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Decarbonisation in Supply Chains

School of Management
Procurement and Supply Chain Management

MSc THESIS
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Supervisor: Banu Ekren
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Abstract

This thesis examines how decarbonisation contributes to firm-level supply-chain performance. Motivated by the predominance of Scope 3 emissions and fragmented evidence across operations, sustainability, and policy outlets, it consolidates and interprets current knowledge to inform managerial and policy decisions. Using a systematic literature review aligned with Denyer & Tranfield and PRISMA, the review searched Scopus and EBSCO Business Source Complete, applied pre-specified, protocolised eligibility criteria, and appraised study quality with a calibrated rubric. Searches covering 2015–2025 identified 793 records; after de-duplication and screening, the PRISMA flow was 793 → 676 → 150 → 60, yielding 60 studies for synthesis. Descriptive mapping is followed by thematic synthesis through a barriers–opportunities–benefits lens.

Findings show that environmental, operational, and financial improvements align when four conditions operate together: (1) decision-grade data routines make information usable at the speed of operations; (2) credible external signals (e.g., prices, rules) are contracted into supplier relationships so incentives persist; (3) collaboration density is designed—tight where interdependence is high, loose elsewhere—to keep governance costs bounded; and (4) practices are embedded in planning and control so benefits accumulate rather than stall in pilots. A pragmatic sequence emerges—establish data routines and align incentives; right-size collaboration; embed in planning and control—with a feedback loop in which realised benefits finance the upkeep of data and governance. Boundary conditions include tier distance and SME heterogeneity, asset specificity and capital cycles, and data sensitivity with assurance needs.

The thesis recentres decarbonisation on network governance—treating information as infrastructure, articulating policy–contract complementarity, and formalising collaboration density as a design variable—and offers role-specific actions for lead firms, SMEs, and multinationals. Policy implications emphasise

consistent, contractable disclosure and assurance ‘without exposure’. Limitations concern database scope, English-only coverage, sectoral skew, and single-coder synthesis; future work should validate mechanisms longitudinally and develop SME-centred enablement and collaboration-design rules.

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Keywords:

Scope 3 emissions; multi-tier governance; carbon accounting; digital traceability; carbon pricing; policy–contract coupling; collaboration density; systematic literature review; operational embedment; circular economy.

Acknowledgements

This section is not mandatory, but you may wish to acknowledge the support or contributions of other people who have helped with your thesis or with your studies in general.

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1 Introduction

This thesis focuses on firm-level supply-chain decarbonisation. Despite growing corporate commitments, decision-useful evidence on how supply chains actually achieve and sustain emissions reductions remains fragmented and operationally thin. Firms are now judged not only on the carbon they emit directly but also on the much larger share that sits upstream and downstream in their supply chains. Because indirect emissions can account for the vast majority of a product's life-cycle footprint (Fernandez & Pérez, 2023), meaningful progress toward net-zero will depend on coordinated action that reaches well beyond a company's own walls. Hence, supply chain transparency is now essential—yet the academic insights managers need remain scattered.

At the same time, tightening disclosure rules, investor scrutiny and customer expectations are turning value-chain transparency from a “nice-to-have” into a licence to operate. Digital traceability platforms, AI-driven forecasting tools and circular business models are emerging at speed, yet the academic evidence that managers and policymakers need to evaluate these solutions remains thin and scattered. Much of the existing research concentrates only on internal operations or direct supplier relationships, assumes perfect data visibility, or sidelines the behavioural frictions that typify real multi-actor networks. Accordingly, this review (i) consolidates dispersed findings into a coherent base, (ii) assesses the robustness of current claims, and (iii) uncovers implementation gaps that inhibit practical decarbonisation in supply chains.

This thesis therefore undertakes a systematic literature review of firm-level supply-chain decarbonisation. By integrating dispersed insights on empirical validation, innovation diffusion, and circular-economy integration, the review produces an actionable conceptual model that clarifies managerial priorities and future research directions. Full methodological procedures and robustness checks are provided in Chapter 2.

1.1 Background and Motivation

Policy pressures. From net-zero pledges and carbon-border levies to local carbon taxes, governments keep turning the screws on firms to slash supply chain emissions (Zhou et al., 2021). Feed carbon costs into facility-location or routing software and the logistics blueprint rarely looks the same afterwards (Eskandarpour et al., 2015). A route tweak, within a city or across an ocean, can make a carbon price bite harder, or take the sting out entirely (Tavasszy, 2021). Since 70 to 90 percent of a typical firm's footprint sits beyond its own gates, decarbonisation has to run the length of the chain (Ghadge et al., 2019).

Reporting and measurement. Beyond policy and network choices, trustworthy numbers remain scarce. Ahi and Searcy (2015) logged more than 2,500 green metrics, yet only a handful show up on company dashboards. Reviews still describe indirect emission data as thin, patchy, hard to line up across firms and rarely checked against independent evidence (Hettler & Graf-Vlachy, 2024). Many studies lean on static input-output tables to count carbon (Kaur et al., 2023), while fuzzy system boundaries and spotty data keep the picture blurry (Moshood et al., 2021).

Digital and innovation pathways. New mapping and traceability apps are already turning pilot ideas into verified cuts (Mubarik et al., 2025). Big data engines sharpen emission forecasts (Kumar et al., 2023). When digital tech, process tweaks and governance rules sit under one roof, the machinery runs smoothly (Xu et al., 2023). Case studies flag customer pressure, sustainable-business value, legitimacy gains and raw competition, all paired with hopes of long-run pay-offs (Zhang et al., 2023). Out on the farm, 50 to 60 percent of potential abatement disappears when producers shrug at new measures (Barnes et al., 2024). In China, more than half of process-related industrial emissions trace back to supply chain loops anchored in non-metallic minerals and construction (Peng et al., 2024).

1.2 Research Questions and Objectives

To guide this study, one overarching research question (RQ) is proposed, supported by three specific objectives (OB1–OB3) that illuminate the principal dimensions embedded in the question.

Research Question (RQ)

How can firms overcome barriers and leverage opportunities to achieve supply chain decarbonisation, and what benefits result from these efforts?

Table 1-1 Objectives

ID	Objective	Description
OB1	Diagnose Barriers	Identify and categorise the barriers and challenges that hinder firms' supply chain decarbonisation initiatives.
OB2	Uncover Opportunities	Explore the key opportunities and enabling conditions that can facilitate or accelerate firms' decarbonisation efforts within their supply chains.
OB3	Assess Benefits	Synthesise the reported operational, environmental and financial benefits that firms achieve after implementing supply chain decarbonisation measures.

Source: The author (2025)

Collectively, these objectives enable a systematic exploration of the barriers, opportunities and benefits encompassed by the overarching RQ, thereby ensuring that evidence synthesis in subsequent chapters remains tightly aligned with the thesis purpose. This thesis uses a systematic literature review. Chapter 2 sets out the search strategy, eligibility rules, quality appraisal and synthesis procedures.

1.3 Structure of the Thesis

The remainder of the thesis is organised as follows. Chapter 2 presents the systematic literature review method and explains the search strategy, eligibility rules,

quality appraisal and the way the evidence is synthesised. Chapter 3 provides the descriptive groundwork, charting when and where the studies appear and how they are distributed by industry, region, firm type and method; it also highlights what this landscape implies for barriers, opportunities and benefits, keeping the discussion linked to OB1 to OB3. Chapter 4 moves from mapping to explanation by developing themes that are organised around OB1 to OB3 and by drawing the links among them, including cross-cutting mechanisms. Chapter 5 interprets the results in light of OB1 to OB3 and the research question, setting out theoretical contributions together with managerial and policy implications, as well as limitations and directions for future research. Chapter 6 concludes by answering the research question and by summarising how the results address OB1 to OB3.

2 Methodology: Systematic Literature Review

This chapter sets out the research design and systematic procedures that underpin the evidence synthesis. It begins by positioning the Systematic Literature Review (SLR) as the primary method for answering the thesis research question and its three objectives. Where narrative and scoping reviews risk inconsistency in study selection and reporting, a systematic literature review employs a predefined, transparent protocol that enhances reproducibility and reduces bias, making it the appropriate approach for this study. In the pages that follow, the review unfolds through four moves: first, the blueprint is laid out; second, relevant studies are located and screened; third, their data are drawn together and synthesised; and last, the findings are written up. Each move stays aligned with the latest PRISMA guidance (Page et al., 2021) and with the systematic-review model proposed by Denyer and Tranfield (2009).

2.1 Planning and Protocol Development

Research on supply chain decarbonisation spans operations, sustainability, engineering, and policy outlets. To reduce selection bias and improve transparency, the protocol was fixed before any searches were run. The protocol is organised around four pillars:

Pillar 1: Research compass and scope (see Sections 2.1.1 and 2.1.2). One research question and three objectives (OB1 to OB3) were set. The phenomenon, the 2015 to 2025 window, and admissible sources (journal articles, conference papers, and high-quality grey literature) were defined, with no sector or geography restricted *ex ante*.

Pillar 2: Eligibility gate and search design (see Sections 2.1.3 and 2.2). Inclusion and exclusion rules were specified, five keyword clusters were designed, and the final Boolean strings were consolidated. Two-stage screening was applied (titles and abstracts, then full texts), and every modification was logged.

Pillar 3: Quality assurance (see Sections 2.1.4 and 2.4). A five-item checklist rated 0 to 3 (plus N/A) was used; the rubric was pilot-tested, and scoring rules and thresholds were documented.

Pillar 4: Transparency and reproducibility (see Section 2.4). Reporting is aligned with PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses; Page et al., 2021), an auditable change log has been kept, and search strings, exports, and appraisal forms will be deposited in the appendices.

These pillars structure the remainder of the method. Section 2.2 details search and selection, Section 2.3 explains data extraction and synthesis, and Section 2.4 describes quality and transparency controls. Overall, the sequence aligns with evidence-informed review guidance and PRISMA 2020 reporting standards (Page et al., 2021; Tranfield et al., 2003) and applies a calibrated five-criterion, four-point appraisal adapted from Habib et al. (2015), ensuring transparency, rigour, and reproducibility. Systematic reviews are well suited to consolidate dispersed findings and surface under-researched threads while informing practice and scholarship (Briner & Denyer, 2012; Snyder, 2019).

2.1.1 Research Compass

This review is guided by one research question: How can firms overcome barriers and leverage opportunities to achieve supply chain decarbonisation, and what benefits result from these efforts? The question is addressed through three objectives: diagnosing barriers (OB1), identifying opportunities and enabling

conditions (OB2), and synthesising environmental, operational, and financial benefits (OB3). The research compass summarised in Table 2-1 anchors subsequent decisions on search, screening, and synthesis, ensuring that the evidence base remains aligned with the thesis aim.

Table 2-1 Research Question and Objectives

ID	Focus
RQ	How can firms overcome barriers and leverage opportunities to achieve supply chain decarbonisation, and what benefits result from these efforts?
OB1 - Diagnose Barriers	Identify and categorise the barriers and challenges that hinder firms' supply-chain decarbonisation initiatives.
OB2 - Uncover Opportunities	Explore the key opportunities and enabling conditions that can facilitate or accelerate firms' decarbonisation efforts within their supply chains.
OB3 - Assess Benefits	Synthesise the reported operational, environmental and financial benefits that firms achieve after implementing supply-chain decarbonisation measures.

Source: The author (2025)

2.1.2 Scope Definition

The phenomenon examined in this review is firm-level supply chain decarbonisation, defined as carbon-reduction interventions that target emissions within a company's value chain (Scope 1, 2, or 3). Studies focused solely on macro-level policy scenarios, aggregate national or regional greenhouse gas inventories, or purely technical models that do not analyse firm-level decision-making are excluded. Pre-specifying such inclusion boundaries is a cornerstone of evidence-informed management reviews, ensuring focus without sacrificing coverage (Tranfield et al., 2003). A publication window from 2015 to 2025 captures scholarship produced after the Paris Agreement yet before the thesis cut-off, balancing historical depth with current relevance. This window also covers the phase when

supply chain disclosure and target-setting accelerated, including the EU Fit for 55 legislative package, the update of ISO 14064-1:2018, and SBTi Supplier Engagement Guidance (European Commission, 2021; ISO, 2018; SBTi, 2023). Evidence is drawn from peer-reviewed journals, conference papers, and high-quality grey literature. High-quality grey literature is included only when issued by reputable public or international bodies (for example, the UN, IEA, OECD, national regulators, or standards bodies), when methods and data sources are described clearly enough to permit verification, and when the document reports primary data or rigorous analysis; opinion pieces and marketing material are excluded. No geographic or sectoral restrictions are imposed at the outset; contextual contrasts are explored later in the synthesis.

