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AI-Enabled Regenerative Supply Chains: A RSSCM Framework

Author: Henry Efe Onomakpo Onomakpo

Affiliation: Student, Steenderenstraat 14, 1107 LC, Amsterdam, The Netherlands.

Corresponding Author: Henry Efe Onomakpo Onomakpo, henryonomakpo@gmail.com, Steenderenstraat 14, 1107 LC, Amsterdam, The Netherlands, +31686447461.

ORCID ID: 0009-0004-9503-4859

Abstract

Addressing a critical gap in sustainable supply chain management (SCM), this study develops and proposes the comprehensive Regenerative Sustainable Supply Chain Management (RSSCM) framework. Synthesized from a systematic literature review and bibliometric analysis of contemporary research, the study identified the essential need to integrate AI-driven optimization, robust resilience strategies, circular economy principles, and ethical governance to achieve actively regenerative outcomes. The resulting RSSCM framework structures these critical components into Optimization, Resilience, and Regeneration pillars, all underpinned by a foundational Governance and Validation layer. This integrated model advocates for strategic digital technology application (AI, IoT) to drive efficiency, resilience, and sustainability, promoting a necessary paradigm shift towards supply chains generating net positive environmental and social impacts. The research provides practitioners with a structured roadmap for transformative change and offers academics a theoretically grounded framework for future inquiry, ultimately advancing progress towards more sustainable and equitable global supply networks.

Keywords: Supply Chain Management, Sustainable Supply Chain, Resilience, Regenerative Supply Chain, Circular Economy, Artificial Intelligence, Digital Technologies, Bibliometric Analysis, Literature Review, Framework Development.

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1 Introduction

Modern supply chain management (SCM) faces a profound transformation, moving beyond traditional operational paradigms focused primarily on efficiency and cost-effectiveness. Global challenges, including climate change, resource scarcity, geopolitical instability, and unforeseen disruptions, necessitate a broadened strategic outlook (Ren et al. 2020). Consequently, ensuring long-term organizational viability while upholding societal responsibility now requires the urgent and effective integration of both resilience and sustainability into core SCM practices (Bui et al., 2021; Dubey et al., 2020). This shift demands more than incremental improvements, calling instead for innovative frameworks that fundamentally rethink supply chain design and management for a future defined by complexity and uncertainty.

Responding to this need, the concept of merging supply chain resilience with advanced sustainability goals, potentially termed Regenerative Sustainable Supply Chain Management (RSSCM), is emerging as a critical area of inquiry. This approach posits that future-proof supply chains must not only endure disruptions and minimize negative externalities but should actively generate positive environmental and social impacts. While existing research explores numerous strategies and technologies (e.g., Artificial Intelligence [AI], Internet of Things [IoT], circular economy principles) to enhance specific aspects like resilience or sustainability, a significant gap remains. The core problem this study addresses is the lack of a holistic, integrated, and actionable framework that synthesizes these diverse elements, optimization, resilience, digital technologies, circularity, and ethical governance into a cohesive model specifically designed to achieve truly regenerative supply chains.

Therefore, the primary purpose of this study is to fill this identified knowledge gap by developing and proposing the comprehensive RSSCM framework. To guide this development, the study seeks to answer the following key research questions:

RQ1: What are the essential components and guiding principles of a regenerative, sustainable supply chain framework applicable across diverse industries?

RQ2: How can organizations effectively implement such a framework and measure the resulting impact of regenerative practices?

Addressing these questions offers significant contributions. For academic researchers, this study aims to advance the theoretical understanding of regenerative sustainability within SCM, establishing a foundation for future empirical work. For industry practitioners, the proposed RSSCM framework provides a practical roadmap and actionable insights for transitioning beyond conventional sustainability towards genuinely regenerative business models.

To fulfil these objectives, this research employs a methodology combining a systematic literature review (SLR) with bibliometric analysis. This rigorous approach allows for the synthesis of existing scholarly knowledge and the identification of current best practices and research trends, which directly inform the development of the proposed RSSCM framework. The subsequent sections will detail the methodology used for the SLR and bibliometric analysis (Section 2), present the key findings derived from the literature synthesis and quantitative analysis (Section 3), elaborate on the proposed RSSCM framework and discuss its implications (Section 4), and finally, offer concluding remarks summarizing the study's contributions and limitations (Section 5).

2 Materials & Methods

This study utilized a mixed-methods design, combining a systematic literature review (SLR) with bibliometric analysis. The findings from these analyses were synthesized to develop the Regenerative Sustainable Supply Chain Management (RSSCM) framework. The methodology was executed following established protocols for scientific rigor.

2.1 Systematic Literature Review (SLR)

An SLR was performed according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework (Page et al., 2021). The review aimed to locate and consolidate research examining the convergence of supply chain resilience, sustainability, circular economy principles, digital technologies (particularly AI), and regenerative concepts.

2.1.1 Data Acquisition

A structured search was executed across two major academic literature databases, Scopus and Dimensions, selected for their coverage of management and engineering fields. The search timeframe spanned publications from January 2016 to December 2024. A specific search query was constructed using Boolean logic (AND/OR) to retrieve articles containing keywords central to the research scope. Key concepts covered were: Supply Chain (e.g., “supply chain”, “logistics”), Sustainability/Regeneration (e.g., “sustainability”, “green”, “circular economy”, “regenerative”), Resilience (e.g., “resilience”, “robustness”, “disruption”), and Technology (e.g., “artificial intelligence”, “AI”, “digital technology”, “IoT”, “blockchain”). The search string used combinations of keywords: (“supply chain” OR “logistics”) AND (“sustainability” OR “green” OR “circular economy” OR “regenerative”) AND (“resilience” OR “robustness” OR “disruption”) AND (“artificial intelligence” OR “AI” OR “digital technology” OR “IoT” OR “blockchain”). This initial search retrieved 2,091 records.

2.1.2 Screening Protocol

Retrieved publications underwent a staged screening procedure, visually documented in the PRISMA flow diagram (Figure 1). Initially, titles and abstracts were assessed for relevance to the study's focus on integrating sustainability, resilience, and technology within SCM. Records clearly outside this scope were eliminated. This resulted in 120 articles proceeding to the next stage. Subsequently, a full-text review was conducted based on pre-defined inclusion and exclusion criteria. Articles were included if they were peer-reviewed journal or major conference publications, written in English, and substantively discussed the integration of sustainability, resilience, regeneration and enabling digital technologies in SCM. Articles were excluded if they addressed only one dimension (e.g., solely resilience), were not in English, were non-research items (e.g., editorials, reviews), or if the full text could not be obtained. During this stage, 9 duplicate entries were identified and removed. Following the full-text evaluation against these criteria, 111 articles formed the final dataset for analysis.

