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DECARBONIZATION AND SUSTAINABLE SUPPLY CHAINS: A SYSTEMATIC REVIEW OF SUPPLIER ENGAGEMENT, DIGITAL TRACEABILITY, AND CARBON GOVERNANCE

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Abstract

Decarbonizing supply chains is becoming a coordinated effort for managing emissions beyond organisations' boundaries. This systematic literature review is aimed at analysing the role supplier engagement, digital traceability and carbon governance play in sustainable supply-chain decarbonization. The 25 peer-reviewed journal articles included in this study were selected and analysed based on the PRISMA 2020 guidelines as used in Scopus and Web of Science from 2015 to 2026 using descriptive analysis and thematic synthesis. The results suggested that supplier collaboration, supplier development, carbon targets, incentives and knowledge sharing increased supplier involvement in emissions reduction. Digital traceability and technologies, such as blockchain, artificial intelligence, IoT, big data analytics and digital twins, improved carbon measurement, transparency and data sharing. Carbon governance enhanced accountability via reporting, standards, monitoring, disclosure and compliance mechanisms. However, financial costs, data-quality limitations, interoperability, supplier resistance, digital capability gaps, and regulatory differences constrained implementation. The review suggests a comprehensive solution that brings together supplier relations, electronic traceability and carbon management with emissions reductions and sustainable supply-chain decarbonization.

Keywords: Supply Chain Decarbonization; Supplier Engagement; Digital Traceability; Carbon Governance; Scope 3 Emissions; Sustainability

1. Introduction

The climate change and shift to a low carbon economy have increased the pressure on organizations to lower their Greenhouse Gas (GHG) emissions across their value chains and operations. Sustainable Supply Chain Management (SSCM) has therefore emerged as crucial for embedding environmental goals into the supply chain, procurement, production and supplier relations (Ahmed et al., 2026; Ghosh et al., 2020). Corporate emissions are typically reported as Scope 1 (direct emissions), Scope 2 (indirect emissions) and Scope 3 emissions (indirect upstream and downstream value-chain emissions). Scope 3 emissions are especially important as they often make up the bulk of an organization's carbon footprint and are often quite difficult to measure and manage (Eckerman et al., 2023; Hettler & Graf-Vlachy, 2023). For decarbonization to go past the organization's limits, supplier involvement is vital for communicating, capability development, incentives, cooperation, and sharing emissions data (Butt et al., 2024; Cloutier et al., 2019). At the same time, digital technologies are offering possibilities for better carbon measurement and traceability, and robust carbon governance is necessary to ensure accountability and trusted management of carbon emissions across supply-chain participants (Zhang et al., 2024; Lee et al., 2026).

Despite growing decarbonization commitments, organizations face substantial difficulties in managing emissions occurring outside their direct operations. Carbon information is often disorganized, lacking, and sometimes contradictory and difficult to validate at the supplier level (Ahmed, Zaidi, & Zohaib, 2026). The lack of standardized information sharing practices further limits accurate Scope 3 measurement (Stenzel & Waichman, 2023), as do limited interoperability and data-privacy concerns. Technologies, like blockchain, can be used to improve transparency and traceability, but there are organizational, technical, cost, and governance challenges with technology implementation (Bager et al., 2022). In addition, carbon-governance arrangements differ by organization, further making it difficult to hold the organization accountable and to coordinate emissions reduction efforts (Govindan et al., 2020).

The current scholarship is scattered across the four domains of SSCM, carbon accounting, supplier engagement and digital technologies and governance. There have been several reviews focusing on sustainable supply chains, Scope 3 reporting, or digital technologies as separate areas of research, and supplier engagement and digital carbon traceability are not fully connected (Jia et al., 2018). There are ongoing challenges with the measurement of Scope 3 emissions, stakeholder coordination, sharing, and emissions management strategies, as evidenced in recent literature (Borchardt et al., 2025; Hettler & Graf-Vlachy, 2023). Therefore, systemic synthesis of supplier engagement, digital traceability and carbon governance are needed.

This is a review of literature that brings together the dispersed streams of literature and provides a unified conceptual framework to understand supply chain decarbonization. The review is a theoretical link between supplier relationships, digital carbon information and governance mechanisms, and practically, it identifies mechanisms that managers can use to enhance management of Scope 3 emissions (Bux et al., 2026). It also offers policy implications in the sense of transparency, accountability, and standardization of carbon, and a structured agenda for future research.

1.1 Research Objectives

RO1: To systematically synthesize the existing literature on the role of supplier engagement, digital traceability, and carbon governance in advancing supply chain decarbonization and sustainability.

RO2: To examine the strategies, mechanisms, technologies, and governance practices through which supplier engagement and digital traceability support carbon measurement, transparency, accountability, and emissions reduction across supply chains.

RO3: To identify key theoretical perspectives, methodological approaches, implementation challenges, and research gaps in the literature and develop an integrated framework and future research agenda for sustainable supply chain decarbonization.

1.2 Research Questions

RQ1: How have supplier engagement, digital traceability, and carbon governance been conceptualized and examined in the literature on supply chain decarbonization and sustainability?

RQ2: What strategies, mechanisms, and digital technologies are reported to facilitate supplier participation, carbon traceability, transparency, and emissions reduction across supply chains?

RQ3: What theoretical, methodological, and empirical gaps remain in the literature, and what future research directions can advance knowledge on decarbonization and sustainable supply chains?

2. Conceptual Background

2.1 Supply Chain Decarbonization

Supply chain decarbonization is the consistent lowering of the Greenhouse Gas (GHG) emissions throughout the production and delivery of goods and services, including from their point of origin to their point of use and when they reach the end-of-life (Dahlmann & Roehrich, 2019; Lintukangas et al., 2022). It is a major aspect of Sustainable Supply Chain Management (SSCM) that integrates environmental impact into business strategies and inter-firm decisions to minimize carbon footprint and achieve net-zero goals (Ghosh et al., 2020). Carbon accounting allows the separation of Scope 1 (the sources owned or controlled by companies) and Scope 2 (energy purchasing) emissions from Scope 3 (upstream and downstream value chain emissions). Scope 3 is particularly significant as it can typically represent the bulk and hardest-to-measure part of an organization's emissions (Hettler & Graf-Vlachy, 2023). However, making a supply chain 'net zero' goes beyond operational efficiency and renewable energy -- it involves engaging suppliers, accounting for carbon footprints, making low-carbon decisions, optimizing logistics and collaborating with value chains (Raynor & Gopalakrishnan, 2025; Bux et al., 2026).

