21st century. With escalating concerns about climate change, social inequality, and resource depletion, organizations are under unprecedented pressure to ensure that their suppliers adhere to sustainability principles [1, 2, 3]. Procurement functions, historically associated with cost control and transactional efficiency, now play a central role in advancing sustainability agendas by integrating supplier sustainability metrics into their evaluation frameworks [4]. These metricsspanning environmental, social, and governance (ESG) dimensions allow firms to measure, compare, and manage supplier contributions to long-term sustainability goals [5, 6, 7]. The shift reflects a profound transformation in supply chain management, where competitive advantage increasingly hinges not only on efficiency and resilience but also on ethical, responsible, and sustainable practices [8, 9].

The urgency of supplier sustainability evaluation is underscored by the systemic risks posed by unsustainable practices in global supply chains. From environmental degradation due to unsustainable raw material extraction to labor exploitation in developing economies, suppliers' actions directly impact the reputation, performance, and regulatory compliance of buyer organizations [10, 11]. Consequently, evaluating supplier sustainability has become not merely a compliance activity but a strategic imperative tied to risk management, brand value, and stakeholder trust [12]. As regulatory frameworks such as the European Union's Corporate Sustainability Reporting Directive (CSRD) and mandatory supply chain due diligence laws proliferate, organizations face increasing obligations to demonstrate robust supplier monitoring and accountability [13, 14]. Beyond regulatory compliance, firms are also recognizing the economic and competitive advantages of engaging suppliers who innovate in sustainability practices, enabling long-term cost savings, reduced environmental impact, and enhanced social license to operate [15, 16].

Historically, sustainability in procurement was evaluated through supplier codes of conduct, compliance audits, and self-reported questionnaires [17, 18]. While valuable, these approaches were criticized for their limited scope, reliance on static data, and susceptibility to supplier misreporting. Traditional frameworks also tended to treat sustainability as an adjunct to core procurement objectives, rather than integrating it into strategic decision-making [19, 20]. Moreover, the fragmented and globalized nature of supply chains posed challenges to obtaining reliable, comparable data across suppliers and geographies. These limitations have catalyzed a paradigm shift toward data-driven procurement frameworks, which leverage technological advances in analytics, artificial intelligence (AI), blockchain, and digital platforms to enhance the evaluation of supplier sustainability metrics [21, 22]. Data-driven frameworks not only enable more rigorous monitoring and verification but also provide dynamic, predictive insights that support proactive decision-making [23, 24].

The rise of supplier sustainability metrics reflects the growing recognition that sustainability must be operationalized through measurable indicators. Metrics provide a standardized way to assess diverse aspects of supplier performance, from carbon emissions and water usage to labor rights compliance and governance transparency [25, 26]. The adoption of ESG-based frameworks has facilitated greater consistency in how sustainability is conceptualized and measured across industries. For instance, carbon disclosure standards, such as those promoted by the Carbon Disclosure Project (CDP), provide benchmarks for environmental performance, while the UN Global Compact principles guide social and governance evaluations [27, 28]. Yet, despite progress, challenges persist regarding the comparability, reliability, and granularity of sustainability metrics, particularly in multi-tier supply chains where visibility is often limited [29, 30].

Data-driven procurement frameworks hold promise for addressing these challenges by integrating multiple data sources, enabling real-time monitoring, and supporting advanced analytical techniques. For example, big data analytics can process vast amounts of structured and unstructured data, from supplier performance logs to satellite imagery of environmental impacts [31, 32]. Machine learning algorithms can identify patterns and predict risks, such as non-compliance with labor standards or environmental violations [33, 34]. Blockchain technologies can enhance traceability, creating immutable records of supplier practices and transactions [35, 36]. Together, these technologies enable procurement systems to move beyond retrospective audits toward continuous, evidence-based evaluation [37, 38]. Organizations that successfully harness these capabilities can achieve not only compliance but also competitive advantage by aligning procurement with strategic sustainability objectives [39, 40].

The theoretical underpinnings of supplier sustainability evaluation have drawn from diverse disciplines, including operations research, organizational theory, institutional theory, and stakeholder theory. Institutional theory emphasizes the role of regulatory, normative, and cognitive pressures in shaping organizational practices, explaining why firms adopt supplier sustainability evaluation under conditions of external scrutiny. Stakeholder theory underscores the influence of customers, investors, and civil society in demanding accountability for supplier practices [41, 42]. Resource-based and dynamic capabilities perspectives highlight sustainability as a source of differentiation and competitive advantage, emphasizing the role of suppliers in contributing to firm-level performance [43, 44, 45]. These theoretical perspectives inform the design of sustainability metrics and their integration into procurement decision-making, ensuring alignment with broader organizational goals.