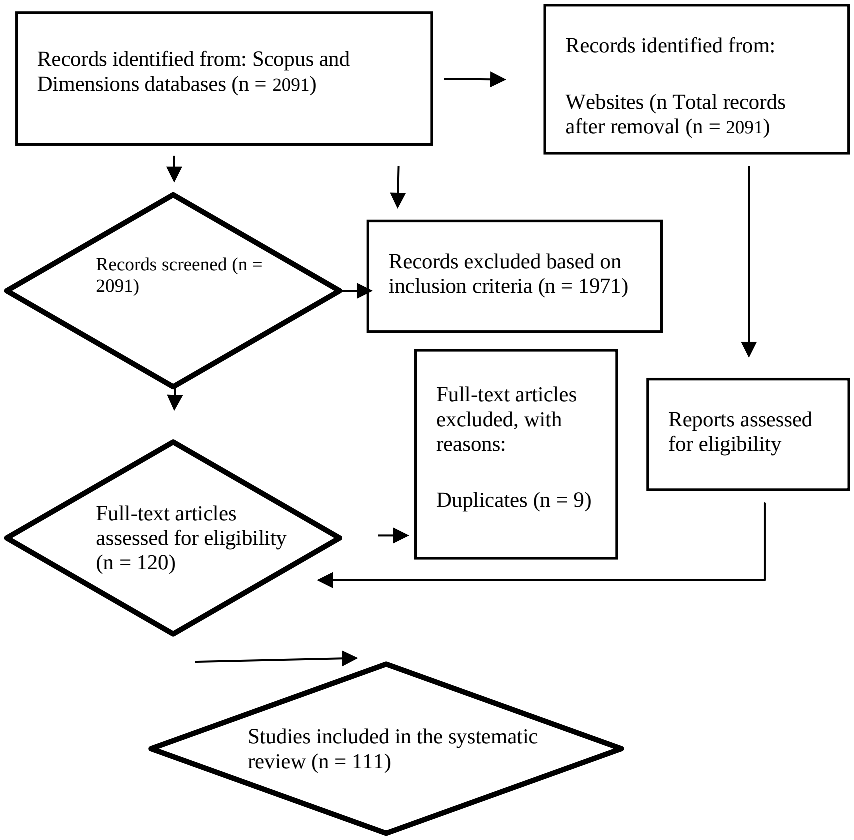

Figure 1: PRISMA flow diagram illustrating the literature screening and selection process.

2.1.3 Information Extraction and Synthesis

Relevant information was systematically extracted from the final 111 articles. The extracted data focused on reported strategies, specific enabling technologies (AI, IoT, Blockchain), underpinning theories (like DCT, TBL), proposed conceptual models or frameworks, highlighted challenges, and suggested future research pathways concerning sustainable, resilient, and regenerative supply chains. This extracted information was then subjected to thematic coding to identify recurring patterns, core concepts, and key relationships, forming the qualitative input for the framework development phase.

2.2 Bibliometric Analysis

To quantitatively map the research landscape identified through the SLR, a bibliometric analysis was conducted on the final set of 111 articles.

2.2.1 Analysis Software and Procedures

The bibliometric computations and visualizations were performed using R statistical software (version 4.5.2) equipped with the "bibliometrix" package, a standard tool for such analyses (Aria & Cuccurullo, 2017). Standard performance metrics were computed, such as annual publication frequency, citation accumulation patterns (total and average per year), and indicators of author impact. The intellectual structure of the field was explored using science mapping techniques native to the bibliometrix package:

For the “Thematic Mapping”, keyword co-occurrence data was analyzed to generate a thematic map, categorizing research themes based on calculated Density and Centrality scores. Whereas, for the “Network Visualization”, relationships between core concepts were visualized through keyword co-occurrence networks (derived from title keywords). Term prominence was assessed via word frequency analysis, presented as word clouds. Ultimately, for the “Collaboration Mapping”, patterns of research collaboration were examined by mapping the geographic origins of corresponding authors and calculating the ratio of single-country publications (SCP) to multiple-country publications (MCP).

2.2.2 Statistical Indicators

This analysis relied on descriptive statistics and network metrics produced by the bibliometrix software. The primary parameters reported are frequency distributions (e.g., publications over time, keyword counts), node centrality measures within networks (e.g., betweenness centrality), and theme density/centrality values used for thematic mapping. No inferential statistical tests aiming for hypothesis confirmation were conducted in this bibliometric phase.

2.3 Regenerative Sustainable Supply Chain Framework (RSSCM) Development

The generation of the proposed RSSCM framework was a direct outcome of synthesizing the SLR and bibliometric analysis results.

2.3.1 Integration of Review Findings

The development process began by systematically integrating the qualitative insights from the thematic coding of the literature (Section 2.1.3) with the quantitative patterns revealed by the bibliometric analysis (Section 2.2). Key themes (like AI for optimization, risk management protocols, circularity methods), high-frequency keywords (“sustainability,” “resilience,” “AI”), influential concepts (dynamic capabilities, TBL), and specific enabling tools (blockchain traceability, IoT monitoring) identified across both analyses were consolidated.

2.3.2 Framework Conceptualization and Architecture

The consolidated findings were then structured using thematic coding and concept mapping techniques. This involved grouping interconnected strategies, technologies, and principles into coherent conceptual clusters. For example, literature findings on AI in demand planning and logistics formed an ‘AI-Driven Optimization’ cluster. Insights on risk identification and contingency planning constituted a ‘Resilience Strategies’ cluster. The framework's architecture, comprising distinct operational pillars and supporting elements, was derived from this structuring process. Logical dependencies identified in the literature (e.g., how optimized processes enhance resilience) informed the relationships between clusters. This led to the definition of core operational pillars: AI-Driven Optimization, Resilience Strategies, Sustainability and Circular Economy Enablers, and Regenerative Practices. Foundational supporting elements were also delineated: Validation and Implementation, Ethical and Adaptive Governance, and Decision Support Systems. This structure aimed to operationalize Dynamic Capabilities Theory and Triple Bottom Line Theory, identified as relevant theoretical lenses during the SLR. The resulting framework provides a novel conceptual model that visualizes the integration of components indicated by the synthesized literature as essential for pursuing regenerative supply chain outcomes.

3 Results / Discussion

This section presents the findings derived from the systematic literature review (SLR) content synthesis and the bibliometric analysis. The results first outline the core enablers and concepts identified in the literature pertinent to Regenerative Sustainable Supply Chain Management (RSSCM) and then detail the quantitative trends and thematic structures revealed by the bibliometric analysis.

3.1 Literature Synthesis Findings: Core Enablers and Theoretical Context for RSSCM

The synthesis of the reviewed literature identified several key strategies, technological enablers, and guiding principles essential for developing RSSCM. These findings provide the foundation for the framework proposed later in the discussion. The analysis revealed the significance of specific operational capabilities and overarching theoretical perspectives.

