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Assessment of Sustainability in Supply Chain Management: Literature Study

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Abstract

This research extensively delves into sustainability measurement in supply chains, examining its importance, approaches, challenges, and prospects. The research commences by analyzing the multifaceted nature of sustainability, including environmental, social, and economic dimensions, and their incorporation into supply chain management methodologies. It highlights several frameworks and tools employed for measurement, such as life cycle assessments, social audits, and economic impact studies, emphasizing the intricate and varied nature of these methodologies. The study examines primary obstacles in measuring sustainability, including the complexity of global supply networks, diverse industries, and the lack of internationally recognized standards. These barriers serve to complicate the process of collecting, analyzing, and comparing data across various businesses and industries. Furthermore, the paper investigates emerging trends, namely the impact of cutting-edge technologies such as blockchain, the Internet of Things (IoT), and artificial intelligence on improving the precision and comprehensiveness of measurements. Moreover, the research examines the incorporation of sustainability measurement into other management systems, such as risk management and financial reporting, which demonstrates the increasing acknowledgment of sustainability as a fundamental business goal. The study underscores the significance of involving stakeholders and the necessity for more flexible and responsive quantification methods to tackle changing sustainability issues. In conclusion, the study consolidates important results and suggests areas for further investigation, such as the creation of uniform measurement frameworks, enhanced techniques for evaluating multi-tier supply chains, and approaches for successful implementation in small and medium-sized businesses. This paper enhances the evolving discipline of sustainable supply chain management by offering a comprehensive analysis of existing methods, obstacles, and potential future directions in sustainability assessment.

Keywords: Supply chain sustainability, Performance measurement, Sustainable development

Introduction

Sustainability Measurement in Supply Chains

In today's business landscape, supply chains have become critical components driving organizational success, particularly in an era of intensified competition (Silvestre et al., 2020). Simultaneously, there has been a significant increase in the emphasis on sustainability across all sectors, compelling organizations to adapt and consider the environmental, social, and economic impacts of their operations (Karmaker et al., 2021). Supply chain management is intricately linked to sustainability, as various activities within the supply chain directly affect resource utilization, pollution emissions, and community well-being (Zhu et al., 2022). For example, selecting environmentally friendly raw materials can reduce negative impacts on ecosystems, while improving working conditions in manufacturing plants can enhance laborers' quality of life.

Consequently, measuring sustainability in supply chains has become paramount, enabling organizations to assess operational efficiency, identify areas for improvement, and make strategic decisions effectively (Bag et al., 2020). However, measuring sustainability in supply chains remains challenging due to the complexity of systems and

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the diversity of relevant indicators. Currently, a variety of methods and tools are utilized to measure supply chain sustainability, such as Life Cycle Assessment (LCA), carbon footprint analysis, and social impact assessments (Nimsai et al., 2023). Nevertheless, gaps persist in the research and development of standardized measurement approaches that can be practically applied across diverse industries.

This literature review aims to explore and analyze concepts, methodologies, and tools used in measuring supply chain sustainability, encompassing environmental, social, and economic dimensions. Furthermore, it seeks to identify gaps in current knowledge and suggest future research directions. The article will begin by defining relevant concepts, followed by a discussion of frameworks and indicators used in measuring supply chain sustainability. It will then address methods and approaches for data collection and analysis, including challenges and limitations inherent to measurement. Finally, it will present trends and future developments in measuring sustainability in supply chains.

This literature review holds significance both academically and industrially, helping researchers and practitioners understand the current status of sustainability measurement in supply chains while identifying opportunities for improvement and innovation (Gold & Schleper, 2017). Moreover, it will contribute to the ongoing dialogue on integrating sustainability into business practices and decision-making processes. As organizations strive to balance economic growth with environmental stewardship and social responsibility, the need for robust and comprehensive sustainability measurement in supply chains becomes increasingly crucial.

This review aims to provide a foundation for further research and practical implementation of sustainability measurement strategies in supply chain management (Gong et al., 2018). By synthesizing current knowledge and highlighting emerging trends, this literature review aspires to contribute to the advancement of sustainable supply chain practices and foster a more resilient and responsible global business environment.

Literature Review

1. Sustainability in the Context of Supply Chains

1.1 Definition of Sustainability Sustainability, in its broadest sense, encompasses the ability to meet present needs without compromising the ability of future generations to meet their own needs (WCED, 1987). In the business context, sustainability is often conceptualized through the Triple Bottom Line (TBL) framework, which integrates environmental, social, and economic dimensions (Elkington, 1998). Recent research by Schaltegger et al. (2020) emphasizes that the definition of sustainability in business has evolved to include not only risk mitigation but also the creation of positive impacts and value for stakeholders.

1.2 Supply Chain Management (SCM) Supply Chain Management (SCM) refers to the coordination and management of all activities involved in sourcing, procurement, conversion, and logistics management (CSCMP, 2021). It encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities (Carter et al., 2015). Key components of SCM include supplier relationship management, demand planning, inventory management, and distribution (Lambert & Enz, 2017).

1.3 Sustainable Supply Chain Management (SSCM)

Sustainable Supply Chain Management (SSCM) integrates sustainability principles into traditional supply chain management practices. Seuring and Müller (2008) define SSCM as "the management of material, information, and capital flows as well as cooperation among companies along the supply chain while taking goals from all three dimensions of sustainable development, i.e., economic, environmental, and social, into account that are derived from customer and stakeholder requirements." Key drivers for adopting SSCM include regulatory pressures, stakeholder demands, competitive advantage, and risk management (Geng et al., 2017). However, implementing SSCM faces challenges such as complexity inherent to global supply chains, lack of transparency, and conflicting objectives among stakeholders (Mani et al., 2018).

