

Review

Key Performance Indicators for Sustainable Supply Chain Management in SMEs: A Bibliometric Review

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Abstract

Background: This study presents a bibliometric analysis of key performance indicators (KPIs) for sustainable supply chain management (SSCM) in small- and medium-sized enterprises (SMEs). Despite growing academic attention, particularly after 2020, important gaps remain in how sustainability performance is measured and assessed in SME contexts. **Methods:** Using the Scopus database, we identified 169 relevant studies published between 2004 and 2025. The dataset was obtained through sustainability- and SME-related keyword filtering, followed by manual screening based on predefined eligibility criteria. **Results:** The findings reveal a research landscape dominated by economic and technological KPI dimensions, with Italy, India, and Indonesia emerging as leading contributors. However, the results also indicate limited research attention to social sustainability, organizational capabilities, and governance within SME supply chains. Overall, eight underexplored KPI domains are identified as opportunities for future research and practical development. **Conclusions:** This analysis clarifies the intellectual landscape of SSCM KPI research and provides evidence-based insights for researchers and practitioners regarding which KPI dimensions are emphasized and which remain underdeveloped for practical application in SME supply chains, without developing or validating a new KPI framework.



Academic Editors: Selman Karagöz,
Derya Deliktas, Ramez Kian and
Emrah Bilgic

Received: 16 December 2025

Revised: 30 January 2026

Accepted: 2 February 2026

Published: 9 February 2026

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Keywords: bibliometric analysis; key performance indicators; small and medium-sized enterprises (SMEs); sustainable supply chain management; supply chain resilience

1. Introduction

The global emphasis on sustainable supply chain management is reshaping how both large and small businesses view performance and responsibility [1]. While multinational corporations have implemented complex sustainability frameworks, SMEs often face foundational barriers, such as a lack of resources, minimal digital infrastructure,

and limited access to specialized talent [2,3]. Given these constraints and the proximity of SMEs to local economies, traditional KPIs for SSCM are usually misaligned, providing insufficient incentives and little practical support [4]. These challenges underscore the need to better understand how sustainability performance has been measured and conceptualized in existing supply chain research, particularly in SME contexts. To ensure methodological transparency, this study is based on 169 Scopus-indexed publications spanning 2004–2025, retrieved on 27 July 2025 and retained through SME- and sustainability-related screening criteria.

A bibliometric analysis of sustainable key performance indicators (KPIs) in supply chain management is essential for advancing both academic and practical understanding of how sustainability is operationalized and measured within this field [5]. While the literature on supply chain sustainability has expanded considerably, the conceptualization and application of KPIs remain fragmented, with indicators often designed for large enterprises and rarely adapted to the context of small- and medium-sized enterprises (SMEs) or sector-specific practices [6]. Bibliometric analysis provides a systematic approach for mapping the intellectual structure of the field; identifying influential publications, authors, and journals; and tracing the evolution of research themes over time [7]. This methodological approach also enables the detection of emerging clusters, such as digital technologies, the integration of Industry 4.0 into processes, and the development of environmental performance measures, while simultaneously revealing underexplored dimensions including social impact, resilience, and governance indicators [8–10]. In this study, bibliometric methods are used not only to map publication patterns but also to synthesize KPI domains and identify systematically underrepresented themes relevant to SMEs.

The purpose of conducting this bibliometric analysis is, therefore, twofold. First, we aim to offer a comprehensive overview of the state of the art on sustainable KPIs in supply chains. Second, we aim to highlight research gaps and future directions that can guide both scholars and practitioners [5,9,10]. Rather than proposing new measurement frameworks, this study focuses on synthesizing existing KPI categories and identifying future-oriented domains that warrant deeper conceptual and empirical attention. Accordingly, this study does not develop, test, or validate a KPI framework, but instead provides a descriptive mapping of existing evidence and research gaps. The contribution is positioned as a bibliometric synthesis, including the identification of eight underexplored KPI domains for SMEs that remain marginal in the current SSCM KPI literature. The results can be applied to refine conceptual discussions, improve KPI design for different organizational contexts, and inform managerial decision making by providing clarity on which performance dimensions are most emphasized in the current scholarship. For scholars, the analysis contributes to the theoretical advancement of sustainable supply chain management by synthesizing dispersed knowledge into coherent research streams [9,11,12]. For practitioners, it offers evidence-based insights into which KPIs are widely adopted, which remain underdeveloped, and how performance measurements can be aligned with sustainability goals. Ultimately, this study contributes to bridging the gap between theory and practice, ensuring that sustainability performance in supply chains is not only measured but also strategically assessed.

The current literature on sustainable supply chain management (SSCM) often overlooks the specific challenges faced by small- and medium-sized enterprises (SMEs). While sustainability has become a critical factor for business continuity and competitiveness, existing KPI frameworks primarily cater to larger corporations, neglecting key dimensions relevant to SMEs [3]. Significant research gaps remain, particularly in relation to human capital, organizational capabilities, governance, resilience, and value co-creation dimensions that are increasingly critical for SMEs but remain under-represented in both the

academic literature and management practice [12–16]. These gaps point to the need for a structured synthesis of sustainability KPI research that clarifies where current measurement approaches fall short and where future inquiry should be directed. To strengthen conceptual grounding, this study also uses established perspectives (e.g., stakeholder-oriented and capability-based views) as interpretive lenses to contextualize why certain KPI domains gain prominence while others remain underexplored in SME-focused sustainability measurement research.

Accordingly, this study adopts a bibliometric approach to examine the evolution, intellectual structure, and thematic gaps of sustainability KPIs in supply chain management, with a particular focus on SME contexts. The research questions are listed below:

RQ1: *How are the evolution and publication trends of sustainability KPIs characterized in the supply chain domain?*

RQ2: *How are the intellectual structure and research dynamics revealed by mapping influential studies?*

RQ3: *What are the existing research gaps and future directions for advancing knowledge on sustainability KPIs, and what are their implications for supply chain performance?*

The remainder of this paper is organized as follows. Section 2 reviews the relevant literature on sustainability KPIs and SSCM in SME contexts. Section 3 describes the bibliometric methodology, including data collection, screening, and analytical procedures. Section 4 presents the bibliometric results, while Section 5 discusses the intellectual structure, research gaps, and practical implications derived from the findings. This section also concludes the study and outlines future research directions.

2. Literature Review

2.1. Evolution of Supply Chain Sustainability

Sustainable supply chain research has developed rapidly since the early 2000s, expanding from primarily addressing environmental concerns to incorporating social justice and the triple bottom line [1,12]. However, reviews highlight a weak translation of these macro trends into SME operations; the language, metrics, and systems of multinational sustainability are often unworkable for smaller enterprises [2,3]. Over the past two decades, the field has shifted from reactive environmental compliance to proactive sustainability integration; however, SMEs continue to struggle with implementing these advancements due to resource constraints and limited access to specialized expertise [4,6]. Despite this conceptual evolution, existing studies provide limited guidance on how these broader sustainability principles are translated into measurable and context-sensitive KPIs suitable for SMEs, particularly in relation to organizational capability and adaptive performance [13,16]. Recent literature increasingly suggests that future SSCM research needs to move beyond normative sustainability goals toward measurement approaches that reflect the operational realities and constraints faced by SMEs [8,11]. Importantly, prior SSCM reviews and bibliometric mappings often remain broad or firm-agnostic, providing limited clarity on how sustainability KPI domains are structured, clustered, and emphasized specifically within SME-oriented research. In this regard, KPI-based measurement plays a critical role in bridging conceptual sustainability priorities and operational implementation, particularly for SMEs that require feasible and context-sensitive indicators.

2.2. Traditional SSCM KPIs in SMEs

Traditional sustainable supply chain management (SSCM) and key performance indicators in small- and medium-sized enterprises often rely on established performance indices

originally designed for larger businesses, covering environmental measures such as carbon emissions, energy and water usage, and recycling rates [17–19]; social indicators such as employee hours spent in community engagement and supplier code compliance [12,16]; and economic metrics including cost savings from process changes, inventory turnover, and supplier reliability [1,20]. However, these frameworks are not contextualized to the SME context, often overlooking practical barriers to data collection, variations across sectors, and the real constraints that SMEs face in adopting digital solutions [3,6].

Despite limited resources, SMEs benefit from SSCM through cost savings, risk reduction, and enhanced competitiveness [4,21]. Key performance indicators (KPIs) are essential in this process, as they translate sustainability goals into measurable outcomes such as carbon reduction, waste efficiency, employee well-being, and supplier engagement [22,23]. Linking SSCM with KPIs ensures accountability, supports informed decision making, and fosters long-term resilience and sustainable growth [8,14]. Nevertheless, much of the existing KPI guidance remains generic and rarely explains how KPI categories and measurement priorities shift under SME constraints or across sector-specific realities.

Nevertheless, the continued reliance on large-firm-oriented KPIs suggests a persistent research gap in the development of SME-specific measurement approaches that capture not only efficiency outcomes but also human, governance, and resilience-related dimensions [12–16]. Emerging studies increasingly emphasize the need for KPI systems that are scalable, feasible, and aligned with SME resource constraints, indicating a shift toward more adaptive and capability-oriented performance measurement [11,15]. Accordingly, SME-oriented KPI research should not only evaluate outcome-based efficiency metrics but also consider capability-building dimensions that enable SMEs to operationalize sustainability under resource constraints. This gap strengthens the need for a structured synthesis that clarifies which KPI domains dominate the literature, and which remain underdeveloped for SME-specific application—thereby motivating a bibliometric mapping approach.

2.3. Sustainability KPI Domains in SSCM Literature

This subsection provides a descriptive synthesis of sustainability KPI domains reported in the SSCM literature. It does not propose, operationalize, or validate a new KPI framework, nor does it prioritize KPI domains through a normative or theory-driven hierarchy. Instead, the categorization reflects patterns of emphasis and omission observed across prior studies, thereby supporting bibliometric gap interpretation. To avoid misinterpretation, this section is presented as a literature-based domain synthesis rather than a proposed KPI framework.

The sustainability performance of a supply chain can be assessed through varied integrated KPIs across multiple dimensions. Environmental impact is measured via the Circular Resource Utilization Rate, which calculates the percentage of recycled or reused inputs relative to total material input [23,24]. Social responsibility is captured through the Local Stakeholder Engagement Index, reflecting scores based on partnerships with SMEs, community investments, and employee training initiatives [1,12,16]. Economic efficiency is evaluated through Digital-Driven Cost Efficiency, which tracks the percentage reduction in operational costs following digital technology adoption [3,7]. Resilience and adaptability are gauged using the Process Innovation Rate, indicating the number of new or improved sustainable processes initiated annually [11,22]. Transparency and traceability are monitored via the Digital Supply Chain Traceability Score, representing the percentage of a supply chain that is digitally traceable using tools such as QR codes, blockchain, or ERP systems [25,26]. Additionally, supplier compliance is measured via the Sustainable Supplier Participation Rate, which reflects the proportion of suppliers audited for sustainability and their subsequent improvements [27,28]. Supply chain emissions are

quantified through the Supply Chain Carbon Footprint, encompassing total greenhouse gas emissions across scopes 1 to 3, ideally tracked using affordable digital tools [18,29]. These examples illustrate how SSCM KPI studies span multiple measurement logics, yet the SME fit and implementation feasibility of these KPIs are not consistently clarified across studies.