Table 2-2 Scope Boundaries

Dimension	Scope boundary
Phenomenon	Supply-chain decarbonisation by firms, covering Scope 1–3 and related managerial or technological approaches
Period	2015 to 2025
Sources	Peer-reviewed journal articles, conference papers, high-quality grey literature
Sector / geography	No a-priori restrictions

Source: The author (2025)

2.1.3 Eligibility Gate

Screening is carried out in two passes. During the title-and-abstract review, coarse filters for language, publication date and topical fit remove obviously irrelevant records; during the full-text review, more detailed criteria test methodological adequacy and conceptual relevance. Each rule and its rationale are listed in Table 2-3. The eligibility gate is operationalised through the keyword pools in

Table 2-4 and the consolidated Boolean string in Table 2-5. Within each of the five concept clusters (i) supply-chain terms, (ii) enterprise terms, (iii) decarbonisation and emission terms, (iv) managerial or technological approaches, and (v) barriers/benefits, synonyms are linked with OR, and the clusters themselves are linked with AND. Domain experts validate the string for both recall and precision, and every modification is logged.

Table 2-3 Inclusion and Exclusion Criteria

Crite- rion	Include	Exclude
Lan- guage	English	Other languages (English dominates SCM research and translation resources are limited)
Publica- tion date	2015 to 2025	Pre-2015 (to preserve currency and policy relevance)
Phe- nome- non fo- cus	Studies analysing firm-level supply-chain decarbonisation interventions that address Scope 1, 2 or 3 emissions and have managerial implications	Macro-level policy analyses, aggregate national or regional GHG inventories, and purely technical models that do not examine firm decision-making
Study type	Empirical (quantitative or qualitative), rigorous conceptual papers, or prior systematic literature reviews	Opinion pieces, un-refereed blogs, or similar low-rigour sources
Availa- bility	Full text retrievable	Abstract-only records (full checks and data extraction impossible)

Source: The author (2025)

Table 2-4 Keyword pools

Concept	Keywords
Supply-chain terms	“supply chain*”; “supply network*”; “value chain*”; upstream; downstream
Enterprise terms	firm*; compan*; corporat*; business*; organisation*; manufacturer*; brand
Decarbonisation & emission terms	decarbon*; “low carbon”; “carbon reduction”; “carbon footprint”; emission reduction; “carbon accounting”; “carbon neutral*”; “net zero”; “zero emission*”; “greenhouse gas*”; ghg; “scope 3”; “indirect emission*”
Managerial / technological approach terms	collaborat*; governanc*; “digital traceab*”; “supply chain mapping”; blockchain*; “big data”; “data analytics”; “carbon pricing”; “carbon disclosure”; “circular economy”; IoT; “internet of things”
Barrier / driver / benefit terms	barrier*; challenge*; obstacle*; driver*; enabler*; opportunit*; benefit*; performance; “cost saving*”; risk*; resilience

Source: The author (2025)

Table 2-5 Final search string (Scopus syntax)

Combination of Keywords
("supply chain*" OR "supply network*" OR "value chain*" OR upstream OR downstream) AND (firm* OR compan* OR corporat* OR business* OR organisation* OR manufacturer* OR brand) AND

(decarbon* OR "low carbon" OR "carbon reduction" OR "carbon footprint" OR "carbon accounting" OR "emission reduction" OR "carbon neutral*" OR "net zero" OR "zero emission*" OR "greenhouse gas*" OR GHG OR "scope 3" OR "indirect emission*")

AND

(collaborat* OR governanc* OR "digital traceab*" OR "supply chain mapping" OR blockchain* OR "big data" OR "data analytics" OR IoT OR "internet of things" OR "carbon pricing" OR "carbon disclosure" OR "circular economy")

AND

(barrier* OR challenge* OR obstacle* OR driver* OR enabler* OR opportunit* OR benefit* OR performance OR "cost saving*" OR risk* OR resilience)

Source: The author (2025)

2.1.4 Quality-Assurance Procedure (adapted from Habib et al., 2015)

After full-text screening, every study was appraised with the quality matrix shown in Table 2-6. Empirical exemplars that meet all five criteria typically report several outcome metrics, including speed, cost efficiency, flexibility and delivery reliability, as demonstrated in Tenhiälä and Helkiö's (2015) 151-plant ERP study. The matrix condenses Habib et al.'s (2015) teaching template into five headline criteria and allocates four possible ratings: 0 when the criterion is not addressed, 1 when it is only hinted at, 2 when it is adequately addressed and 3 when it is fully addressed; "N/A" may be recorded when a criterion is genuinely irrelevant to a particular study design.

The appraisal form was first pilot-tested on a small, methodologically diverse subset of papers to ensure that every rating anchor could be applied unambiguously. Thereafter each article was assessed independently by the author using the calibrated rubric; any residual uncertainties were resolved in consultation with the academic supervisor. All initial scores, subsequent edits and decision rationales

were captured in the workbook's change-log column, providing an auditable trail that meets PRISMA 2020 transparency requirements. With a maximum score of 15, studies scoring 12 – 15 are classified as high quality and enter the main synthesis, those scoring 9 – 11 are retained for sensitivity analysis, while studies scoring below 9 remain available for contextual commentary but are excluded from pooled findings. These cutoffs follow established practice in evidence-informed management reviews and are adapted from Habib et al. (2015), with minor calibration during pilot scoring to reflect the mix of study types in the corpus. The completed appraisal sheets and the resolution log are supplied in an appendix so that every judgement can be traced.

Table 2-6 Quality-Assessment Criteria

(5 Items, 4-Point Scale; Adapted from Habib et al., 2015)

Quality criterion	0	1	2	3	N/A
1 Contribution to theory					
2 Methodological rigour					
3 Critical implications for practice					
4 Overall coherence					
5 Level of citations					

Scoring rule: 0 = not addressed; 1 = partially addressed; 2 = adequately addressed; 3 = fully addressed; N/A = not applicable; Maximum attainable score = 15.

By fixing the research compass, the scope boundaries, the eligibility gate and the Habib-based quality-assurance procedure at the planning stage, and by recording each element under PRISMA 2020, this review establishes a transparent foundation for the search, selection and synthesis steps described in Section 2.2.

2.2 Search Strategy and Study Selection

2.2.1 Information sources

The search drew on two multidisciplinary databases, Scopus and EBSCO Business Source Complete, chosen for their extensive coverage of peer-reviewed literature in operations management, engineering and business. Web of Science was not included because pilot searches indicated substantial overlap with Scopus for the target domains, while Scopus and EBSCO Business Source Complete provide broader coverage of operations, sustainability, and supply chain outlets; using two databases kept the process tractable without materially reducing recall.

2.2.2 Search execution

A single Boolean string combined five concept clusters: (i) supply-chain terms, (ii) enterprise terms, (iii) decarbonisation and emission terms, (iv) managerial or technological approach terms, and (v) barrier/benefit terms. Synonyms within each cluster were linked with OR, and the clusters themselves were linked with AND; the full syntax is provided in Table 2-5. Searches were limited to English-language records published between 2015 and 2025, matching the post-Paris-Agreement focus described in the introduction. After applying language and date filters, Scopus returned 599 records and EBSCO returned 194, producing an initial pool of 793 studies.

2.2.3 Duplicate management

All records were exported to Microsoft Excel. Using the “Remove Duplicates” tool configured to match Title, Author, Publication Year and DOI, 117 exact duplicates were eliminated. A manual line-by-line inspection then captured near duplicates that the automated step had missed, leaving 676 unique references.

2.2.4 Screening workflow

Screening proceeded in two successive passes. In the title-and-abstract pass, records were retained only if they examined firm-level supply-chain decarbonisation interventions (Scope 1, 2 or 3) and reported barriers, opportunities or benefits, which reduced the dataset to 150 papers and set aside 526 off-topic items. In the

subsequent full-text pass, the 150 articles were assessed against all inclusion rules; 90 were excluded because the full text was unobtainable or the study failed the methodological or conceptual criteria, leaving 60 studies that met every criterion and progressed to data extraction and synthesis.

2.2.5 PRISMA flow diagram

See the PRISMA diagram below for a concise view of the pathway from the initial 793 records to the 60 studies retained.

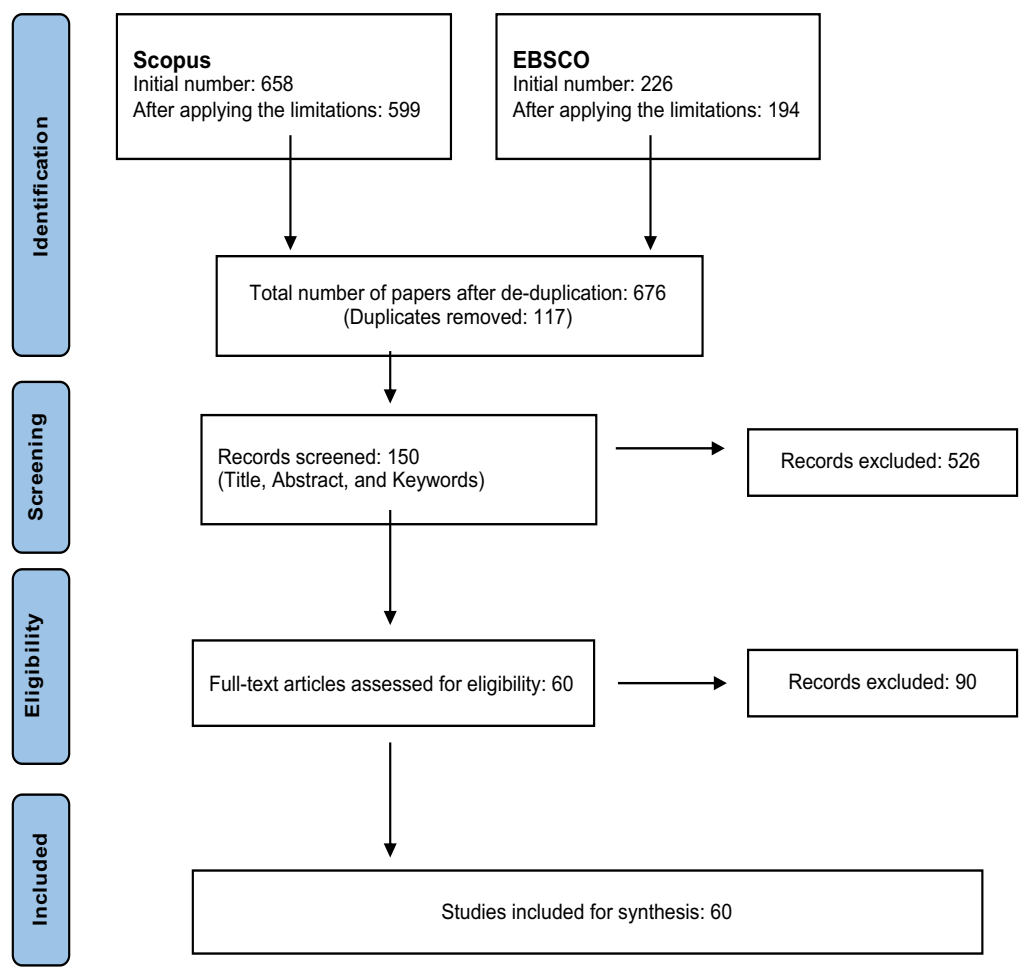


Figure 2-1 PRISMA Diagram of SLR Basic Steps

Source: The Author (2025)

2.3 Data Extraction and Synthesis

This chapter concentrates on the two pivotal tasks that follow the confirmation of the final set of studies within a systematic literature review: data extraction and data synthesis. Data extraction identifies and records every detail relevant to the review question, whereas data synthesis integrates those details so that underlying patterns can be recognised and explained. All information was captured in a single structured template (Table 2-7 Data-Extraction Template). The template is expressly organised to serve the twin objectives of this thesis, describing the published record and explaining firm-level supply-chain decarbonisation themes. It records two complementary strands of evidence. The descriptive items (article title, author list, outlet, year, academic domain, industry context, geographic focus, firm type, research type, methodology and the emission scope addressed) outline the basic profile of each study. The analytical items (barriers, enablers or opportunities, benefits, key findings and stated limitations) capture the material required for interpretation, and a single quality score, QScore on a 0–15 scale, summarises methodological rigour. To ensure consistency, the form was pilot-tested on a small set of methodologically diverse papers, and headings that proved ambiguous were refined immediately. The researcher then worked through the remaining studies in turn, completed the agreed variables, and revisited each record after a brief interval to check for internal inconsistencies. Questions that could not be resolved during this self-audit were discussed with the academic supervisor, and every ruling was documented on the extraction sheet so that future readers can trace each decision. The information gathered in this manner now fulfils two functions. The descriptive strand (years of publication, research methods, regional distribution and similar features) provides the basis for the summary statistics presented in Chapter 3. The analytical strand is carried forward to Chapter 4, where a thematic synthesis will reveal the recurring obstacles, enabling mechanisms and value propositions that characterise firm-level supply-chain decarbonisation. In this way, a straightforward yet systematic protocol links the raw literature to the descriptive results of Chapter 3 and the explanatory framework of Chapter 4.