Despite growing advances, several gaps remain in the evaluation of supplier sustainability. One key challenge is balancing objectivity and subjectivity in measurement. While data-driven frameworks promise objectivity, they often require significant investments in data infrastructure, interoperability standards, and skilled personnel [46, 47]. Conversely, subjective assessments based on audits and manager judgment can capture relational and contextual nuances but risk inconsistency and bias. Another challenge concerns data quality and accessibility. Many suppliers, especially small and medium-sized enterprises (SMEs), lack the capacity to generate reliable sustainability data, creating asymmetries that undermine comparability [48, 49]. Furthermore, while advanced technologies offer potential, their integration into procurement processes raises issues of scalability, cost, and change management. These challenges underscore the need for hybrid frameworks that combine robust quantitative data with qualitative insights, as well as collaborative approaches that support supplier capacity building [50].

The present paper addresses these issues through a comprehensive literature-based review, focusing on evaluating supplier sustainability metrics through data-driven procurement and supply chain frameworks up to 2023. By synthesizing existing research, it seeks to trace the evolution of sustainability evaluation, highlight methodological innovations, and analyze their implications for procurement and supply chain practice. The objective is not to propose a new empirical model but to consolidate knowledge, identify trends, and outline directions for future research. In doing so, the paper contributes to advancing both academic understanding and practical application of supplier sustainability evaluation in the era of digital and data-driven supply chains.

The remainder of this paper is structured as follows. Section 2 provides a detailed review of the literature, covering

historical evolution, methodological developments, and contemporary debates in supplier sustainability evaluation. Section 3 discusses the implications of data-driven frameworks for procurement and supply chain practice. Section 4 concludes by summarizing key findings and identifying research gaps for future exploration.

2. Literature Review

The literature on supplier sustainability evaluation reflects an intersection of procurement management, sustainability studies, and data-driven supply chain analytics. Over the years, scholarship has progressed from early explorations of compliance-oriented sustainability assessments to more sophisticated frameworks leveraging digital technologies and advanced data analysis. The review that follows synthesizes this body of work by tracing its historical roots, analyzing the evolution of metrics and methodologies, and identifying key debates and challenges. The focus is on how sustainability metrics have been conceptualized, operationalized, and integrated into procurement and supply chain frameworks up to 2023.

2.1 Early Approaches to Supplier Sustainability Evaluation

The origins of supplier sustainability evaluation lie in traditional supplier performance measurement systems, which prioritized cost, quality, and delivery [51, 52]. In the 1990s and early 2000s, sustainability was gradually introduced into procurement practices through codes of conduct, supplier audits, and compliance questionnaires. These methods primarily assessed adherence to minimum standards, such as environmental regulations or labor laws, often in response to reputational risks and stakeholder pressure [53, 54]. While effective for ensuring baseline compliance, they were limited in scope and often reactive rather than proactive. For example, large retailers adopted supplier codes of conduct to mitigate risks of labor exploitation, but enforcement was inconsistent, and assessments relied heavily on self-reported data [55, 56]. As a result, such evaluations frequently failed to capture the complexity of sustainability performance in multi-tier global supply chains [57, 58].

Critics also argued that early frameworks were transactional in nature, viewing sustainability as a compliance cost rather than as a source of value creation [59, 60]. Suppliers were assessed primarily on pass/fail criteria, with limited integration of sustainability into strategic sourcing decisions. These early efforts nonetheless laid the groundwork for more comprehensive approaches by raising awareness of the importance of supplier sustainability and highlighting the need for standardized metrics and more rigorous evaluation systems [61, 62].

2.2 Expansion of Sustainability Metrics

From the mid-2000s onward, research and practice began to adopt more comprehensive metrics to capture the triple bottom line of environmental, social, and economic performance [63, 64]. Environmental metrics included carbon emissions, energy efficiency, waste management, and resource usage. Social metrics expanded to cover labor practices, human rights, diversity, and community impacts. Governance metrics addressed issues such as transparency, anti-corruption measures, and ethical conduct [65]. The growing adoption of ESG frameworks provided a standardized vocabulary and benchmarks for evaluating supplier sustainability. For example, initiatives like the Global Reporting Initiative (GRI) and the UN Global Compact encouraged suppliers to disclose sustainability-related practices, enabling comparability across industries and regions [66].