A comprehensive literature review of key performance indicators (KPIs) in supply chain and organizational management reveals a diverse set of categories reflecting both traditional and emerging priorities. Financial KPIs focus on investment returns, cost control, and financial risk, forming the backbone of performance evaluation [20]. Transportation and Logistics KPIs assess the efficiency of goods movement, route optimization, port operations, and reverse logistics [30,31]. System and Technology KPIs emphasize the integration of digital tools such as IoT, AI, blockchain, ERP, and real-time monitoring to enhance operational visibility and responsiveness [26,32,33]. Production and Operations KPIs measure manufacturing efficiency, inventory management, and process capabilities [22,24].

However, some KPI domains remain underexplored. Human Capital and Organizational Capability, which includes workforce skills, talent retention, and development, is notably underdeveloped [13,34]. Stakeholder Engagement KPIs gauge consumer satisfaction, brand perception, and stakeholder relationships [12,16]. Risk and Resilience Management KPIs assess the ability of business supply chains to recover from disruptions and maintain continuity [14,15]. Integrated Performance Measurement approaches such as Balanced Scorecard and SCOR offer holistic views by combining multiple dimensions [35,36]. Other critical but under-represented areas include R&D and Innovation Performance, Quality and Safety Performance (e.g., defect rates, compliance), Governance and Transparency (e.g., traceability, data disclosure), Resource and Energy Management (e.g., energy and water usage), Crisis and Disruption Management, and Social and Community Engagement KPIs, which reflect local employment and community development [26,37,38].

Taking together, these gaps indicate that existing KPI systems continue to privilege operational and technological efficiency, while offering limited insight into capability-building, governance, and resilience-oriented performance dimensions [8,11,14]. This imbalance is particularly critical for SMEs, as capability-oriented and governance-related KPIs are often necessary for sustainability implementation under resource constraints. Recent bibliometric evidence further suggests that future SSCM research should prioritize integrating these underrepresented KPI domains into more coherent and SME-relevant measurement systems [5,9]. In line with this, the present study uses bibliometric mapping to clarify dominant KPI emphases and systematically identify underexplored domains for SMEs, without proposing or validating a new KPI framework.

Bibliometric analysis of sustainable supply chain KPIs found that scholarly output in the field has accelerated significantly since 2015, with leading contributions concentrated in operations and environmental management journals. The dominant themes emphasize environmental indicators such as carbon accounting, energy efficiency, waste management, circularity metrics, and supplier sustainability assessments, while social and governance dimensions remain comparatively underexplored [5,9]. Research clusters are largely concentrated in Europe and East Asia, and collaboration networks reveal a regional rather than global orientation [10]. Methodologically, data-driven approaches including multi-criteria decision making (MCDM), data envelopment analysis (DEA), the analytic hierarchy process (AHP), and emerging machine-learning-based dashboards have been increasingly adopted for designing sustainability KPIs [23,39]. Nevertheless, methodological convergence remains limited, with highly cited studies prioritizing composite indices and lifecycle-based measures that lack standardized definitions and boundary conditions, thereby constraining comparability and benchmarking across industries and firm sizes [8]. These limitations strengthen the case for a focused bibliometric synthesis that clarifies which KPI domains are

emphasized and which remain insufficiently developed for SME-oriented application, while positioning empirical validation and framework development as future research directions. These limitations highlight the need for future research to complement bibliometric insights with more context-sensitive and empirically grounded approaches, particularly within resource-constrained SME environments. Overall, this literature synthesis establishes a structured conceptual foundation for the subsequent bibliometric analysis by clarifying (i) which KPI domains dominate SSCM measurement research and (ii) which domains remain insufficiently developed for SME-specific application.

3. Methodology

3.1. Data Sources

This study employs a sequential mixed-method design that combines bibliometric analysis and qualitative content analysis to strengthen descriptive mapping and interpretive synthesis, within a theoretically grounded sequential mixed-methods design. The bibliometric phase is used to map the intellectual structure of the literature and identify dominant themes, which subsequently inform and guide the qualitative analysis. This systematic sequencing enables a comprehensive examination of key performance indicators (KPIs) for sustainable supply chain management by capturing both the structural patterns of scholarly production and the underlying conceptual logic reflected in the literature. It should be noted that this study does not claim methodological novelty; rather, it applies established bibliometric procedures in combination with qualitative content analysis to enhance the interpretive depth of a descriptive bibliometric review.

The bibliometric analysis was conducted to explore the research landscape related to KPIs in sustainable supply chain management. Data was retrieved from the Scopus database on 27 July 2025, selected for its extensive coverage of peer-reviewed academic literature and citation records. The literature search was performed using the basic search interface of Scopus, targeting article titles, abstracts, and keywords. The initial Boolean query, “Supply chain” AND KPI*, yielded 709 documents. To ensure thematic relevance, the search was refined using the query (TITLE-ABS-KEY (“supply chain”) AND TITLE-ABS-KEY (KPI*) AND TITLE-ABS-KEY (sustain*)) and limited to publications at the final stage of the research process (PUBSTAGE = final), resulting in 175 records, which were further reduced to 173 finalized publications. This stepwise strategy (broad search followed by thematic refinement) was applied to reduce construct contamination and ensure that the retrieved documents aligned with sustainability-focused KPI research in supply chains.

Subsequently, the dataset was restricted to articles, review papers, and conference papers published in English by applying the language filter (LIMIT-TO (LANGUAGE, “English”). This refinement produced an initial dataset of 172 records spanning the period from 2004 to 2025. A manual screening process was then conducted to exclude editorial papers, leading to a final sample of 169 studies used for bibliometric mapping and subsequent qualitative content analysis. During data cleaning, duplicate records were checked and removed, retracted documents were excluded where applicable, and books/book chapters were not included, consistent with the selected Scopus document type filters. To ensure internal consistency and reproducibility, the final dataset was fixed at 169 documents (2004–2025), and this number is used consistently throughout the manuscript.

The detailed PRISMA 2020 checklist and study selection flow diagram are provided in Appendix A (Table A1 and Figure A1). Regarding the literature search and screening, the identification and selection process was conducted in accordance with the PRISMA 2020 statement [40]. Since this study is a bibliometric review, PRISMA items related to risk of bias assessment and effect size synthesis are not applicable.

3.2. Data Analysis

This study employed a mixed qualitative research design integrating descriptive analysis, bibliometric mapping, and qualitative content analysis based on secondary data from the Scopus database. Descriptive and performance analyses were first conducted to examine publication patterns, sources, citations, and keyword distributions, providing an overview of the field's development. Specifically, descriptive indicators (e.g., annual publication trends and geographic distribution) were reported to characterize the evolution of SSCM KPI research over time.

The dataset was then exported in CSV format and analyzed using bibliometric techniques in VOSviewer (version 1.6.19). Network analyses focusing on co-occurrence, co-citation, authorship, and relational structures were performed to identify dominant research streams, emerging themes, and conceptual gaps. The analysis utilized the local moving algorithm developed by Van Eck and Waltman [41], while bibliometric indicators were interpreted in light of disciplinary norms, including publication practices, citation behavior, and research collaboration patterns [7]. For keyword co-occurrence analysis, a minimum occurrence threshold was applied to improve interpretability, and the association strength normalization method was used as the standard VOSviewer setting to generate comparable link strengths. Network and overlay visualizations were generated to support thematic interpretation. All bibliometric parameters (database source, retrieval date, document types, language filter, and software version) are explicitly reported to enhance transparency and replicability of the analysis.

Building on the bibliometric results, a purposeful sample of recent and conceptually central articles was selected for qualitative content analysis. An iterative coding process was applied, beginning with concept-driven coding, to capture key conceptual domains such as resource and energy management, social and community engagement, innovation performance, integrated performance measurement, human capital, risk and resilience, crisis management, quality and safety, and governance. The analysis further examined the causal logic and implications of identified research gaps, advancing a conceptual typology that clarifies theoretical inconsistencies and informs future research, policy development, and managerial practice. The qualitative phase was used to interpret how KPI domains were conceptually framed across studies, and to synthesize underrepresented dimensions highlighted by bibliometric patterns, rather than to validate or empirically test a KPI framework. Accordingly, the qualitative synthesis is used to support gap interpretation and domain clarification, not to construct, test, or validate a KPI framework.

4. Results

4.1. Document per Year Distribution

The bibliometric search covering key performance indicators (KPIs) in sustainable supply chain management within SMEs retrieved 169 publications published from 2004 to 2025. This figure reflects the final screened dataset reported in Section 3.1. The temporal distribution reveals steadily growing research interest in this field. From 2004 to 2010, the number of publications published remained minimal, with fewer than three articles published annually. A gradual increase began in 2011, but it was not until 2017 that a noticeable upward trend emerged. A significant growth phase was observed from 2020 onward, during which period the number of publications increased markedly, rising from 12 articles in 2020 to 16 in 2021, before sharply increasing to 28 in 2024, with 17 already recorded for 2025. This pattern suggests that the body of literature is rapidly expanding in response to the growing global emphasis on sustainability and performance measurement in SME supply chains. Indeed, 2024 marked the peak of scholarly output, highlighting

an intensified academic focus on sustainable supply chain performance measurement in recent years (see Figure 1).

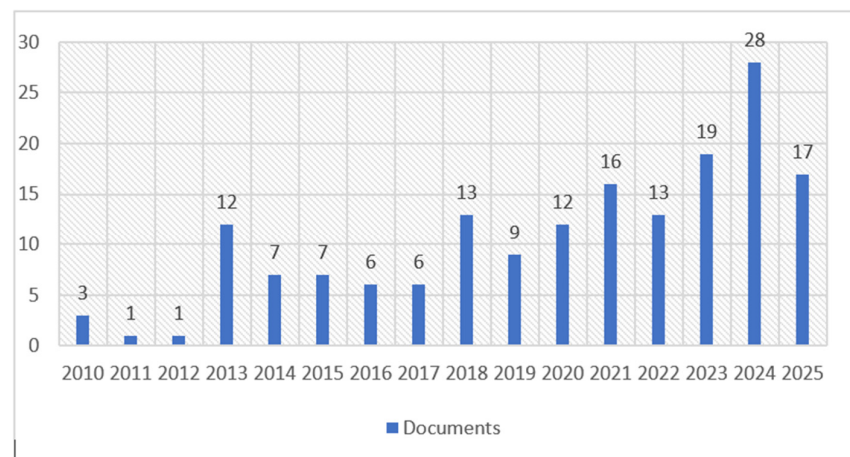


Figure 1. The number of publications per year (2004–2025).