The modern supply chain management (SCM) paradigm has broadened considerably beyond traditional metrics of efficiency and cost-effectiveness, now urgently requiring the integration of both resilience and sustainability for long-term viability and societal responsibility (Bui et al., 2021; Dubey et al., 2020). This review explored the dynamics of supply chain resilience within the sustainable supply chain management context, integrating key strategies and technological enablers identified in the literature. Two theoretical frameworks were found particularly relevant for grounding the development of the RSSCM model. Firstly, Dynamic Capabilities Theory (DCT) emphasizes the importance of an organization's ability to integrate, build, and reconfigure internal and external competencies to address rapidly changing environments (Teece, 2007). This perspective supports the need for AI-driven optimization and adaptive resilience strategies crucial for future-proof supply chains. Secondly, the Triple Bottom Line (TBL) Theory provides a robust lens for assessing the effectiveness of sustainable practices and circular economy principles by requiring consideration of their integrated economic, social, and environmental dimensions (Elkington, 1998). This theoretical grounding is crucial for understanding how the enablers identified in the literature translate into tangible impacts across all three dimensions.

3.1.1 AI-Driven Optimization and Resilience Strategies Findings

The literature synthesis highlighted the AI-Driven Optimization Core as foundational. A central theme was the increasing recognition of Intelligent Demand Forecasting, leveraging AI to improve accuracy and responsiveness compared to traditional methods, thereby reducing waste and costs (Hu et al., 2023; Nweje & Taiwo, 2025; Sun et al., 2022). Dynamic Inventory Management, often utilizing Reinforcement Learning (RL), emerged as critical for enabling real-time stock adjustments and agility in response to demand fluctuations and disruptions (Zamani et al., 2023). Specific algorithms targeting waste reduction, particularly for perishable goods, were identified as vital for both economic and environmental performance (Fasihi et al., 2023; Nayal et al., 2023; Ponte et al., 2020). Furthermore, Logistics Orchestration using technologies like Genetic Algorithms and IoT analytics for dynamic routing and carbon-aware transportation was shown to significantly decrease fuel consumption and emissions while improving efficiency (Shahed et al., 2021; Sun et al., 2022; Tian et al., 2023; Wangsa et al., 2022).

Building on optimization, the synthesis identified key Resilience Strategies. Advanced Risk Assessment methods, including stochastic modelling and NLP analysis of ESG reports, were found essential for predicting disruptions and evaluating supplier sustainability and ethics more comprehensively (Choudhary et al., 2023; Hülagü et al., 2025; Shahed et al., 2021; Yontar, 2023). Mitigation Frameworks incorporating systems dynamics for redundancy planning (e.g., multi-sourcing, buffer inventories) and blockchain for swift network rerouting were strongly supported in the literature (De-Arquer et al., 2022; Dutta et al., 2020; Hülagü et al., 2025; Nayal et al., 2023; Shahed et al., 2021; Tiwari et al., 2023). Effective Recovery Protocols, utilizing optimization algorithms for resource reallocation and digital twin simulations for stress-testing, were deemed crucial for minimizing disruption impacts (Piyathanavong et al., 2024; Zamani et al., 2023; Zhao et al., 2023).

3.1.2 Integrating Sustainability and Circular Economy Principles Findings

The integration of Sustainability and Circular Economy Enablers was found to be crucial. Carbon Accountability mechanisms, particularly Blockchain-powered Life Cycle Assessment (LCA) platforms and AI-driven "Digital Green Twins," were identified as key for transparent emissions tracking and management (Charles et al., 2023; Difrancesco et al., 2023; Hong & Xiao, 2024; Wangsa et al., 2022; Yontar, 2023). IoT sensors for real-time waste analytics and AI-guided product design for disassembly were highlighted as essential for improving material circularity and resource recovery (Cammarano et al., 2023; Eslamipoor & Sepehriar, 2024; Kaur et al., 2022; Kleinekorte et al., 2020; Zrelli & Rejeb, 2024). Resource Stewardship, emphasizing efficient water and energy use through IoT and predictive maintenance, along with Ethical Sourcing dashboards integrating ESG analytics, was consistently identified as vital (Acquaye et al., 2017; Govindan et al., 2019; Khattak et al., 2022; Nhu et al., 2024; Sahoo et al., 2024). A robust Regulatory Compliance Architecture, featuring NLP-enhanced global regulation databases and automated compliance engines, alongside blockchain-enabled audit trails (especially for Scope 3), was deemed necessary for navigating complex global standards (Al-Okaily et al., 2024; Huang et al., 2024; Khan et al., 2022; Tiwari et al., 2023).

3.1.3 Regenerative Practices and Governance System Findings

The review indicated a necessary broadening of focus towards Regenerative Practices aiming for net positive impacts. This included AI-optimized logistics for Ecosystem Restoration initiatives and promoting supplier engagement in biodiversity-positive practices (Mwangi et al., 2022; Wangsa et al., 2022; Zarrat-Dakhely-Parast et al., 2021). Social Equity Mechanisms, such as fair-trade analytics using advanced technologies and the integration of living wage calculators into contracts, were identified as essential for comprehensive sustainability and economic justice (Guo & Wu, 2023; Hou et al., 2022; Mwangi et al., 2022).

Finally, the synthesis pointed to the criticality of Validation, Governance, and Decision Support Systems. Advanced Decision Support Systems, including immersive Metaverse collaboration hubs and multi-objective trade-off analyzers, were identified as tools to empower complex decision-making (Akbari & Hopkins, 2022; Deng et al., 2023; Tian et al., 2023; Vaitinadin, 2024; Yousefi et al., 2017). Effective Validation and Implementation Processes rely on clearly defined environmental and economic Key Performance Indicators (KPIs) and the use of industry-specific pilot frameworks or sandboxes for testing and refinement. (Acquaye et al., 2017; Gozali et al., 2024; Jain et al., 2022; Nhu et al., 2024; Ramirez-Peña et al., 2020b). Ethical and Adaptive Governance mechanisms, incorporating AI bias safeguards (e.g., algorithmic fairness audits) and stakeholder co-creation through participatory design, were found necessary for ensuring equity, transparency, and continuous adaptation (Arji et al., 2023; Camarinha-Matos et al., 2024; Guo & Wu, 2023; Petratos & Faccia, 2023; Singh et al., 2023; Sunmola et al., 2023).

3.2 Bibliometric Analysis Findings

This section presents the quantitative results from the bibliometric analysis of the 111 selected articles published between 2016 and 2025, focusing on publication trends, author contributions, geographic distribution, and thematic structures.

3.2.1 Annual Production and Citation Trends

Table 1 shows the annual scientific production and corresponding citation metrics for the reviewed literature. The number of published articles demonstrated a general upward trend from 2016 (5 articles) to a peak in 2022 (32 articles), followed by a slight decrease in 2023 (23 articles) and 2024 (18 articles, data likely incomplete). Mean Total Citations per Article (MeanTCperArt) was highest for articles published in earlier years, such as 2018 (151) and 2020 (213.25), and generally decreased for more recent publications, which is expected due to shorter citation windows. However, the Mean Total Citations per Year (MeanTCperYear), which accounts for the number of citable years, remained relatively stable for the period 2018-2023 (ranging from 9.96 to 18.88, excluding the 2020 peak of 35.54), suggesting a consistent, ongoing citation impact for established articles within the field. A significant drop in citations for 2024 and 2025 was anticipated, given the very limited time for these articles to accrue citations.