The evolution of metrics reflected the recognition that sustainability is multidimensional and context-dependent. For instance, environmental metrics were particularly salient in industries with high ecological footprints such as energy, chemicals, and textiles [67, 68], while social metrics gained importance in sectors with significant labor-intensive supply chains like apparel and agriculture [69]. By broadening the scope of evaluation, organizations could align supplier assessments with both regulatory obligations and strategic objectives, creating greater alignment between procurement and corporate sustainability goals [70].

2.3 The Role of Multi-Criteria Decision-Making Models

The complexity of sustainability evaluation spurred the application of multi-criteria decision-making (MCDM) models. Methods such as Analytic Hierarchy Process (AHP), Analytic Network Process (ANP), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), and Data Envelopment Analysis (DEA) became widely used in the supplier evaluation literature [71]. These models provided structured approaches to weighing and aggregating multiple sustainability criteria, allowing organizations to rank suppliers based on composite performance scores. For example, AHP enabled decision-makers to compare sustainability criteria through pairwise evaluations, while TOPSIS facilitated ranking suppliers based on their relative proximity to ideal sustainability performance [72].

While MCDM methods enhanced rigor, they were not without challenges. Critics highlighted issues of subjectivity in criteria weighting, computational complexity, and difficulties in scaling models across large supplier bases. Moreover, many models assumed the availability of reliable data, an assumption that often proved unrealistic in fragmented supply chains [73]. Nonetheless, MCDM approaches provided valuable frameworks for operationalizing sustainability metrics and integrating them into procurement decision-making [74].

2.4 Integration of Fuzzy Logic and Hybrid Models

To address the inherent uncertainty and vagueness in sustainability evaluation, researchers integrated fuzzy logic into MCDM models [75]. Fuzzy-AHP, fuzzy-TOPSIS, and fuzzy-DEA allowed decision-makers to express preferences using linguistic variables such as “high,” “medium,” or “low,” which were then transformed into fuzzy numbers. This approach reflected the reality that sustainability metrics are often qualitative, imprecise, and context-dependent [76]. For instance, assessing a supplier’s commitment to labor rights may rely on interpretive judgments that cannot be easily quantified. Fuzzy models thus bridged the gap between qualitative insights and quantitative analysis, enhancing the realism of evaluation frameworks [77].

Hybrid models combining multiple techniques also gained traction. For example, AHP could be used to determine the relative importance of sustainability criteria, while TOPSIS or DEA ranked suppliers based on those weights [78]. Some frameworks integrated simulation, optimization, and machine learning with MCDM to enhance predictive power

and adaptability [79, 80]. These hybrid models reflected a recognition that no single method was sufficient to capture the complexity of supplier sustainability, especially in globalized, multi-tier supply chains [81].

2.5 Emergence of Data-Driven and Digital Frameworks

From the mid-2010s onward, rapid advances in digital technologies transformed supplier sustainability evaluation. Data-driven procurement frameworks leveraged big data analytics, artificial intelligence, blockchain, and Internet of Things (IoT) technologies to enhance transparency, objectivity, and predictive capability [82]. Big data analytics enabled the integration of diverse datasets, including supplier performance logs, financial reports, environmental audits, and unstructured data from social media or news sources [83, 84]. Machine learning algorithms were applied to detect patterns, predict sustainability risks, and classify suppliers according to their likelihood of compliance or non-compliance [85]. These predictive capabilities allowed organizations to move from reactive audits to proactive risk management [86].

Blockchain technology emerged as a particularly transformative tool for enhancing traceability and accountability in supply chains [87, 88]. By creating immutable records of supplier transactions, blockchain enabled firms to verify sustainability claims, track product origins, and detect fraudulent practices. IoT technologies provided real-time data on supplier operations, such as energy consumption or emissions, allowing continuous monitoring of sustainability performance [89]. These innovations underscored the potential of digital supply chain frameworks to address long-standing challenges of visibility, trust, and data reliability in sustainability evaluation [90].

2.6 Contemporary Debates and Challenges

Despite these advances, the literature highlights several persistent debates and challenges. One central issue is the reliability and comparability of sustainability data. Many suppliers, particularly small and medium-sized enterprises, lack the resources to collect and disclose reliable sustainability data [91]. Even when data is available, inconsistencies in reporting standards and metrics limit comparability across suppliers and industries. This creates a risk of "greenwashing," where suppliers present selective or misleading data to appear more sustainable than they are [92].