Rather than reflecting publication growth alone, the post-2020 acceleration indicates increasing attention to translating sustainability agendas into measurable KPI-based approaches that can support monitoring, reporting, and decision-making in supply chains. This surge indicates a shift from broad sustainability discourse toward measurement-oriented operationalization, reflecting increasing pressure for traceable and auditable KPI systems in SME supply chains. In addition, the trend suggests that recent research increasingly aligns with digitalization and resilience-related concerns, which are frequently discussed as enabling conditions for sustainability measurement and performance monitoring in SME-oriented supply chains.

4.1.1. Most Cited Papers and Authors

Among the 169 publications analyzed, the bibliometric analysis reveals key developments in sustainability research within supply chains, showcasing a diverse range of approaches and industry applications. As shown in Table 1, the most frequently cited contribution, Caniato et al. (2012) [42], employs a longitudinal case-based research approach to examine environmental sustainability in the fashion industry, thereby reflecting the sector's significant ecological footprint and establishing foundational empirical approaches for sustainability assessment. Bai and Sarkis (2014) [28] advance operational measurement systems through developing sustainable supplier performance assessment indicators grounded in environmental management systems, while Mangiaracina et al. (2015) [31] quantify the environmental implications of B2C e-commerce logistics using lifecycle assessment (LCA) methodologies. Koh et al. (2013) [19] presents a quantitative optimization-based decision support system for decarbonizing supply chains by utilizing mathematical modeling approaches. Concurrently, High-impact publications (2017–2024) increasingly emphasize data-driven and technological innovations, such as distributed hierarchical data architectures (Accorsi et al., 2018) [43], enabling real-time supply chain visibility, and IoT-based performance monitoring approaches (Yadav et al., 2020) [33]. Emerging research extends sustainability analysis to previously underexplored domains, including agri-food supply networks and public health initiatives, indicating the increasing integration of sustainability across sectors and disciplines. The citation structure suggests that highly influential studies are often not SME-specific, implying that SME-oriented KPI research continues to draw heavily on broader SSCM measurement approaches, which may limit contextual validity for resource-constrained SMEs. This pattern highlights that

the intellectual foundations of sustainability KPI measurement are frequently anchored in cross-sector and large-firm settings, while SME-focused evidence remains comparatively less cited and less consolidated. As a result, SME-specific KPI challenges may be addressed through adaptation of dominant approaches rather than through dedicated SME-grounded measurement streams.

Table 1. List of top-cited research articles (2004–2025).

No.	Document Title	Authors	Source	(Y)	(C)	DOI
1	Environmental sustainability in fashion supply chains: An exploratory case based research	[42]	International Journal of Production Economics, 135(2), pp. 659–670	2012	439	https://doi.org/10.1016/j.ijpe.2011.06.001
2	Determining and applying sustainable supplier key performance indicators	[28]	Supply Chain Management, 19(3), pp. 275–291	2014	193	https://doi.org/10.1108/SCM-12-2013-0441
3	A review of the environmental implications of B2C e-commerce: a logistics perspective	[31]	International Journal of Physical Distribution and Logistics Management, 45(6), pp. 565–591	2015	188	https://doi.org/10.1108/IJPDLM-06-2014-0133
4	A triple bottom line balanced set of key performance indicators to measure the sustainability performance of industrial supply chains	[44]	Sustainable Production and Consumption, 26, pp. 648–691	2021	133	https://doi.org/10.1016/j.spc.2020.12.018
5	Decarbonising product supply chains: design and development of an integrated evidence-based decision support system—the supply chain environmental analysis tool (SCEnAT)	[19]	International Journal of Production Research, 51(7), pp. 2092–2109	2013	101	https://doi.org/10.1080/00207543.2012.705042
6	A hierarchical data architecture for sustainable food supply chain management and planning	[43]	Journal of Cleaner Production, 203, pp. 1039–1054	2018	84	https://doi.org/10.1016/j.jclepro.2018.08.275
7	Environmental and economic assessment of fresh fruit supply chain through value chain analysis. A case study in chestnut industry	[11]	Production Planning and Control, 26(1), pp. 1–18	2015	79	https://doi.org/10.1080/09537287.2013.839066
8	Performance assessment of circular-driven sustainable agri-food supply chain towards achieving sustainable consumption and production	[13]	Journal of Cleaner Production, 372, 133698	2022	70	https://doi.org/10.1016/j.jclepro.2022.133698
9	Development of IoT based data-driven agriculture supply chain performance measurement framework	[45]	Journal of Enterprise Information Management, 34(1), pp. 292–327	2020	68	https://doi.org/10.1108/JEIM-11-2019-0369
10	Evaluating the effect of key performance indicators of vaccine supply chain on sustainable development of mission indradhanush: A structural equation modeling approach	[35]	Omega, 101, 102258	2021	65	https://doi.org/10.1016/j.omega.2020.102258

4.1.2. Most Prolific Authors

Authorship productivity analysis identifies R. Accorsi and R. Manzini as the most prolific contributors, with each having published five papers in this field, as shown in Table 2. These leading researchers represent concentrated expertise in sustainable supply chain KPI development. A secondary tier of highly productive scholars includes M. Demartini, M.A. Moktadir, S.K. Paul, A.Y. Ridwan, and F. Tonelli, with each having contributed three publications in this field. Additionally, members of a tertiary tier of active contributors, comprising E. Amrina, E. Bottani, A. Cascini, G. Casella, L.P. Ferreira, M. Germani, and K. Govindan, have each authored two manuscripts in this field. This distribution pattern indicates that knowledge production on sustainable supply chain KPIs is concentrated among a core group of researchers, though collaborative contributions remain significant. This concentration suggests that the intellectual leadership of SSCM KPI research remains anchored in a relatively small set of author networks, which may shape the thematic dominance of technology- and efficiency-oriented KPI logics observed in subsequent analyses. In bibliometric terms, such concentration may also reinforce path dependency in dominant KPI themes, potentially limiting the visibility of emerging or underrepresented KPI domains that are highly relevant for SME contexts.

Table 2. Authors with the highest number of publications in this field.

Author	Documents	Author	Documents
Accorsi, R.	5	Amrina, E.	2
Manzini, R.	5	Bottani, E.	2
Demartini, M.	3	Cascini, A.	2
Moktadir, M.A.	3	Casella, G.	2
Paul, S.K.	3	Ferreira, L.P.	2
Ridwan, A.Y.	3	Germani, M.	2
Tonelli, F.	3	Govindan, K.	2

4.1.3. Geographic Distribution of Publications

The distribution of publications by country indicates that Italy leads with 34 papers (20.1%), followed by India (23 papers; 13.6%) and Indonesia (19 papers; 11.2%). Other notable contributors include the United Kingdom (16 papers; 9.5%) and the United States (13 papers; 7.7%). Countries such as Australia (9 papers; 5.3%), China (7 papers; 4.1%), France (7 papers; 4.1%), Germany (7 papers; 4.1%), Brazil (6 papers; 3.6%), Portugal (6 papers; 3.6%), and Spain (6 papers; 3.6%) also show significant contributions (see Figure 2 and Table 3).

This geographic concentration is pronounced: approximately 44.9% of global research originates from Italy, India, and Indonesia, indicating significant regional dominance. Darker shades indicate countries with a higher number of publications, while lighter shades represent lower publication output. The prominence of these three nations may reflect developed institutional capacity and research networks, potentially driven by local economic contexts. In interpretive terms, this pattern may also be associated with the strong presence of SME-intensive sectors and the increasing policy and market emphasis on sustainable supply chain practices in these contexts, which can stimulate publication activity. However, this regional concentration implies that SME-oriented KPI evidence is unevenly distributed across regions, limiting cross-context comparability and highlighting the need for geographically diverse empirical validation in future research. Accordingly, the geographic concentration observed here should be interpreted as a bibliometric indicator

of research activity rather than as evidence of superior KPI implementation maturity in specific countries.

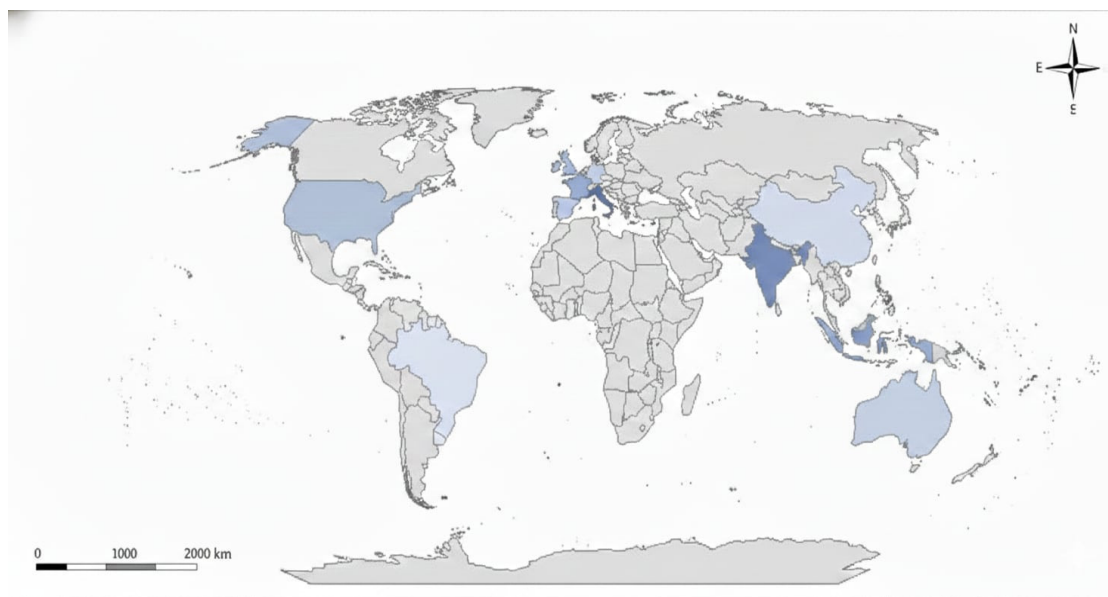


Figure 2. Geographic distribution of publications on sustainability KPIs in supply chains.

Table 3. Documents categorized by country.