Table 2-7 Data Extraction Template

Descriptive Fields	Description
D1 Article Title	Original title of the paper
D2 Authors	List all authors in citation order
D3 Source Reference	Journal or conference name, volume–issue–pages, DOI
D4 Year of Publication	YYYY
D5 Academic Domain	e.g., Supply Chain, Operations, Sustainability
D6 Industry Context	e.g., Manufacturing, Agriculture, Energy
D7 Geographic Context	Country or region studied
D8 Firm Type	Large enterprise, SME, brand owner, manufacturer, etc.
D9 Research Type	Empirical, Conceptual, SLR, Case Study
D10 Methodology	Data source, sample size, analytical approach
D11 Emission Scope	Scope 1, Scope 2, Scope 3, or “Multiple”
Analytical Fields	Description
A1 Barriers / Challenges	Technological, organisational, external-environment aspects
A2 Enablers / Opportunities	Collaborative mechanisms, policy instruments, digital technologies, market drivers

A3 Benefits	Environmental, operational, financial outcomes (e.g., CO ₂ -e % reduction, cost savings)
A4 Key Findings	Findings directly related to the research objectives
A5 Limitations	Author-reported or reviewer-assessed study constraints
Quality & Notes	Description
QScore (0–15)	Sum of Table 2-6 quality-assessment criteria
Notes / Follow-up	Items requiring clarification or further action

Source: The Author (2025)

Theme development. Thematic synthesis followed three steps. First, open coding of extracted statements in a Microsoft Excel workbook. Second, axial grouping that mapped codes to OB1 to OB3 and merged near synonyms. Third, clustering into higher-order themes with brief working definitions. Codes and themes were refined after a short calibration trial, then checked in a second-pass self-audit for consistency. Single-coder risk was mitigated by the calibration trial, a maintained change log, and discussion of edge cases with the academic supervisor.

2.4 Ensuring Rigour and Transparency

2.4.1 Reproducibility

To enable independent verification, the full search strings, raw search-engine export files, and article-level appraisal forms will be deposited in the appendices. This material allows any third party to replicate the identification, screening, and quality-assessment steps exactly as executed in the present review.

2.4.2 Audit Trail

A chronological log has been kept throughout the project, capturing every decision to include, exclude, re-code, or otherwise modify the dataset. Each entry records the timestamp, the rationale, and, where relevant, the supporting literature. Any deviation from the registered protocol is explicitly justified in the log, thereby providing a transparent trail for external auditors.

2.4.3 Ethical considerations

Because the study analyses only publicly available literature, it involves no human participants and therefore does not require institutional ethics approval. The author affirms that no personal or sensitive data were processed and declares that there are no financial or professional conflicts of interest that could bias the review.

2.5 Chapter Summary

This chapter has detailed a systematic, staged protocol covering search-strategy design, two-pass screening, calibrated quality appraisal and data extraction. By making every procedural step traceable and by documenting the rationale for any adaptation, the review safeguards both rigour and transparency. Chapter 3 applies these procedures to map descriptive patterns in the literature, profiling years, geographies, industries, firm types, and methods. It also signals what this landscape implies for OB1 barriers, OB2 opportunities, and OB3 benefits, preparing the ground for the thematic analysis in Chapter 4.

3 Descriptive Analysis

Building on the systematic review protocol outlined in Chapter 2, this chapter maps the evidence base by year, geography, industry, firm type, and method. It contributes directly to OB1 barriers, OB2 opportunities, and OB3 benefits, and provides the descriptive baseline that bridges the evidence-assembly work of Chapter 2 with the thematic analysis in Chapter 4.

Descriptive mapping establishes transparency in the evidence base and reduces the risk of premature theorising, clarifying what is studied before interpreting why and how.

Using the dual-strand extraction template (Table 2-7), the final corpus of 60 studies was coded for publication metadata, methodological profile, contextual variables, and a quality score calculated on a 0 to 15 scale.

Summarising and visualising these attributes not only underpins OB1 to OB3 but also highlights where the existing literature is concentrated and where potential gaps may lie. By articulating these patterns, the chapter situates the review within the broader decarbonisation research agenda and explains why a more detailed thematic exploration is needed next.

The remainder of the chapter is structured as follows: Section 3.1 analyses the chronological distribution of publications; Section 3.2 maps their geographical distribution; Section 3.3 profiles industry sectors together with firm-type characteristics; Section 3.4 outlines the methodological distribution; and Section 3.5 distils the key descriptive insights and signals the transition to Chapter 4.

3.1 Chronological Distribution

As illustrated in Figure 3-1, scholarly interest in supply-chain decarbonisation has risen sharply since 2022. Only one paper appeared in 2016, but annual output rose from 7 papers in 2022 to 10 in 2023 and 17 in 2024, an increase of 143 percent relative to 2022; it reached 18 in the first half of 2025. In total, 73 percent of the corpus was published after 2022. The near absence of studies before 2015 is consistent with an evidence base forming after the Paris Agreement and the subsequent expansion of disclosure rules and standards, rather than a simple reporting lag. The timing of this surge coincides with several policy milestones, including the EU “Fit-for-55” legislative package (European Commission, 2021), the update of ISO 14064-1:2018 for organisational GHG accounting (ISO, 2018), and the release of SBTi’s Supplier Engagement Guidance that emphasises

Scope-3 target-setting along the chain (SBTi, 2023), suggesting that regulatory and standard-setting activity may have catalysed academic attention.

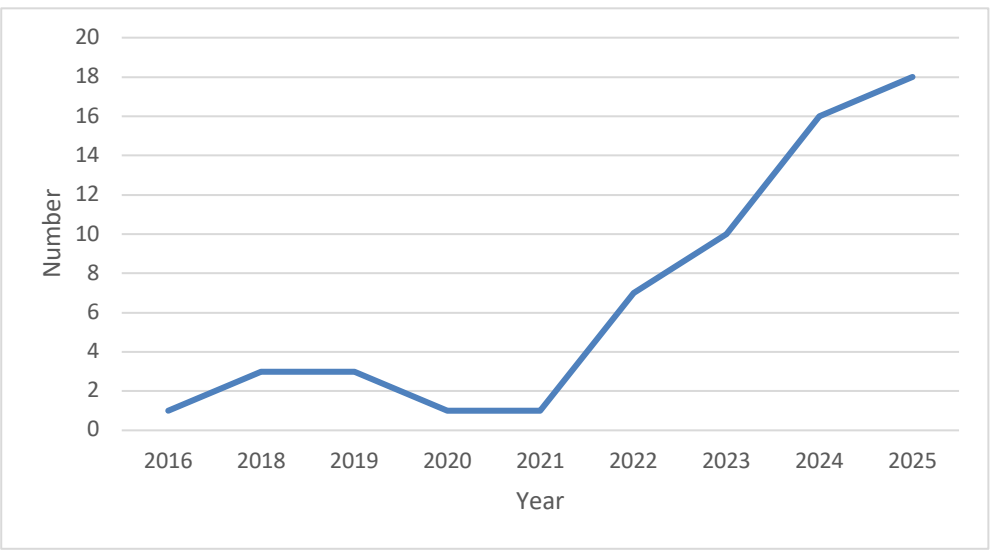


Figure 3-1 Year-wise Distribution of Selected Articles

3.2 Geographical Distribution

Analysing where supply chain decarbonisation studies originate is vital because regional contexts shape both the feasibility of mitigation measures and the kinds of barriers, opportunities, and benefits that firms report. A geographically diverse evidence base, therefore, keeps the review from being anchored to a single regulatory or cultural viewpoint and, in turn, enhances the external validity of any conclusions drawn. As summarised in Figure 3-2, the corpus spans every inhabited continent. Papers from the Asia-Pacific region total 18 (30%), followed by global or multi-country samples, 15 (25%); Europe, 12 (20%); North America, 9 (15%); South America, 4 (7%); and Africa, 2 (3%). At the country level, China contributes nine papers, the United States contributes seven, and the United Kingdom contributes four. This imbalance raises external validity concerns, as findings drawn mainly from regulation-rich and capital-intensive contexts may not transfer to lower-income settings; results for SMEs and smallholders in Africa and parts of South America should therefore be interpreted with caution.

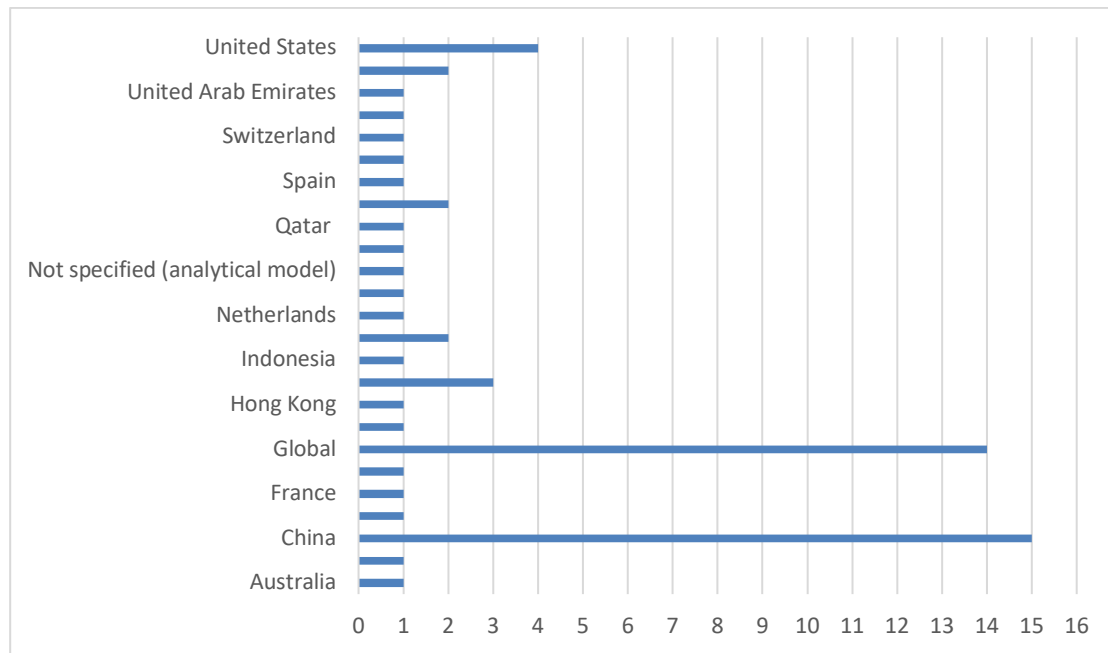


Figure 3-2 Statistics of Source Countries

3.3 Industry & Firm-Type Profile

3.3.1 Industry

Understanding which industries and firm types appear most often in the literature helps explain why certain barriers, opportunities and benefits receive greater emphasis. Figure 3-3 shows that manufacturing value chains dominate the corpus with 25 papers (42%). Cross-sector or multi-industry studies rank second (9, 15%), followed by agriculture and food (8, 13%), services and commerce (6, 10%), construction and the built environment (5, 8%), energy and resource extraction (4, 7%) and transport and logistics (3, 5%). This suggests that the barriers documented are mostly technology-centric, whereas organisational and cultural barriers in services remain underexamined. This pattern highlights OB2 opportunities in under-represented service settings and cautions against broad OB1 generalisation across sectors.