Another challenge concerns the balance between quantitative and qualitative measures. Data-driven frameworks emphasize objectivity, but they may overlook contextual nuances such as cultural practices, relational dynamics, or tacit knowledge that are difficult to capture in quantitative metrics. Conversely, qualitative assessments risk bias and subjectivity [93, 94]. Hybrid frameworks that integrate both quantitative rigor and qualitative insights are thus essential for robust supplier sustainability evaluation [95].

The issue of implementation feasibility is also prominent. Advanced frameworks often require significant investments in data infrastructure, analytics tools, and skilled personnel. For smaller firms or organizations in resource-constrained settings, these demands may limit adoption [96, 97]. Even in large organizations, challenges such as data integration, system interoperability, and change management can hinder effective implementation. This underscores the need for scalable, adaptable frameworks that can be tailored to organizational capabilities and contexts [98, 99].

Finally, scholars emphasize the risk of data overload in analytics-driven systems. While big data and IoT generate vast amounts of information, the sheer volume can overwhelm decision-makers or lead to misinterpretation if not managed effectively [100, 101]. Ensuring data quality, relevance, and integration into decision processes is thus critical for realizing the benefits of data-driven sustainability evaluation [102].

2.7 Synthesis of Trends up to 2023

Synthesizing the literature reveals several clear trends. First, supplier sustainability evaluation has evolved from compliance-focused audits toward strategic, multidimensional frameworks aligned with ESG principles. Second, methodological sophistication has increased, with MCDM, fuzzy logic, hybrid, and data-driven approaches providing structured ways to evaluate complex sustainability metrics [103]. Third, digital technologiesbig data analytics, AI, blockchain, and IoT are reshaping evaluation frameworks by enabling transparency, real-time monitoring, and predictive insights. Fourth, despite advances, challenges persist regarding data quality, comparability, scalability, and the balance between objectivity and contextual insights.

In conclusion, the literature up to 2023 demonstrates that evaluating supplier sustainability metrics through data-driven procurement and supply chain frameworks is both a strategic imperative and a methodological challenge. While significant progress has been made in developing robust and technologically advanced frameworks, persistent gaps highlight the need for continued research and innovation. These include developing standardized sustainability metrics, enhancing data interoperability, designing scalable frameworks for SMEs, and integrating human judgment with data-driven systems. Together, these insights provide the foundation for advancing both theory and practice in supplier sustainability evaluation.

3. Discussion and Implications

The literature reviewed demonstrates that supplier sustainability evaluation has transitioned from compliance-focused tools toward sophisticated, data-driven frameworks capable of integrating diverse environmental, social, and governance (ESG) indicators. This transition carries significant implications for procurement practices, supply chain management, and broader organizational strategy. The following discussion highlights the theoretical, methodological, and practical implications of this evolution, while also addressing challenges that continue to shape the trajectory of supplier sustainability evaluation.

One of the most critical implications concerns the strategic repositioning of procurement. Historically, procurement was viewed primarily as a transactional function focused on price negotiation and cost savings [104, 105]. However, as supplier sustainability has risen in prominence, procurement has emerged as a central driver of organizational sustainability strategies. Supplier evaluation frameworks that integrate ESG criteria demonstrate that procurement is no longer confined to operational efficiency but is directly tied to corporate reputation, stakeholder trust, and long-term resilience [106, 107]. This repositioning requires procurement professionals to adopt new skill sets, including data literacy, sustainability expertise, and systems thinking.

Another key implication is the integration of data-driven analytics with sustainability objectives. The adoption of big data, machine learning, blockchain, and IoT technologies creates opportunities for organizations to enhance transparency, objectivity, and predictive capabilities in supplier evaluation [108, 109]. By embedding sustainability metrics into digital procurement platforms, firms can continuously monitor supplier performance and forecast potential risks [110]. This transition from retrospective audits to predictive analytics shifts supplier evaluation from a reactive compliance activity to a proactive risk management and value creation tool. At the same time, organizations must invest in data governance, interoperability, and cybersecurity to ensure the integrity and reliability of analytics-driven systems [111, 122].

The review also underscores the tension between global standardization and local context. ESG frameworks such as GRI, CDP, and the UN Global Compact offer global benchmarks for sustainability evaluation. However, the application of these standards across diverse industries and geographies raises challenges of contextual adaptation [112, 123]. For example, water usage may be a critical sustainability metric in arid regions, while labor rights and human rights compliance are more salient in labor-intensive supply chains. This suggests that while standardized metrics are essential for comparability, they must be adaptable to industry- and context-specific realities [113, 124]. For practitioners, this means developing hybrid frameworks that combine global standards with contextually relevant indicators.