Country/Territory	Documents	Country/Territory	Documents
Italy	34	China	7
India	23	France	7
Indonesia	19	Germany	7
United Kingdom	16	Brazil	6
United States	13	Portugal	6
Australia	9	Spain	6

4.1.4. Fields of Research

The analysis shows that research on KPIs for sustainable supply chains is primarily concentrated in the field of Engineering (78 documents; 46.2%), followed by Business, Management and Accounting (63 documents; 37.3%) and Computer Science (58 documents; 34.3%). Environmental Science (44 documents; 26.0%) and Decision Sciences (36 documents; 21.3%) also represent significant contributions, while fields such as Social Sciences (26 documents; 15.4%) and Energy (24 documents; 14.2%) provide additional but secondary perspectives (see Figure 3). This disciplinary concentration indicates that sustainable supply chain KPI research remains predominantly framed within technical and management-oriented domains. Other disciplines, including Mathematics, Materials Science, Economics, and the Natural Sciences, are less represented, suggesting limited cross-disciplinary integration between socioeconomic, behavioral, and technical perspectives. This skew suggests that current KPI research and measurement approaches may privilege operational and technological dimensions, while comparatively underrepresenting social resilience, circular economy principles, and stakeholder engagement within SME-oriented sustainability assessment. This disciplinary imbalance is important because KPI development is not only a technical measurement task but also a socio-organizational process,

particularly for SMEs where resource constraints and informal governance structures shape what can be measured and acted upon.

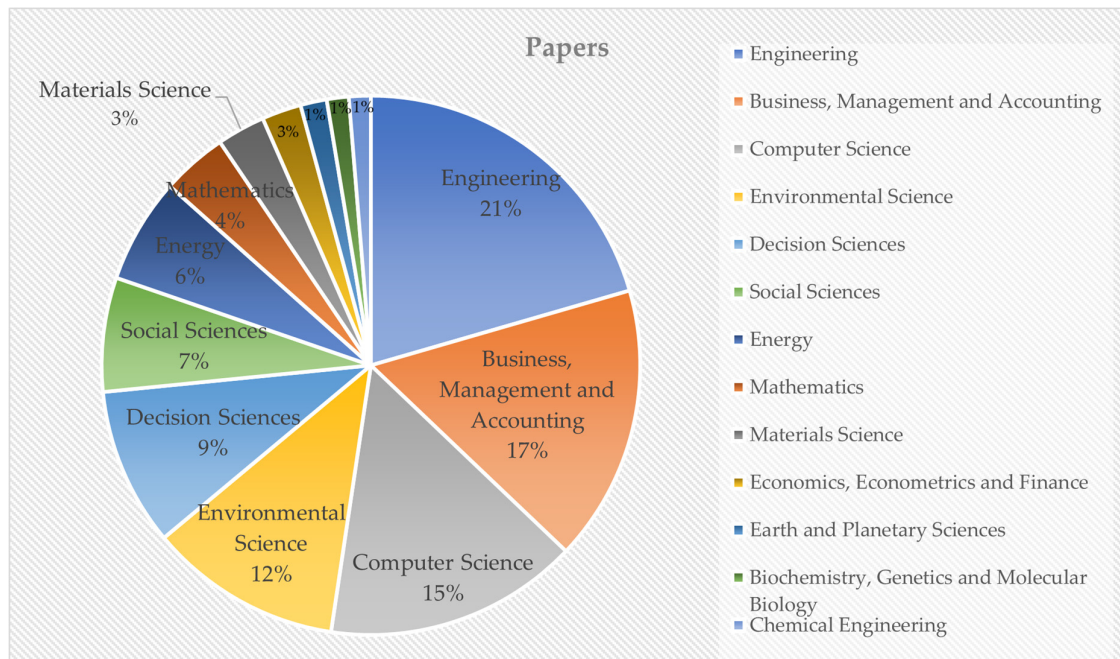


Figure 3. The categorization of sustainable supply chain KPI studies by field of study.

4.1.5. KPI Categories and Research Distribution

Based on the table provided in Table 4, these data represent a multi-label classification of research articles. This means that a single study can be categorized under multiple, relevant KPI categories. Data analysis reveals that the Systems and Technology category has the highest number of papers with 102, closely followed by Production and Operations with 101. This suggests a strong research focus on the application of technology to enhance production and operational processes. Furthermore, Transportation and Logistics and Social and Community Engagement both have 84 manuscripts, highlighting growing interest in both supply chain management and the social impact of business.

In contrast, the categories with the fewest papers are Crisis and Disruption Management (9 papers) and Human Capital and Organizational Capability (10 papers). These critical research gaps suggest that these areas represent either emerging domains requiring urgent scholarly attention or established yet understudied fields where research investment remains inadequate relative to organizational needs, particularly given contemporary challenges regarding supply chain resilience and workforce capability management. Notably, the weak representation of crisis- and human capability-related KPI domains indicates that the literature remains more developed in measuring operational outputs than in capturing capability-building conditions that are often critical for SME sustainability performance.

From a bibliometric perspective, this conclusion is derived from the relative frequency of publications across KPI categories and reflects patterns of research emphasis rather than normative judgments about managerial priority or implementation importance. These findings therefore indicate underrepresented analytical domains within the existing literature, which may inform directions for future empirical investigation. Accordingly, the KPI distribution presented here is treated as evidence of thematic concentration and omission within the literature rather than as a prescriptive KPI prioritization scheme.

Table 4. Distribution of research papers by key performance indicator (KPI) category (2004–2025).

KPI Category	Number of Papers
Systems and Technology	102
Production and Operations	101
Transportation and Logistics	84
Social and Community Engagement	84
Financial	60
Integrated Performance Measurement	60
Resource and Energy Management	40
Marketing and Stakeholder Engagement	38
Quality and Safety Performance	30
Risk and Resilience Management	22
Governance and Transparency	13
Human Capital and Organizational Capability	10
Crisis and Disruption Management	9

4.1.6. Analysis of Key Performance Indicators (KPIs) in Sustainable Supply Chains

This analysis, based on a systematic literature review, categorizes KPIs within sustainable supply chains. The findings are grouped into two primary perspectives: an analysis based on sustainability components and a more detailed breakdown based on specific KPI categories. This presentation provides both a high-level sustainability component view and a category-level mapping of KPI emphasis across the reviewed studies. The purpose of this categorization is to clarify bibliometric patterns of emphasis across KPI domains, rather than to propose or validate a KPI framework.

This table classifies research based on the primary sustainability dimension addressed. The data reveal a strong focus on the economic aspects of sustainability, followed by environmental and operational considerations. The data provided highlights that academic research on key performance indicators (KPIs) in sustainable supply chains predominantly focuses on the economic dimension, which accounts for the majority of studies (65.1%; 110 studies). This concentration reflects a research emphasis on financial outcomes, such as cost reduction, profitability, and return on investment—metrics are frequently used in the reviewed studies. The environmental component is the second most studied area (18.3%; 31 studies), focusing on metrics such as carbon emissions, resource consumption, and waste management. In contrast, operational excellence (7.1%), social aspects (5.3%), and risk management (3.0%) each receive significantly less attention, indicating relatively lower representation in the reviewed literature across these dimensions. Overall, the results indicate an uneven distribution of research attention across sustainability dimensions. From a bibliometric perspective, this imbalance reflects differences in publication emphasis across sustainability components, rather than confirming the relative importance of each dimension in SME practice. The percentages in Table 5 are calculated based on the total number of studies ($n = 169$), where each study is assigned to its primary sustainability component.

Table 5. Analysis of KPIs by sustainability component.

Component	Number of Studies	Percentage	Representative KPIs	Key Research Insights
Economic	110	65.1%	Cost, Profit, ROI, Efficiency, Competitiveness	Research is heavily concentrated on economic outcomes, using methods such as DEMATEL, ANP, and TLS. Studies also explore the use of AI to predict supply chain performance and financial factors (e.g., risk) as barriers to sustainability.
Environmental	31	18.3%	Carbon emissions, Energy efficiency, Waste management, Environmental impact	Key research focuses on developing frameworks for sustainable waste management and green management approaches. KPIs are used to measure carbon emissions and energy efficiency.
Operational Excellence	12	7.1%	Quality, Lead time, Inventory management, Innovation, Technology adoption	Research integrates modern technologies such as machine learning and automation with KPIs for Industry 5.0. Focus areas include optimizing processes and tracking performance metrics, including lead time and inventory.
Social	9	5.3%	Ethics, Safety, Employee welfare, Social responsibility, Human rights	This category, while smaller, includes notable research on managing stakeholder influence and the impact of social sustainability on supply chain performance. KPIs focus on ethical and social metrics.
Risk Management	5	3.0%	Resilience, Crisis management, Business continuity	Research in this area examines KPIs that measure a supply chain's ability to withstand and recover from disruptions.

This table presents a more granular classification of KPIs, revealing the growing dominance of technology- and sustainability-focused metrics in recent academic discourse. The analysis is based on 169 studies published between 2004 and 2025. The analysis of KPI categories reveals a clear hierarchy of research focus, with a strong emphasis on System and Technology KPIs, which have the highest average score (12.88). This prominence corresponds to an increased research focus on digital transformation and the integration of Industry 4.0/5.0 technologies, such as artificial intelligence, IoT, and blockchain, within sustainable supply chain measurement approaches. Sustainability KPIs are the second most studied category, with an average score of 8.25, indicating substantial research attention to environmental metrics and circular economy practices. These patterns suggest that KPI research has increasingly prioritized data-enabled monitoring and technology-supported decision making, which may partially explain the high visibility of system-oriented KPI categories in recent years. The rankings and average scores reported in Table 6 reflect category-level emphasis derived from KPI category occurrences across the reviewed studies

and therefore should be interpreted as weighted publication attention rather than as direct measures of KPI effectiveness.

Table 6. Rankings of key performance indicators (KPIs) in sustainable supply chains by average score.

KPI Category	Average Score	Key Findings and Representative KPIs	Representative References
System and Technology KPIs	12.88	Highest-ranked category (62.7%); focuses on Industry 4.0/5.0 technologies, including AI, IoT, blockchain, and Digital Twin.	[45–47]
Sustainability KPIs	8.25	Second-ranked category (18.9%); focusing on carbon reduction, energy efficiency, and the circular economy.	[48–50]
Production and Operations KPIs	6.34	Focuses on traditional operational efficiency, including OEE, lead time, and lean manufacturing.	[51–53]
Transportation and Logistics KPIs	3.39	Examines efficiency in logistics through metrics such as TOVE, route optimization, and reverse logistics.	[18,48,54]
Integrated Performance Measurement KPIs	2.27	Limited coverage (1.8%); focuses on multi-dimensional KPI integration approaches.	[55–57]
Innovation and Strategy KPIs	1.98	Research in this category explores frameworks and strategic models for KPIs.	[58–60]
Resource and Energy Management KPIs	1.60	Focuses on the efficiency of resource and energy utilization.	[61–63]
Financial KPIs	1.38	These KPIs (e.g., profit, cost) are often integrated into other categories rather than being a standalone focus.	[50,64,65]
R&D and Innovation Performance KPIs	1.36	Addresses the measurement of research, development, and innovation activities.	[66–68]
Marketing and Stakeholder Engagement KPIs	1.34	Focuses on measuring external relationships and stakeholder involvement.	[14,69,70]
Human Capital and Organizational Capability KPIs	1.07	Low representation; addresses workforce capability and organizational development indicators.	[71–73]
Social and Community Engagement KPIs	0.85	Examines KPIs related to community involvement, local employment, and social impact.	[69,74,75]
Quality and Safety Performance KPIs	0.66	Focuses on measuring defect rates, safety, and compliance with standards.	[76–78]
Risk and Resilience Management KPIs	0.49	Low representation; focuses on disruption recovery and supply chain resilience indicators.	[79–81]

Table 6. Cont.