2.2 Supplier Engagement

Supplier engagement is the engagement by purchasing organizations of suppliers in reaching environmental and carbon-reduction goals. Good engagement is not just about compliance, it's about building relationships, developing suppliers, setting emissions reduction goals, conducting sustainability audits, providing incentives, feedback, and sharing knowledge (Cloutier et al., 2019). Communication, trust building, technical guidance, effective use of supplier information, continuous feedback and incentive programs all have been identified as important mechanisms in reducing Scope 3 emissions based on empirical evidence (Butt et al., 2024). Focal firms can also leverage supplier assessment and sustainability criteria to factor in carbon performance when making purchasing decisions; collaborative relationships can enhance suppliers' environmental capabilities and carbon accountability (Liew & Cao, 2024).

2.3 Digital Traceability

Digital traceability is the ability to capture, link and trace the information attached to materials, products, processes and emissions in their supply-chain networks. In decarbonization contexts, it allows organizations to collect emissions data for their suppliers, to know where the emissions are coming from, to identify the carbon hotspots and to enhance transparency beyond the organization's boundaries (Lee et al., 2026; Villena & Dhanorkar, 2020). The significance of primary data sharing is key as Scope 3 calculations often rely on industry averages and approximations when supplier-specific data is unavailable (Stenzel & Waichman, 2023). Digital traceability can thus contribute to detailed and product-specific carbon footprint information and to the continuous monitoring of energy flows, transport flows and resource flows (Mathur & Bansal, 2024).

2.4 Digital Technologies for Carbon Traceability

A portfolio of complementary digital technologies is becoming a key enabler to carbon traceability. By establishing a blockchain-based system for emissions tracking, blockchain can enhance transparency, verification, and accountability (Alotaibi et al., 2024; Tidy et al., 2015). Smart sensors and IoT devices can gather energy, transportation and resource-use data in real-time, and AI and big data analytics can analyze the data and identify patterns, emission hotspots and inform predictive decision-making (Palaniappan et al., 2026). While cloud-based platforms can facilitate scalable integration and sharing of data, digital twins can simulate and represent physical processes within the supply chain for monitoring, simulation, and optimization (Liu et al., 2022; Karlsson et al., 2019). All of these technologies combined can help further improve carbon-accounting platforms by linking emissions measurement to the decision-making process.

2.5 Carbon Governance

Carbon governance includes the policies, rules, responsibilities, reporting frameworks, standards and mechanisms of accountability used to manage and report carbon performance in supply chains. Good governance involves setting measurable requirements by setting emissions targets, supplier compliance criteria, monitoring, disclosure and verification (Govindan et al., 2020). While scope 3 reporting remains an important aspect of transparency, reporting is incomplete and inconsistent between organizations (Hettler & Graf-Vlachy, 2023; Palaniappan et al., 2026). Enforcement and standardized reporting can enhance accountability, as firms are incentivized to monitor and limit emissions across their supply chain and within the company (Shi et al., 2025). The governance framework for achieving supply-chain decarbonization of corporate net-zero commitments includes standards, certification, supplier compliance, transparency in reporting and credible carbon data (Jia et al., 2018).

3. Methodology

3.1 Research Method

This study focused on decarbonization and sustainable supply chains and used a systematic literature review (SLR) to compile the research findings, paying special attention to supplier engagement, digital traceability and carbon governance. The review was conducted following the PRISMA 2020 guidelines, which were designed to streamline and report the literature identification, screening, eligibility, inclusion, appraisal, and synthesis processes (Page et al., 2021). The unit of analysis was individual peer-reviewed journal article, and the systematic selection process led to the analytical sample of 25 studies.

3.2 Review Protocol

Predefined review protocol was created prior to the database search, to improve methodological consistency and repeatability. The research questions, databases, time frame for the review, search terms and Boolean operators, eligibility criteria, screening stages, quality assessment of the literature, data extraction and data synthesis procedures were outlined in the protocol. This was a pre-planned process in line with PRISMA 2020's focus on explicitly reporting how evidence was identified, selected, appraised, and synthesized (Page et al., 2021).

3.3 Databases

Various search strategies were made in Scopus and Web of Science. These databases were the primary sources used to locate peer-reviewed research that related to supply-chain decarbonization and its technology and governance aspects. Use the Boolean operators to search strings which include related words such as supply chain, decarbonization, carbon emissions, net zero, Scope 3, supplier engagement, digital traceability, blockchain, IoT, artificial intelligence, carbon governance and other similar words.

3.4 Review Period

Studies published from 2015-2026 were included in the review. This timeline was chosen to reflect the evolution of supply-chain decarbonization, Scope 3 management, engagement with suppliers on sustainability, digitalization, blockchain, IoT, AI-powered traceability, carbon disclosure, governance and the development of net-zero strategies. This was complemented by the increased relevance of Scope 3 reporting, for decarbonizing the supply-chain (Hettler & Graf-Vlachy, 2023).

3.5 Review Sample and Unit of Analysis

The unit of analysis was individual peer-reviewed journal articles. The records obtained from both databases were duplicated, title and abstract screened, full text evaluated, quality assessed and selected by criteria. After applying these procedures, 25 studies were included in the evidence base to be used for descriptive and thematic synthesis.

3.6 Inclusion and Exclusion Criteria

3.6.1 Inclusion Criteria. Studies included were English language, peer-reviewed journal articles published between 2015 and 2026, that meaningfully discussed supply chains, decarbonization or carbon reduction/neutrality or net-zero practices, and discussed supplier engagement or digital traceability or carbon transparency or carbon governance. Studies were also needed to have adequate conceptual or empirical evidence and meet the predetermined criteria for methodological quality.