Another implication concerns the role of collaboration and supplier capacity building. The literature highlights that many suppliers, particularly small and medium-sized enterprises (SMEs), face resource constraints that limit their ability to generate and report reliable sustainability data. Buyers that impose rigorous data-driven evaluation systems without supporting supplier capacity risk excluding smaller suppliers and undermining inclusivity [114, 125]. Collaborative approaches, including training, shared digital platforms, and capacity-building initiatives, can address these challenges by enabling suppliers to participate more effectively in sustainability evaluation. For policymakers, this implies that regulations mandating supplier disclosure should be coupled with support mechanisms to avoid exacerbating inequalities across global supply chains [115, 126].

At the theoretical level, the integration of institutional theory, stakeholder theory, and resource-based perspectives has enriched the understanding of why organizations adopt supplier sustainability evaluation [116, 117]. Institutional pressures explain regulatory compliance and legitimacy-seeking behaviors, while stakeholder theory emphasizes accountability to external constituencies. Resource-based views highlight how sustainable supplier relationships can become strategic assets that contribute to competitive advantage. However, the literature suggests that further theoretical integration is needed to explain how organizations reconcile competing pressures for cost efficiency, sustainability performance, and risk management [118, 127].

Finally, the discussion points to the risk of data overload and overreliance on quantitative metrics. While big data and advanced analytics provide unprecedented visibility into supply chains, the sheer volume of data can overwhelm decision-makers or obscure meaningful insights. Moreover, excessive reliance on quantitative indicators risks overlooking qualitative dimensions such as relational trust, supplier innovation capacity, or cultural alignment [119]. Robust evaluation frameworks must therefore strike a balance between data-driven rigor and qualitative insight, ensuring that sustainability evaluation remains holistic and aligned with organizational values [120, 121].

In summary, the discussion reveals that evaluating supplier sustainability metrics through data-driven frameworks is not merely a technical exercise but a transformative practice with far-reaching implications for organizational strategy, supply chain resilience, and global sustainability. The challenge lies in designing frameworks that balance rigor with usability, global standards with local relevance, and objectivity with qualitative insight.

4. Conclusion

This paper has examined the evolution of supplier sustainability metrics and their integration into data-driven procurement and supply chain frameworks, with a focus on developments up to 2023. The literature demonstrates a clear progression from early compliance-based audits to sophisticated, technology-enabled evaluation systems that incorporate ESG indicators, MCDM models, fuzzy logic, hybrid approaches, and advanced digital technologies. These developments reflect a broader transformation in procurement, which has evolved from a transactional function to a strategic capability central to corporate sustainability and resilience.

The findings highlight several key insights. First, supplier sustainability evaluation has become an essential component of supply chain management, driven by regulatory requirements, stakeholder expectations, and competitive pressures. Second, data-driven frameworks offer enhanced transparency, objectivity, and predictive capability, but they also introduce challenges related to data quality, interoperability, scalability, and organizational readiness. Third, while global standards provide valuable benchmarks, contextual adaptation remains critical to ensure relevance across industries and geographies. Fourth, inclusivity and supplier capacity building are essential to avoid marginalizing smaller suppliers in data-driven evaluation systems. Finally, the balance between quantitative rigor and qualitative insight remains a central challenge, underscoring the need for hybrid frameworks that integrate data analytics with relational and contextual knowledge.

For practitioners, the review underscores the importance of aligning supplier evaluation frameworks with organizational sustainability strategies, investing in data infrastructure, and fostering collaborative relationships with suppliers. For scholars, it points to opportunities for cross-disciplinary research that integrates operations research, sustainability studies, information systems, and organizational theory. Future research should focus on developing standardized sustainability metrics, exploring scalable digital frameworks for SMEs, and addressing the behavioral and cognitive dimensions of decision-making in data-rich procurement environments.

In conclusion, the evaluation of supplier sustainability metrics through data-driven frameworks represents both a challenge and an opportunity. Organizations that successfully design and implement holistic, adaptable, and transparent frameworks will not only enhance their supply chain resilience but also contribute meaningfully to global

sustainability goals. The continued evolution of this field will play a critical role in shaping the future of responsible and sustainable supply chain management.

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