KPI Category	Average Score	Key Findings and Representative KPIs	Representative References
Governance and Transparency KPIs	0.41	Limited coverage; focuses on transparency, auditability, and corporate governance indicators.	[43,47,82]
Crisis and Disruption Management KPIs	0.12	Lowest-ranked category; focuses on crisis response and disruption recovery indicators.	[80,83,84]

Identification of sustainability components (see Table 5): Each included study (n = 169) was categorized under one primary sustainability component based on its main research objective and the KPI focus emphasized in the paper. This classification was carried out through qualitative content analysis by reviewing the title, abstract, author keywords, and the KPI descriptions provided in each study. To avoid overlap each paper was assigned to a single dominant component (economic, environmental, operational excellence, social, or risk management). When more than one sustainability dimension was discussed, the component most closely aligned with the research question and KPI application was selected.

In contrast, several crucial KPI domains register limited academic engagement. Human Capital and Organizational Capability KPIs show low representation (mean value = 1.07), suggesting limited research attention to the human dimension within sustainable supply chains. Furthermore, the categories of Quality and Safety Performance (0.66), Risk and Resilience Management (0.49), and Crisis and Disruption Management (0.12) are among the lowest-represented dimensions, highlighting comparatively low visibility in the reviewed literature. These findings suggest that while technological and environmental aspects are well documented, human-, risk-, and governance-related KPI domains receive comparatively less attention in SSCM KPI studies (see Table 6). Overall, the results indicate an uneven distribution of research attention across KPI categories. Importantly, the low representation of these domains should be interpreted as an evidence-based signal of underexplored research areas within the literature, rather than as an assessment of their practical relevance for SMEs. This underrepresentation is also consistent with the observation that socio-organizational and resilience-oriented KPI domains tend to require more context-specific data and interpretive effort, which may contribute to their lower visibility in KPI-focused SSCM publications.

4.2. Co-Occurrence Analysis and Bibliographic Coupling

4.2.1. Keyword Co-Occurrence and Thematic Clusters

This analysis, based on a bibliographic study, identifies and groups key terms into three distinct thematic clusters as shown in Figure 4; node size reflects keyword frequency and link thickness represents the strength of co-occurrence among keywords, generated using VOSviewer. The network visualizations and the associated tables provide a clear overview of the conceptual relationships and focal points within the research domain. The analysis applied a minimum occurrence threshold of 5, and of the 1280 identified keywords, 46 satisfied this criterion, reflecting the most frequently discussed concepts in literature. This threshold was selected to balance analytical clarity with sufficient thematic coverage, ensuring that only conceptually salient terms were included in the network interpretation. Accordingly, the cluster structure reflects co-occurrence patterns among high-frequency keywords, rather than an exhaustive representation of all concepts discussed across the full dataset.

indicates that KPI operationalization is frequently discussed through applied settings (e.g., agri-food), where measurement practices and data availability may shape KPI selection.

Cluster 3: Technological Innovation and Industry 4.0/5.0 Integration. This cluster is characterized by its focus on advanced digital technologies and forward-looking solutions for supply chain optimization, as presented in blue color. Terms such as artificial intelligence, Industry 4.0, and simulation indicate an emphasis on leveraging emerging technologies to enhance operational efficiency and resilience. The presence of logistics, manufacturing, and supply chain management within this cluster demonstrates how technological innovations are being applied to improve process optimization and resource utilization. The inclusion of green supply chain and sustainability indicates the presence of technology-related concepts linked to sustainability objectives. Overall, this cluster highlights a concentration of digital and technology-oriented themes within the keyword network (see Figure 4). The prominence of this cluster reflects the increasing visibility of digitalization and data-driven approaches within the SSCM KPI literature, as captured through bibliometric patterns. Notably, the keyword profile suggests that technology is frequently positioned as an enabler of KPI data capture, traceability, and real-time monitoring, which may contribute to its strong co-occurrence with sustainability measurement terms.

The network visualizations reveal strong interconnections among the three clusters. The most prominent terms, such as key performance indicators, supply chain management, and sustainable development, act as central nodes that connect the different groups. This shows that the research in this domain is organized around interconnected thematic areas where foundational principles (Cluster 1), practical applications (Cluster 2), and technological advancements (Cluster 3) are linked through shared keywords. These interconnections indicate thematic convergence within literature, rather than causal relationships among the identified clusters. In other words, the network indicates shared conceptual space across themes, but does not establish directionality or influence among clusters.

The overall coherence of these clusters indicates the co-occurrence of sustainability-, technology-, and management-related concepts within the reviewed literature (see Table 7). The colored visualizations further emphasize these thematic groupings, making it clear which terms are most closely related.

The temporal evolution of research themes is evident through color-coded network analysis. The first cluster, with darker, bluish nodes, includes foundational terms such as carbon footprint, case studies, and performance measurement, indicating that these were prominent topics in the earlier part of the research period. The second cluster, primarily greenish-yellow nodes, shifts towards the practical application of these concepts with terms such as benchmarking, environmental management, and food supply chain, suggesting a more recent focus on implementing management systems and operational strategies. The third cluster, with bright, yellow-colored nodes, is characterized by a concentration of technology-related terms, featuring recent terms such as artificial intelligence, Industry 4.0, and simulation. This color progression from dark blue to yellow illustrates a temporal transition in keyword prominence, moving from an initial emphasis on fundamental concepts and measurement frameworks to the strategic integration of management practices, and most recently to the application of advanced technologies to address supply chain and sustainability challenges. This temporal pattern reflects shifts in research emphasis over time, as captured through keyword emergence, rather than a linear evolution of theory. Consistent with this, the overlay map should be interpreted as indicating relative recency of keyword prominence (based on average publication year), not as evidence that earlier themes were replaced or resolved.

Table 7. Three cluster keywords.

Cluster 1	Cluster 2	Cluster 3
carbon footprint	benchmarking	artificial intelligence
case studies	decision support systems	balanced scorecard
decision making	environmental management	efficiency
economic and social effects	food supply	green supply chain
enterprise resource planning	food supply chain	industry 4.0
environmental impact	industrial management	key performance indicators
information management	KPIs	logistics
key performance indicator	life cycle	manufacturing
key performance indicators	manufacture	performance assessment
KPI	product design	simulation
performance	supply chains	supply chain management
performance indicators	sustainable development	sustainability
performance management	sustainable performance	
performance measurement	waste management	
performance measurements		
supply chain		
supply chain performance		
sustainable supply chains		
systematic literature review		

Furthermore, keyword frequency analysis reveals a strong scholarly focus on the intersection of key performance indicators (KPIs) and sustainable development, which are the most prominent keywords in the dataset, exhibiting the highest frequency of occurrence and total link strength. Following these, benchmarking and supply chains also demonstrate significant influence, indicating strong co-occurrence relationships in the keyword network. Additional prominent terms include supply chain management, sustainability, and decision making, though with comparatively lower frequencies. The collective presence of these keywords indicates that a substantial body of research addresses the use of sustainability-related metrics within supply chain performance studies (see Table 8). These frequency patterns provide an evidence-based overview of dominant research topics, without implying normative prioritization of specific KPI domains. Importantly, high occurrence and link strength indicate keyword centrality within the network, but not necessarily conceptual completeness of KPI domains for SMEs.

The network overlay visualization generated via VOSviewer illustrates the co-occurrence of keywords within the literature on supply chain KPIs and sustainability. Prominent keywords such as “key performance indicators,” “sustainable development,” “supply chain management,” and “sustainability” appear as central nodes, indicating their high frequency and strong interconnections with other terms. The network also highlights related concepts including “decision making,” “performance measurement,” “environmental management,” and “life cycle,” which suggests that KPI research in this area draws on both performance measurement and sustainability assessment perspectives.

Table 8. Total link strength and keyword occurrence.

	Keyword	Occurrence	Total Link Strength
1.	key performance indicators	60	296
2.	sustainable development	63	296
3.	benchmarking	52	290
4.	supply chains	52	240
5.	supply chain management	48	204
6.	sustainability	48	164
7.	decision making	16	92
8.	supply chain	17	65
9.	information management	8	58
10.	sustainable supply chain	11	58
11.	environmental impact	11	56
12.	manufacture	9	55
13.	key performance indicator	10	51
14.	food supply	7	45
15.	life cycle	8	45
16.	performance measurement	10	44
17.	economic and social effects	8	43
18.	KPIs	11	42
19.	performance measurements	7	41
20.	food supply chain	6	39

The color gradient represents the temporal evolution of keywords, with recent trends (2021–2022) emphasizing emerging topics such as “industry 4.0,” “carbon footprint,” and “manufacturing,” indicating increasing prominence of these terms in the later period of the dataset (see Figure 5). In VOSviewer overlay maps, this temporal pattern reflects the average publication year of keyword occurrences, providing an indicative view of emerging thematic directions rather than a causal explanation of topic growth. Accordingly, the overlay visualization is used here to support interpretation of emerging research attention, not to infer drivers of change. Additionally, the node size represents the total link strength of bibliographic coupling for each country.

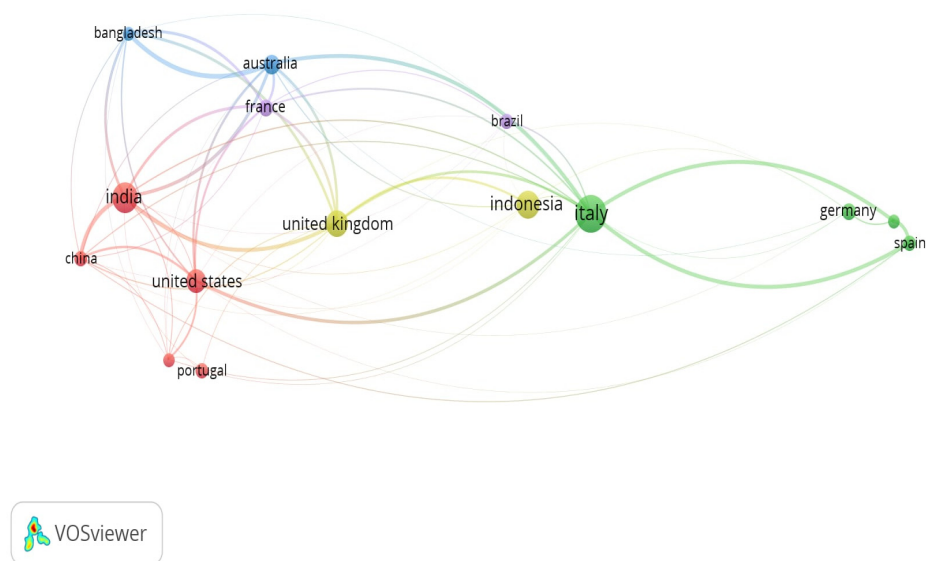


Figure 6. Network visualization of bibliographic coupling by country using VOSviewer.