3.6.2 Exclusion Criteria. Studies published outside the period indicated, not written in English, and duplicate studies, conference papers, book, book chapters, editorials, commentaries, reviews, dissertations, theses and grey literature were excluded from the study. Studies lacking in supply-chain or carbon-sustainability relevance, purely technical studies with no supply-chain implications and studies lacking in analytical information and/or did not meet the quality criteria were also excluded.

3.7 Study Selection Process

Study selection was done based on the PRISMA 2020 framework (Page et al., 2021). Records were located in the databases (Scopus and Web of Science) and duplicates were eliminated. Second, titles followed by abstracts were screened for their eligibility based on the inclusion criteria. Third, potentially relevant studies were fully text-counted, with reasons recorded for exclusion. The fourth step was to evaluate eligible articles for the clarity of objectives, methodological appropriateness, adequacy of evidence, analytical transparency, credibility of findings and relevance. Lastly, the studies were assessed systematically with the

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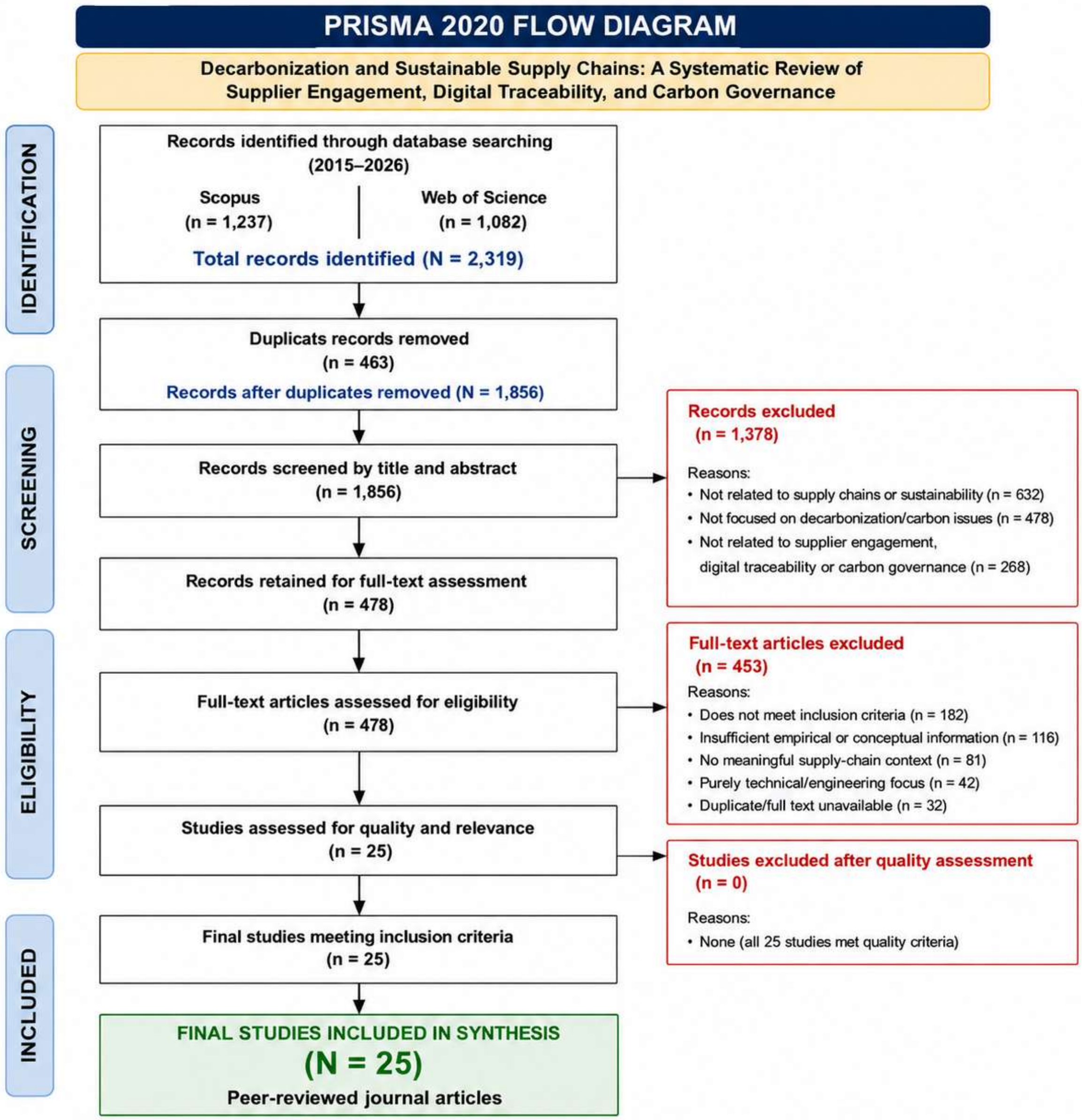
criteria, according to the core dimensions of the review: decarbonization, supplier engagement, digital traceability, carbon governance, carbon measurement, transparency, emissions reduction and supply-chain sustainability. The final 25-study analytical sample was obtained through this procedure that led to the final sample for subsequent descriptive and thematic synthesis.

Figure 1

PRISMA 2020 Flow Diagram of the Study Selection Process



Note. The figure presents the identification, screening, eligibility assessment, quality evaluation, and final inclusion stages of the systematic review. Following the PRISMA 2020 guidelines, a total of 2,319 records were identified from Scopus and Web of Science, resulting in 25 peer-reviewed journal articles being included in the final synthesis (Page et al., 2021).

3.8 Data Extraction and Coding

A data-extraction and coding sheet was created to structure the data from the 25 studies that were included in the final sample for the systematic review. A standardized extraction form ensured consistency in data collection for study features and enabled a systematic comparison between the various research designs.

Structured and pilot-tested extraction procedures have been suggested in systematic reviews due to their benefits in enhancing transparency, reproducibility, and consistency for evidence synthesis (Iannizzi et al., 2023; Guo et al., 2025).