Table 1: Annual scientific production and citations.

Year	Articles	MeanTCperArt	N	MeanTCperYear	CitableYears
2016	5	82	5	8.2	10
2017	5	51	5	5.67	9
2018	1	151	1	18.88	8
2019	4	69.75	4	9.96	7
2020	8	213.25	8	35.54	6
2021	15	71.93	15	14.39	5
2022	32	49.03	32	12.26	4
2023	23	39.65	23	13.22	3
2024	18	10.78	18	5.39	2
2025	3	0.67	3	0.67	1

Source: Author’s compilation from literature using bibliometric analysis of Scopus and Dimension databases.

3.2.2 Author Productivity and Impact

Figure 2 visualizes the production timeline and citation impact (Total Citations per Year) for the most relevant authors in the dataset. The analysis indicated several authors with sustained contributions across multiple years, including “Kumar A., Khan T., and Khan SAR”. The visualization showed that “Choi T.” had a publication in 2020 with a notably high citation impact per year (represented by a larger circle). “Junaid M.” and “Fathollahi-Fard A.M.” also appeared as authors with significant citation influence, particularly associated with their more recent publications.

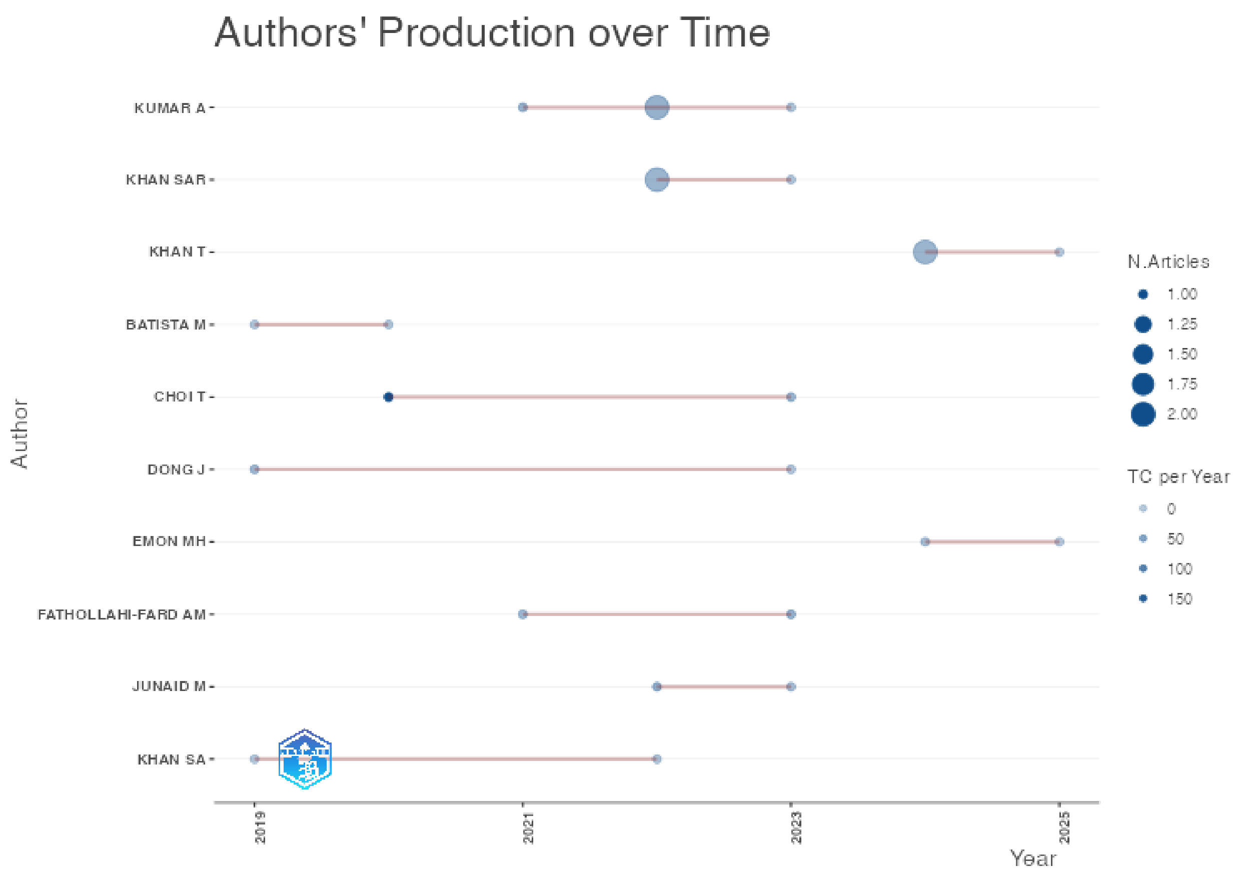

Figure 2: Overview of author contributions and impact on research findings.

Source: Author's compilation from literature using bibliometric analysis of Scopus and Dimension databases.

3.2.3 Global Footprint: Geographic Distribution

Figure 3 illustrates the geographic distribution of the publications based on the corresponding author's country. China contributed the highest number of articles, followed by India. The analysis revealed variations in international collaboration patterns; India showed the highest proportion of multiple-country publications (MCP), followed by China. Several countries, including the USA and Spain, had only single-country publications (SCP) within this dataset, while others, like Canada, Australia, and several European nations, exhibited 100% MCP, indicating strong international collaboration links for authors based there.