1.4 Dimensions of Sustainability in Supply Chains

1.4.1 Environmental Sustainability

Environmental sustainability in supply chains focuses on minimizing negative impacts on the natural environment. This includes resource conservation, pollution prevention, waste reduction, and biodiversity preservation (Ahi & Searcy, 2015). Recent studies by Govindan et al. (2020) highlight the importance of circular

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economy principles for enhancing environmental sustainability within supply chains.

1.4.2 Social Sustainability

Social sustainability in supply chains addresses the human and societal aspects of business operations. Key areas include labor practices and human rights, community engagement, health and safety, and diversity and inclusion (Yawar & Seuring, 2017). Mani et al. (2016) emphasize the growing importance of social sustainability in supplier selection and evaluation processes.

1.4.3 Economic Sustainability

Economic sustainability in supply chains ensures long-term profitability while considering ethical and sustainable practices. This dimension encompasses fair trade practices, local economic development, innovation, and competitiveness (Carter & Rogers, 2008). Recent research by Geissdoerfer et al. (2018) suggests that integrating sustainability can lead to increased economic performance through innovation and improved stakeholder relationships.

The interplay between these three dimensions – environmental, social, and economic – forms the foundation of sustainable supply chain management, presenting both challenges and opportunities for organizations striving to balance profitability with responsibility (Dubey et al., 2017).

2. Definitions and Concepts in Sustainable Supply Chain Measurement

2.1 Measuring Sustainable Supply Chains

2.1.1 Importance of Measurement in SSCM

Measurement plays a crucial role in Sustainable Supply Chain Management (SSCM) by providing quantifiable data for decision-making and performance evaluation. Beske-Janssen et al. (2015) argue that effective measurement enables organizations to assess their progress toward sustainability goals, identify areas for improvement, and communicate performance to stakeholders. Furthermore, measurement facilitates benchmarking and continuous improvement in sustainable practices (Searcy, 2016).

2.1.2 Key Principles of Sustainability Measurement

Effective sustainability measurement in supply chains adheres to several key principles. These include relevance and materiality, ensuring that measured aspects are significant to the organization and its stakeholders; completeness and accuracy, providing a comprehensive and precise representation of performance; consistency and comparability, allowing for meaningful analysis over time and across organizations; and transparency and verifiability, enabling stakeholders to understand and validate the measurement process (GRI, 2021; Kühnen & Hahn, 2019).

2.1.3 Frameworks for Measuring Sustainability in Supply Chains

Several frameworks guide the measurement of sustainability in supply chains. The Global Reporting Initiative (GRI) provides widely adopted standards for sustainability reporting (GRI, 2021). The UN Sustainable Development Goals (SDGs) offer a global framework for addressing sustainability challenges, with increasing adoption in corporate sustainability strategies (Sachs et al., 2019). The ISO 14000 series provides standards for environmental management systems; while emerging Circular Economy indicators focus on resource efficiency and waste reduction (Kristensen & Mosgaard, 2020).

2.1.4 Types of Sustainability Measures

2.1.4.1 Quantitative Measures

Quantitative measures in SSCM include Key Performance Indicators (KPIs) that provide numerical data on specific aspects of sustainability performance. Life Cycle Assessment (LCA) offers a comprehensive approach to evaluating environmental impacts throughout a product's life cycle (Hellweg & Milà i Canals, 2014). Carbon footprint and water footprint measurements focus on specific environmental impacts and are increasingly used in supply chain management (Montoya-Torres et al., 2015).

2.1.4.2 Qualitative Measures

Qualitative measures in SSCM include supplier assessments, which evaluate suppliers' sustainability practices through questionnaires and audits (Gimenez & Sierra, 2013). Stakeholder feedback provides valuable insights into the perceived sustainability performance of an organization. Case studies and best practice benchmarking offer in-depth analysis of successful sustainability initiatives in supply chains (Beske et al., 2014).

2.1.5 Challenges in Measuring Sustainability in Supply Chains

Measuring sustainability in supply chains faces several challenges. Data collection and

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quality issues arise due to the complexity and global nature of modern supply chains (Bai & Sarkis, 2014). The lack of standardization in measurement approaches hinders comparability across organizations and industries (Ahi & Searcy, 2015). Balancing competing priorities, such as economic performance and environmental protection, presents ongoing challenges in sustainability measurement (Wu & Pagell, 2011).

2.1.6 Emerging Trends in Sustainability Measurement

Emerging trends in sustainability measurement leverage technological advancements. Big data and analytics enable more comprehensive and real-time sustainability performance monitoring (Hazen et al., 2016). Blockchain technology enhances traceability and transparency in supply chains (Saberi et al., 2019). Artificial Intelligence and Machine Learning facilitate predictive analytics and optimization of sustainable practices (Nishant et al., 2020). The Internet of Things (IoT) enables real-time monitoring of sustainability parameters throughout the supply chain (Ben-Daya et al., 2019). These definitions and concepts provide a comprehensive foundation for understanding and measuring sustainability in supply chains, reflecting the evolving nature of the field and the increasing importance of sustainable practices in global business operations.

2.2 The Importance of Sustainability Measurement in Supply Chains

Sustainability measurement in supply chains has become increasingly crucial in today's business environment. This section explores the necessity of effective measurement tools and explains how measurement aids in decision-making and process improvement.

2.2.1 The Need for Effective Measurement Tools

The complexity and global nature of modern supply chains necessitate robust and efficient measurement tools for sustainability. Several factors underscore this need.

2.2.2 Complexity Management Supply chains often span multiple countries and involve numerous stakeholders. Effective measurement tools help organizations navigate this complexity by providing clear, comparable data (Carter & Rogers, 2008).

2.2.3 Regulatory Compliance With increasing environmental and social regulations, companies need reliable tools to measure and report their compliance. Effective measurement ensures adherence to legal requirements and industry standards (Gualandris et al., 2015).