For each article, bibliographic and contextual information was extracted, including the author(s), publication year, journal, country, industry or sector, and research context. The methodological characteristics were categorized based on research design, research method, sample / data source, and theoretical perspective. Special consideration was paid to the major concepts of the review. For this reason, information was collected on supplier-engagement mechanisms, digital technologies, digital-traceability practices, carbon-governance mechanisms, carbon-measurement approaches and carbon-transparency practices. During the coding process, the following main findings, implementation challenges, sustainability outcomes, emissions-reduction outcomes, identified research gaps, and future research recommendations were also captured. They were used as the analytical framework for the following descriptive analysis and thematic synthesis.

3.9 Quality Assessment

Studies were evaluated prior to being included in the review in terms of methodological and conceptual elements of the study. The quality appraisal is essential part of a systematic review as poor research design, poor quality of evidence, poor analytical transparency, or poor reporting can diminish the reliability of the synthesis (Shaheen et al., 2023). The significant role of ensuring that the application of quality appraisal criteria and their inclusion in selection and interpretation of studies is transparent has also been highlighted in recent methodological research (Lindsay et al., 2025).

3.10 Data Analysis and Synthesis

The final sample of 25 peer-reviewed journal articles was analyzed using two complementary approaches: that of descriptive analysis and thematic synthesis. These were used to analyze literature characteristics and to look for commonalities in terms of supplier engagement, digital traceability, digital technologies, carbon governance, implementation challenges and supply-chain decarbonization (Ghosh et al., 2020). The analysis followed the research goals and research questions of the study regarding conceptualization, mechanisms, technologies, governance practices, challenges and gaps in the existing literature.

3.10.1 Descriptive Analysis. The descriptive analysis revealed that the research on supply-chain decarbonization was spread across various research years, countries, industries, journals, methodology, theory, and research context. The examined literature indicated an increase in scientific interest in Scope 3 emissions, supplier sustainability, digital traceability, carbon transparency and carbon governance (Borchardt et al., 2025). Research was conducted in various geographical and sectoral contexts, revealing the increasing importance of decarbonization in different contexts of the supply chain (Jia et al., 2018). There was also methodological diversity, with a range of studies using empirical, conceptual, qualitative, quantitative and mixed research methods. There were theoretical differences depending on the sustainability management focus, interorganizational relationships, technology adoption, institutional pressures, and carbon accountability. Other digital technologies were also discussed in the literature, such as blockchain, the Internet of Things, artificial intelligence and big-data analytics, digital twins, cloud-based platforms, smart sensors and carbon-accounting systems, amongst others (Lee et al., 2026; Ströher et al., 2025). Overall, the descriptive findings showed that the field was multidisciplinary and increasingly technology-oriented, although the distribution of studies remained uneven across countries, industries, and methodological contexts.

3.10.2 Thematic Synthesis

3.10.2.1 Engaging Suppliers for Decarbonization. Supplier engagement was identified as a key enabler to take decarbonization beyond the remit of focal organizations. The studies reviewed highlighted that the practices of supplier collaboration, supplier development, carbon-reduction targets, sustainability requirements, incentive programs, and sharing knowledge with suppliers are important for enhancing the participation of suppliers in reducing emissions (Butt et al., 2024). These mechanisms contributed to the building of environmental capacities and led suppliers to be more actively involved in carbon-management goals (Cloutier et al., 2019).

3.10.2.2 Digital Traceability and Carbon Transparency. The need for digital traceability as an essential pillar for enhancing carbon transparency in the supply-chain networks was highlighted. The literature highlighted carbon tracking, data collection at supplier level, sharing of emissions data, transparency in the supply chain, carbon measurement and product-level carbon information (Stenzel & Waichman, 2023). Greater traceability facilitated identification of carbon intensive activities and enhanced the visibility and reliability of information on Scope 3 emissions (Hettler & Graf-Vlachy, 2023).

3.10.2.3 Digital Technologies for Decarbonization. Digital technologies have become increasingly prominent in the support of carbon measurement, monitoring, verification, and decision making. Several enabling technologies were mentioned, including blockchain, IoT, AI, big data analytics, digital twins, cloud platforms, smart sensors and carbon-accounting platforms (Liu et al., 2022). They helped in gathering real-time data, monitoring emissions, integrating data within large, multi-layered supply-chain networks, predictive analysis, and in providing a better understanding of the systems (Mathur & Bansal, 2024).

3.10.2.4 Carbon Governance and Accountability. Carbon governance became an important tool that was created to move carbon information into accountability. The identification of responsibilities of actors in the supply chain was facilitated through standards, carbon reporting, disclosure practices, monitoring systems, compliance requirements and regulatory mechanisms (Shi et al., 2025). Enhanced transparency and implementation of organizations and suppliers in line with emission reduction targets were also found as a result of effective governance structures (Liew & Cao, 2024).

3.10.2.5 Implementation Challenges and Research Gaps. However, there were still several problems to overcome regarding implementation. Financial costs, insufficient technological infrastructure, data quality, supplier resistance, lack of standardized carbon data, interoperability issues, lack of digital skills, capability issues and regulatory differences were among the most significant barriers identified in the literature (Bager et al., 2022). Many gaps in theory, method and evidence were also identified during the synthesis. In general, the results indicated that implementing supply chain decarbonization needed to combine supplier engagement, digital traceability, and technological capabilities, along with carbon-governance measures, and future research was required to deliver more robust empirical evidence, carbon-governance systems, and a more direct measure of actual supply chain decarbonization impacts (Bux et al., 2026).

4. Results

The findings from the systematic literature review were presented based on the descriptive and thematic dimensions described in the review protocol. A total of 25 peer-reviewed journal articles were finally selected, with the articles appearing in the period from 2015–2026. The analysis compared the features, publication trends, geographical distribution and methodological approaches and theoretical perspectives presented in the literature. The thematic synthesis then addressed issues of supplier engagement, digital traceability, carbon governance, and problems with implementing decarbonization in the supply chain.