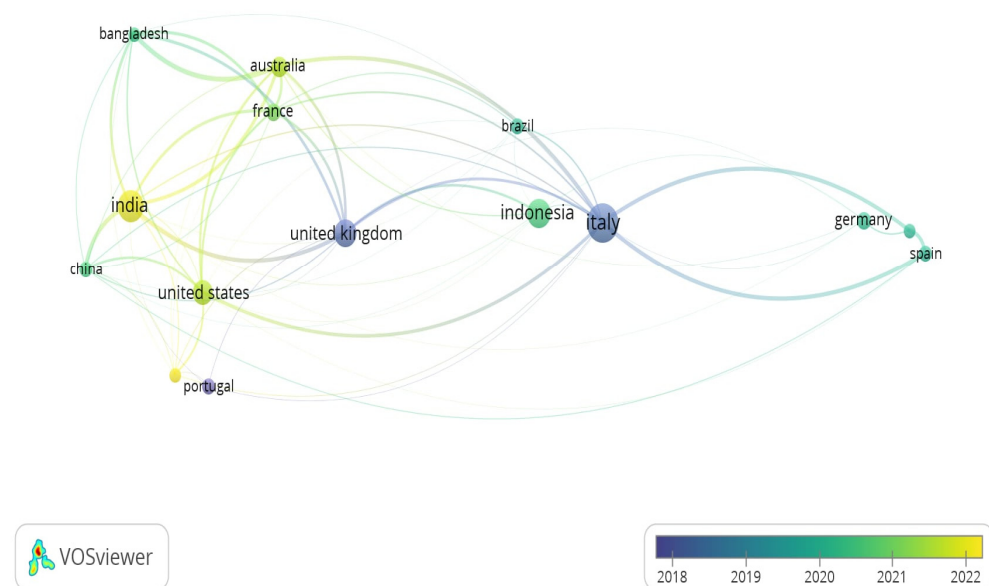


Figure 7. Overlay of bibliographic coupling by country.

Table 9 presents a bibliometric analysis of research output by country, demonstrating significant variance in scholarly contributions and influence. Italy is most frequently represented in the dataset, with 34 documents and 1212 citations, thus attaining the most substantial total link strength (1398). This indicates the highest level of connectivity within the coupling network among the listed countries. Countries such as Australia and India also show a strong academic presence, evidenced by their high citation counts and total link strengths, despite publishing fewer documents than Italy. In contrast, several countries, including Malaysia and Portugal, demonstrate a lower volume of scholarly output and lower coupling indicators, as indicated by their smaller number of documents and citations and lower link strength. These differences illustrate uneven participation in the bibliographic coupling network, which may be influenced by publication focus, database coverage, and citation practices rather than direct research collaboration or policy-driven coordination (see Table 9). Accordingly, these coupling results provide an interpretive basis for discussing intellectual similarity and citation-based connectivity across countries, rather than a measure of co-authorship collaboration intensity.

Table 9. Bibliometric analysis of research output by country.

	Country	Documents	Citations
1.	Italy	34	1212
2.	Australia	9	255
3.	India	23	535
4.	United Kingdom	16	377
5.	Bangladesh	5	120
6.	France	7	78
7.	Norway	4	55
8.	United States	13	346
9.	Greece	5	104
10.	Spain	6	65
11.	China	6	312
12.	Canada	3	38
13.	Indonesia	19	124
14.	Germany	7	85
15.	Turkey	5	71
16.	Switzerland	3	5
17.	Brazil	6	101
18.	Estonia	3	41
19.	Malaysia	3	29
20.	Portugal	6	98

5. Discussion

5.1. Research Gaps and Theoretical Implications

5.1.1. Future-Oriented Sustainability KPIs for SMEs: Insights from Bibliometric Gaps

The bibliometric analysis shows that several critical components of sustainable supply chain KPIs remain underexplored, indicating not only thematic gaps in the literature but also limitations in how sustainability performance is currently conceptualized and measured in SME supply chains. From a bibliometric perspective, these gaps reflect patterns of scholarly attention and omission, rather than deficiencies in practice or evidence of causal relationships. To strengthen conceptual grounding without extending beyond bibliometric inference, the gaps identified below are interpreted using established theoretical perspec-

tives (e.g., Dynamic Capabilities Theory and Stakeholder Theory) as interpretive lenses rather than as theories tested in this study.

Human Capital and Organizational Capability constitute particularly pronounced gaps, as workforce skills, talent retention, and organizational learning directly influence adaptive capacity yet remain weakly reflected in dominant KPI systems [34]. The limited presence of these indicators in the bibliometric corpus suggests that existing SSCM KPI research continues to privilege operational and technological efficiency over capability-based performance dimensions in SME contexts. Interpreted through Dynamic Capabilities Theory, this underrepresentation is notable because capability-building indicators (e.g., learning readiness, reconfiguration ability) are central to how SMEs adapt sustainability practices under resource constraints, yet remain marginal within KPI-focused SSCM publications.

Marketing and Stakeholder Engagement also warrant further attention, particularly regarding how consumer trust, stakeholder collaboration, and brand reputation can be operationalized and measured within supply chain contexts [1,12,16]. Bibliometric mapping indicates that such indicators are often treated as peripheral or supplementary, rather than as core components of sustainability performance measurement. From a Stakeholder Theory perspective, this pattern suggests that stakeholder-facing KPI domains (e.g., trust, transparency, relational quality) are less visible than internal efficiency metrics, despite their relevance for sustaining legitimacy and collaborative compliance in SME supply chains.

Risk and Resilience Management has emerged as increasingly critical amid contemporary supply chain volatility, yet existing KPI frameworks continue to insufficiently capture dimensions such as recovery speed, adaptive capacity, and disruption preparedness [8,14,15]. This underrepresentation highlights a disconnect between emerging supply chain risks and the KPI domains emphasized in current SSCM research. Conceptually, resilience-oriented indicators align with organizational resilience perspectives, yet bibliometric evidence suggests that these KPI domains remain weakly embedded relative to technology- and efficiency-centered measurement logics.

Beyond these individual domains, the bibliometric results point to a broader imbalance in sustainability performance measurement practices. Integrated Performance Measurement approaches, such as the Balanced Scorecard and the SCOR model—are frequently referenced in the literature, yet they remain weakly adapted to holistically link operational, social, and environmental dimensions within SME contexts [35,36]. This gap suggests that future KPI applications should move beyond fragmented assessments toward indicators that support integrated decision-making across sustainability dimensions. This finding does not imply the inadequacy of these models but rather reflects their limited operationalization within SME-oriented KPI research. More specifically, SCOR and Balanced Scorecard-oriented applications are often designed for standardized processes, formal reporting structures, and relatively stable data infrastructures, which may be difficult for SMEs with informal governance, limited analytics capacity, and constrained monitoring resources. As a result, these systems may insufficiently capture SME-specific constraints and adaptation needs even when they are cited as “holistic” measurement models.

Similarly, research on research and development and innovation performance remains limited, with insufficient emphasis on indicators capturing technology adoption, learning intensity, and sustained investment in sustainability-oriented solutions [32]. Such indicators are particularly relevant for SMEs seeking to align innovation and digital transformation initiatives with longer-term sustainability objectives. From a bibliometric standpoint, innovation-related KPIs are often subsumed under technology or efficiency categories,

reducing their visibility as distinct sustainability drivers. Interpreted through Dynamic Capabilities Theory, this pattern is consequential because innovation and learning mechanisms function as enabling conditions for SMEs to operationalize sustainability beyond compliance-driven outputs.

Additional under-represented areas include Quality and Safety Performance, which could integrate defect rates and compliance standards into sustainability metrics, and Governance and Transparency, where KPIs covering traceability and disclosure would enhance accountability frameworks [25,26]. From a bibliometric perspective, the limited presence of these domains reflects patterns of scholarly emphasis rather than the absence of practical relevance, as these indicators are rarely embedded within sustainability-oriented measurement systems, limiting their ability to inform broader sustainability trade-offs in SME supply chains.

While Resource and Energy Management has received moderate attention, the bibliometric evidence indicates that research remains unevenly distributed, with substantial research still needs to be conducted on renewable resource utilization, water efficiency, and energy intensity metrics, particularly in light of increasing environmental and regulatory pressures faced by SMEs.

Finally, Crisis and Disruption Management and Social and Community Engagement are critical but under-represented. The low frequency of these themes in the bibliometric dataset suggests that KPIs measuring recovery capacity, emergency response effectiveness, community employment contributions, and local development impact remain marginal within the current SSCM KPI literature, despite their growing relevance under conditions of heightened supply chain uncertainty [14,15]. This underrepresentation is consistent with the broader tendency of KPI research to focus on measurable operational outputs rather than preparedness and response capabilities, which may be harder to quantify and standardize across SME contexts.

Building on these identified bibliometric gaps, Table 10 synthesizes a master set of sustainability KPI domains that highlight priority measurement areas for future research and practice in SME supply chains. From a bibliometric standpoint, this synthesis reflects patterns of concentration and omission observed in existing literature, rather than the development or validation of new indicators. Rather than introducing new indicators or proposing a unified framework, the table consolidates existing KPI categories and repositions them analytically based on their relative visibility and underrepresentation within the bibliometric dataset, according to their potential role in supporting adaptive capacity, stakeholder engagement, and resilience under contemporary supply chain conditions [12,14–16]. Accordingly, the master KPI table functions as an orientation and sense-making device, helping to bridge current measurement gaps with future sustainability challenges faced by resource-constrained SMEs, without implying empirical testing or normative implementation guidance. In addition, the table supports an explicit comparison with dominant measurement systems (e.g., SCOR and Balanced Scorecard) by highlighting KPI domains that remain weakly represented or absent in efficiency-centered and standardization-driven measurement logics, particularly human capital, resilience, governance, and crisis management, which strengthens the manuscript's contribution as a bibliometric synthesis of structural omissions rather than as a competing KPI framework.

Table 10. A Future-Oriented Sustainability KPI Agenda for SMEs' Sustainable Supply Chain Management.