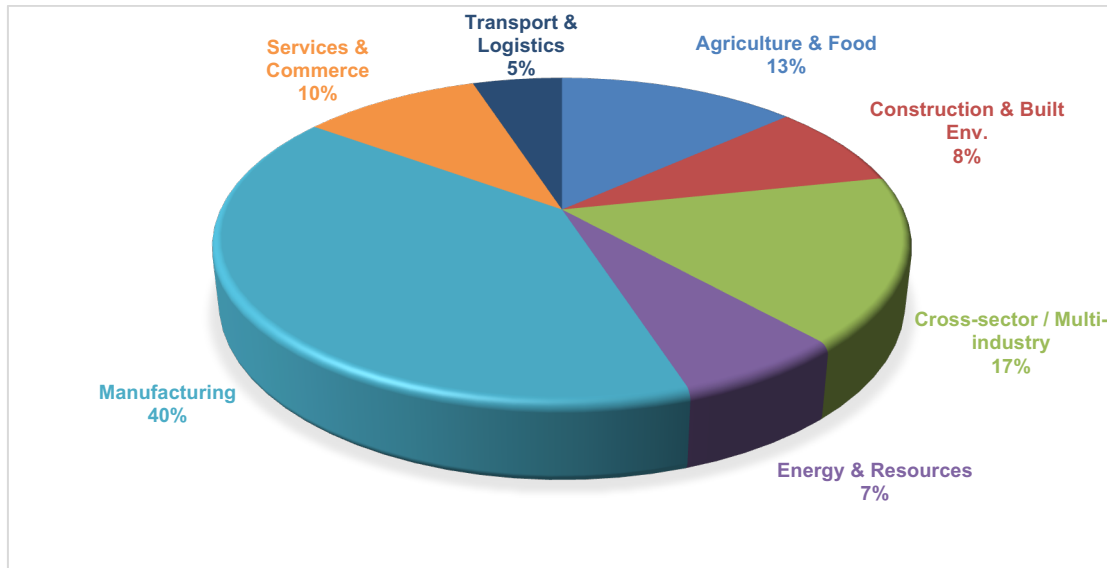


Figure 3-3 Industry coverage across included studies

3.3.2 Firm

Figure 3-4 profiles the types of firms examined. Medium-to-large enterprises and multi-stakeholder ecosystems each account for 16 papers (27% apiece). Supply-chain dyads or triads contribute 10 papers (17%), while large listed corporations appear in 7 papers (12%). Large private or state-owned enterprises make up 4 papers (7%), the same number as SMEs and smallholders (4, 7%). Public-sector or non-profit settings are covered in 3 papers (5%). The limited SME coverage constrains what can be inferred about enablement beyond large or multi-stakeholder settings. This gap points to OB2 opportunities to test low-cost data routines, shared platforms, and simple contract tools for SME-heavy tiers, and it cautions against broad OB1 generalisation from large-firm contexts.

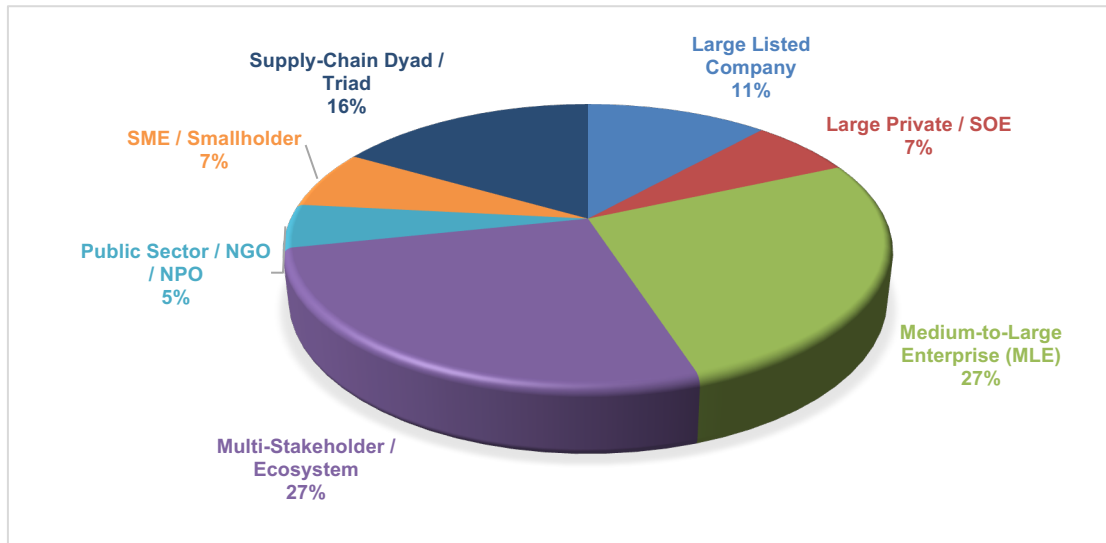


Figure 3-4 Focal firm types across included studies

3.4 Research Types

Figure 3-5 employs a donut chart to lay out the research approaches used in the sixty studies under review. At first glance, empirical quantitative work occupies almost half of the ring, twenty-six papers, or 44 %. These studies lean on large-sample surveys or secondary databases and apply statistical or econometric tools to see how factors such as collaboration intensity, technological capability, or governance structure affect carbon performance

In practice, quantitative hypothesis-testing approaches continue to dominate the literature. Reading the chart clockwise, simulation and modelling claims the next largest share, 25 % (fifteen papers). Authors in this camp construct optimisation, game-theoretic, system-dynamics, or agent-based models, then run “what-if” scenarios to explore how prices, policies, or demand shocks might spread through a supply chain’s carbon footprint. These exercises offer tidy counterfactuals that raw field data seldom permit, but they also rest on assumptions that can look fragile when real-world complexities intrude. The remaining slices are thinner and more evenly spread. Mixed-method contributions amount to six papers (10%) and typically pair a survey with follow-up interviews or match life-cycle assessment to a case vignette. Case-based and other qualitative inquiries add

five papers (8%); their close-up narratives reveal how power, culture, and everyday routines shape decarbonisation, insights that spreadsheets alone cannot provide. Systematic literature reviews supply four papers (7%), charting what is already known and pointing out blind spots. Finally, conceptual essays and small-sample qualitative pieces appear twice each (3% apiece), a reminder that there is still room for fresh theorising and exploratory fieldwork. Taken together, the pattern is familiar: scholars tend to favour survey data and mathematically tidy models, while research that traces long-term organisational change or builds new conceptual lenses remains comparatively scarce. This reliance on surveys and modelling risks over-quantification and may under-represent behavioural and process mechanisms that case-based or longitudinal designs tend to reveal, which in turn can make OB3 benefits harder to observe. Chapter 4 will bring every strand of evidence into play, combining quantitative results, model insights, and qualitative detail to assemble a balanced account of barriers, opportunities, and benefits.

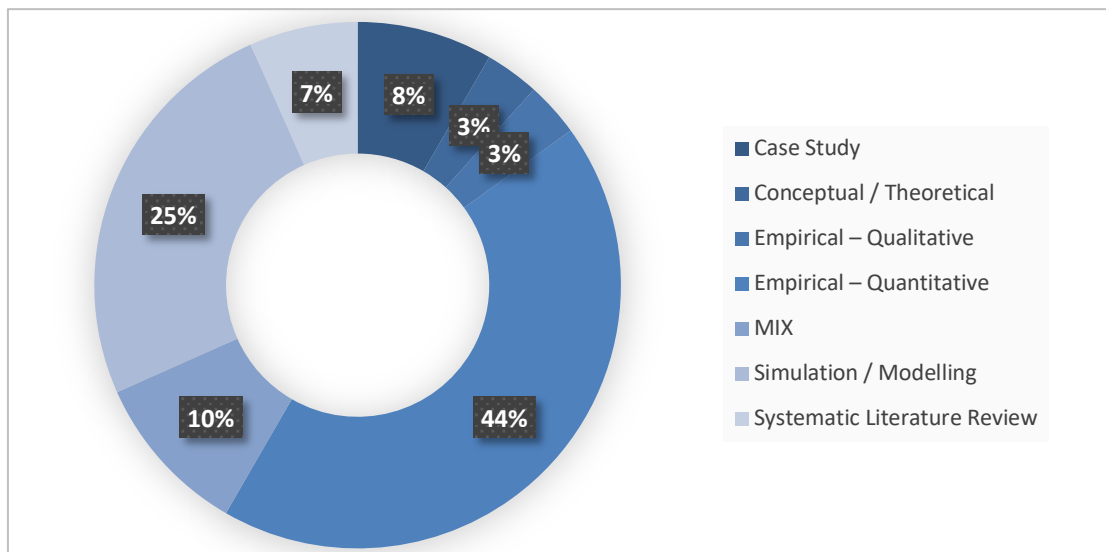


Figure 3-5 Research approaches across included studies

3.5 Summary & Transition

Chapter 3 set out to map the basic contours of the evidence base. Three patterns stand out. First, research activity has surged since 2022 but remains unevenly

distributed, with Asia–Pacific and China especially prominent; this imbalance hints at region-specific barriers that still need illumination (links to OB1). Second, the corpus leans toward manufacturing chains and large or multi-stakeholder firms, while SMEs and service-sector contexts receive limited attention; fresh opportunities may therefore lie in understudied industries and smaller enterprises (OB2). Third, survey data and modelling dominate, whereas longitudinal case work is scarce, making it harder to trace the full range of operational and financial benefits that firms claim (OB3). These observations underscore the importance of a structured synthesis that can integrate diverse but partial findings. These descriptive findings provide the empirical backdrop for Chapter 4’s thematic analysis, which organises the evidence by OB1 barriers, OB2 opportunities, and OB3 benefits, and develops cross-cutting themes that connect them.

4 Thematic Analysis

Building upon the analytical groundwork of the previous chapters, this section moves to the task of knitting the evidence into a coherent story. This chapter addresses the driving question: How can firms overcome barriers and leverage opportunities to achieve supply chain decarbonisation, and what benefits result from these efforts? To answer, the study uses three objectives (OB1 to identify barriers, OB2 to uncover opportunities, and OB3 to gauge benefits), together forming a barriers, opportunities and benefits lens that shapes this chapter.

A four-stage SLR protocol, described in Chapter 2, yielded a final pool of sixty studies, all passing eligibility and quality checks (see Table 2-6). Their bibliographic details and analytical fields were logged in an Excel data-extraction sheet (Table 2-7). Chapter 3 then profiled the corpus, noting a post-2022 surge in publications, diverse industrial settings and a broad mix of methods, which together furnish a textured evidence base.

This chapter threads the evidence into an integrated narrative. Sections 4.2–4.4 develop the dominant themes behind barriers, opportunities and benefits. Section 4.5 synthesises cross-cutting themes that link these strands. Section 4.6 offers a

data synthesis that interprets interrelations and implications. Sections 4.7–4.8 summarise key findings and close the chapter, preparing the bridge to Chapter 5.

4.1 Data Set and Methodology

4.1.1 Corpus Overview

The final corpus consists of sixty reviewed studies. Chapter 3 profiled their publication years (Figure 3-1), geographical distribution (Figure 3-2), industrial contexts (Figure 3-3 & Figure 3-4) and research methods (Figure 3-5). Roughly seventy-three percent were published after 2022. Industry-wise, manufacturing dominates with forty-two per cent of the papers, followed by cross-sector studies at fifteen per cent, agriculture and food at thirteen per cent, services and commerce at ten per cent, construction at eight percent, energy and resource extraction at seven per cent, and transport and logistics at five percent. This breadth supplies a solid platform for thematic interpretation.