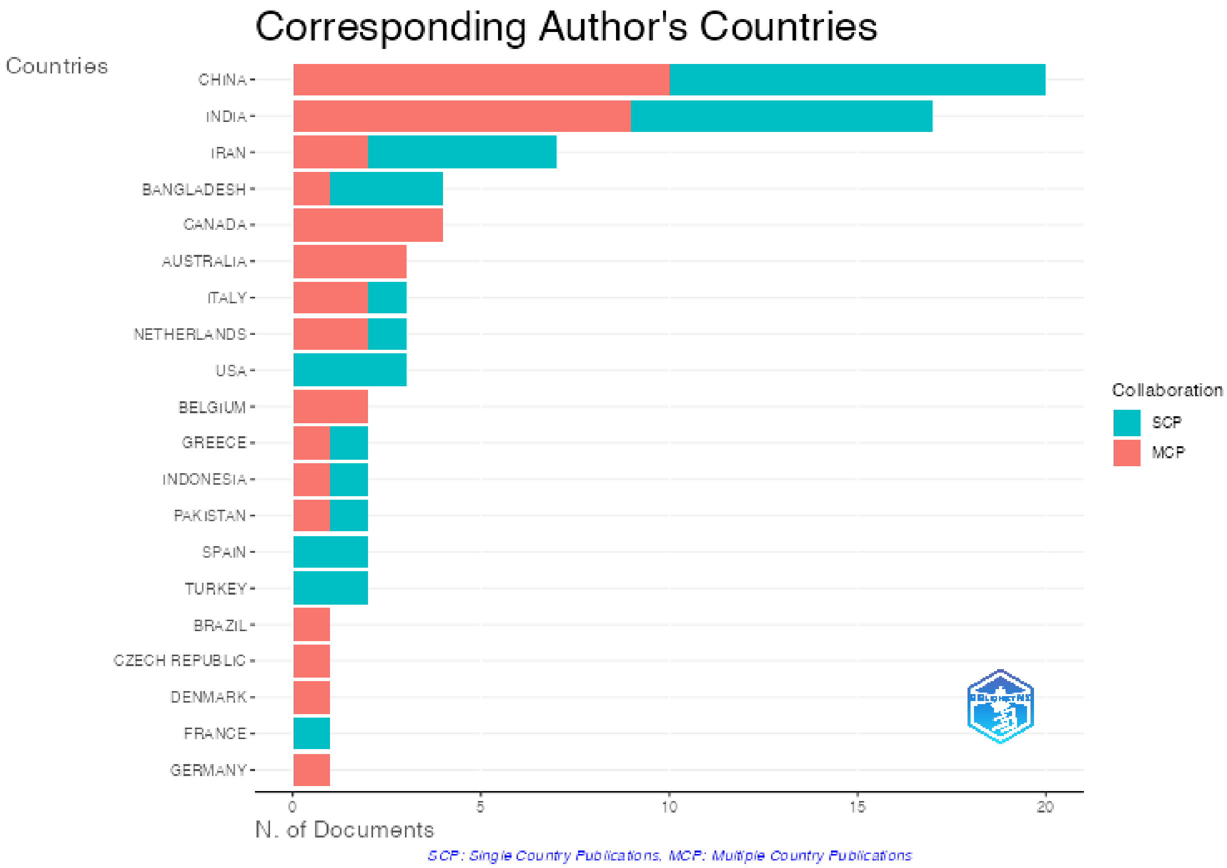

Figure 3: Distribution of corresponding author's countries in the study.

Source: Author's compilation from literature using bibliometric analysis of Scopus and Dimension databases.

3.2.4 Thematic Landscape Analysis

Figure 4 presents a thematic map based on keyword co-occurrence analysis, plotting clusters based on their density (development degree) and centrality (relevance degree). Four quadrants represent different theme types: Motor Themes (upper-right: well-developed and important), Basic Themes (lower-right: important but less developed), Niche Themes (upper-left: well-developed but isolated), and Emerging/Declining Themes (lower-left). The analysis identified "supply chain" (Cluster 3, Basic Themes quadrant) as the most central theme (centrality: 21210.640, occurrences: 91), connected to "chain performance" and "chain quality management". Sustainability-related themes like "closed-loop supply" and "sustainable logistics" (Cluster 1, Motor Themes) and "environmental sustainability" (Cluster 2, Niche Themes) were prominent. "Circular economy" (Cluster 5, Basic Themes) appeared as an important foundational concept. "Supplier selection" (Cluster 4, Niche Themes) showed high centrality (3343.053), indicating its importance in connecting different research streams, focusing on “green supplier” and “selection model”. “Sustainable food” (Cluster 8, Emerging/Declining Themes) emerged as a distinct, developing application area.

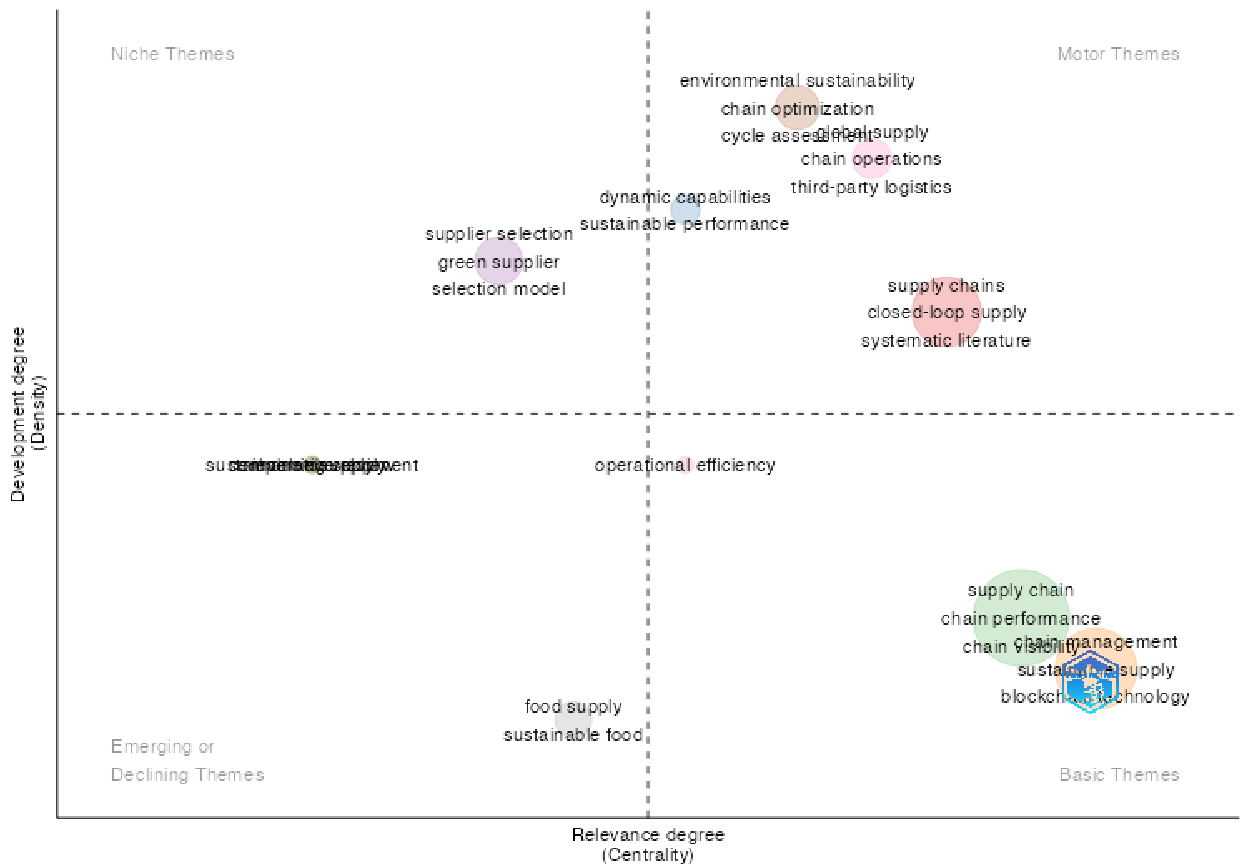

Figure 4: Thematic map of publications in sustainable supply chain research. It highlights the critical aspects, showing key themes in the recent literature.