KPI Category	Future-Oriented KPI	Sustainability Dimension	Conceptual Focus	Bibliometric Gap Addressed	Theoretical Anchor	Key Sources
Resource and Energy Management	Circular Resource Utilization Rate	Environmental	Share of reused/recycled materials	Circularity KPIs are less studied than cost KPIs	Circular Economy Theory	[8,23]
	Renewable Energy Adoption Intensity	Environmental	Level of renewable energy use	Energy transition indicators are underexplored in SMEs	Ecological Modernization Theory	[1,5,17]
	Water Efficiency and Stress Exposure	Environmental	Water use adjusted for local scarcity	Water-related KPIs are rarely examined	Natural Resource-Based View	[1,6]
Social and Community Engagement	Local Stakeholder Engagement Intensity	Social	Strength of local collaboration	Social value KPIs receive limited attention	Stakeholder Theory	[12,16]
	Decent Work Coverage across Suppliers	Social	Supplier labor standard compliance	Labor KPIs are weakly operationalized	Social Sustainability Theory	[12,16]
R&D and Innovation Performance	Sustainable Innovation Investment Intensity	Economic/ Environmental	R&D spending on sustainable innovation	Innovation KPIs emphasize tech over sustainability outcomes	Dynamic Capabilities Theory	[3,17,22]
	Green Digital Technology Adoption	Governance/ Environmental	Digital tools for sustainability monitoring	Digital sustainability KPIs remain fragmented	Socio-Technical Systems Theory	[3,22,26]
Integrated Performance Measurement	Integrated ESG Performance Alignment	ESG	Alignment of ESG KPIs in one system	ESG integration is limited in SME measurement systems	Balanced Scorecard Theory	[35,36]
	Sustainability Trade-off Transparency	ESG	Visibility of cost–service–sustainability trade-offs	Trade-offs are rarely made explicit	Multi-objective Decision Theory	[8,35,36]
Human Capital and Organizational Capability	Green Skills and Learning Readiness	Social/ Governance	Workforce readiness for sustainable practices	Human capital KPIs are among the least studied	Human Capital Theory	[13,34]
	Organizational Learning for Sustainability	Governance	Ability to learn and adapt	Learning-oriented KPIs are underrepresented	Organizational Learning Theory	[13,34]
Risk and Resilience Management	Supply Chain Resilience Capability	Resilience	Ability to absorb and adapt to disruptions	Resilience KPIs are weakly embedded in KPI systems	Organizational Resilience Theory	[14,15]
	Disruption Recovery Speed	Resilience	Time to restore operations	Recovery speed indicators lack standardization	Resilience Engineering	[14,15]
Crisis and Disruption Management	Crisis Preparedness Coverage	Resilience/ Governance	Extent of contingency planning	Crisis KPIs are marginal in SSCM research	Crisis Management Theory	[14,15]

Table 10. Cont.

KPI Category	Future-Oriented KPI	Sustainability Dimension	Conceptual Focus	Bibliometric Gap Addressed	Theoretical Anchor	Key Sources
Quality and Safety Performance	Sustainability-Adjusted Quality Performance	Environmental/Economic	Quality outcomes adjusted for environmental impact	Quality KPIs are rarely linked to sustainability	Total Quality Management	[35,36]
Governance and Transparency	Digital Supply Chain Traceability	Governance	Visibility across supply chain tiers	Governance and transparency KPIs are underdeveloped	Transparency and Accountability Theory	[25,26]
	ESG Disclosure Responsiveness	Governance	Speed and completeness of ESG reporting	Responsiveness is often overlooked	Corporate Governance Theory	[25,38]

5.1.2. Implementation Barriers in SME Contexts

Several implementation barriers identified in the SSCM literature help explain why many of the future-oriented KPI domains discussed in the preceding subsection remain weakly embedded in SME supply chain practices. This research highlights several key implementation barriers faced by SMEs aiming to adopt sustainable supply chain management (SSCM). While the relevance of sustainability-oriented KPIs is increasingly acknowledged, SMEs continue to face persistent challenges in operationalizing and integrating sustainability-related performance measurements within their supply chains. A primary challenge is limited integration among the various SSCM components, indicating that current approaches lack the holistic coherence necessary to achieve effective implementation [6]. From a bibliometric perspective, this fragmentation is reflected in the dominance of isolated KPI categories, rather than integrated measurement approaches, within the existing literature. Furthermore, there is a pronounced scarcity of comprehensive research and validated practical tools addressing risk management and collaborative mechanisms within this domain [21]. This theoretical and methodological gap constrains SMEs' capacity to proactively prepare for and effectively mitigate supply chain disruptions, particularly in volatile and resource-constrained environments [14,15]. These barriers provide a plausible explanation for why capability- and resilience-oriented KPI domains remain underrepresented in bibliometric outputs, even as they are frequently discussed as practical priorities for SMEs.

The findings also reveal a persistent overemphasis on economic KPIs, with critical sustainability dimensions, particularly risk management, governance, and inter-organizational collaboration, receiving disproportionately limited attention [8,12,16]. This imbalance mirrors the bibliometric patterns identified in Section 4, where economic and technology-oriented indicators significantly outweigh capability- and resilience-based measures. As a result, several capability-based and resilience-oriented KPI domains highlighted in Section 5.1.1—such as human capital development, organizational learning, and adaptive resilience—remain insufficiently operationalized in SME performance measurement systems [14,15,34]. Rather than indicating a lack of relevance, this underrepresentation suggests structural and methodological constraints in how SSCM performance is currently measured and reported in SME-focused research. This imbalance constitutes a significant barrier to achieving genuinely sustainable and resilient supply chain configurations in SME contexts. In practical terms, these constraints suggest that KPI adoption pathways for SMEs must account for feasibility (data availability, digital readiness) and capability-building (skills, learning routines), rather than assuming that standardized KPI systems can be directly transferred from large-firm settings.

5.2. Practical Implications and Implementation Pathways

To effectively implement sustainable supply chain management (SSCM), SMEs are advised to adopt a balanced approach that goes beyond a singular focus on technology. In light of the implementation barriers discussed in Section 5.1.2, effective implementation requires aligning sustainability measurement priorities with organizational capabilities and resource constraints. This implication is directly derived from the bibliometric evidence, which shows a strong concentration of technology-oriented KPIs alongside comparatively limited attention to human capital and organizational capability dimensions. A critical best practice is the strategic integration of both technological infrastructure and human capital development, ensuring that digital transformation initiatives are complemented by systematic investments in workforce readiness and capability enhancement [22,34]. This provides decision-support guidance for SME managers by suggesting sequencing: starting with feasible data-capture KPIs (often technology-enabled), while simultaneously building the organizational capabilities needed to expand toward human, governance, and resilience-oriented KPI domains that are currently underrepresented in literature.

Rather than treating sustainability KPIs as standalone reporting tools, SMEs should embed them within existing technology-enabled performance measurement systems, creating more unified approaches that simultaneously assess digital maturity and sustainability-related outcomes, including environmental and social performance [43]. This recommendation reflects the observed dominance of isolated KPI categories in the literature and responds to the lack of integrated performance measurement identified in the bibliometric analysis. This integration helps reduce fragmentation and supports more consistent decision-making across SSCM components. Importantly, this guidance is framed as an implication derived from bibliometric concentration/omission patterns, not as prescriptive implementation instructions or validated best-practice claims.

Moreover, SMEs should prioritize developing basic but context-appropriate risk preparedness architectures, including the deployment of resilience-oriented KPIs such as supply chain resilience capability and disruption recovery time metrics [14,15,33]. These practices are informed by the persistent underrepresentation of risk, resilience, and crisis-related KPIs in the bibliometric results, despite their growing relevance in contemporary supply chain contexts. These KPIs are particularly relevant for translating future-oriented measurement domains—such as resilience and adaptive capacity—into actionable monitoring practices without imposing excessive measurement complexity. Collectively, these practices support the gradual and feasible implementation of SSCM, enabling SMEs to strengthen sustainability and adaptability while remaining sensitive to their limited resources and operational realities. Where appropriate, SMEs may leverage enabling technologies discussed in the literature (e.g., IoT for monitoring, AI for anomaly detection, blockchain for traceability) to reduce the monitoring burden and improve data reliability, particularly for governance and transparency KPIs, while keeping implementation proportional to SME capacity.

5.3. Limitations and Future Research Directions

This study identifies several methodological and scope limitations and provides a clear agenda for future research. A significant limitation is the limited focus on non-economic aspects of SSCM, particularly human capital, organizational capabilities, and risk management. As discussed in Section 5.1, these dimensions are increasingly recognized as critical for SME sustainability yet remain weakly embedded in dominant KPI systems [8,14,15,34]. This imbalance reflects not only research gaps but also the structural tendency of bibliometric analyses to privilege highly cited, efficiency- and technology-oriented theme. Future research should concentrate on developing more integrated sustainability KPI mea-

surement approaches that encompass multiple sustainability dimensions and explicitly account for SME constraints, while empirically validating these approaches in diverse SME contexts. This includes creating specialized KPIs for Crisis and Disruption Management and measurement tools that can assess human-centric aspects. Such efforts would help translate the future-oriented KPI domains identified in this study into empirically testable constructs within SME contexts.

Additionally, there is a clear need for more in-depth studies on the integration of technology with sustainability, particularly exploring how emerging technologies including AI can drive sustainable outcomes [14,15,34]. Rather than focusing solely on technological efficiency, future research should examine how technology-enabled KPIs support human decision-making, organizational learning, and resilience-building in SMEs. This shift is necessary to counterbalance the dominance of technology-focused indicators identified in the bibliometric results. Future research should also focus on developing KPIs for human–AI collaboration and creating frameworks for climate-resilient and circular economy-oriented supply chains, addressing the evolving challenges and opportunities in the field. Future empirical studies may extend the KPI modeling perspective by incorporating stochastic environments, fuzzy environments, and multi-objective optimization settings to better capture uncertainty, ambiguity, and sustainability trade-offs in SME supply chains.

A significant constraint is the bibliometric methodology's inherent focus on publication patterns rather than practical implementation outcomes, potentially overlooking industry innovations not yet documented in the academic literature [7]. Moreover, citation-based indicators may delay the visibility of emerging or practice-driven KPI domains that have not yet accumulated academic prominence. The analysis reveals substantial under-representation of non-economic SSCM dimensions, particularly human capital, organizational capabilities, and proactive risk management frameworks. Accordingly, future studies are encouraged to complement bibliometric insights with empirical and mixed-method approaches to validate and refine the KPI domains highlighted in this review. Such approaches are essential to assess contextual feasibility and implementation outcomes that cannot be inferred from bibliometric mapping alone. Future research should therefore prioritize developing and empirically validating integrated KPI measurement approaches that reflect multiple sustainability dimensions in SME supply chains.

5.4. Conclusions

Based on the presented bibliometric analysis, research on sustainable supply chain KPIs in SMEs has grown significantly, especially since 2020. The academic literature predominantly focuses on economic and technological aspects, with Italy, India, and Indonesia leading in terms of research output. However, there are notable gaps in the literature, particularly concerning risk and crisis management, human capital, and social sustainability [8,14,15,34]. While the field shows strong collaboration among key countries, the overall research remains concentrated within technical and management domains.