4.1 Characteristics of Included Studies

The 25 studies selected constituted a diverse set of papers on various aspects of decarbonization of the supply chain, from the technological, organizational, relational and governance angles. The studies varied regarding their geographical context, industrial setting, methodological design, theoretical orientation and primary research focus. The topics of their research primarily involved Scope 3 emissions management, supplier sustainability engagement, carbon data sharing, digital traceability, blockchain enabled transparency, carbon accounting, carbon disclosure and supply-chain governance. This is a sign of the multidisciplinary nature of decarbonization, which is now a field for research that includes sustainability management, supply-chain management, information systems, operations management, and environmental governance.

The results of the included studies are summarized in Table 1 with regard to author, publication year, country, industry or sector, research method, and main research focus.

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Table 1
Characteristics of Selected Studies

Author/Year	Country	Industry/Sector	Research Method	Main Research Focus
Tidy et al. (2015)	United Kingdom	Food retail / supermarket supply chains	Case study / qualitative	Supplier relationship management and supplier engagement for reducing GHG emissions
Jia et al. (2018)	Developing countries	Cross-sector sustainable supply chains	Literature review	Sustainable supply-chain management practices and challenges in developing countries
Dahlmann & Roehrich (2019)	United Kingdom / international supply chains	Cross-sector supply chains	Empirical qualitative study	Partner engagement and management of climate-change information across supply chains
Karlsson et al. (2019)	Sweden	Construction / road infrastructure	Case study / scenario analysis	Pathways for achieving net-zero carbon emissions in construction supply chains
Cloutier et al. (2019)	International	Cross-sector supply chains	Literature review	Collaborative mechanisms supporting sustainability-oriented supply-chain initiatives
Ghosh et al. (2020)	International	Cross-sector supply chains	Systematic literature review	Carbon-footprint management and sustainable supply-chain practices
Govindan et al. (2020)	International	Multi-tier supply chains	Systematic literature review	Sustainability tensions and conceptual framework development in multi-tier supply chains
Villena & Dhanorkar (2020)	Global / multi-country	Global supply chains	Quantitative empirical study	Institutional pressures, managerial incentives, and carbon transparency
Liu et al. (2022)	International	Supply-chain management	State-of-the-art review	Blockchain-based digital twins for supply-chain traceability, integration, and management
Bager et al. (2022)	Coffee supply chain / Honduras context	Agro-food / coffee	Case study	Opportunities and limitations of blockchain for sustainable supply-chain traceability
Lintukangas et al. (2022)	Finland	Cross-sector supply chains	Quantitative empirical study	Determinants of organizational engagement in supply-chain carbon management
Hettler & Graf-Vlachy (2023)	International	Cross-sector supply chains	Systematic literature review	Scope 3 carbon-emission reporting as an enabler of supply-chain decarbonization

Author/Year	Country	Industry/Sector	Research Method	Main Research Focus
Stenzel & Waichman (2023)	International	Cross-sector supply chains	Conceptual / analytical study	Supply-chain data sharing for improving Scope 3 emissions measurement
Eckerman et al. (2023)	United States	Utility supply chains	Practice-oriented / conceptual study	Strategies for decarbonizing utility supply chains and addressing value-chain emissions
Alotaibi et al. (2024)	International	Cross-sector supply chains	Conceptual / analytical study	Blockchain-enabled carbon accountability, transparency, traceability, and verification
Butt et al. (2024)	Cross-sector / international	Circular supply chains	Empirical study	Supplier engagement mechanisms for reducing Scope 3 emissions
Liew & Cao (2024)	Cross-sector	Green supply chains	Quantitative / analytical study	Green supply-chain management and carbon accountability
Mathur & Bansal (2024)	Cross-sector	Supply chains	Technology-focused analytical study	IoT-enabled measurement and quantification of Scope 3 supply-chain emissions
Zhang et al. (2024)	China	Low-carbon supply chains	Evolutionary game analysis	Blockchain traceability adoption and stakeholder behavior in low-carbon supply chains
Borchardt et al. (2025)	International	Sustainable supply chains	Systematic literature review	Scope 3 emissions management, practices, challenges, and research gaps
Raynor & Gopalakrishnan (2025)	Cross-sector	Corporate supply chains	Conceptual / analytical study	Environmental attribute certificates as a mechanism for Scope 3 decarbonization
Shi et al. (2025)	Cross-sector / corporate firms	Corporate / industrial sector	Quantitative empirical study	Voluntary emissions disclosure, carbon transparency, and environmental performance
Ströher et al. (2025)	European / cross-organizational context	Sustainable supply chains	Design-oriented / empirical study	Automated carbon-data sharing across organizational boundaries
Lee et al. (2026)	International	Construction supply chains	Systematic literature review	Digital technologies, governance, procurement, and carbon-data quality for decarbonization
Palaniappan et al. (2026)	India	Corporate supply chains	Longitudinal quantitative analysis	Supply-chain climate policies and focal firms' efforts to reduce Scope 3 emissions

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Note. Table 1 summarizes the principal characteristics of the 25 studies included in the systematic review according to author and publication year, geographical context, industry or sector, research method, and main research focus.

4.2 Publication Trends

The publication trends showed rising academic interest in the decarbonization of the supply-chain during the review period. Older research mainly focused on sustainable supply-chain management, carbon accounting, environmental performance and sustainable practices of the suppliers (Ghosh et al., 2020). More recent research began to integrate Scope 3 emissions, net zero targets, traceability (digital) aspects, carbon-data transparency, and advanced technologies (Borchardt et al., 2025). Blockchain, artificial intelligence, IoT technologies, digital twins and carbon accounting platforms are just a few examples of a new paradigm of sustainability management, moving away from traditional sustainability management and toward digital supply-chain decarbonization (Lee et al., 2026). The pattern indicated that the amount of research related to carbon transparency has been growing over the last few years, thanks to technological development and growing organizational pressure toward carbon transparency.