2.2.4 Stakeholder Expectations Investors, customers, and NGOs increasingly demand transparency in sustainability performance. Measurement tools enable organizations to meet these expectations by providing verifiable data (Meixell & Luoma, 2015).

2.2.5 Risk Management Sustainability risks in supply chains can have significant financial and reputational impacts. Effective measurement helps for early risk identification and mitigation (Giannakis & Papadopoulos, 2016).

2.2.6 Continuous Improvement Without measurement, it's challenging to identify areas for improvement. Effective tools provide the basis for setting targets and tracking progress over time (Beske-Janssen et al., 2015).

2.2.7 How Measurement Aids Decision-Making and Process Improvement

Sustainability measurement plays a pivotal role in enhancing decision-making and driving process improvements in supply chains.

1. Data-Driven Decision Making measurement provides quantifiable data that supports informed decision-making. For instance, lifecycle assessment data can guide product design choices for improved environmental performance (Hellweg & Milà i Canals, 2014).

2. Performance Benchmarking Measurement allows organizations to benchmark their performance against industry standards and competitors, identifying areas for improvement (Searcy, 2016).

3. Resource Allocation By quantifying sustainability performance, organizations can prioritize resources towards areas with the greatest potential for improvement or impact (Wu & Pagell, 2011).

4. Supplier Management Measurement enables effective supplier evaluation and selection based on sustainability criteria, fostering a more sustainable supply base (Gimenez & Sierra, 2013).

5. Process Optimization Regular measurement and analysis can reveal inefficiencies in processes, leading to optimizations that improve both sustainability and operational performance (Brandenburg et al., 2014).

6. Innovation Driver Sustainability measurement can highlight areas where innovation is needed, driving research and

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development efforts towards more sustainable solutions (Nidumolu et al., 2009).

7. Stakeholder Communication Measurement provides concrete data for reporting to stakeholders, enhancing transparency and trust (Gualandris et al., 2015).

8. Long-term Strategy Development Consistent measurement over time allows organizations to track long-term trends, informing strategic planning and goal-setting (Schaltegger & Wagner, 2017).

In conclusion, effective sustainability measurement in supply chains is not just a reporting tool but a strategic asset. It provides the necessary insights for organizations to make informed decisions, continuously improve their processes, and create long-term value while minimizing negative environmental and social impacts. As supply chains continue to evolve in complexity and global reach, the importance of robust and efficient sustainability measurement tools will only increase, driving the need for ongoing innovation in this field.

2.3 Current State of Sustainability Measurement in Supply Chains

Diversity of Methods and Tools

The field of sustainability measurement in supply chains has evolved rapidly, resulting in a wide array of methods and tools available to organizations. This diversity reflects the complexity of sustainability issues and the varied needs of different industries and organizations.

1. Standardized Frameworks Global Reporting Initiative (GRI) Widely adopted for sustainability reporting, providing standardized metrics across environmental, social, and economic dimensions (GRI, 2021). UN Sustainable Development Goals (SDGs) Increasingly used as a framework for aligning corporate sustainability efforts with global priorities (Sachs et al., 2019).

2. Life Cycle Assessment (LCA) Comprehensive method for assessing environmental impacts throughout a product's lifecycle (Hellweg & Milà i Canals, 2014). Various software tools are available, such as SimaPro and GaBi, offering different levels of complexity and industry-specific databases.

3. Carbon and Water Footprinting Focused tools for measuring specific environmental impacts, gaining popularity due to increasing concerns about climate change and water scarcity (Montoya-Torres et al., 2015). Examples include the GHG Protocol for carbon accounting and the Water Footprint Network's assessment methodology.

4. Supplier Assessment Tools Questionnaires and audit protocols designed to evaluate supplier sustainability performance (Gimenez & Sierra, 2013). Industry-specific initiatives like the Sustainable Apparel Coalition's Higg Index for the textile industry.

5. Circular Economy Indicators An emerging set of metrics focused on resource efficiency, waste reduction, and closed-loop systems (Kristensen & Mosgaard, 2020). Examples include material circularity indicator and recycling rates.

6. Social Impact Assessment Tools for measuring social sustainability aspects, including labor practices, community impact, and human rights (Yawar & Seuring, 2017). The Social Life Cycle Assessment (S-LCA) methodology gaining traction.

7. Integrated Scorecards Balanced Scorecard approach adapted for sustainability, integrating sustainability metrics with traditional financial and operational measures (Hansen & Schaltegger, 2016).

8. AI and Big Data Analytics Emerging tools leveraging artificial intelligence and big data for real-time sustainability performance monitoring and predictive analytics (Hazen et al., 2016).

2.4 Challenges in Selection and Implementation

While the diversity of methods and tools offers flexibility, it also presents significant challenges in selection and implementation.

1. Lack of Standardization The multitude of approaches makes it difficult to compare performance across organizations or even within complex supply chains (Ahi & Searcy, 2015). Challenge in selecting the most appropriate tools for specific organizational needs.

2. Data Collection and Quality Gathering accurate and comprehensive data, especially from suppliers in different geographical locations, can be resource-intensive (Bai & Sarkis, 2014). Ensuring data quality and reliability across diverse sources remains a significant challenge.

3. Complexity and Resource Requirements Many tools, particularly comprehensive ones like LCA, require significant expertise and resources to implement effectively (Hellweg &

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Milà i Canals, 2014). Small and medium-sized enterprises may find it challenging to allocate necessary resources.

4. Balancing Breadth and Depth Striking a balance between comprehensive measurement and focused, actionable metrics is often difficult (Searcy, 2016). There is a risk of information overload or oversimplification.

5. Supply Chain Visibility Limited visibility beyond tier-one suppliers hinders comprehensive sustainability measurement (Busse et al., 2017). There are challenges in cascading measurement practices throughout the supply chain.

6. Alignment with Business Strategy Integrating sustainability measurement with overall business strategy and operations can be challenging (Schaltegger & Wagner, 2017). It is difficult to demonstrate the direct link between sustainability performance and financial outcomes.