These patterns suggest that existing KPI research continues to privilege operational efficiency, while offering more limited insight into capability-based, resilience-oriented, and human-centered performance dimensions that are increasingly critical for SMEs [12,14–16]. Rather than proposing new KPIs or validated frameworks, this study contributes by clarifying the intellectual structure, thematic concentrations, and persistent gaps in SSCM KPI research through bibliometric synthesis. Accordingly, the study's added value lies in identifying underexplored KPI domains and positioning them as a future research agenda for SME-oriented sustainability measurement, rather than claiming framework novelty or empirical KPI validation. Our analysis concludes that to achieve a truly holistic understanding, future studies should prioritize developing integrated frameworks and

address the under-researched dimensions of sustainability and resilience. In this regard, the value of the present study lies in providing an evidence-based orientation for future empirical and theory-driven research, rather than prescriptive or practice-level solutions. In this regard, the bibliometric synthesis presented in this study provides an evidence-based foundation for guiding future empirical research and advancing sustainability performance measurement in SME supply chains.

Author Contributions: Conceptualization, W.S., S.P., P.P. and C.S.; methodology, W.S., P.P. and C.S.; software, W.S., S.P. and C.S.; validation, S.P., P.P., V.K. and S.S.; formal analysis, W.S., S.P., P.P. and C.S.; investigation, S.P., P.P., V.K. and S.S.; resources, W.S. and S.P.; data curation, P.P., V.K. and S.S.; writing—original draft preparation, W.S., S.P., P.P., C.S., V.K. and S.S.; writing—review and editing, W.S., S.P., P.P., C.S., V.K. and S.S.; visualization, W.S. and C.S.; supervision, S.P. and P.P.; project administration, W.S.; funding acquisition, W.S. and S.P. All authors have read and agreed to the published version of the manuscript.

Funding: This research was partially supported by the International Research Collaboration Scheme (Contract Number: WU-CIA-04204/2025).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: No new data were created or analyzed in this study. Data sharing is not applicable to this article. However, relevant information supporting this study's findings is available from the corresponding author upon reasonable request.

Acknowledgments: This project was also conducted under the Reinventing University program, supported by the Ministry of Higher Education, Science, Research and Innovation, Walailak University.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

KPIs	Key Performance Indicators
SSCM	Sustainable Supply Chain Management
SSCM	Small- and Medium-sized Enterprises
AI	Artificial Intelligence
IoT	Internet of Things
ERP	Enterprise Resource Planning
SCOR	Supply Chain Operations Reference
R&D	Research and Development
ROI	Return on Investment
MCDM	Multi-Criteria Decision Making
DEA	Data Envelopment Analysis
AHP	Analytic Hierarchy Process
LCA	Life Cycle Assessment

Appendix A. PRISMA 2020 Reporting Checklist and Study Selection Flow Diagram

This appendix provides the PRISMA 2020 checklist and the PRISMA flow diagram to improve transparency and reproducibility of the literature identification and screening process [40]. As this study is a bibliometric review, PRISMA items related to risk-of-bias assessment and effect-size synthesis are not applicable and are indicated accordingly.

Appendix A.1. PRISMA 2020 Checklist

Table A1. PRISMA 2020 checklist for the systematic identification and screening process applied in this bibliometric review.

Section and Topic	Item	Checklist Item	Location in Manuscript
Title	1	Identify the report as a systematic review.	Title; Methods (Section 3.1)
Abstract	2	Provide a structured summary of the review.	Abstract
Introduction	3	Describe the rationale for the review in the context of existing knowledge.	Introduction (Section 1)
	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	Introduction (Section 1); Research Questions (RQ1–RQ3)
Methods	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	Methods (Section 3.1)
	6	Specify all information sources (e.g., databases, registers) and the date last searched.	Methods (Section 3.1)
	7	Present the full search strategies for all databases, registers, and websites, including any filters and limits used.	Methods (Section 3.1)
	8	Specify the methods used to decide whether a study met the inclusion criteria, including how many reviewers screened each record and whether they worked independently.	Methods (Section 3.1)
	9	Specify the methods used to collect data from reports, including how many reviewers collected data and whether they worked independently.	Methods (Section 3.2)
	10a	List and define all outcomes for which data were sought.	Not applicable (bibliometric review)
	10b	List and define all other variables for which data were sought.	Methods (Section 3.2)
	11	Specify the methods used to assess risk of bias in the included studies.	Not applicable (bibliometric review)
	12	Specify the effect measures used in the synthesis or presentation of results.	Not applicable (bibliometric review)
	13a	Describe the processes used to decide which studies were eligible for each synthesis.	Methods (Sections 3.1 and 3.2)
	13b	Describe any methods required to prepare the data for presentation or synthesis.	Methods (Section 3.2)
	13c	Describe any methods used to tabulate or visually display results.	Methods (Section 3.2); Results (Section 4)
	13d	Describe any methods used to synthesize results and provide a rationale for the choice(s).	Methods (Section 3.2)
	13e	Describe any methods used to explore possible causes of heterogeneity among study results.	Not applicable (bibliometric review)
	13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.	Not applicable (bibliometric review)
14	Describe any methods used to assess risk of bias due to missing results in a synthesis.	Not applicable (bibliometric review)	
15	Describe any methods used to assess certainty (or confidence) in the body of evidence.	Not applicable (bibliometric review)	

Table A1. Cont.

Section and Topic	Item	Checklist Item	Location in Manuscript
Results	16a	Describe the results of the search and selection process, from the number of records identified to the final number of included studies (ideally using a flow diagram).	Methods (Section 3.1); Appendix A.2 (Figure A1)
	16b	Cite studies that might appear to meet the inclusion criteria but were excluded, and explain why they were excluded.	Not applicable/not reported (bibliometric scope)
	17	Cite each included study and present its characteristics.	Results (Section 4)
	18	Present assessments of risk of bias for each included study.	Not applicable (bibliometric review)
	19	Present results for all outcomes for each included study.	Not applicable (bibliometric review)
	20a	Summarize characteristics of the studies and present results of risk of bias assessments.	Not applicable (bibliometric review)
	20b	Present results of all syntheses conducted.	Results (Section 4); Discussion (Section 5)
	20c	Present results of investigations of heterogeneity among study results.	Not applicable (bibliometric review)
	20d	Present results of sensitivity analyses conducted to assess robustness of the synthesized results.	Not applicable (bibliometric review)
	21	Present assessments of risk of bias due to missing results in a synthesis.	Not applicable (bibliometric review)
	22	Present assessments of certainty (or confidence) in the body of evidence.	Not applicable (bibliometric review)
	Discussion	23a	Provide a general interpretation of the results in the context of other evidence.
23b		Discuss any limitations of the evidence included in the review.	Discussion (Section 5.3)
23c		Discuss any limitations of the review processes used.	Discussion (Section 5.3)
23d		Discuss implications of the results for practice, policy, and future research.	Discussion (Section 5.2)
Other Information	24a	Provide registration information for the review, including register name and registration number.	Not applicable/not registered
	24b	Indicate where the review protocol can be accessed or state that a protocol was not prepared.	Not applicable
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	Not applicable
	25	Describe sources of financial or non-financial support for the review and the role of funders.	Funding section
	26	Declare any competing interests of review authors.	Conflicts of Interest section
	27	Report which of the following are publicly available: template data collection forms; data extracted from included studies; data used for analyses; analytic code; other materials.	Data Availability Statement

Note: Items marked as “Not applicable” are those that do not apply to bibliometric reviews focusing on mapping publication structures rather than assessing intervention effects or risk of bias.

Appendix A.2. PRISMA 2020 Flow Diagram of Study Selection

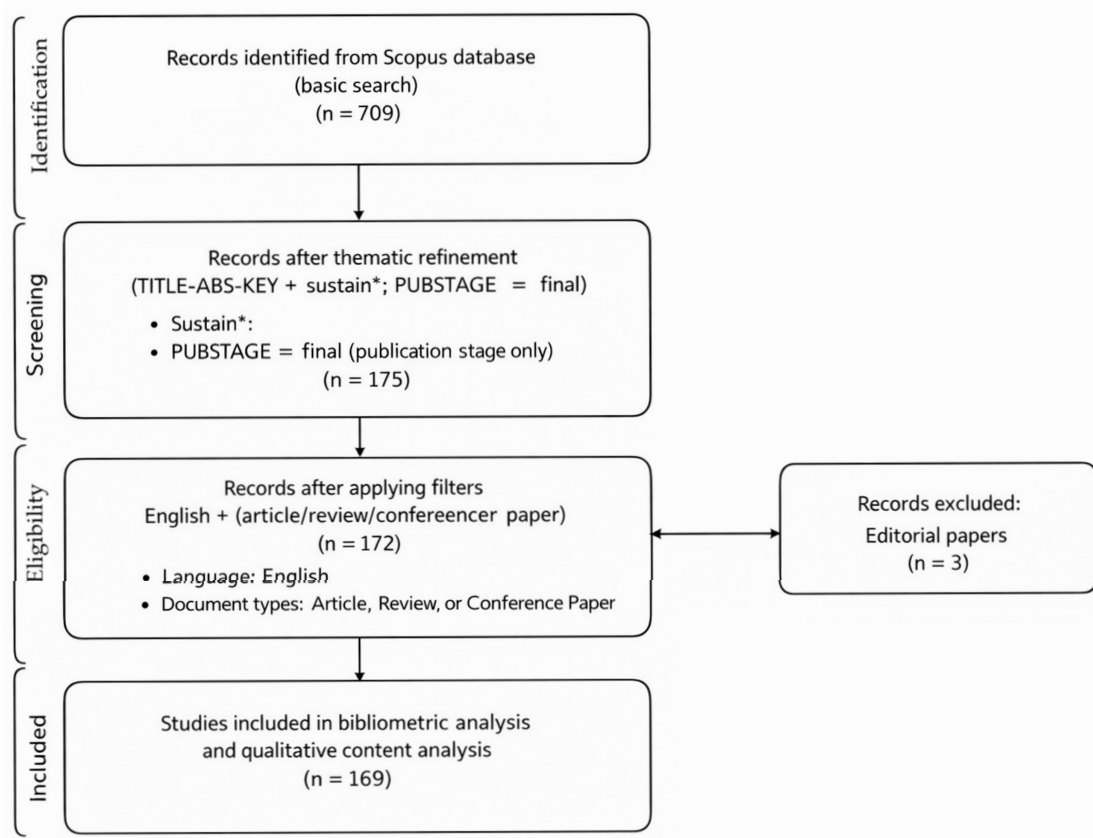


Figure A1. PRISMA 2020 Flow Diagram.

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