4.3 Geographic Distribution

The geographical analysis revealed that the topic of decarbonizing the supply chain had been addressed in research in various and different national and institutional settings. Research from the developed countries typically focused on sophisticated carbon reporting, digitalization, regulatory requirements and reporting, supplier transparency and net-zero approaches. Comparatively, the studies undertaken in the emerging economies focused more on implementation capacity, supplier development, technological readiness, infrastructure constraints and institutional constraints (Jia et al., 2018). Meanwhile, the review found reasonably weak evidence from a few under-researched and under-represented areas. This geographical disparity indicated the need for more empirical research of decarbonization approaches in settings with less digital infrastructure, loose or complex supply chains, and changing environmental regulations.

4.4 Methodological Distribution

The reviewed studies used various methodological approaches as it is an interdisciplinary field of study. Overall, quantitative studies typically explored the relationships between different sustainability practices, supplier capabilities, technology adoption, environmental performance and carbon outcomes. Qualitative studies were used to gain deeper insight into organizational practices, supplier relationships, barriers and within the governance processes. Case-study research proved to be very helpful in understanding how digital technologies and carbon-management efforts have been used or not in particular settings of the supply chain (Bager et al., 2022). The mixed-method studies were based on quantitative patterns and contextual explanations whilst the conceptual studies provided frameworks and propositions relating to decarbonization mechanisms. The methodological variety helped to broaden the scope of the literature, but there was significant variability in the design and outcome measures of all the studies, which made it difficult to make direct comparisons across studies (Guo et al., 2025).

4.5 Theoretical Perspectives

Various theories were used to explain how supply-chain decarbonization can be achieved in literature. Stakeholder Theory was one of the explanations for the role of the stakeholders, namely the customers, regulatory bodies, the investors, suppliers and others, in the carbon-management practices of corporations. The institutional theory focused on regulatory, normative and competitive pressures that motivate the organization to implement sustainability and disclosure practices. The Resource Based View and Dynamic Capabilities (RBDC) provided the lens to emphasize the role of organizational resources, technological capabilities, knowledge and adaptive capacity to realize the decarbonization goals. Transaction Cost Theory provided answers to the coordination of suppliers, sharing information, monitoring and governance arrangements. Theoretical frameworks based on technology were also used to understand the adoption and implementation of digital traceability technologies (Zhang et al., 2024). These views revealed that decarbonization was not a single explanatory mechanism, but rather comprised technological, relational, organizational and institutional aspects.

4.6 Supplier Engagement Findings

Engaging suppliers was identified as a key enabler to take decarbonization actions beyond the confines of an organization. Butt et al. (2024) found that the thematic synthesis identified practices that are important for suppliers to engage in: supplier collaboration, supplier development, sustainability requirements, carbon-reduction targets, incentives, knowledge sharing, training, and information exchange. Coordinated strategies seemed to be especially significant when suppliers did not possess technical information or carbon measuring tools. This supplier development allowed focal organizations to increase environmental capacity in their supply chains, and carbon targets and sustainability requirements set their expectations on emissions performance (Cloutier et al., 2019). This suggested that the optimal way to engage suppliers involved two types of tools: the supportive tools (knowledge sharing, capability development and others) and the accountability tools (targets, monitoring and sustainability requirements).

4.7 Digital Traceability Findings

Digital traceability was always linked to the enhancement of visibility of carbon-related information in the supply-chain networks. The implementation of carbon tracking, supplier-level data collection, information sharing and product-level carbon measurement allowed organizations to better understand their sources of emissions and track Scope 3 emissions (Stenzel & Waichman, 2023). Various technologies such as blockchain, Internet of Things (IoT), artificial intelligence (AI), big-data analytics, cloud platforms, smart sensors, digital twins, and carbon-accounting systems were used for various parts of this process. The use of IoT and sensors enabled data collection over time (Mathur & Bansal, 2024), and blockchain added increased reliability and security of data (Alotaibi et al., 2024). The analysis of huge amounts of data and the identification of carbon intensive activities were done with the help of AI and big data. The digital traceability, in turn, helped in the carbon measurement, transparency, data sharing and improved decisions on decarbonization.

4.8 Carbon Governance Findings

A key mechanism that arose in the process of turning carbon information into carbon responsibilities and action was carbon governance. The literature reviewed highlighted carbon-reporting systems, carbon emission disclosure, sustainability standards, monitoring, compliance, and regulation (Shi et al., 2025). Governance systems provided clarity on roles and responsibilities of focal organizations and suppliers and set expectations on carbon-data provision and emission reduction. The monitoring and reporting also helped to enhance transparency, enabling organizations to assess the performance of their suppliers and make progress towards their carbon targets. Based on the synthesis, the lack of governance mechanisms to connect with information and accountability (Liew & Cao, 2024) is a problem with digital transparency. Carbon governance thus complemented engagement with suppliers and digital traceability, which are instruments for coordinated decarbonization, with its standards, responsibilities and control mechanisms.

4.9 Implementation Challenges

While there were great advantages to be gained by engaging suppliers, the key challenges identified in the literature reviewed were significant. Technological challenges encompassed lack of infrastructure, interoperability issues, cyber security and data-integration problems. Organizational barriers included lack of skills and capacities, lack of resistance to change, lack of digital skills and lack of coordination of multiple actors in supply chains. Another key constraint was financial -- the cost of implementing technologies and gathering good quality supplier information, especially with smaller suppliers. Issues that arose were incomplete and inconsistent carbon information, non-standardized and difficult to verify carbon information (Hettler & Graf-Vlachy, 2023). There were also differences in regulations between countries, making global supply chain reporting and compliance more complex. Other factors that hindered transparency were supplier resistance and a lack of willingness to share sensitive information.

Overall, the findings indicated the need for interplay between supplier engagement, digital traceability, technological capabilities and carbon governance for a supply chain to become decarbonized. Supplier engagement helped to ensure participation; digital technologies increased carbon visibility; and governance mechanisms helped to give carbon information a sense of accountability and coordinated action (Bux et al., 2026). Nevertheless, the technological, organizational, financial, data related, supplier related and regulatory factors remained as barriers to implementation, which also calls for important future theoretical and empirical studies.