Source: Author's compilation from literature using bibliometric analysis of Scopus and Dimension databases.

3.2.5 Keyword Co-Occurrence Network and Word Cloud Analysis

Figure 5 displays a network graph of keyword co-occurrence based on article titles, revealing two main clusters. Cluster 1, “Sustainable Supply Chain Management,” was centered around “supply chain management” (betweenness: 10, PageRank: 0.214) and strongly linked to “sustainable supply chain” (closeness: 0.083, PageRank: 0.114), “green supply chain,” and “chain management practices.” Cluster 2, “Supply Chain Performance and Resilience,” was dominated by “supply chain performance” (betweenness: 15, PageRank: 0.235) and connected to “supply chain visibility” and “supply chain resilience.” Keywords like “green supply chain,” “chain management practices,” “supply chain visibility,” and “supply chain resilience” showed zero betweenness centrality, suggesting they were more terminal nodes within these specific clusters in the title keyword network.

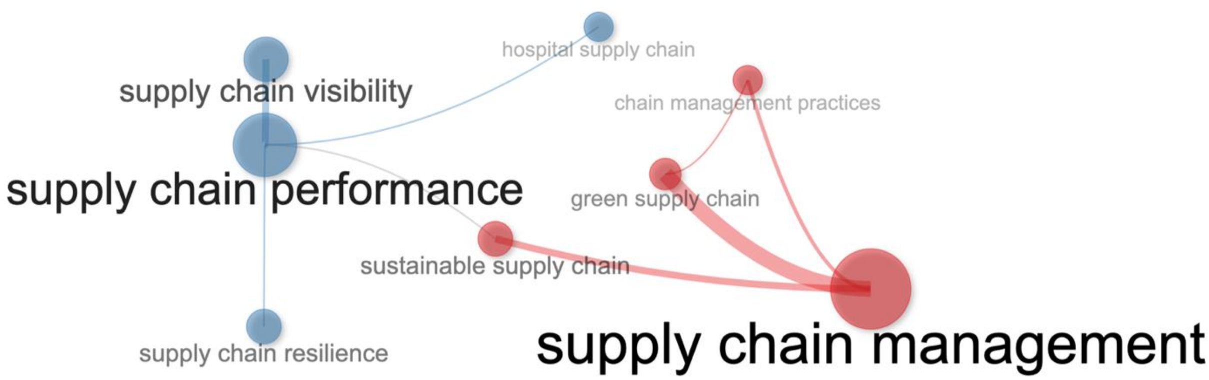

Figure 5: Co-occurrence word network of keyword centrality and clustering. It shows keywords in the title of sustainable supply chain literature for the study.

Source: Author's compilation from literature using bibliometric analysis of Scopus and Dimension databases.

Figure 6 complements the network analysis by displaying a word cloud that depicts the frequency of key terms across the full examined literature (titles, abstracts, keywords). The phrases “supply chain management” and “supply chain performance” were the most popular, as seen by their magnitude. Other commonly used words were “supply chain resilience,” “supply chain visibility,” and “sustainable supply chain.” Concepts like as “artificial intelligence AI” and “structural equation modelling” were also used, albeit less frequently than the core SCM concepts.

Figure 6: Word cloud analysis of key terms. It presents a visualization of the most frequently occurring terms within the supply chain research literature. The size of each term in the word cloud is proportional to its frequency.

Source: Author's compilation from literature using bibliometric analysis of Scopus and Dimension databases.

3.3 Discussion

This section interprets the findings presented in Section 3, discusses their implications, elaborates on the proposed Regenerative Sustainable Supply Chain Management (RSSCM) framework as the main contribution answering the research questions, and outlines the study's significance, limitations, and directions for future research.

3.3.1 Interpretation of Findings

The literature synthesis (Section 3.1) confirmed the multifaceted nature of advancing supply chains beyond traditional sustainability. The consistent identification of AI-driven optimization, robust resilience strategies, circular economy principles, ethical governance, and dedicated regenerative practices underscores the need for an integrated approach. The findings strongly suggest that technologies like AI, IoT, and Blockchain are no longer peripheral but core enablers for achieving efficiency, transparency, resilience, and sustainability simultaneously. The theoretical lenses of Dynamic Capabilities Theory (Teece, 2007) and the Triple Bottom Line (Elkington, 1998) provide a valuable framework for understanding how organizations can leverage these enablers to adapt and thrive while creating holistic value. DCT explains the organizational capacity needed to implement these complex changes, while TBL provides the multi-dimensional performance perspective required for truly sustainable and regenerative outcomes.

The bibliometric analysis (Section 3.2) quantitatively supports the growing academic interest in this field, particularly the surge in publications until 2022 (Table 1). The sustained citation impact per year indicates the topic's established relevance. The geographic distribution (Figure 3) highlights significant research activity in Asia (China, India) but also strong collaborative networks involving North American and European institutions. The thematic analysis (Figure 4, Figure 5, Figure 6) provides critical insights. The centrality of "supply chain management" and "supply chain performance" confirms their foundational role. However, the strong presence and connection of terms like "sustainability," "resilience," "visibility," "circular economy," and "digital technologies" (including AI) reveal the evolution of the field towards more integrated and technologically enabled models. The emergence of "sustainable food" as a distinct cluster points towards sector-specific applications gaining traction. The high centrality but niche positioning of "supplier selection" suggests it is a critical but perhaps specialized area connecting broader themes. Overall, the bibliometric results paint a picture of a dynamic field grappling with the integration of sustainability, resilience, and advanced technologies, reinforcing the need for a comprehensive framework like the RSSCM.

3.3.2 The Proposed RSSCM Framework

Building upon the literature synthesis and bibliometric findings, this study proposes the Regenerative Sustainable Supply Chain Management (RSSCM) framework (Figure 7) as a holistic and integrated model to address the identified research gap. The framework is structured around three core operational pillars, "Optimization, Resilience, and Regeneration", all supported by a foundational layer of Governance and Validation. This layered structure is intentional, suggesting a progression where optimization enables resilience, which in turn enables regeneration, all guided by ethical governance.