4.1.2 Single-Coder, One-Pass Coding

An Excel workbook served as the data-extraction sheet, its columns drawn from Table 2-7 in Chapter 2 and covering bibliographic details, Barrier, Opportunity, Benefit and notes. After a short trial on six to eight papers ensured field clarity, all sixty studies were coded in a single pass. New concepts were added, merged or refined within the same workbook, keeping the codebook and data aligned throughout without additional pilot rounds or duplicate coding.

4.1.3 Transparency and Traceability

The search strings, databases and inclusion criteria are detailed in Table 2-3 to Table 2-5 of Chapter 2, and the complete screening pathway is visualised in the PRISMA diagram (Figure 2-1). During identification, the Excel “Remove Duplicates” tool, combined with DOI and title matching, eliminated 117 exact duplicates, leaving 676 unique records; subsequent screening reduced the set to 60 studies. For thematic coding, an update log sheet inside the workbook briefly noted each adjustment to fields or codes and recorded the rationale for inclusion

or exclusion decisions. Workbook versioning preserved all historical states, ensuring complete transparency and traceability of the process.

4.2 Barrier Themes

4.2.1 Policy & External-Governance Barriers

Eight of the sixty studies (13 %) highlight obstacles that originate outside the focal firm, chiefly volatile or suppressed carbon-price signals, fragmented or ambiguous rules, and weak market incentives.

First, evidence from New Zealand's emissions-trading scheme shows how a long-standing price cap and a "one-for-two" surrender provision collapsed allowance prices, leaving investors with little faith in carbon signals; equity markets consequently price only extreme swings in permit returns rather than the fundamental cost of carbon (Kennett et al., 2023).

Second, several modelling studies reveal how incentive design can blunt corporate momentum. In a dual-channel e-commerce supply-chain model, when the carbon-trading price (t) is set too low, the manufacturer's optimal abatement-investment level (θ) drops, weakening both the platform's and the manufacturer's incentives to decarbonise and ultimately slowing green investment (Yang, 2023). In a related analysis of allocation rules, permits distributed on the basis of historical emissions rather than performance benchmarks give firms little pressure to reduce emissions, and the high fixed cost of blockchain-based monitoring then appears unjustifiable, suppressing adoption of transparency tools (Wang et al., 2023).

In summary, weak or inconsistent external frameworks erode the predictability that long-term decarbonisation investments require. Section 4.3 will examine policy mixes, collaborative architectures and digital mechanisms that these studies propose as remedies. Across jurisdictions, compromise design features such as price caps, exemptions, free allocations, and rebates produce uneven, intermittent signals that firms struggle to plan against.

4.2.2 Data & Information Barriers

Nineteen of the sixty studies (32 %) flag data and information shortfalls as a central brake on supply-chain decarbonisation. The most pressing gap remains unreliable Scope 3 data, followed by patchy digital and traceability systems. A recent systematic review by Hettler and Graf-Vlachy (2024) shows that most Scope 3 activity data sits with suppliers beyond the first tier, because many smaller suppliers find primary data collection too costly, lead firms fall back on industry averages, which widens inventory uncertainty.

Data gaps are especially acute in food service. Jungbluth et al. (2016) document that Swiss workplace canteens seldom receive consistent information on product origin, transport mode or greenhouse heating, so emission factors can vary by up to 100 % between outlets.

In heavy industry, Jiang et al. (2024) find that IoT sensors and real-time dashboards expose carbon hotspots only after a prior supply-chain-mapping exercise has bridged information gaps; otherwise the hotspots stay hidden.

In sum, fragmented reporting rules and immature digital infrastructure slow collective abatement and increase compliance costs. Section 4.3 will discuss the standardised protocols, supplier collaborations and digital tools the same corpus proposes as remedies. Taken together, these data and information gaps keep OB1 at the forefront: without decision-grade activity data beyond the first tier, verification and reconciliation costs dominate and coordinated abatement stalls.

4.2.3 Organisational and Operational Barriers

Thirty-three of the sixty studies, about fifty-five percent of the sample, trace slow progress in decarbonisation to factors inside the firm or within its closest business circle. Four problems surface most often: large capital outlays, collaboration that becomes cumbersome, gaps in mind-set and know-how, and vulnerability that grows with multi-tier supply-chain complexity.

High cost is the first brake. A field study of heavy-industry pioneers observes that the full bill for producing, converting, storing and moving green hydrogen still

towers above fossil alternatives, so managers defer projects despite growing policy interest (Baglieri, 2024).

Collaboration can also backfire. Analysing 330 multi-tier buyer–supplier networks, Sharma et al. (2022) find a U-shaped link between network density and greenhouse-gas performance; once the web becomes densely connected, additional monitoring and negotiation consume more resources than they save and partners drift back to arm’s-length dealings.

People and knowledge form the third barrier. A global survey of 270 construction professionals reports that 75 % cite the absence of visible leadership, 63 % flag scepticism toward recycled materials, and 64 % emphasise insufficient understanding of circular-economy deconstruction processes as “Very Important” or “Absolutely Essential” obstacles, while purely technical limits rank lower (Rajčić et al., 2025).

Structural fragility magnifies physical risk. Evidence from Australian agrifood SMEs shows that floods, droughts and bushfires can cripple performance, yet membership in social-capital-rich consortia cushions the damage through shared information, pooled resources and joint lobbying (Ali & Gölgeci, 2021).

Taken together, cultural and behavioural inertia, misaligned roles and incentives, siloed budgets, and diffuse process ownership often outweigh technical limits; these organisational frictions constitute OB1 barriers even where technology is available. Section 4.3 examines levers at this organisational layer, including alliances and coordination structures, digital traceability and analytics, and cost and risk allocation mechanisms embedded in contracts and policy, and shows how these designs support adoption.

4.3 Opportunity Themes

This section frames OB2 opportunities as levers that directly counter the barriers in Section 4.2. We group them into three layers: (1) governance and collaboration designs, such as alliances, visible leadership, and right-sized

coordination, which make external signals durable and assign ownership across functions and tiers; (2) digital traceability and analytics that convert dispersed, sensitive information into decision-grade data aligned with planning and control; and (3) contractual, policy, and financing mechanisms that allocate costs and risks fairly and help adoption move beyond pilots. Together, these levers prepare the ground for the benefit pathways discussed in Section 4.4.

4.3.1 Cross-level Collaborative Governance

Cross-level collaboration blends grass-roots partnerships with clear, top-down coordination, and the mix helps supply networks trim carbon faster than either approach on its own. Evidence from the Dutch Chemelot chemical cluster shows that greater autonomy for the cluster authority, together with public support and patient capital, lets the site escape the familiar traps of incremental action, short-term thinking, and siloed decision making, and it achieves deep emission cuts as a result (Janipour et al., 2022). At the firm-to-firm level, B. Yu et al. (2020) model a manufacturer–retailer game and report that revenue sharing contracts beat cost sharing alternatives by lifting both joint profit and abatements, especially when carbon taxes rise and consumers care more about the planet. Read together, these studies suggest that networks organised by the firms themselves, formal coordinating bodies, and incentives that share benefits fairly reinforce one another, laying solid ground for the digital tools and financial levers discussed in the sections that follow.

4.3.2 Digital-Tool Opportunities

Building on earlier governance levers, digital innovation strengthens the data bedrock of supply-chain decarbonisation along three complementary paths. First, a blockchain prototype within the WWF Low Carbon Manufacturing Programme records every cotton-to-garment transaction on a permissioned ledger and links each entry to a tokenised carbon-credit scheme, giving all actors simultaneous visibility of provenance and emissions (Lam & Lei, 2019). Second, a survey of 437 manufacturers in electronics, food and construction shows that the combination of Internet-of-Things sensors and predictive analytics improves both carbon and financial outcomes once it is woven into day-to-day operations, with supply-

chain transparency acting as the bridge between insight and action (Belhadi et al., 2024). Third, within a European cruise-shipbuilding network, the Corporate Sustainability Reporting Directive extends mandatory disclosure to Scope 3 emissions, pushing the lead company to collaborate more closely with suppliers, rely on a higher share of primary data and design a common system that automates information flows (Jokinen et al., 2025). Immutable tracing, analytics-driven transparency and rule-based data collaboration therefore converge to accelerate coordinated mitigation across tiered networks. This reading aligns with the digital supply chain literature, which positions traceability as both a technical artefact and a governance mechanism; it enables assurance, selective transparency, and performance terms that can be written into contracts.

4.3.3 Financial and Policy Enablers

Robust price signals and patient capital are indispensable for turning low-carbon blueprints into bricks-and-mortar investments.

A stylised game-theoretic study of two rival supply chains shows that a moderate carbon tax, when paired with two-part-tariff coordination contracts, gives both firms room to earn higher joint profit while cutting emissions more steeply than either cost-sharing or laissez-faire settings (W. Yu et al., 2022). The finding underlines an important point: internal incentive schemes work best when they are synced with an external price on carbon.

The same coupling of policy and contractual design resurfaces at sector scale. A survey of 149 experts predicts that international shipping can meet the International Maritime Organization's 2030 intensity target through short-term operational tweaks, yet will miss net-zero in 2050 unless politics, global governance and charter-party rules converge to derisk alternative-fuel infrastructure (Laskar et al., 2025). Experts highlight a harmonised greenhouse-gas levy as the prime unlock, with adjustments to charter-party terms viewed as a complementary, though still important, step most likely to unlock long-horizon fuel switching.

Evidence from energy-intensive manufacturing makes the investment hurdle even clearer. Interviews across steel, chemicals, cement and glass confirm that

investor ESG pressure, the European Emissions Trading System and new instruments such as carbon contracts-for-difference jointly reshape every element of the business model, from value proposition to partner network (Mais & Bauernhansl, 2024). Public funding streams lower early-stage risk, yet firms still cite cumbersome application rules and the need for supply-chain-wide cost sharing.

Finally, an empirical study on green-hydrogen supply networks illustrates how blended finance closes the gap between pilot scale and commercial roll-out. National subsidies, the EU Hydrogen Strategy and place-based industrial alliances reduce capital costs and coordinate demand aggregation, while digital twins guide asset deployment along the corridor (Bag, Gupta, et al., 2025). Together, these papers show that well-designed carbon pricing, targeted subsidies and contract architectures can convert techno-economic potential into bankable projects.

4.4 Benefits Themes

This section operationalises OB3 by mapping how decarbonisation translates into measurable environmental, operational, and financial benefits. It synthesises evidence on the size and drivers of these effects and shows where outcomes are contingent on decision-grade data, contractable signals, and the fair allocation of costs and risks.

4.4.1 Environmental Benefits

Environmental improvements appear through three recurring routes in supply networks: circular use of materials, cleaner equipment and operational control, and process-level use of biogenic carbon. A prospective assessment of the United Kingdom wood system reports that recycling medium-density fibreboard (MDF) into circular use yields about seventy-five percent more cumulative mitigation by 2050 than business as usual; when combined with cascading wood use and afforestation, the cumulative effect is estimated at approximately 258.8 million tonnes of carbon dioxide equivalent by mid-century (Forster et al., 2023).

Livestock feed substitution offers a second illustration. In a Greek pig operation that replaced twenty percent of conventional feed with bakery-meal by-products, the life cycle assessment records sizeable gains: land occupation falls by roughly thirty percent, marine eutrophication and freshwater ecotoxicity improve by around twenty percent, human carcinogenic toxicity drops by about twenty-five percent, and water use declines by roughly fifteen percent. Further optimisation of collection logistics can add an improvement of about five percent, and a centralised hub is recommended to stabilise supply and reduce transport burdens (Melas et al., 2023).