5. Discussion

5.1 Supplier Engagement and Supply Chain Decarbonization

The results highlight the importance of supplier engagement as a strategy for expanding decarbonization efforts beyond the company's own scope of action, with a specific focus on Scope 3 emissions (Butt et al., 2024). Knowledge sharing, supplier development, technical assistance and other collaborative efforts such as joint sustainability projects can help build supplier capacity to measure and reduce emissions (Cloutier et al., 2019). Carbon targets, sustainability requirements, incentives, and performance monitoring offer more formal pathways to link supplier behavior with organizational climate goals, compared to the current situation. The synthesis suggests that collaboration and compliance are not enough on their own but need to be combined to achieve improved conditions for continued cooperation from suppliers and emissions reduction.

5.2 Digital Traceability and Carbon Transparency

The review also shows that digital traceability can help overcome some of the ongoing challenges in the carbon visibility in complex supply chains. The collection, tracking and sharing of carbon data by suppliers help firms more easily identify sources of carbon emissions and measure their carbon performance (Stenzel & Waichman, 2023). This is especially true of Scope 3 emissions, which are often the subject of limited information and estimations, affecting the accuracy of emissions measurements (Hettler & Graf-Vlachy, 2023). Carbon data, however, can only have meaningful impacts when they are reliable, standardized, interoperable, and shared between supply chain partners (Lee et al., 2026).

5.3 New Technologies and Decarbonization

Digital technologies offer unique, but complementary, carbon management capabilities. Blockchain ensures data integrity, transparency and verification (Alotaibi et al., 2024), and IoT devices and smart sensors can help to gather operational and emission data continuously (Mathur & Bansal, 2024). AI and big-data analytics enable the understanding of complex data sets and understanding of emission hotspots, while digital twins and cloud platforms enable simulation, integration and information sharing (Liu et al., 2022). But implementation costs and infrastructure restrictions, interoperability issues, and lack of digital skills can limit these technological benefits (Bager et al., 2022).

5.4 Carbon Governance and Accountability

The results also highlight that better carbon information does not necessarily result in carbon emissions reductions. Carbon governance mechanisms offer tools that help to convert information into organizational responsibility and action. Requirements of standards, reporting and disclosure, monitoring systems, compliance mechanisms and clearly defined accountability structures set expectations for focal firms and suppliers (Shi et al., 2025). Governance is thus important to establish an institutional basis for making carbon transparency into credible decarbonization practices (Liew & Cao, 2024).

5.5 Integration of the Three Areas

The review in totality provides a holistic picture of sustainable supply-chain decarbonization. Supplier engagement creates participation and capabilities, digital traceability creates credible carbon visibility, and carbon governance creates carbon accountability and coordinated action (Ghosh et al., 2020). The dimensions are thus interwoven and not independent. They offer a more robust approach to measuring Scope 3 emissions, reporting on carbon, holding suppliers accountable, cutting emissions, and ultimately, creating more sustainable supply chains (Bux et al., 2026).

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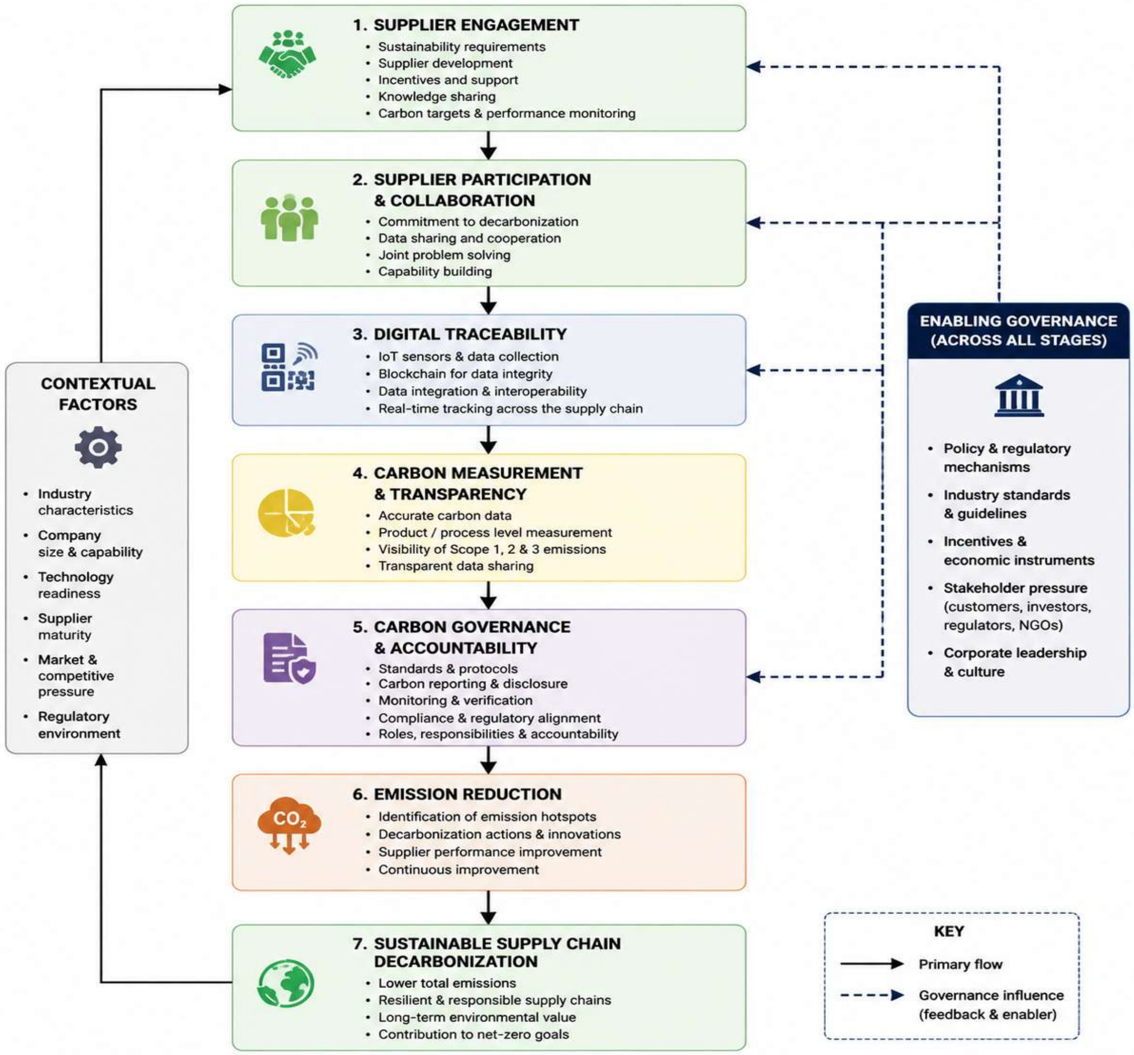
Figure 2