7. Regulatory Compliance Keeping up with evolving regulations and ensuring measurement tools meet compliance requirements across different jurisdictions (Gualandris et al., 2015).

8. Stakeholder Expectations Addressing diverse and sometimes conflicting stakeholder expectations in sustainability measurement and reporting (Meixell & Luoma, 2015).

9. Technology Integration Integrating new measurement tools with existing IT systems and processes can be technically challenging and resource-intensive (Hazen et al., 2016).

In conclusion, while the current state of sustainability measurement in supply chains offers a rich array of methods and tools, organizations face significant challenges in selecting and implementing the most appropriate approaches. The key lies in understanding organizational needs, industry context, and stakeholder expectations to develop a tailored approach to sustainability measurement that is both effective and feasible.

2.5 Framework for Measuring Sustainability in Supply Chains

The measurement of sustainability in supply chains typically follows a triple bottom line approach, encompassing environmental, social, and economic dimensions. This framework provides a comprehensive view of an organization's impact and performance across these three interconnected areas.

Environmental indicators, highlighting the growing concern for ecological impact. Key measures include greenhouse gas emissions, energy efficiency, water usage, waste management, and biodiversity impact. These indicators provide a holistic view of a supply chain's environmental footprint.

Greenhouse gas emissions, measured in CO2 equivalent, directly address climate change concerns. Energy efficiency metrics help companies optimize resource use and reduce costs. Water usage indicators are crucial in addressing scarcity issues, while waste management metrics promote circular economy principles. The inclusion of biodiversity impact demonstrates a growing awareness of supply chains' effects on ecosystems.

The social dimension of sustainability is equally important, focusing on the human aspect of supply chains. The framework includes indicators for labor practices, human rights compliance, community impact, diversity and inclusion, and product responsibility.

These indicators ensure that companies maintain ethical standards throughout their supply chains. By measuring factors such as workplace safety, adherence to human rights principles, and community development initiatives, organizations can foster positive relationships with workers and local communities. The inclusion of diversity and product responsibility metrics further emphasizes the broader social impact of supply chain operations.

The economic dimension completes the sustainability triad, focusing on long-term financial health and ethical business practices. Key indicators include financial performance, innovation and R&D, local economic impact, fair trade practices, and risk management.

These metrics go beyond traditional financial measures to include sustainability-focused investments and their returns. By assessing local economic contributions and fair-trade practices, companies can ensure their operations benefit all stakeholders. The inclusion of risk management emphasizes the importance of anticipating and mitigating sustainability-related challenges.

This comprehensive framework of sustainability indicators provides a robust tool for organizations to assess and improve their supply chain practices. By addressing environmental, social, and economic factors,

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companies can create more resilient, ethical, and sustainable supply chains. As global awareness of sustainability issues grows, such frameworks will become increasingly vital in guiding business practices and fostering responsible corporate citizenship.

Methodology

The measurement of sustainability in supply chains is a complex process that requires a systematic approach to data collection, analysis, and reporting. This overview provides a comprehensive look at the methods and approaches used in each of these crucial stages.

Data Collection

The measurement of sustainability in supply chains is inherently complex and requires a systematic approach to data collection, analysis, and reporting. This section provides a comprehensive overview of the methods used in each of these critical stages.

Effective sustainability measurement begins with robust data collection practices, utilizing both primary and secondary sources to provide a complete picture of supply chain performance.

Primary Data Collection

Organizations often start with direct engagement with supply chain stakeholders. This involves standardized surveys and questionnaires distributed to suppliers and other key partners, as noted by Mani et al. (2018), enabling consistent data collection across diverse supply chain actors. To validate responses, site visits and audits are conducted. Gimenez & Sierra (2013) emphasize that on-site assessments are critical for verifying sustainability practices and identifying improvement areas.

In addition to surveys and audits, in-depth interviews with key personnel provide valuable qualitative insights that may not be captured through quantitative data alone (Seuring & Müller, 2008). The use of Internet of Things (IoT) technology has also revolutionized data collection, as IoT sensors now offer real-time data on various sustainability metrics, such as energy use and emissions (Ben-Daya et al., 2019).

Secondary Data Collection

Secondary data collection complements primary methods by analyzing existing documents. This includes reviewing sustainability reports from suppliers (Tachizawa & Wong, 2014), accessing industry databases for benchmarking (Ahi & Searcy, 2015), and evaluating reports from government agencies and NGOs (Gold et al., 2010).

Ensuring Data Quality

Ensuring data quality is paramount throughout the collection process. Bai & Sarkis (2014) emphasize the need for robust verification processes to ensure accuracy. Standardizing data formats and units across the supply chain is crucial for meaningful analysis (Beske-Janssen et al., 2015). Clear data governance protocols, including guidelines for data ownership, access, and security, are essential for managing large volumes of information (Hazen et al., 2016).

Data Analysis

After data collection, the next critical step is analysis, which combines quantitative and qualitative methods to derive meaningful insights.

Quantitative Analysis

Statistical methods are commonly used to identify trends and correlations within the data, revealing patterns in sustainability performance (Brandenburg et al., 2014). Life Cycle Assessment (LCA) provides a comprehensive view of environmental impacts throughout a product's lifecycle (Hellweg & Milà i Canals, 2014).

For more complex decision-making, multi-criteria decision analysis methods, such as the Analytic Hierarchy Process (AHP) or Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), are applied. Govindan et al. (2015) demonstrate how these techniques help balance multiple sustainability criteria in supplier evaluation.

Qualitative Analysis

Qualitative methods complement quantitative approaches by offering context-rich insights. Content analysis of reports and interviews can reveal qualitative patterns not captured by numerical data (Seuring & Gold, 2012). Case study analysis provides an in-depth look at specific sustainability initiatives (Pagell & Wu, 2009), while stakeholder mapping helps assess the influence and interests of various stakeholders, guiding engagement strategies (Meixell & Luoma, 2015).