On the operations side, evidence from the United Kingdom construction context maps a practical bundle of measures that includes switching to biofuels, introducing electric and hydrogen machinery, setting equipment standards and targets, and using telematics and machine control to track idling and fuel burn. Construction equipment in the country is responsible for nearly ten million tonnes of carbon dioxide equivalent each year, or about two percent of national emissions, which makes systematic uptake of these measures relevant at sector scale and beneficial for local air quality (Saif et al., 2025).

Process-level utilisation of biogenic carbon adds a third strand. A winery in Spain that captures carbon dioxide from alcoholic fermentation and reacts it to produce sodium carbonate reports a corporate carbon-footprint reduction of 16.79 percent across Scopes 1, 2 and 3, while shifting impacts downstream by supplying a lower-impact chemical input (Gueddari-Aourir et al., 2022).

Viewed together, these cases point to complementary environmental gains that extend beyond greenhouse gases to land occupation, aquatic indicators, toxicity measures and local pollutants, and they make a practical case for coordinated adoption across multi-tier supply networks.

4.4.2 Operational Benefits

Digital reporting and traceability improve day-to-day coordination by making emissions information usable at the speed of operations. Building on that need, a design science study describes and prototypes a permissioned consortium

blockchain that uses non-fungible tokens and smart contracts to standardise emissions handoffs with cradle-to-grave provenance, automate verification, and provide near real-time records that reduce reconciliation across tiers while supporting assurance. The paper also discusses confidentiality safeguards, including the use of zero-knowledge proofs in the related literature, and explains an emissions handoff logic that prevents double-counting and connects energy providers via sidechains to support operational monitoring and audit readiness (Jenkins et al., 2025).

Beyond the data plumbing, digital innovation capabilities translate into more resilient and reliable supply operations. Using survey data from 279 firms in high carbon sectors, Bag and colleagues conceptualise digital innovation for the circular economy as a higher-order construct that combines capability, focus, collaboration, and governance, and they find significant performance gains. The effects are stronger for circular supply chain sustainability than for resilience, and among the dimensions, collaboration and governance weigh most in practice (Bag, Routray, et al., 2025).

Network-level routines also yield operational payoffs. In a structural equation model of South African manufacturers, organisational culture strengthens supplier relationship management, which then drives green supplier development. Both innovation and flexibility raise sustainable supply network performance, while coercive pressures modestly amplify the link from innovation to network outcomes (Bag et al., 2018).

Taken together, standardised Scope 3 routines, verifiable chain of custody, and digitally governed collaboration compress information delays, reduce reconciliation and audit effort, and build the repeatable workflows that make low-carbon operations predictable at scale. By embedding decision-grade data and contractable carbon signals in planning and control, firms turn compliance risk into process value. Section 4.5 elaborates this risk-to-value pathway and its boundary conditions.

4.4.3 Financial Benefits

Financial gains materialise through lower operating cost, coordinated profit outcomes under market-based regulation and reduced exposure to penalties and disruption. A carbon accounting case framework shows that moving to repeatable measurement and reporting practices can unlock cost-saving opportunities and support capital decisions, for example, when life cycle comparisons justify fleet electrification and when supplier footprints in procurement reduce transition risk as targets tighten (Onat et al., 2025).

Under emissions trading, contract design influences whether abatement remains profitable for network partners. In an industrial symbiosis model with a waste supplier and a downstream user, cap and trade induce reductions once allowances bind, but profit can be eroded when waste supply exceeds demand; a quantity discount contract restores coordination so that both firms improve profits while total reductions increase under stringent rules and downstream abatement rises under moderate rules (Cao et al., 2025).

Risk has direct financial consequences. A cross-country study across six manufacturing industries finds that sustainability efforts are associated with lower supply chain risk, which implies fewer disruption costs and less need for costly expediting and buffer inventories; the effect is strongest in emerging economies and remains significant in OECD settings, with complementarity with reactive tactics most evident in India (Gouda & Saranga, 2018).

Compliance exposure also carries cash impacts. Using a machine learning approach for Fortune 500 firms in carbon intensive sectors, evidence shows that Scope 3 accounts for the dominant share of corporate emissions, and models predicting environmental penalties highlight total emissions, engagement with public agencies, and environmental scores as key features; engagement with public agencies is associated with measurable differences in penalty outcomes, highlighting the value of verifiable data flows for avoiding fines and remediation costs (Seera et al., 2025).

Taken together, disciplined carbon accounts, incentive-compatible contracts, embedded sustainability capabilities and credible disclosure lower operating and compliance costs while preserving or improving profitability, providing the financial foundation for scaling low-carbon supply networks. Financial outcomes remain contingent on regulatory stability, highlighting the importance of OB2 enablers in unlocking OB3 benefits.

4.5 Cross-Cutting Themes

This section weaves together the narratives of barriers, opportunities, and benefits to show how they interact across multi-tier supply networks. To preserve transparency and consistency, we retain the single-coder, one-pass procedure and workbook versioning introduced in Section 4.1, and we ground the argument in the analyses reported in Sections 4.2 to 4.4.

The first recurring theme is that data usability functions as infrastructure for coordination (reduces OB1 information barriers; enables OB2 decision-grade data routines; supports OB3 environmental and operational outcomes). Evidence across §§4.2–4.4 shows that critical activity and emissions information often reside with suppliers beyond the first tier. In such settings, lead firms revert to averages, which widens uncertainty and weakens incentives to coordinate. When data are embedded in everyday work and exchanged in a standard cadence and format, cross-tier reconciliation and assurance burdens recede, information delays shrink, and operations become more predictable. In this reading, data routines are not a reporting add-on but a designed part of the process that turns traceability rules into a shared language for collaboration.

A second theme concerns the complementarity between external policy signals and internal contractual design (enables OB2 governance alignment; supports OB3 financial and operational outcomes; depends on OB1 regulatory stability). Weak or volatile prices undermine long-horizon investments, especially when low-carbon choices must be coordinated across multiple layers of a network. By

contrast, when a credible price signal or equivalent regulation is coupled with incentive-compatible contracts such as revenue sharing or two-part tariffs, private returns become more predictable, partners remain aligned, and digital or process levers are normalised rather than relegated to ad hoc projects. Evidence at both firm and sector level in §§4.2–4.4 repeats this coupling, indicating that policy and contracts jointly determine whether opportunities persist long enough to materialise as benefits.

A third theme is that collaboration density should be designed rather than maximised (reduces OB1 coordination costs; conditions OB3 outcomes by matching interdependence and cadence). In multi-tier settings, excessively dense networks can backfire as monitoring, negotiation, and coordination costs mount, diluting environmental and economic performance. Transparent allocation of decision rights and information boundaries keeps linkages tight where necessary and loose where possible, which contains governance spillovers and lays the ground for the diffusion of digital tools and financial enablers (see §4.3; §4.4).

Finally, the themes converge in a risk-to-value translation (links OB2 enablers to OB3 operational and financial outcomes by embedding decision-grade signals in planning and control). Where routinised data and workable governance coexist, day-to-day operations run faster and more predictably, compliance exposure falls thanks to verifiable data flows, and vulnerability to disruptions is cushioned by routines that build social capital. Under regulatory and market uncertainty, such a bundle also sustains investment momentum. These mutually reinforcing effects are where the operational and financial strands of §4.4 meet, showing how decarbonisation can yield resilience and returns in addition to environmental outcomes.

Taken together, data usability, the coupling of policy and contracts, a designed approach to collaboration density, and the translation from risk to value form a continuous line of reasoning: they mend information breaks beyond the first tier, convert external signals into internal incentives through governance and contracts, keep coordination costs within affordable bounds, and, in doing so, align

environmental, operational, and financial performance. Section 4.6 will carry these themes forward into a synthesis that states the underlying mechanisms more explicitly and links them back to OB1–OB3.

4.6 Data Synthesis

This synthesis explains how the evidence assembled in Sections 4.2 to 4.5 fits together as a causal story for supply-chain decarbonisation. Without introducing new sources, it articulates the mechanisms that connect barriers, opportunities and benefits, and clarifies when those mechanisms are likely to hold.

Mechanisms. For clarity, OB1 denotes barriers, OB2 opportunities, and OB3 benefits; M1 to M4 denote the four mechanisms below. First, decision-grade data routines make coordination possible at scale. As shown across §§4.2–4.5, routinised measurement and standardised exchanges shrink uncertainty and reconciliation costs beyond the first tier, lowering OB1 barriers and enabling OB2 opportunities to be targeted where abatement is cheapest. Second, the coupling of policy and contracts converts external signals into internal incentives: when credible rules or prices are paired with incentive-compatible terms, for example, pass-through or sharing clauses, partners stay aligned long enough for opportunities to persist and mature into OB3 benefits (see §§4.2, 4.4–4.5). Third, designed rather than maximised collaboration density contains monitoring and negotiation overheads; clear decision rights and information boundaries keep links tight where necessary and loose where possible, which accelerates the diffusion of digital and financial enablers observed in §§4.3–4.4. Fourth, operational embedment translates risk into value, and once data and governance are workable, day-to-day planning runs faster and more predictably, compliance exposure falls, and resilience improves, which matches the operational and financial strands evidenced in §4.4 and closes the loop by freeing resources to sustain measurement and collaboration (§§4.4–4.5).

Sequence and feedback. The evidence suggests a pragmatic order: establish data routines (M1) and align incentives (M2), then right-size collaboration (M3) to support adoption, after which operational embedment (M4) delivers benefits.

Positive feedback arises when OB3 benefits, for example, lower disruption and assurance costs, finance the upkeep of M1–M3 (from §4.4 to §4.5). By contrast, weak signals and poor data create a pilot trap: projects remain ad hoc, coordination costs dominate, and benefits do not self-reinforce (§§4.2–4.4).

Contingencies and boundary conditions. Three conditions modulate effects observed in §§4.2–4.5: (C1) tier distance and supplier heterogeneity, where further tiers and SME-heavy bases require more enablement and simpler data requirements; (C2) asset specificity and capital cycles, where long-lived assets need stable signals and fair cost-sharing to avoid stranded risk; (C3) data sensitivity and assurance, where confidentiality constraints call for designs that protect proprietary information while keeping records verifiable. Where these conditions are unmet, M1–M4 weaken and benefits attenuate.