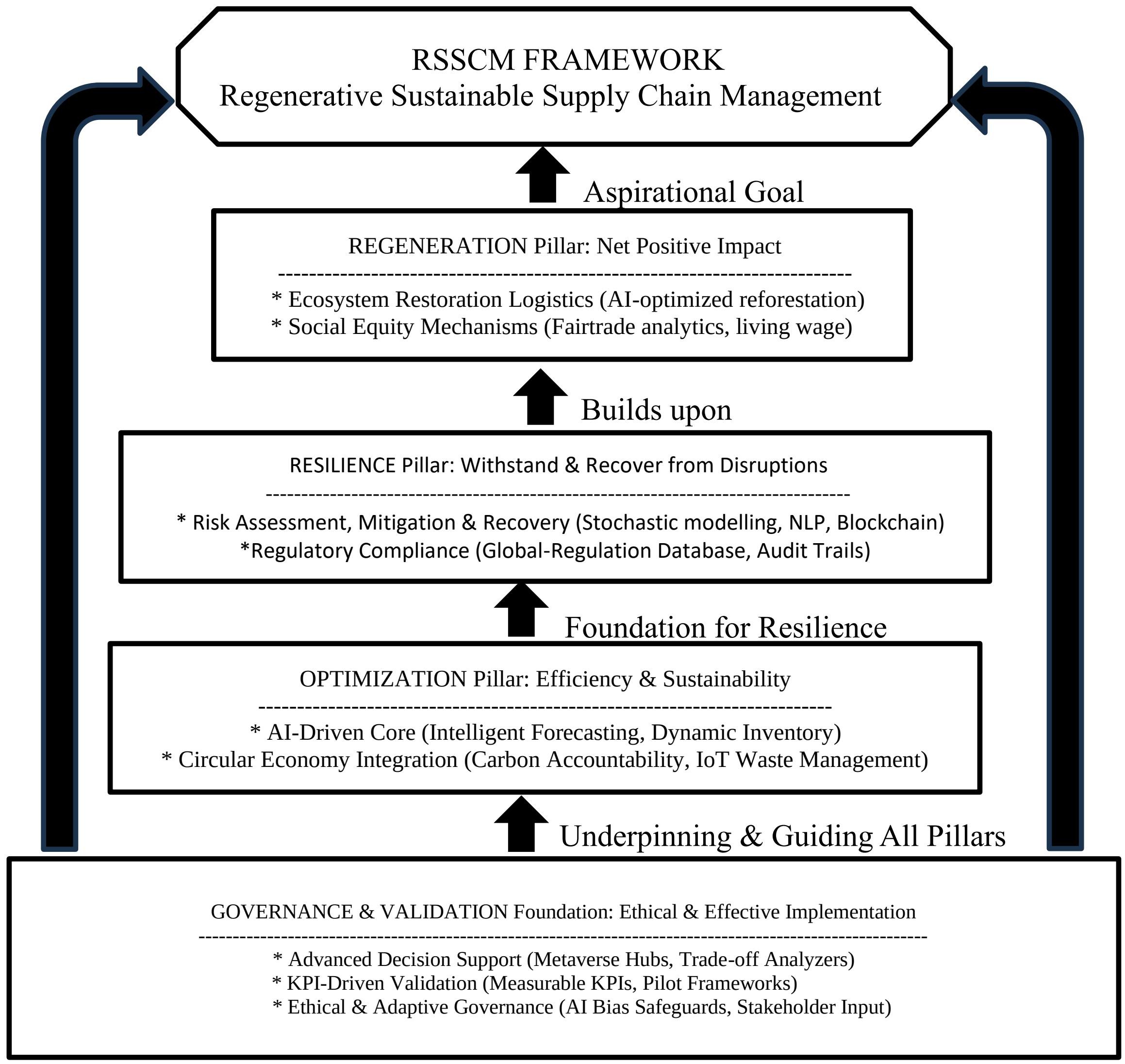

Figure 7: Regenerative supply chains: A Framework for Resilience and Sustainability leveraging Dynamic Capabilities and the Triple Bottom Line.

3.3.3 Optimization Pillar: Enhancing Efficiency and Sustainability through Intelligent Technologies

As depicted in Figure 7, this pillar forms the operational base, directly reflecting the findings on AI-driven optimization (Section 3.1.1) and the prominence of performance and management terms in the bibliometrics (Section 3.2.5). It emphasizes integrating AI and IoT for Intelligent Demand Forecasting (Hu et al., 2023; Sun et al., 2022), Dynamic Inventory Management (Zamani et al., 2023), and optimized Logistics Orchestration (Shahed et al., 2021; Tian et al., 2023). Crucially, it embeds Sustainability & Circular Economy Integration through mechanisms like Carbon Accountability via blockchain/digital twins (Charles et al., 2023; Difrancesco et al., 2023) and IoT for Waste & Material Circularity (Cammarano et al., 2023; Kaur et al., 2022), AI-guided Product Design (Eslamipoor & Sepehriar, 2024), Resource Stewardship (Acquaye et al., 2017), and Ethical Sourcing Dashboards (Govindan et al., 2019; Khattak et al., 2022). This aligns with TBL by seeking simultaneous economic and environmental gains.

3.3.4 Resilience Pillar: Ensuring Disruption Withstands and Recovery

Building upon the optimization base, this pillar addresses the critical need for robustness identified in the literature and bibliometrics (Section 3.2.5, e.g., "supply chain resilience"). It incorporates Comprehensive Resilience Strategies, including advanced Risk Assessment (Choudhary et al., 2023; Hülagü et al., 2025), Mitigation planning using systems dynamics and blockchain (De-Arquer et al., 2022; Dutta et al., 2020), and data-driven Recovery Protocols leveraging optimization and digital twins (Piyathanavong et al., 2024; Zamani et al., 2023). It also includes the Regulatory Compliance Architecture identified in the synthesis (Section 3.1.2) as essential for navigating uncertainties and ensuring stability (Al-Okaily et al., 2024; Huang et al., 2024). This pillar reflects the adaptive capacity central to DCT.

3.3.5 Regeneration Pillar: Moving to Net Positive Environmental & Social Impact

This pillar represents the framework's highest aspiration, moving beyond minimizing harm (conventional sustainability) to actively creating positive environmental and social value, as suggested by the literature synthesis (Section 3.1.3). It centers on Regenerative Practices for Positive Impact, such as AI-optimized Ecosystem Restoration Logistics (Wangsa et al., 2022; Zarrat-Dakhely-Parast et al., 2021) and promoting biodiversity-positive supplier operations (Mwangi et al., 2022). It explicitly incorporates Social Equity Mechanisms, utilizing fair-trade analytics and living wage calculators to foster ethical sourcing and community well-being throughout the supply chain (Guo & Wu, 2023; Mwangi et al., 2022), directly addressing the social dimension of TBL.

3.3.6 Governance and Validation Foundation: Ethical Implementation, Stakeholder Engagement, Continuous Improvement

Underpinning all pillars, this foundation ensures ethical and effective implementation, drawing from the synthesis findings (Section 3.1.3). It includes Advanced Decision Support Systems like Metaverse hubs and trade-off analyzers (Akbari & Hopkins, 2022; Deng et al., 2023; Vaitinadin, 2024) to manage complexity. The Validation & Implementation Framework component relies on KPI-driven validation using measurable indicators identified in the literature and pilot frameworks for iterative testing (Gozali et al., 2024; Jain et al., 2022). Critically, it incorporates Ethical and Adaptive Governance through AI bias safeguards and stakeholder co-creation (Arji et al., 2023; Camarinha-Matos et al., 2024; Petratos & Faccia, 2023), ensuring the framework adapts ethically and inclusively over time, reflecting principles from both TBL (social or governance) and DCT (adaptation).