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Advanced Analytical Techniques

As technology advances, more sophisticated techniques are being adopted. Big data analytics allows organizations to process large datasets, uncovering patterns that traditional methods might miss (Hazen et al., 2016). Predictive modeling is used to forecast future sustainability performance, enabling proactive issue resolution (Sarkis & Zhu, 2018). Machine learning and artificial intelligence methods are increasingly applied to recognize patterns and optimize performance across complex supply chains (Nishant et al., 2020).

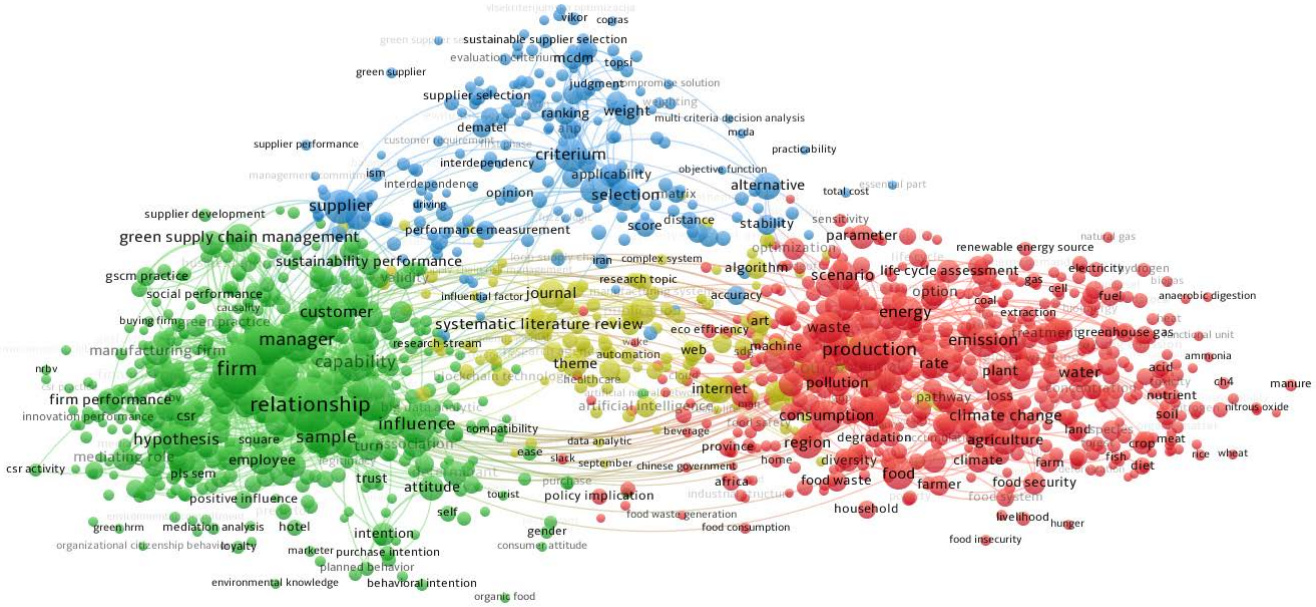

Figure 1 Mapping relation form Paper 5,000 scopus.

Results

Figure 1 presents a complex network visualization of interconnected concepts related to sustainability, supply chain management, and environmental impact. This visualization appears to be the result of a systematic literature review, as evidenced by the central position of terms like "systematic literature review" and "journal" (Tranfield et al., 2003). The network can be broadly divided into three main clusters, each representing a distinct but interrelated aspect of sustainable supply chain management.

The blue cluster, occupying the upper portion of the image, focuses on supplier-related concepts and decision-making processes. Key terms in this cluster include "supplier selection," " criterion," "weight," and "multi criteria decision analysis." This cluster highlights the importance of sustainable supplier selection and evaluation methods in supply chain management. The prominence of these terms suggests a significant research focus on developing and implementing frameworks for assessing suppliers based on sustainability criteria (Govindan et al., 2015). The inclusion of terms like "fuzzy AHP" and "TOPSIS" the use of advanced decision-making techniques in this context, reflecting the complexity of balancing multiple sustainability criteria in supplier selection processes (Kannan et al., 2014).

The green cluster, positioned on the left side of the image, emphasizes organizational and relational aspects of sustainable supply chain management. Prominent terms in this cluster include "firm", "relationship", "customer", "manager", and "green supply chain management". This cluster underscores the importance of stakeholder relationships and the integration of sustainability practices into core business operations. The presence of terms like "social performance" and "innovation performance" suggests a focus on the broader impacts of sustainable practices on organizational outcomes (Seuring & Müller, 2008). This cluster also includes concepts related to employee attitudes and behaviors, indicating research interest in the successful implementation of sustainable supply chain practices (Daily et al., 2012).

The red cluster, dominating the right side of the image, primarily deals with environmental

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and production-related concepts. Key terms in this cluster include "emission", "energy", "waste", "water", "climate change", and "agriculture". This cluster represents a strong emphasis on the environmental impacts of supply chain operations and resource management in production processes. The inclusion of terms like "life cycle assessment" and "greenhouse gas" indicates a focus on comprehensive environmental impact analysis methodologies (Hellweg & Milà i Canals, 2014). The presence of agriculture-related terms suggests significant attention to sustainability issues in food supply chains, a critical area given the sector's substantial environmental footprint (Garnett, 2011).

Central to the image are terms related to research methodologies and dissemination, such as "systematic literature review", "journal", and "research topic". This centrality emphasizes the academic nature of the visualization and suggests that it represents the current state of research in the field of sustainable supply chain management. The interconnectedness of the clusters illustrates the complex and multifaceted nature of sustainability in supply chains, encompassing supplier relations, organizational management, and environmental considerations.