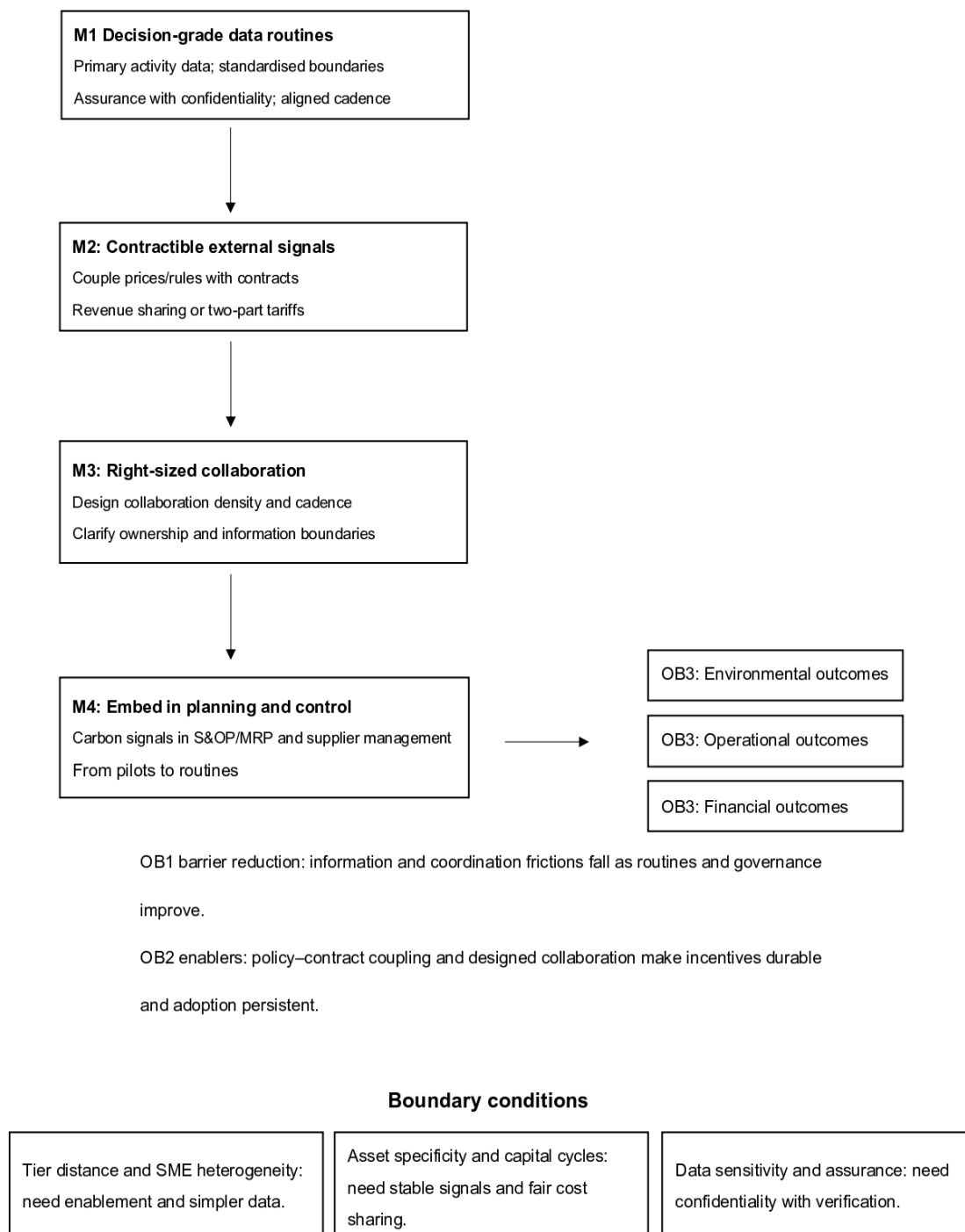


Figure 4-1 Summarises the mechanism-to-outcome framework

To formalise the synthesis while respecting the methodological boundaries of an SLR, the following are stated as propositions (not hypotheses). An SLR aggregates heterogeneous, mostly non-experimental evidence and therefore does not claim causal identification; the propositions make the underlying mechanisms explicit and set up “how” questions for future empirical and design-oriented research.

Synthesis propositions (for OB1–OB3).

P1 (OB1): Where decision-grade data routines are in place, information asymmetries and verification frictions decline across tiers, reducing barriers to coordinated action (§§4.2–4.5).

P2 (OB1 to OB2): Where external signals are credibly coupled with incentive-compatible contracts, partners invest in low-carbon options rather than reverting to averages (§§4.2, 4.5).

P3 (OB2): Where collaboration density is designed rather than maximised, adoption costs remain bounded and enablers diffuse along critical interfaces (§§4.3–4.4).

P4 (OB2 to OB3): When digital and process levers are embedded in planning and control, operational reliability improves and assurance costs fall, yielding observable benefits (§4.4).

P5 (OB3 to OB2/OB1): When benefits accumulate, they finance and legitimise the upkeep of data and governance routines, reinforcing the cycle (§§4.4–4.5).

Taken together, these mechanisms, sequences and contingencies provide the integrative explanation our review seeks: decarbonisation contributes to supply chains by converting data discipline and aligned incentives into adoptable practices that deliver operational, environmental and financial outcomes, with benefits feeding back to sustain the system. Section 4.7 summarises the findings and prepares the bridge to Chapter 5.

4.7 Summary of Findings

OB1 (Barriers): evidenced across §§4.2–4.6

- Limited visibility and assurance beyond the first-tier push firms back to averages.
- Incentives and governance are often misaligned.
- Coordination costs rise when collaboration density is not deliberately designed.

OB2 (Opportunities): enabling conditions (evidenced across §§4.2–4.6)

- Decision-grade data routines make information usable at the speed of operations.
- Coupling policy with contracts converts external signals into internal incentives.
- Capabilities are built as collaboration is right-sized rather than maximised.

Under these conditions, low-carbon options can be targeted where abatement is cheapest, and enablers diffuse along critical interfaces (see §§4.2–4.6).

OB3 (Benefits): §§4.3–4.6

- Environmental, operational, and financial performance gains materialise,
- especially where practices are embedded in day-to-day control.

Sequence and feedback loop: §§4.2–4.6

- Establish decision-grade data routines and align incentives.
- Right-size collaboration to support adoption.
- Embed practices operationally so that benefits accrue.

As benefits accumulate, they finance and legitimise the upkeep of data and governance routines; weak signals and poor data trap projects in ad hoc pilots.

4.8 Chapter Summary

Chapter 4 developed the thematic results and then integrated them into a coherent explanation of how supply-chain decarbonisation works in practice. Sections 4.2 to 4.4 mapped barriers, opportunities and benefits; Section 4.5 drew cross-cutting themes that connect these strands; and Section 4.6 synthesised the

mechanisms, sequences and contingencies that make outcomes more likely. The core message is that, in multi-tier settings, decision-grade data routines and the coupling of policy and contracts enable targeted adoption through designed collaboration, after which operational embedment converts risk into value. Where these conditions hold, environmental, operational and financial improvements reinforce one another. The mechanisms identified here advance understanding by moving beyond descriptive mapping to an explanatory model of supply-chain decarbonisation.

This chapter, therefore, closes with a clear bridge to Chapter 5. The next chapter interprets these findings against the literature and practice, discusses implications for managers and policymakers, and outlines where future research should focus given the boundary conditions identified here. In short, Chapter 5 moves from ‘what the evidence shows’ to ‘what the evidence means’ for designing and governing multi-tier decarbonisation.

5 Discussion and Implications

This chapter moves from what the evidence shows to what the evidence means for theory, practice, and policy in firm-level supply-chain decarbonisation, and thereby addresses the Discussion & Conclusions criterion for the thesis. It follows the Chapter 5 structure we set earlier and the university’s SLR guidance (restate RQ/OBs; interpret themes; set out implications; limitations; and future research). It answers the research question (RQ): How can firms overcome barriers and leverage opportunities to achieve supply chain decarbonisation, and what benefits result from these efforts?

5.1 Reconnecting with the Research Objectives

Research question: How can firms overcome barriers and leverage opportunities to achieve supply chain decarbonisation, and what benefits result from these efforts?

Objectives (OB1–OB3). Diagnose barriers; uncover opportunities; assess benefits. These anchor the discussion below and keep claims tied to the evidence base assembled in earlier chapters.

Bridge from Chapter 4. The synthesis established four interlinked mechanisms: M1 decision-grade data routines, M2 coupling of policy and contracts, M3 designed collaboration density, and M4 operational embedment. The evidence suggests a practical sequence—start with M1 and M2, right-size collaboration (M3), then embed practices (M4)—with feedback when OB3 benefits finance the upkeep of data and governance routines.

5.1.1 Findings by Objective

OB1. The review consistently identifies multi-tier visibility gaps, misaligned incentives, and rising coordination overheads as binding constraints; these are most attenuated when decision-grade data routines (M1) are institutionalised (see Sections 4.2.1–4.2.3). This confirms that visibility gaps are not merely technical but governance-related and must be addressed as institutional barriers.

OB2. Opportunities become adoptable when external signals are contracted into relationships (M2) and collaboration is right-sized (M3) to contain governance costs (see Sections 4.3.1–4.3.3 and 4.5). In practice, these designs move adoption from pilots to persistence, so that opportunities persist long enough to mature into OB3 benefits.

OB3. Environmental, operational, and financial benefits materialise once practices are embedded in day-to-day planning and control (M4); benefits then help finance the upkeep of data and governance routines (see Sections 4.4.1–4.4.3 and 4.5). Taken together, this closes the loop: realised benefits finance and legitimise the upkeep of data and governance routines under the boundary conditions identified in Chapter 4.

5.2 Theoretical Contributions

Contributions to the field — Theoretical: This section recentres decarbonisation on network governance by elevating M1 as infrastructure, specifying M2 as a governance complement, and formalising M3 collaboration density as a design variable (with M4 explaining risk-to-value translation). Building on Seuring and Müller (2008) and network governance theory (Provan & Kenis, 2008), we extend sustainable supply chain management (SSCM) by shifting the unit of analysis from firm-centric programmes to modes of network governance, and by emphasising shared information routines and contract-embedded standards as the governance backbone.

From firm-centric action to network governance. The findings re-centre supply-chain decarbonisation on network design and governance rather than standalone firm initiatives. Treating Scope-3 traceability and emissions exchanges as infrastructure (M1) reduces reconciliation and verification frictions across tiers, directly addressing OB1's information gaps. This extends transparency and multi-tier governance perspectives in supply chain management by positioning data cadence and formats as a shared collaboration substrate rather than a reporting add-on. This infrastructural stance answers calls in multi-tier supply chain management (SCM) to extend visibility and control beyond the first tier—either by directly linking to critical second-tier suppliers or by relying on first-tier suppliers to transmit information and sustainability governance requirements upstream (Mena et al., 2013; Wilhelm et al., 2016).

Policy–contract complementarity. By showing that credible external signals (e.g., prices, rules) must be contracted into relationships—through pass-through, sharing, or two-part tariffs—to stabilise private returns long enough for adoption to persist, M2 reframes regulation as a governance complement rather than a distant backdrop. This helps explain when OB2 opportunities mature into OB3 benefits. Building on transaction cost economics (Williamson, 1985) and the supply chain contracts literature (Cachon, 2003), incentive-compatible contracts—such as revenue-sharing contracts and two-part tariffs (a wholesale per-unit price plus a fixed, e.g., licensing, fee)—coordinate decisions by aligning local objectives

with system-wide goals, thereby internalising external price- or rule-based signals into bilateral payoffs.

Interrelation of themes. M1 data routines make M2 contract coupling operable; M2 stabilises private returns long enough for adoption to persist. Together, they define the feasible corridor within which M3 collaboration density can be designed without recreating overhead. M4 operational embedment then converts risk into value. Effects are strongest where signals are stable and assets are long-lived, and weakest under short contracts or volatile demand (see Sections 4.2–4.5). The interdependence among M1–M4 reflects organisational complementarities: performance gains are superadditive when practices are implemented as a coherent bundle rather than in isolation (Milgrom & Roberts, 1995). The boundary conditions align with classic TCE: higher asset specificity and performance ambiguity heighten hold-up and measurement hazards, increasing the value of credible safeguards and commitments (e.g., contract-embedded terms, assurance routines) to protect specific investments (Williamson, 1985).

Collaboration density as a design variable. Prior work often implies that “more collaboration is better.” Our synthesis instead theorises collaboration density as a designed choice that trades diffusion benefits against monitoring and negotiation overheads, aligning with OB2’s enabling conditions and tempering coordination burdens that otherwise revive OB1’s barriers. This challenges the prevailing assumption in SSCM that more collaboration is always better and offers a corrective theoretical proposition: collaboration density should be deliberately right-sized to maximise diffusion benefits while bounding monitoring, negotiation, and assurance overheads; beyond a threshold, added ties erode net performance. This view aligns with research on embeddedness, which shows that over-embedded, high-density ties can reduce adaptability and create lock-in (Uzzi, 1997), and with network-governance theory, which argues that different governance modes—shared governance, lead organisation, and the network administrative organisation (NAO)—are efficient under different contingencies (e.g., number of participants, trust, goal consensus) and entail characteristic tensions that evolve over time (Provan & Kenis, 2008).

Risk-to-value translation. M4 explains how operational embedment converts risk into value: once data and governance are workable, planning accelerates, compliance exposure falls, resilience improves, and financial returns are more likely to materialise alongside environmental outcomes. This integrative account clarifies why environmental, operational and financial performance can co-move rather than trade off. Framed in resilience theory, operational embedment builds buffers and flexibility that reduce performance losses and shorten time to recovery, converting exposure into recoverable performance (Sheffi & Rice, 2005). Viewed through a dynamic-capabilities lens, M4 institutionalises the sensing–seizing–reconfiguring cycle: decision-grade data sharpen sensing; incentive-aligned contracts and business models enable seizing; and routinised planning, control, and reconfiguration processes sustain adaptation—together translating risk into sustained value (Teece, 2007).