3.3.7 Answering the Research Questions

The proposed RSSCM framework and the preceding analysis directly address the research questions.

RQ1: What are the key components and principles of a regenerative, sustainable supply chain framework that can be applied across different industries? The key components are the four integrated layers: Optimization, Resilience, Regeneration, and Governance and Validation, as detailed in Section 3.3.2 and visualized in Figure 7. The guiding principles, reinforced by the literature synthesis (Section 3.1) and bibliometric keywords (Figure 6), include: strategic technology integration (AI, IoT, Blockchain), holistic TBL sustainability, circular economy adoption, proactive resilience, ethical and adaptive governance, data-driven decision-making (KPIs), stakeholder engagement, and an overarching aim for net positive regenerative impact.

RQ2: How can organizations effectively implement and measure the impact of regenerative practices within their supply chains? The framework suggests a phased implementation (Section 3.2.4): starting with strategic alignment, adopting enabling technologies (Optimization/Resilience pillars), redesigning processes for circularity and ethics, fostering collaboration, using pilot frameworks for validation, measuring impact via specific KPIs (environmental, economic, social – derived from the Validation/Governance foundation), and ensuring adaptive governance for continuous improvement. Effective measurement requires moving beyond traditional metrics to capture net positive environmental and social contributions, leveraging tools like LCA, fair-trade analytics, and living wage assessments identified in the literature synthesis (Section 3.1.2, 3.1.3).

3.4 Contribution to Knowledge and Framework Validation

This research contributes to the existing body of knowledge by synthesizing fragmented research on supply chain sustainability, resilience, digital transformation, and circular economy into a single, cohesive, and theoretically grounded (DCT, TBL) Regenerative Sustainable Supply Chain Management (RSSCM) framework. It moves beyond incremental approaches to propose a model aiming for a net positive impact. The structured presentation of core enablers (Section 3.1) and the bibliometric analysis (Section 3.2) provide empirical grounding from the existing literature. However, as primarily based on a literature review and bibliometric analysis, empirical validation of the RSSCM framework across diverse industries and contexts is crucial future work. Such validation would refine the framework's components and implementation strategies, enhancing its practical utility. Case studies and longitudinal research are needed to assess its real-world applicability and effectiveness.

3.5 Significance for Academia and Industry

For academia, the RSSCM framework provides a defined paradigm and structured agenda for future research into regenerative sustainability within SCM. It offers a foundation for empirical testing of the interplay between optimization, resilience, and regeneration, and for developing robust metrics (KPIs) to assess regenerative outcomes. It explicitly links SCM practices to DCT and TBL theories in the context of regeneration.

For industry practitioners, the framework serves as a strategic roadmap for moving beyond compliance or basic sustainability towards creating supply chains that are resilient, efficient, and actively contribute positive environmental and social value. It provides actionable insights into leveraging digital technologies (AI, IoT), implementing circular principles, ensuring ethical governance, and fostering stakeholder collaboration to achieve regenerative goals, ultimately enhancing long-term viability and competitive advantage.

3.6 Limitations and Future Research Directions

The primary limitation of this study is its nature as a literature review and framework proposal; the RSSCM framework requires empirical validation to confirm its effectiveness and generalizability across different industries (e.g., manufacturing, agriculture, healthcare) and operational contexts. Current literature, as highlighted by the review, also lacks standardized, widely accepted metrics specifically designed to measure the net positive or regenerative impact, moving beyond traditional sustainability KPIs.

Future research should prioritize empirical validation through case studies and pilot implementations of the RSSCM framework. Developing and standardizing industry-relevant KPIs for regenerative outcomes is a critical need. Longitudinal studies are essential to track the performance, adaptive capacity, and long-term impact of supply chains adopting the RSSCM model. Further investigation into the synergistic integration of the framework with cutting-edge technologies, particularly exploring blockchain's full potential for transparency and traceability in complex regenerative systems, and examining advanced analytical tools (e.g., sophisticated multi-objective optimization, AI-driven impact modelling) for operationalizing the framework's principles are key future direction.

4 Conclusion

This study addressed a significant gap in sustainable supply chain management by developing the comprehensive Regenerative Sustainable Supply Chain Management (RSSCM) framework, derived from a systematic literature review and bibliometric analysis. The principal contribution is the RSSCM framework itself, a novel, theoretically grounded model integrating Optimization, Resilience, and Regeneration pillars, all supported by a crucial Governance and Validation foundation. This framework directly answers the research questions by defining the essential components and principles for regenerative supply chains applicable across industries (RQ1) and outlining a structured approach for their implementation and impact measurement (RQ2).

The core finding of this research is that progressing beyond incremental sustainability requires a fundamental shift towards the synergistic integration offered by the RSSCM framework, explicitly aiming for net positive environmental and social impacts. The analysis confirmed the critical role of digital technologies, especially Artificial Intelligence (AI) and the Internet of Things (IoT), as indispensable enablers for achieving the necessary efficiency, resilience, transparency, and regenerative capabilities.

The RSSCM framework holds significant implications. For academic researchers, it provides a structured agenda for future empirical investigation, particularly focusing on validating the framework's elements and developing robust Key Performance Indicators (KPIs) tailored to regenerative outcomes. For industry practitioners, it offers a practical roadmap for implementing regenerative principles, moving beyond conventional sustainability to build supply chains that are economically viable, environmentally restorative, and socially equitable.

The primary limitations of this study include its foundation in existing literature, necessitating empirical validation of the proposed RSSCM framework to confirm its real-world effectiveness. Additionally, the current lack of standardized metrics for assessing regenerative impact poses a challenge addressed by this framework's structure but requires further methodological development. Future research, as detailed in the discussion (Section 3.6), should therefore prioritize empirical testing across diverse sectors, the creation of specific regenerative KPIs, longitudinal analysis of framework adoption, and the exploration of advanced technological integration.

In essence, this research asserts that the future of responsible and effective supply chain management lies in embracing a regenerative paradigm. The RSSCM framework provides a concrete structure for organizations to navigate this transition, fostering the development of supply chains that are not merely sustainable and resilient but actively contribute to a thriving planet and society.

5 Conflict of Interest

The author declares that there are no conflicts of interest.

6 Author Contributions

Henry Efe Onomakpo Onomakpo conceived the study, performed the literature review, conducted the bibliometric analysis, developed the framework, and wrote the manuscript.

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9 Data Availability Statement

The bibliometric data analyzed in this study originates from the Scopus, Dimensions, and ScienceDirect databases. Due to the proprietary nature of these databases, direct access to the raw data is subject to individual subscription agreements with the respective database providers. However, the processed data, along with the analytical code used in this study (primarily utilizing the "bibliometrix" package in R, which can be assessed on https://cran.r-project.org/package=bibliometrix), is deposited on the publisher's website. The materials will remain archived permanently.

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