The visualization also includes terms related to emerging technologies and methodologies, such as "artificial intelligence", "blockchain technology", and "internet of things". This indicates that the field is evolving to incorporate cutting-edge technologies in addressing sustainability challenges in supply chain management (Saberi et al., 2019).

In conclusion, this network visualization effectively demonstrates the holistic approach required in addressing sustainability challenges in modern supply chain management. It highlights the need for integrated strategies that consider multiple stakeholders, environmental impacts, and technological innovations across the entire supply chain ecosystem. The complexity of the network underscores the interdisciplinary nature of sustainable supply chain management research and practice, reflecting the field's evolution towards more comprehensive and nuanced approaches to sustainability (Carter & Rogers, 2008).

The final stage in the measurement process is reporting and communicating results. This stage is crucial for driving action based on the insights gained from data collection and analysis.

Internal reporting often takes the form of dashboards that provide real-time monitoring of key sustainability performance indicators. Searcy (2016) emphasizes the importance of these visual tools in making complex sustainability data accessible to decision-makers. Many organizations are also integrating sustainability metrics into their balanced scorecards, a practice (Hansen & Schaltegger, 2016) note as effective for aligning sustainability with overall business strategy. Regular management reports synthesizing key findings and recommendations are also crucial for informing strategic decision-making (Schaltegger & Wagner, 2017).

External reporting is equally important for transparency and stakeholder engagement. Many organizations publish comprehensive sustainability reports following established standards such as the Global Reporting Initiative (GRI, 2021). There's also a growing trend towards integrated reporting, which combines financial and non-financial performance information into a single report, as discussed by Churet & Eccles (2014). For consumer-facing companies, product labeling has become an important way to communicate sustainability performance directly to customers (Hardt et al., 2017).

Effective stakeholder communication goes beyond formal reports. Many organizations hold regular stakeholder engagement sessions to discuss sustainability performance and gather feedback (Meixell & Luoma, 2015). Online platforms and social media are increasingly used for more frequent and interactive communication about sustainability efforts (Tachizawa & Wong, 2014; Etter, 2014).

Finally, the reporting process should feed into a cycle of continuous improvement. This involves establishing feedback loops to incorporate stakeholder input, as suggested by Beske-Janssen et al. (2015). Regular benchmarking against industry best practices helps organizations identify areas for improvement (Searcy, 2016). Setting clear sustainability targets and regularly reviewing progress against these targets is crucial for driving ongoing performance improvements (Schaltegger & Wagner, 2017).

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In conclusion, measuring sustainability in supply chains is a complex but crucial process. By employing a comprehensive approach to data collection, analysis, and reporting, organizations can gain valuable insights, drive improvements, and demonstrate their commitment to sustainability to both internal and external stakeholders. As the field continues to evolve, new technologies and methodologies will likely emerge, offering even more sophisticated ways to measure and manage supply chain sustainability.

Challenges and Limitations

The measurement of sustainability in supply chains, while crucial for modern business practices, faces numerous challenges and limitations. These obstacles stem from the inherent complexity of global supply chains, the diversity of industries involved, and the lack of universally accepted standards. This article explores these challenges in depth, providing insights into the difficulties organizations face when attempting to quantify and assess their sustainability efforts.

The complexity of supply chains presents a formidable challenge in sustainability measurement. Modern supply chains often span multiple countries and involve numerous tiers of suppliers, each with its own operational practices and local contexts. As noted by Mena et al. (2013), this complexity makes it difficult to obtain a comprehensive view of sustainability performance across the entire supply chain. Organizations often have limited visibility beyond their first-tier suppliers, leading to potential blind spots in their sustainability assessments. Sarkis (2012) points out that this lack of transparency can result in overlooking significant environmental or social impacts occurring in the deeper tiers of the supply chain.

Furthermore, the interconnectedness of supply chain actors means that sustainability initiatives in one part of the chain can have unforeseen consequences elsewhere. For instance, a decision to source more sustainable materials might inadvertently lead to increased transportation emissions if the new suppliers are located farther away. Capturing these complex interactions and trade-offs in sustainability measurements is a significant challenge, as highlighted by Brandenburg et al. (2014).

The diversity of industries involved in global supply chains adds another layer of complexity to sustainability measurement. Different sectors have varying sustainability priorities and impacts. For example, the environmental concerns of a technology company might center around electronic waste and energy consumption, while a food and beverage company might focus more on water usage and agricultural practices. This diversity makes it challenging to develop standardized measurement approaches that can be applied across different industries.

Moreover, as Ahi and Searcy (2015) discuss, the sustainability impacts of different industries can vary significantly in their nature and scale. Some impacts, such as carbon emissions, are relatively straightforward to quantify across industries. Others, like biodiversity loss or community impact, are more qualitative and context-dependent, making cross-industry comparisons difficult. This variability poses challenges in developing comprehensive sustainability metrics that are relevant and applicable across diverse supply chains.

The lack of universally accepted standards for sustainability measurement in supply chains further complicates the issue. While numerous frameworks and guidelines exist, such as the Global Reporting Initiative (GRI) or the UN Global Compact, there is no single, universally adopted standard for measuring supply chain sustainability. This lack of standardization, as pointed out by Beske-Janssen et al. (2015), leads to inconsistencies in how organizations define, measure, and report on their sustainability performance.

The absence of standardized metrics makes it challenging to compare sustainability performance across different organizations or even within the same organization over time. It also creates difficulties for stakeholders, including investors and consumers, who seek to assess and compare the sustainability performance of different companies. Searcy (2016) argues that this lack of comparability can hinder the effectiveness of sustainability initiatives and reporting.

Furthermore, existing standards and frameworks often struggle to keep pace with evolving sustainability challenges and stakeholder expectations. New issues, such as microplastics pollution or the social impacts of artificial

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intelligence, may not be adequately covered by current measurement frameworks. This gap between emerging sustainability concerns and established measurement practices can lead to incomplete or outdated assessments of supply chain sustainability.