5.3 Practical Implications

Contributions to the field — Practical: This section distils role-specific actions (Who/What/How/KPIs) that institutionalise M1–M4 in day-to-day operations.

Lead firms (OEMs/brand owners).

1. Institutionalise decision-grade data: build cadence, formats, and minimum viable data into everyday workflows; treat Scope-3 information as process data, not an annual exercise (addresses OB1).

KPIs: data cadence (update interval, days) → reduction in reconciliation time (hours/days); primary-data coverage (% of spend/suppliers with primary data); supplier digital connections (% integrated via portal/API).

2. Couple signals with contracts: align partners by pairing regulatory/carbon-price signals with pass-through, sharing or two-part tariffs so incentives persist (enables OB2→OB3).

KPIs: % of suppliers (or spend) aligned under incentive-compatible terms;

contracts with pass-through/gain-share/two-part tariffs (%); sourcing events using carbon-inclusive TCO (%); suppliers with SBT-aligned targets (%).

3. Design collaboration density: keep links tight where necessary and loose where possible; contain governance overheads while enabling the diffusion of digital and financial levers.

KPIs: governance overheads (coordination hours/meeting count; average contract cycle time); share of critical interfaces designated “tight” vs “loose” (%/ %); collaboration-platform adoption (% active suppliers); abatement per coordination hour (tCO₂e per 100h).

4. Embed practices operationally: migrate pilots into planning/control so realised benefits help finance the upkeep of data and governance routines.

KPIs: planning cycles with carbon constraints (% of S&OP cycles); pilot-to-BAU migration rate (%); realised abatement (tCO₂e/year) & cost per tCO₂e; reliability lift (OTIF / schedule adherence); share of realised savings reinvested in data/governance (%).

SMEs and tier-2+ suppliers (who make up >80% of the global supplier base). Lower adoption costs by simplifying data requirements (templates/defaults), using shared platforms, and tying enablement (training, financing) to the lead firm’s routines—especially in heterogeneous, SME-heavy networks. This scale logic clarifies why SMEs matter and strengthens OB2 by making opportunities actionable at scale.

Multinational enterprises. Calibrate collaboration and contracting to asset specificity and capital cycles; in long-lived assets, stable signals and fair cost-sharing reduce stranded-asset risk and keep partners aligned.

5.4 Policy and Governance Implications

Consistency and contractability. Disclosure rules and price signals bite only when translated into contract terms. Embed EU CSRD/ESRS (esp. E1 Scope-3) and IFRS S2 data requirements—cadence, minimum viable fields, responsibilities, audit rights—into value-chain agreements, and pair EU ETS/CBAM cost signals with incentive-compatible clauses (pass-through, gain-share, two-part tariffs) so external signals shape private returns and persist (European Parliament & Council, 2022; European Commission, 2023; IFRS Foundation, 2023; European Parliament & Council, 2023).

Assurance without exposure. Specify verification against GHG Protocol boundaries and ISO 14064-1 quantification, and reference ISAE 3000/3410 for assurance levels. Use aggregation and tiered-access rules to keep records auditable while protecting proprietary data; otherwise, M1–M2 weakens and benefits attenuate (WRI & WBCSD, 2011; ISO, 2018; IAASB, 2012, 2013).

Ecosystem standards. Industry bodies should converge on a minimum viable Scope-3 dataset aligned with the GHG Protocol and SBTi Supplier Engagement Guidance and promote joint reporting protocols interoperable with CSRD/ESRS. This lowers cross-tier reconciliation costs and anchors findings in active policy debates (WRI & WBCSD, 2011; SBTi, 2023; European Commission, 2023).

5.5 Conflicting Evidence and Research Gaps

Sectoral and regional skew. The corpus leans toward manufacturing and Asia-Pacific/China; services and SMEs are under-represented. This limits generalisability and can hide context-specific barriers/enablers.

Method gaps. Survey and modelling work dominate; longitudinal case studies remain scarce, making it harder to trace how operational and financial benefits accumulate and under what conditions they persist.

Short-run payoff ambiguity. Some sectors report environmental gains without clear short-term financial returns—consistent with our finding that benefits typically require operational embedment and sustained incentives to manifest.

These gaps underscore why evidence synthesis—rather than isolated case studies—is essential.

5.6 Limitations of This Review

1. Scope and language. The review window (2015–2025) and English-only inclusion criteria risk omitting non-English and earlier studies.
2. Single-coder extraction. Coding was executed in a single pass by one coder using a structured extraction sheet and audit trail; despite controls, some subjectivity may remain.
3. Representativeness. Sectoral, regional and methodological imbalances in the evidence base constrain external validity.

These limitations do not invalidate findings but delimit their scope, a necessary trade-off in systematic reviews.

5.7 Future Research Directions

(i) SME enablement & collaboration design

1. SME-centred enablement. Test simplified decision-grade data specs, shared platforms, and contract toolkits that lower adoption costs in SME-heavy tiers; evaluate spillovers to OB1–OB3.
2. Designing collaboration density. Develop prescriptive frameworks for sizing “tight vs loose” collaboration under varying uncertainty/asset profiles, and quantify trade-offs between diffusion speed and governance overheads.

(ii) Mechanism validation & methodology

3. Mechanism validation. Use longitudinal/field experiments to probe when M1–M4 hold, how feedback loops emerge, and which boundary conditions (tier distance, asset specificity, data sensitivity) switch effects on/off.
4. Methodological advancements. Prioritise multi-tier longitudinal field designs; dual-coder reliability for thematic synthesis; quasi-experimental tests of contract clauses (e.g., pass-through vs two-part tariffs); and open, minimum-viable Scope-3 data templates to improve reproducibility.

(iii) Policy–contract performance & social layer

5. Policy–contract–performance link. Model and test how specific regulatory signals, once contracted, alter private returns and accelerate multi-tier adoption.
6. The social layer. Examine culture, leadership and trust as amplifiers/dampeners of data routines and contract credibility; connect to resilience via social-capital mechanisms noted in the synthesis.

Methodological advancements. Future work should prioritise longitudinal multi-tier field designs that trace M1–M4 over time; dual-coder reliability for thematic synthesis; quasi-experimental evaluations of contract clauses (e.g., pass-through vs. two-part tariffs); and open, minimum viable Scope-3 data templates to improve reproducibility (aligning with the quality-assurance set-up described in Section 2.1.4).

5.8 Chapter Summary

This chapter addresses the Discussion & Conclusions criterion and highlights theory, practice, and policy contributions separately. It reframed decarbonisation as a network-governance challenge underpinned by M1–M4. Theoretical contributions elevate data routines to infrastructural status, specify policy–contract coupling as a governance complement, treat collaboration density as a design variable, and explain risk-to-value translation via operational embedment. Practically,

firms should institutionalise decision-grade data, contract external signals, right-size collaboration, and embed practices; policymakers and industry bodies should enable assurance without exposure and promote joint reporting protocols. We also surfaced sectoral/method gaps and review limitations, and set out a forward agenda centred on SMEs, mechanism validation, collaboration design, policy–contract performance, and the social layer. These insights prepare the ground for the concluding chapter.

6 Conclusion

This concluding chapter steps back from the discussion to render a judgement on the research question and to state what holds, under what conditions, and what remains uncertain. Because the evidence base is fragmented across sectors and methods, a protocolled systematic literature review (SLR) provides the most defensible basis for the conclusions that follow—by transparently aggregating and appraising heterogeneous studies rather than relying on isolated cases. It proceeds outcome-first and avoids re-arguing mechanisms: Section 6.1 addresses the RQ/OBs directly; Section 6.2 distils the most durable takeaways; Section 6.3 clarifies this thesis’s contributions to theory and practice; Section 6.4 translates them into principles and context-specific decision rules; Section 6.5 notes limitations and future work; Section 6.6 offers closing remarks. Where detail is needed, we cross-refer to Chapters 4–5 rather than repeat them.

6.1 Addressing Research Questions

Decarbonisation contributes to supply-chain environmental, operational, and financial performance when four governance conditions are met: (i) decision-grade data routines and standardised exchanges (M1); (ii) credible external rules or prices coupled with incentive-compatible contract terms (M2); (iii) collaboration density designed—not maximised—to support diffusion at critical interfaces (M3); and (iv) digital and process levers embedded in planning and control (M4). Where any element is missing, initiatives fragment into pilots and value fades.

6.2 Summary of Key Findings

- What improves together: environmental, operational and financial outcomes can co-move when M1–M4 operate as a bundle and adoption persists long enough for routines to bed in.
- Boundary conditions:
 1. Tier distance & SME heterogeneity → keep data “just enough” and enable upstream tiers.
 2. Asset specificity & capital cycles → stable signals + fair cost/benefit sharing.
 3. Data sensitivity & assurance → confidentiality with verifiability.

6.3 Contributions to the Field

- Theoretical. The thesis recentres decarbonisation on network governance: data cadence as infrastructure (M1), policy–contract complementarity (M2), and collaboration density as a design variable (M3), with operational embedment explaining risk-to-value translation (M4). This extends SSCM by shifting attention from firm-centric programmes to governance modes that institutionalise shared information routines and contract-embedded standards.
- Practical. Provide a minimal adoption-quality triad usable across tiers: (1) coverage of decision-useful Scope-3 data; (2) share of spend/contracts under carbon clauses; (3) governance hours per project (proxy for collaboration density). These KPIs operationalise M1–M3 and link to M4 when embedded in planning and control.

6.4 Recommendations

- Principle 1 — Prioritise contractable signals. Pair credible prices/rules with pass-through, gain-share, or two-part tariffs so incentives persist along tiers.
- Principle 2 — Keep data “just enough” and routine. Treat Scope-3 as process data (cadence, minimum fields, audit rights), not an annual exercise.
- Principle 3 — Design collaboration density. Keep links tight where interdependence is high, loose elsewhere, to bound governance costs while enabling diffusion.
- Principle 4 — Embed in planning and control. Wire carbon constraints into S&OP, sourcing, and performance routines so benefits accumulate beyond pilots.

Context rules. In volatile settings, stabilise incentives first; with long-lived assets and clear policy, move to embed; with sensitive data, combine aggregation and assurance; in SME-heavy tiers, simplify and enable before scaling.

6.5 Limitations and Future Research

This review’s scope (2015–2025; English-only) and sectoral/method skew constrain external validity; single-coder synthesis may leave some subjectivity. As outlined in Section 5.7, priorities include SME-centred enablement and collaboration-design rules, longitudinal mechanism validation of M1–M4 (incl. quasi-experimental contract tests), and open, minimum-viable Scope-3 data templates to strengthen reproducibility.

6.6 Closing remarks

In conclusion, decarbonisation contributes positively to supply chains when information is decision-useful, incentives are contractable, collaboration is

deliberate, and practices are operationally embedded; under these conditions, environmental, operational, and financial outcomes can reinforce one another.

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Appendices

Whilst Heading 1 to Heading 6 can be used to number headings in the main body of the thesis, Heading styles 7–9 have been modified specifically for lettered appendix headings with Heading 7 having the 'Appendix' prefix as shown below.

Appendix A Ethical approval letter



22 May 2025

Dear Mr Ho ,

Reference: CURES/25286/2025

Project ID: 28549

Title: Decarbonisation in Supply Chains

We are pleased to inform you that you have successfully declared that your research project is a **Literature Review – based solely on openly available literature which is in the public domain, and you are undertaking desk-based research not involving any other form of data or information.**

You have also confirmed that your project **does not meet** any of the literature review specified exceptions, listed both within the relevant section of the CURES form and below:

1) Your supervisor has requested that you apply for approval through CURES because:

- The journals or data are in a sensitive area (please discuss this with your supervisor)
- The project will be embargoed i.e. **will not be publicly available via the Cranfield library immediately or longer term**

2) Approval is/will be specifically required by another external body e.g. journal publishers

Therefore, **you do not require ethical approval** and your CURES application will be automatically closed.

Please keep a copy of this letter safe, if this exception is in relation to your thesis project, you will need to include a copy with your final thesis submission.

If you have any queries, please contact CURES Support.

We wish you every success with your project.

Regards,

CURES Team