Integrated Conceptual Framework for Supply Chain Decarbonization through Supplier Engagement, Digital Traceability, and Carbon Governance



Note. The figure represents the integrated framework created based on the results of the systematic review and the relationship between supplier engagement, supplier participation and collaboration, digital traceability, carbon measurement and transparency, carbon governance and accountability, emission reduction and the decarbonization of the supply-chain. All the activities in the decarbonization processes are affected by contextual factors and enabling governance mechanisms.

6. Research Gaps and Future Research Agenda

The systematic review revealed significant gaps in the theoretical, methodological, empirical and technological literature on decarbonization of the supply chain. Although in theory, the research on the topic so far is still fragmented, with suppliers being engaged as a separate topic and digital traceability as a separate one, and carbon governance as a separate one. The research should be conducted in the future using a multi-theoretical perspective to better understand how relational, technological, organizational and institutional mechanisms interact to support decarbonization. There is also a need for more theory to account for new forms of digital carbon governance and accountability.

In terms of methods, limited longitudinal and mixed-method research hinders the understanding of the evolution of decarbonization practices over time. Longitudinal and cross-country designs, as well as supplier-level designs, should be used in future studies to bring out the differences in institutional conditions and implementation processes. However, empirical evidence is scarce in developing economies, SMEs, multi-tier supply chains and Scope 3 emissions, which suggest greater context in need of investigation.

There are also technological gaps to be addressed, including AI-based carbon-accounting solutions, scalability of blockchain technology, integration of IoT solutions, digital-twin technology and carbon-data interoperability. Future work should include a study on the ability of those technologies to deliver measurable emission reductions, as well as increasing transparency. Further research is needed on supplier digital capability, carbon-data standardization, regulatory differences, and governance mechanisms of carbon information generated by AI, to improve accountable and sustainable supply-chain decarbonization.

7. Practical and Policy Implications

The results have implications for supply-chain managers, suppliers, policy makers and technology providers looking to further sustainable supply-chain decarbonization. The findings highlight how critical it is to increase supplier collaboration, knowledge sharing, capability building and establish clear carbon-reduction goals for supply-chain managers. In addition, managers need to create effective carbon-data sharing processes and weave supplier carbon performance into procurement, monitoring and sustainability decisions.

The results underscore the importance for suppliers to build up their capacities to measure, report and share emissions accurately and in a digital way. Suppliers need to make carbon reporting more transparent and meaningful and engage more actively in collaborative decarbonization efforts with focal firms. This participation can further enhance environmental capability, and adherence to new carbon obligations.

At the policy level, there is a need for uniform carbon reporting and disclosure standards to enhance the consistency and comparability of carbon data along supply chains. Financial, technical and capacity building assistance should be provided to SMEs that could be more disadvantaged in technology adoption, and policymakers should support the introduction of digital carbon-traceability systems.

Carbon-data platforms are also another crucial aspect of the technology providers' job: creating interoperable platforms that will be able to connect data from organizations and from different tiers of suppliers. More attention needs to be given to ensuring the accuracy, transparency, verifiability, and compatibility of data, including ensuring that digital technologies contribute to reliable carbon measurement, accountability, and emissions reduction through supply-chain networks.

8. Conclusion

The present systematic literature review aimed at bringing together the research on the topic of supplier engagement, digital traceability and carbon governance, to offer an integrated understanding of decarbonizing supply chains in the context of sustainable supply chains. The results showed that supplier engagement is a must-have for going beyond the boundaries of organizations and specifically addressing Scope 3 emissions. Participation and the ability to reduce carbon emissions among suppliers can be enhanced through collaboration, supplier development, carbon targets, sustainability requirements, incentives, and knowledge sharing. The use of digital traceability also plays a role in decarbonization by enhancing carbon measurement, sharing, visibility and transparency in and across complex supply chains. Blockchain, IoT, AI, big-data analytics, digital twins, and carbon-accounting platforms offer complementary capabilities to collect, integrate, verify and analyze carbon information.

The review also underscored the importance of carbon governance to turn carbon information into accountability and action through standards, reporting and disclosure, monitoring and compliance processes. But financial costs, lack of digital infrastructure and data quality, interoperability, supplier resistance, capability gaps, and regulatory differences continue to hinder effective implementation. The integrated approach proposed adds to the existing literature by showing that the three elements of the proposed framework (supplier engagement, digital traceability and carbon governance) can be mutually reinforcing tools to help reduce emissions and to build sustainable supply chains. Further studies are needed based on the application of this approach for the application of the approach in the future should be extended through longitudinal, cross-country, and supplier-level research, with more focus on SMEs, emerging economies, multi-tier supply chains, Scope 3 emissions, carbon accounting with the help of AI, data standardization, and governance of emerging digital carbon technologies.

Contribution of Authors

All the authors participated in the ideation, development, and final approval of the manuscript, making significant contributions to the work reported.

Conflict of Interest Statement

The authors declare no conflict of interest.

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Informed consent was obtained from all participants.

Data Availability

This study relies exclusively on publicly available secondary sources, including corporate disclosures, industry reports, and peer-reviewed literature, all of which are cited in the References section.

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