The challenges of data collection and verification add another dimension to the difficulties of sustainability measurement in supply chains. Obtaining accurate, timely, and comprehensive data from multiple tiers of suppliers is often a resource-intensive process. Boström et al. (2015) highlight the challenges of ensuring data quality and reliability, particularly when dealing with suppliers in regions with different regulatory environments or reporting practices.

Additionally, the cost and effort required to implement comprehensive sustainability measurement systems can be prohibitive, especially for smaller organizations or those operating in resource-constrained environments. This can lead to inequalities in sustainability reporting capabilities across the supply chain, potentially skewing overall assessments of sustainability performance.

In conclusion, while measuring sustainability in supply chains is essential for promoting responsible business practices, it is fraught with challenges. The complexity of global supply networks, the diversity of industries involved, and the lack of universally accepted standards all contribute to making sustainability measurement a complex and often imperfect process. Addressing these challenges requires ongoing collaboration between academia, industry, and policymakers to develop more robust, flexible, and universally applicable measurement approaches. As supply chains continue to evolve and new sustainability challenges emerge, the methods and frameworks for measuring sustainability must also adapt to ensure they remain relevant and effective.

Future Trends and Developments in Sustainability Measurement for Supply Chains

As the field of sustainability in supply chain management continues to evolve, new trends and developments are emerging that promise to revolutionize how organizations measure and manage their sustainability performance. This article explores two key areas of future development new technologies in measurement and the integration of sustainability measurement with other management systems. The rapid advancement of technology is significantly impacting the landscape of sustainability measurement in supply chains. One of the most promising developments is the application of blockchain technology. Saberi et al. (2019) highlight how blockchain can enhance transparency and traceability in supply chains, providing a tamper-proof record of sustainability-related data. This technology allows for real-time tracking of products from source to consumer, verifying sustainability claims and reducing the risk of greenwashing. For instance, blockchain can be used to track the origin of raw materials, ensuring they come from sustainable sources and have been processed under fair labor conditions.

Another technological trend is the increasing use of Internet of Things (IoT) devices for data collection. As discussed by Ben-Daya et al. (2019), IoT sensors can provide real-time data on various sustainability metrics, such as energy consumption, water usage, and emissions. This continuous stream of data allows for more accurate and timely measurement of sustainability performance. For example, smart meters can monitor energy use in real-time, enabling immediate identification and response to inefficiencies. Artificial Intelligence (AI) and Machine Learning (ML) are also set to play a crucial role in the future of sustainability measurement. Nishant et al. (2020) explore how these technologies can analyze vast amounts of sustainability data, identifying patterns and insights that might be missed by human analysts. AI can help in predicting future sustainability trends, optimizing resource allocation, and even suggesting innovative solutions to sustainability challenges. For instance, ML algorithms could analyze historical data to predict potential sustainability risks in the supply chain, allowing for proactive mitigation strategies.

The development of advanced analytics capabilities is another significant trend. Big Data analytics, as highlighted by Hazen et al. (2016), allows organizations to process and analyze enormous volumes of sustainability data from diverse sources. This capability enables more comprehensive and nuanced understanding of sustainability performance across complex global supply chains. Advanced analytics can

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help in identifying correlations between different sustainability metrics, understanding the impact of specific initiatives, and benchmarking performance against industry standards. In terms of integration with other management systems, there is a growing trend towards holistic approaches that embed sustainability measurement into core business processes. The concept of integrated reporting, as discussed by Churet and Eccles (2014), is gaining traction. This approach combines financial and non-financial (including sustainability) performance into a single, coherent report, reflecting the interconnected nature of these aspects in modern business.

There is also an increasing focus on aligning sustainability measurement with broader risk management systems. Giannakis and Papadopoulos (2016) emphasize the importance of integrating sustainability risks into enterprise risk management frameworks. This integration allows organizations to better understand and manage the complex interplay between sustainability performance and overall business risks. The integration of sustainability measurement with supply chain management systems is another key trend. As Tachizawa and Wong (2014) note, this integration allows for more effective decision-making by providing sustainability data alongside traditional supply chain metrics like cost and delivery time. For example, supplier selection processes are increasingly incorporating sustainability criteria alongside traditional factors, necessitating integrated measurement systems.

Furthermore, there is a growing trend towards the integration of sustainability measurement with product lifecycle management systems. This approach, as explored by Gmelin and Seuring (2014), allows organizations to consider sustainability impacts from the design phase through to end-of-life management. Such integration enables more comprehensive sustainability assessments and facilitates the development of more sustainable products from the outset. The future also holds potential for more standardized and interoperable sustainability measurement systems. While the current lack of standardization is a challenge, efforts are underway to develop more universally accepted frameworks. The work of organizations like the Sustainability Accounting Standards Board (SASB) and the Global Reporting Initiative (GRI) is moving towards more standardized metrics and reporting formats. This standardization will facilitate better comparison and benchmarking across industries and supply chains.

In conclusion, the future of sustainability measurement in supply chains is characterized by technological innovation and increasing integration with other business systems. These developments promise to make sustainability measurement more accurate, comprehensive, and actionable. As organizations navigate these changes, they will need to stay abreast of technological advancements and be prepared to adapt their measurement systems accordingly. The integration of sustainability measurement with other management systems will require a holistic approach to business management, breaking down silos between sustainability and other business functions. While these developments present challenges, they also offer exciting opportunities for organizations to enhance their sustainability performance and create more resilient, responsible supply chains.

Results and discussion

The measurement of sustainability in supply chains has become a vital component of modern business management, reflecting the increasing importance of environmental, social, and economic considerations in global commerce. This review has examined various aspects of sustainability measurement, covering conceptual frameworks, practical challenges, and future trends. Below, key findings are synthesized, and directions for future research are identified.

Multidimensional Nature of Sustainability

A primary insight from this review is the complex, "Multidimensional Nature of Sustainability" and "Diversity of Measurement Tools and Methodologies" in supply chains. The Triple Bottom Line (TBL) framework, encompassing environmental, social, and economic dimensions, serves as a comprehensive foundation for sustainability measurement. However, these dimensions are deeply interconnected, presenting challenges for measurement and management. As Ahi and Searcy (2015) suggest, a holistic approach is necessary to effectively capture the nuanced interactions between different sustainability aspects.

Diversity of Measurement Tools and Methodologies

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The evolving nature of the field is reflected in the wide array of available tools and methodologies, ranging from life cycle assessments to social audits and economic impact analyses. This diversity offers organizations flexibility but also highlights a significant gap in standardization, making comparability and benchmarking across industries challenging. Beske-Janssen et al. (2015) stress the need for standardized approaches that facilitate meaningful comparisons while allowing for industry-specific adaptations.

Role of Technology in Sustainability Measurement

Emerging technologies such as blockchain, Internet of Things (IoT), and artificial intelligence (AI) are transforming data collection, analysis, and reporting processes. As Ben-Daya et al. (2019) note, these technologies offer the potential for real-time, accurate, and comprehensive sustainability measurements. However, their implementation introduces challenges related to data management, privacy, and potential disparities between large corporations and smaller suppliers.

Integration with Other Management Systems

The integration of sustainability measurement with other management systems is a critical trend. The shift towards integrated reporting and the incorporation of sustainability metrics into enterprise risk management and supply chain management systems reflect a growing recognition of sustainability as a core business objective. Churet and Eccles (2014) highlight that this integration supports more holistic decision-making by aligning sustainability with traditional business metrics.

Persistent Challenges

Despite advancements, several challenges persist Complexity of Global Supply Chains: Obtaining comprehensive sustainability data across multi-tier supply chains remains difficult, particularly beyond the first-tier suppliers (Mena et al., 2013). Stakeholder, Diversity Different priorities and capabilities among stakeholders complicate the consistent implementation of measurement practices.

Evolving Nature of Sustainability Concerns: As new sustainability issues emerge, existing measurement frameworks may struggle to keep pace, requiring ongoing adaptation (Sarkis, 2012).

Future Research and Development Priorities

The following key areas emerge as priorities for future research and development, Standardization and Comparability. Research should focus on developing more standardized frameworks for sustainability measurement, enabling meaningful comparisons across industries while allowing for context-specific adaptations. Technology Integration, Future research should explore the practical implementation of emerging technologies in sustainability measurement, such as AI for predictive analytics and blockchain for enhanced transparency and traceability. Multi-Tier Supply Chain Measurement, more effective methods are needed to measure sustainability performance across all supply chain tiers, particularly in complex global networks.

Impact Measurement

Research should aim to better quantify the actual impact of sustainability initiatives, transitioning from output metrics to outcome-based measurements that demonstrate tangible effects. Stakeholder Engagement, Effective stakeholder engagement in the sustainability measurement process is crucial. Future studies should focus on approaches that ensure diverse stakeholder priorities are reflected in measurement practices. Dynamic Measurement Systems, As sustainability challenges evolve, more adaptive measurement systems are needed to incorporate new concerns and metrics quickly. Integration with Business Strategy, Further exploration is needed on how to effectively integrate sustainability measurement with overall business strategy and decision-making processes. Focus on SMEs, developing feasible and effective sustainability measurement approaches for small and medium-sized enterprises (SMEs) is essential, given their limited resources compared to larger corporations.

Conclusions and Recommendations

Conclusions

Multidimensional Nature of Sustainability: Sustainability in supply chains is inherently complex, encompassing environmental, social, and economic dimensions. The interconnectedness

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of these dimensions requires a holistic approach to measurement, recognizing that improvements in one area may impact others.

Diverse Tools and Methodologies, A wide array of tools and methodologies exists for sustainability measurement, ranging from life cycle assessments to social audits and economic impact analyses. However, the lack of standardization remains a significant challenge, hindering comparability and benchmarking across industries and supply chains.

Technological Advancements, Emerging technologies like blockchain, IoT, and AI are revolutionizing sustainability measurement by providing real-time, accurate, and comprehensive data. These technologies offer new opportunities for enhancing transparency and traceability, though they also introduce challenges related to data management and privacy.

Integration with Business Processes, there is a growing trend toward integrating sustainability measurement with other management systems, such as enterprise risk management and supply chain management. This integration enables more holistic decision-making and ensures that sustainability is considered alongside traditional business metrics.

Challenges in Measurement, despite advancements, significant challenges persist, particularly in obtaining comprehensive data from multi-tier supply chains and addressing the varying priorities of different stakeholders. The complexity of global supply chains and the evolving nature of sustainability concerns continue to complicate effective measurement.

Recommendations

- Key Conclusions

Multidimensional Nature of Sustainability, Sustainability in supply chains is inherently complex, requiring a holistic approach to measurement that accounts for the interconnected environmental, social, and economic dimensions.

Diverse Tools and Methodologies, while a wide range of tools and methodologies exist for sustainability measurement, the lack of standardization remains a significant challenge, hindering comparability across industries.

Technological Advancements, Technologies like blockchain, IoT, and AI are revolutionizing sustainability measurement by enhancing transparency and real-time data accuracy. However, they also present new challenges related to data management and privacy.

- Integration with Business Processes

There is a growing trend toward integrating sustainability measurement with other management systems, enabling more comprehensive decision-making that aligns sustainability with core business strategies.

Challenges in Measurement, Significant challenges persist, particularly in obtaining comprehensive data from multi-tier supply chains and addressing varying stakeholder priorities. The complexity of global supply chains and the evolving nature of sustainability concerns continue to complicate effective measurement.

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